PA IN PRACTICE III

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COVER: A drone being used to monitor crop establishment and plant health (using NDVI).
PHOTO: Evan Collis

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Contents

Abbreviations and units of measurement

Abbreviations	
Apparent electrical conductivity	ECa
Artificial intelligence	AI
Australian Pesticides and Veterinary Medicines Authority	APVMA
Cation exchange capacity	CEC
Colour infrared	CIR
Conditioned Latin hyper-cube sampling	cLHS
Controlled-traffic farming	CTF
Decision support systems	DSS
Digital elevation model	DEM
Economic optimum nitrogen rate	EONR
Electrical conductivity	EC
Electromagnetic	EM
Electromagnetic induction	EMI
Enhanced vegetation index	EVI
Gamma radiometrics	GR
Global Positioning System	GPS
Green on brown	GoB
Green on green	GoG
Growing season rainfall	GSR
Ion selective field effect transistor	ISFET
Leaf area index	LAI
Light detection and ranging	LiDAR
Lin's concordance correlation coefficient	LCCC
Long-wave infrared	LIR
Maximum residue limit	MRL
Mid-infrared	MIR
Moderate resolution imaging spectroradiometer	MODIS
Near-infrared	NIR
Normalised average partial profit	NPP
Normalised difference red edge	NDRE
Normalised difference vegetation index	NDVI
On-farm experimentation	OFE
Organic carbon	OC
Pattern Intersection height	PIH
Phosphorus buffering index	PBI
Plant-available water content	PAWC
Precision agriculture	PA
Proximal soil sensing	PSS
Pulse width modulation	PWM
Real-time kinematic	RTK
Return on investment	ROI
Root mean square error	RMSE
Short-wave infrared	SWIR
Thermal infrared	TIR
Topographic wetness index	TWI
Total count	TC
Ultraviolet	UV
Unmanned aerial vehicle	UAV
Variable rate	VR
Variable-rate application	VRA
Variable-rate technology	VRT
Vegetation index	VI
Water use efficiency	WUE

Measurements	
Centimetres	cm
Gigahertz	GHz
Hectares	ha
Kilograms	kg
Kilometres	km
Litres	L
Metres	m
Millimetres	mm
Tonnes	t

Row spacing conversions

Row spacings are often quoted in inches, centimetres and millimetres. For consistency, all row spaces in this publication are presented in centimetres. The table below provides a useful conversion tool.

Conversion tool

Inches	Centimetres
7.2	18.0
9.0	22.5
9.6	24.0
12.0	30.0
14.4	36.0
15.0	37.5
16.8	42.0

Foreword

In 2021, the Society of Precision Agriculture Australia (SPAA) undertook a comprehensive survey targeting growers and agronomists who participated in a nationwide series of Hands-on Precision Agriculture workshops, supported by GRDC. The results highlighted growers' concerns about escalating prices of fertilisers and the potential effects to their operations. Although the cost of urea has since fallen, the unpredictable nature of fertiliser prices continues to be a pressing issue to manage.

With this backdrop, and the increasing demand from growers seeking guidance on utilising precision agriculture (PA) tools and methodologies to manage inputs and optimise fertiliser, GRDC and SPAA delivered the 'Precision Fertiliser Decisions in a Tight Economic Climate' project to address these concerns and knowledge gaps.

This new edition, *PA in Practice III*, stands as the flagship publication for the 'Precision Fertiliser' project. Although there have not been any big developments in PA technology since the second edition *(PA in Practice II)* was published in 2012, the benefits experienced by early adopters are now clearly demonstrable.

PA in Practice III includes comprehensive frameworks for using foundational PA techniques such as on-farm experimentation, yield and soil mapping, as well as lessons drawn from the experiences of other growers.

The layout of *PA in Practice III* has been thoughtfully planned, with each chapter beginning by introducing the key terminology followed by detailed explanations of the application methods and rationale. The chapters then present grower case studies, demonstrating these methods in action.

For example, Chapter 2, Getting started with PA, provides a thorough overview of all the critical aspects to consider when delving into PA. This includes how to choose the right PA platform, understanding the commonly used spatial layers, and grasping the fundamentals of satellite remote sensing. The chapter concludes with a case study of the Dyer family from Kaniva, Victoria, who have successfully leveraged data to optimise operations.

To ensure the quality of *PA in Practice III*, SPAA was fortunate to engage an experienced science writer and soil scientist, Alisa Bryce, to compile, write and edit the content. Alisa has worked hard to produce an asset that is grower-friendly, current, logical and interesting. She has done an incredible job and should be very proud of the final product.

I also acknowledge the efforts of the SPAA team. Ange McAvoy, our executive officer, has demonstrated great commitment in managing both the delivery of *PA in Practice III* and the 'Precision Fertiliser' project. Brent Perkins, our communications administrator, has been dedicated behind the scenes in providing support to Ange and Alisa to deliver the publication.

Thank you to the SPAA Editorial Committee – Rob Bramley, Patrick Filippi, Beth Humphris, Dale Kirby, Denis Pozzebon, Frank D'Emden and Julie O'Halloran – which has been a big help to Alisa and the team with assistance on the technical aspects of the manual and the initial scope and direction.

Thank you to our project collaborators, including Colin Hinze (Pinion Advisory), Reuben Wells (AgLogic), Tim Neale (DataFarming), Bindi Isbister (Agrarian) and Alice Butler (FARMANCO), for the incredible work they put into delivering variable-rate workshops around the country and assisting with content for *PA in Practice III*.

Thank you to Maureen Cribb and Luke Dawson from GRDC, who have consistently provided a supportive and friendly voice over the phone, offering guidance and encouragement to the team throughout the project.

And finally, thank you to all the grower champions who have been generous with their time by sharing their personal experience of PA in practice. Their stories have been developed into case studies, videos, podcasts and articles that have enriched the project overall.

I hope you enjoy reading *PA in Practice III* as much as I have.

P. Honey

Phil Honey
SPAA president

Chapter 1: Introduction

Photo: Nathan Simpson

Since the first edition of *PA in Practice* was published in 2008, precision agriculture has continued to evolve and become more mainstream. What was new or less common in 2008 – yield mapping, real-time kinematic (RTK) guidance and precision sowing, for example – is now standard practice across many Australian grain farms.

Soaring fertiliser prices over the past few years sparked widespread interest in variable-rate fertiliser applications, with growers seeking to manage rapidly rising costs without sacrificing yields or quality.

Chapter 6 gives multiple examples of growers' variable-rate fertiliser practices used to optimise profits. A common theme across the stories is that growers are not necessarily saving money with variable-rate application (VRA) (although some growers, such as James Venning, saved $100,000 in one season), but are instead allocating resources more efficiently.

While fertiliser has been in focus of late, there are a wide range of PA practices and technologies that can be used throughout the season. *PA in Practice III* explores some of the ways growers are using PA, including:

- using on-farm trials to inform variable-rate decisions (Chapter 3);
- yield mapping and protein monitoring to make multiple decisions, such as tracking nutrient exports and refining nitrogen rates, as well as using yield maps to generate long-term insights such as profit-and-loss maps (Chapter 4);
- mapping and managing soil drainage, acidity, dispersion and salinity (Chapter 5);
- precision sowing and variable-rate seeding to deal with stubble and soil issues (Chapter 7); and
- mapping and managing weeds with drones, automatic spot spraying and robots (Chapter 8).

Interspersed with grower stories are tips and advice from growers and agronomists on topics such as setting up the harvester for yield monitoring.

In the second edition *(PA in Practice II)*, published in 2012, PA consultant Andrew Whitlock pointed out that PA was a moving target – it is about the evolution of agronomy, developing a multi-layered picture of what is happening in the paddock. PA allows growers to collect information year-on-year, throughout the growing season, to tackle constraints and challenges in a step-by-step approach, identifying and managing the most limiting factors down to fine-tuning the system through incremental changes.

This aspect of PA has not changed, and growers have access to more data than ever (a challenge in itself) to make better farming decisions. Getting started with PA means taking a good look at what data is available and how it might be brought together. Chapter 2 looks at the various spatial layers and data sources available to help make PA decisions, and what growers should look for when choosing a PA platform.

A managed approach to digital change

**By Dr Emma Leonard, AgriKnowHow –
building capability and capacity in agriculture**

How many people does it take to change a light bulb? You might say one, or perhaps two – one to hold the stepladder, the other to change the bulb. Or like the old joke, you might say four – one to hold the bulb and three to turn the ladder. Or before answering you might want to know more information – where is the bulb located, how big is the bulb, why does it need changing?

With such a relatively simple task eliciting multiple responses, it is not surprising that trying to bring about change in more complex tasks and integrated processes can be challenging. Adoption of digital agriculture (DA), of which precision agriculture (PA) is a component, is an example of a complex change.

To support greater on-farm adoption of appropriate digital technologies, my PhD (*A Change Management Approach to Unlocking the Value of Digital Agriculture for Family Farming Businesses*) used a change management approach to unlock the on-farm value of digital agriculture. This chapter shares the concepts of digitalisation of process and change management and how these have been brought together in a digital adoption framework. It also presents how the framework can be used on-farm and in extension programs to help guide and measure continual digital improvement.

What is digital agriculture?

As a relatively immature term in the life span of agriculture, the definition of DA continues to evolve. Where mechanical agriculture is enabled by machines and chemical agriculture by agrochemicals, digital agriculture is underpinned by connected technologies that use data to support more strategic decisions and actions.

Data is at the heart of DA. Sometimes the data, its collection, analysis and interpretation might be obvious, such as in an accounting system. In other situations, such as auto-steer, only the reaction to the data is easily observed. Farming businesses already collect and use multiple types of data from different sources and for different uses. DA offers the opportunity to integrate, analyse and generate actions from these data sources in new and improved ways.

Animal identification is a useful example of the difference between a manual and a digital, data-driven approach. A conventional livestock ear tag shows an animal's unique identification number; good eyesight and being physically close enough to read the tag are the only requirements for using such a tag. If this is upgraded to a digital ear tag, every animal on farm can be located remotely, activity can be tracked and individual animals can be managed according to weight, reproductive or health status. However, the use of digital ear tags introduces additional complexity to the system as they require a power source, connection to the internet, a technology to read the tag, analytical software and the skills to use the software to turn the data into actions.

To make the change from a manual/analogue system to a digital alternative needs proof of value and planning; change management offers a guided way to manage such a conversion.

Going digital is much more than buying a weather station you can view remotely via an app. That is an example of using an agtech solution to digitise data to perform a task, i.e. to remotely view recent and current weather data for a specific location. That is just one of three phases of going digital. These phases are:

1. digitisation of data;
2. digitalisation of process; and
3. digital transformation.

Going digital is as much about a change in technology as it is about a change in mindset regarding how data is used in a business. Remote access to weather data is a digitisation of data. An example of a digital process that uses weather data is the automated distribution of a fire danger alert. Behind the automated text message of a fire danger alert are algorithms that combine wind, temperature and humidity data gathered from multiple weather stations and issues warnings to an address list when a fire danger rating trigger point is reached. To take the same weather data and use it in a digitally transformed system would require the alarm to trigger an action, such as automatically cut-off power to a harvester.

Understanding the digital status of your data sources and the degree of digitalisation desired in a process is important knowledge that supports appropriate digital adoption.

An example of how this can be done is outlined in the section headed 'Change management in practice' later in this chapter.

Process maps for agricultural digitalisation

Every farm will have multiple examples of processes that could be digitalised or digitally transformed, but the tasks and data flows have not been fully mapped. Mapping these processes and understanding the data sources and integrations is fundamental to appropriate product development and purchase decisions. The spray process for selective herbicides has been mapped against 10 tasks (Tables 1.1 and 1.2).

Both tables are constructed around the same 10 tasks that have been allocated to a step in the OODA (observe, orient, decide, act) decision cycle. The first part of the table maps each task against where it occurs, how it is executed, when it occurs in relation to other tasks in the process, who might be responsible for execution and potentially the time input required. Other factors could be added such as pretraining or licences required, safety requirements, etc.

The lower part of the table identifies the current digital phase, the technology required and the six factors known to impact on digital change (Leonard et al., 2022; Leonard et al., 2017). As technology evolves, the approach to the six factors will evolve. Hence Table 1.1 represents the current common incumbent solutions and Table 1.2 an innovative, more digitalised approach. The ultimate would be each task is digitally transformed; however, that might not be

Table 1.1: Process map for a commercially operated manual approach to in-crop herbicide management.

TASK	**Number**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	OODA	Observe	Orient	Decide	Orient	Orient	Act	Act	Act	Act	Act
	What	Check for weed germination	Compare to target	Create solution plan	Source inputs	Identify enabling & limiting factors	Prepare equipment & spray mix	Apply herbicide	Record conditions & actions	Clean & maintain equipment	Complete management & compliance records
	Where	Paddock	Office/ute	Office/ute	Office	Office/ute	Shed	Paddock	Tractor/shed	Shed	Tractor/office
	How	Visual/count	Based on experience	Based on knowledge	Look in shed, or check inventory and order	Check weather forecasts, growth stages, equipment & labour availability	Measure & mix ingredients in correct proportions & order. Select correct nozzle	Mechanical boom spray	Notebook, spray diary, spray app	Manual	Collate data from machinery, management and spray records
	When	Post crop emergence	After inspection	After inspection	Prior to spraying	Prior to spraying	Immediately prior to spraying	At spraying	At spraying	Post spraying	Post spraying
	Who	Agronomist			Manager		Operator				Manager/ operator
	Time input	20 minutes 100ha	TBC					Dependent on boom width and location	TBC		
INCUMBENT SOLUTIONS	**DIGITAL PHASE**	**Manual**		**Digital**	**Manual/ digital**	**Manual**			**Manual/ digital**	**Manual**	
	Connectivity	None/cellular/broadband internet			Cellular/ broadband internet	None/ cellular/ broadband internet	None		None/ cellular/ broadband internet	None/ internet	None/ broadband internet
	Technology	Quadrant, reference material	Paddock records	Paddock records, pesticide fact sheets, agronomy software	Management records/ inventory, Phone	Internet, phone	Measuring jug/scales, pre-tank mixer, in-tank agitator	Rate controller, autosteer GPS	Weather station, rate controller GPS if coverage map produced	None	Management, compliance and machine software
	Data input	Paddock code, crop type, growth stage	Weed species, density, crop type, growth stage of crop & weeds, control threshold	Weed species, growth stage density, crop type growth stage	Total herbicide required	Appropriate weather conditions from label	Herbicide, ingredient quantities and mixing order, droplet size	Paddock name, location, rate, operator	Location speed, nozzle, pressure, boom height	Cleaning chemical, disposal method	Location, herbicide, nozzle size, weather at start and end of spraying
	Data output	Weed species, density	Decision to spray or wait. If spray, go to step 3	Herbicide recipe, rates, nozzle, total inputs required	Order	Forecast weather conditions	Time	Coverage map or total chemicals used, chemical left in tank, time	Total chemical used by area, weather conditions during spraying	Confirmation of cleaning, maintenance requirements and urgency	Compliance record
	Data analysis		Difference between target & actual weed density		Stocks to requirement	Comparison between forecast & label			Actual to anticipated chemical used		Inventory update, gross margin information
	Data ownership	Farming business		Herbicide recipe owned by agronomist	Farming business			Farming business &/or mapping software company, BOM		Farming business	
	Skills and training	Agronomy	Agronomy/ management	Agronomy	Administrative	Management	Mechanical	Mechanical	Administrative	Mechanical	Administrative

Source: © Emma Leonard

Table 1.2: Process map for an innovative digitalised approach to in-crop herbicide management.

	Number	1	2	3	4	5	6	7	8	9	10
TASK	OODA	Observe	Orient	Decide	Orient	Orient	Act	Act	Act	Act	Act
	WHAT	Check for weed germination and spatially locate	Compare to target by species and soil type	Create solution plan	Source inputs	Identify enabling & limiting factors	Prepare equipment & spray mix	Apply herbicide	Record conditions & actions	Clean & maintain equipment	Complete management & compliance records
	Where	Remote	Remote	Office			Shed	Paddock		Shed	Shed/office
	How	Satellite biomass map, remote growth stage observations Paddock records	Comparison to models, edge computing	Automated cross-referencing of weeds to herbicide database	Automated generation of herbicide order from step 3 and cross-referenced to inventory	Weather forecasts, growth stage, equipment and labour availability	Connect spray rig to automatic dosing equipment	Tractor-mounted sensor or autonomous boom with sensors	Automatically collected from nearest weather station to location and from spray machine	Attached to an auto flush system, manual damage inspection supported by AR goggles	Automatically collated by interoperable software
	When	Post crop emergence	After inspection	After inspection	Prior to spraying	Prior to spraying	Immediately prior to spraying	At spraying	At spraying	Post spraying	Post spraying
	Who	Automated and digital agronomist					Advanced operator	Automated		Operator/ automated	Automated
	Time input	To be determined as process develops									
INCUMBENT SOLUTIONS	DIGITAL PHASE	Digitalised				Digital, digitalised		Digitalised		Digitalised	Digitally transformed
	Connectivity	Broadband internet				Broadband internet, narrow band		GPS guidance, radio frequency/ wi-fi	Broadband internet, narrow band		Broadband internet, cellular
	Technology	Weed identification software, video or remote growth stage observation system	Digital twin, models	Product label and weeds databases & automated decision software, paddock and application software		Weather sensors, growth stage, equipment booking system	Automatic dosing and mixing equipment	Rate controller, autosteer, GPS, weed sensor	Weather station, rate controller, GPS	Auto flush system, maintenance app	Compliance & paddock management software
		Paddock management software									
	Data input	Paddock code, crop type, growth stage, weed species, density, control threshold			Current herbicide and adjuvants on hand	Appropriate weather conditions from label	Herbicide, ingredient quantities and mixing order, droplet size	Paddock code, location, rate operator	Location, speed, nozzle, pressure, boom height	Cleaning chemical, disposal method, parts/service requirements	Location, herbicide, nozzle size, weather at start and end of spraying
	Data output	Spray application map, spray products and quantity report ROI, droplet size and application set-up details			Auto-generated order	Spray weather window calendar, alerts	Confirmation of correct set-up	Coverage map, application conditions machinery set-up report		Maintenance report based on in-machine sensors/ recorders, cleaning report	Automated collation of all data into a single compliance report & transfer paddock and inventory software
	Data analysis	Weed type and location	Weed density to target	Herbicide type, rate, quantities	Total products required to be purchased versus inventory	Rolling forecast and alerts around targets	Auto-reading of set-up information, auto-response and confirmation	Location, autosteer, variable speed relating to weed density		Cross-ref of parts to inventory, identification of service level to current and previous machine hours, dosing and mixing to size of spray tank	Cross-check compliance criteria have been met
	Data ownership	Data agreements with multiple software provider, multiple subscriptions									
	Skills and training	Software, digital data analysis, agronomy			Software, digital data analysis, management		Software, hardware, mechanical required				Software, administrative

Source: © Emma Leonard

desired or feasible for every task.

From Tables 1.1 and 1.2 it can be seen that the spray process links to other processes such as product purchasing, staff, management, compliance recording and machinery maintenance logs. A detailed map of data flows within and with connected processes would also be valuable.

The actions, data sources, analysis and outputs from each task should be considered in the development of a digitalised process.

While many of the tasks are the same for a non-selective herbicide that could also be applied on-the-go using weed sensing technology, this would require a specific digital task map. Table 1.1 illustrates that we are already implementing complex processes in agriculture but these are often discussed on a task-by-task basis rather than as a whole process.

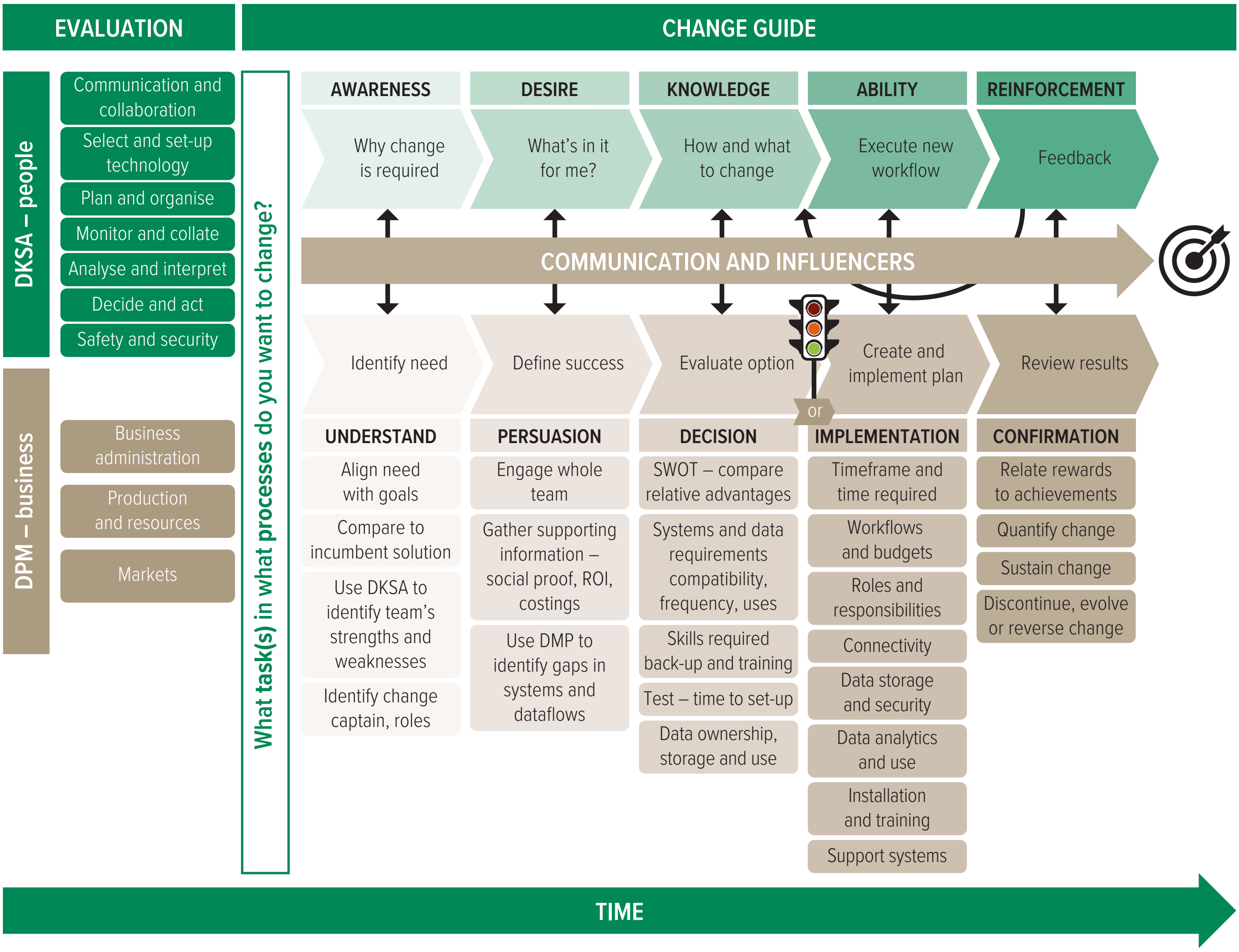
Considering tasks within a process is essential for digitalisation, where data from multiple tasks often using multiple software programs is required to be integrated.

Change management 101

Change management applies structured and quantifiable approaches to implement change or make the positive decision not to change. There are several key elements in a change management process:

- The proposed change is based on a need.
- The need is then aligned with the business goals. For family businesses, it must also align with personal goals. If the need does not align, the change should be suspended or reconsidered.
- Managing the change from evaluation through delivery and review is the responsibility of a nominated individual, the change leader.
- Two-way open communication between management and operations is essential at all stages of the change process. The change leader or captain has the responsibility of sharing the change idea with the team members, listening and accommodating their concerns and suggestions, and identifying and sourcing the resources required to successfully implement the change.

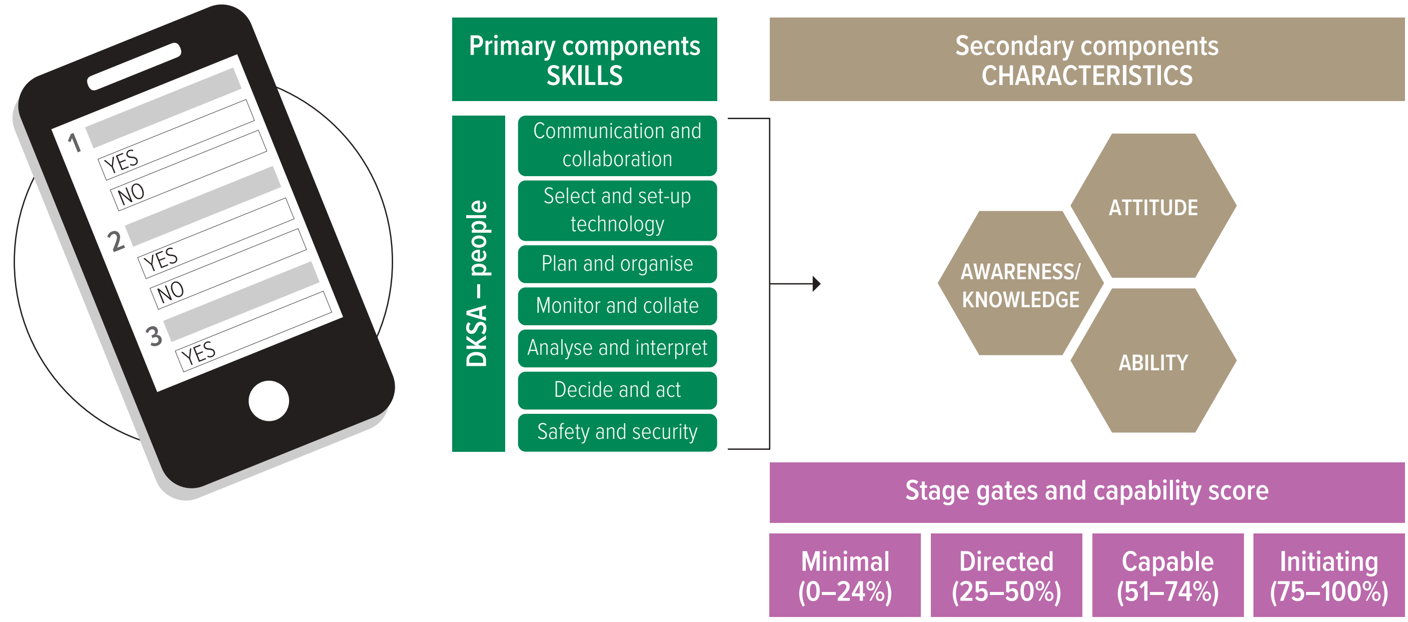
Figure 1.1: A stepwise adoption framework for digital agriculture constructed around the people and business aspects of change.



DKSA = Digital Knowhow Self-Assessment DPM = Digital Process Maturity

Source: © Emma Leonard

Figure 1.2: Digital Knowhow self-assessment components and scores.



DKSA = Digital Knowhow Self-Assessment

Source: © Emma Leonard

The change leader is not hands-on at every point but takes a leadership role. **Having a single person responsible for a change has been shown to be vital for the successful implementation of change in a timely and cost-effective manner.**

In my research I found that the concept of considering changes at a process level rather than as a task was rare. Needs were rarely actively aligned with business goals, so changes could easily be driven by personal wants. Appointing a dedicated change leader was inconsistent with the way family farming businesses operated. Either the most senior manager would self-appoint to lead all changes, or all members enthusiastic for the change would work as a team without a leader. The former approach does not capitalise on individuals' specific strengths and the lack of a team leader results in a lack of responsibility and accountability for the change to be successfully completed or abandoned if necessary.

A stepwise approach to digital change

The digital adoption framework is presented in Figure 1.1. The framework consists of two halves. The upper half relates to the people who will be impacted by the change and uses steps from the ADKAR (Awareness, Desire, Knowledge, Ability and Reinforcement) change management structure (Hiatt, 2006). The lower half relates to business and is based on the five sequential steps of Roger's innovation decision. Reading from left to right the framework consists of an assessment of the current status.

Two quick and easy evaluation tools were built and tested with family farming businesses to assess the maturity of their digital skills and processes. The maturity information is then considered against the desired change to help guide the choice of change leader and to highlight strengths and weaknesses in the team and systems. This information feeds into the initial steps of the change guide. The five steps are completed over time to achieve a defined success target, at which point the evaluation process can be repeated to assess the degree of change achieved. Internal and external communication and influences play a key part in supporting or derailing change. This highlights the importance of clear, open communication between all members of the business. The digital change framework was developed and tested by five family farming business teams that kindly worked with me during my PhD.

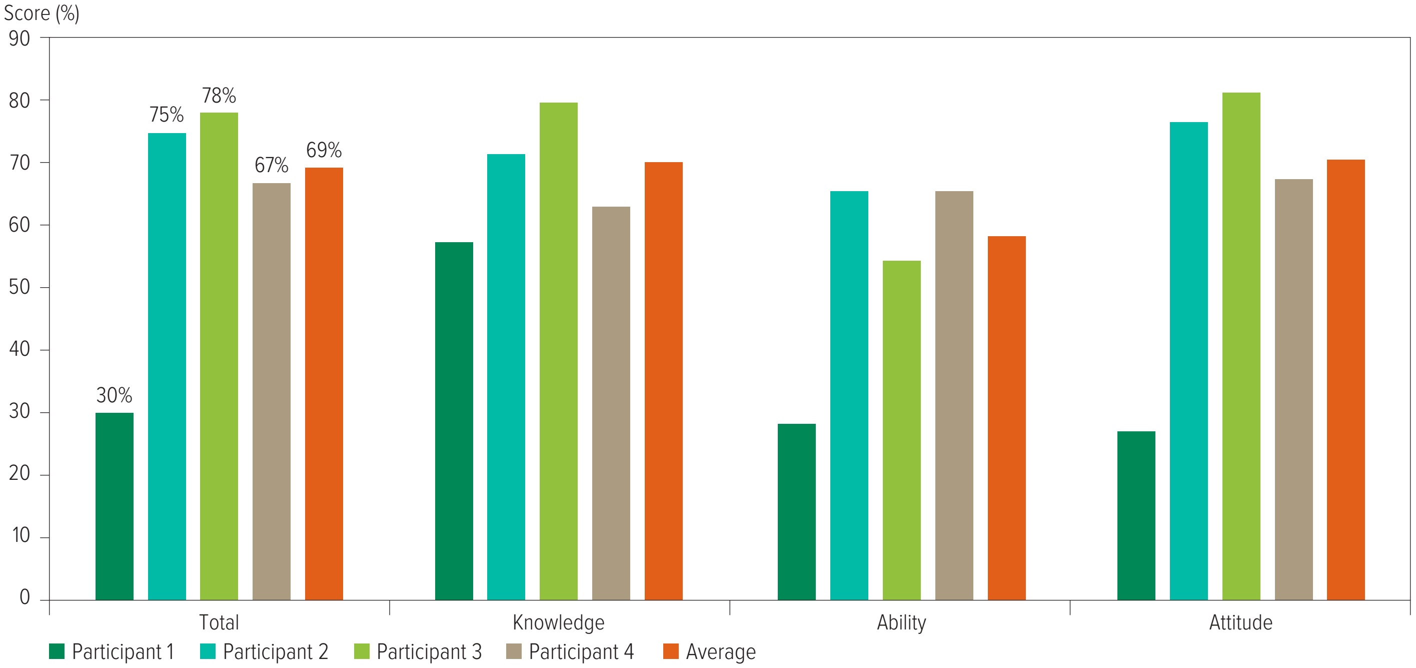
Change management in practice

When discussing digital adoption with farmers, advisers and providers, it was often referred to as a 'journey'. Let's work with this analogy. Consider a road trip: it has a starting point, a mode of transport, a destination, and some assumed or sourced knowledge regarding how to reach the destination (e.g. a map). However, initiation of the journey requires more than these elements. The traveller needs to be aware of the reason for the journey and to have the motivation and time to make the journey. The success, enjoyment, cost and duration of the journey depends on all elements being addressed before it starts, to a greater or lesser degree.

This is also true for the change journey, especially for a complex change such as digital agriculture. These journeys are often very specific to the needs of an individual farming business. Therefore, it became my objective to create a digital adoption framework that could be used by a diverse range of agricultural businesses to provide the user with personalised answers, from which actions could be initiated.

However, it is hard to plan a journey if you do not know from where you are starting; it is the same when managing change. Before starting a change journey, it is important to identify your starting point. Knowing your current position in terms of digital capability and process makes adoption more direct, practical and successful. As part of my digital adoption framework, two evaluation tools were developed with and tested by the farmers, employees and trusted advisers in the participating business teams.

Figure 1.3: An example of the results from the DKSA from a four-person farm business team.



A score of 50% or more is required to operate in the digital workforce.

Source: © Emma Leonard

Digital skills

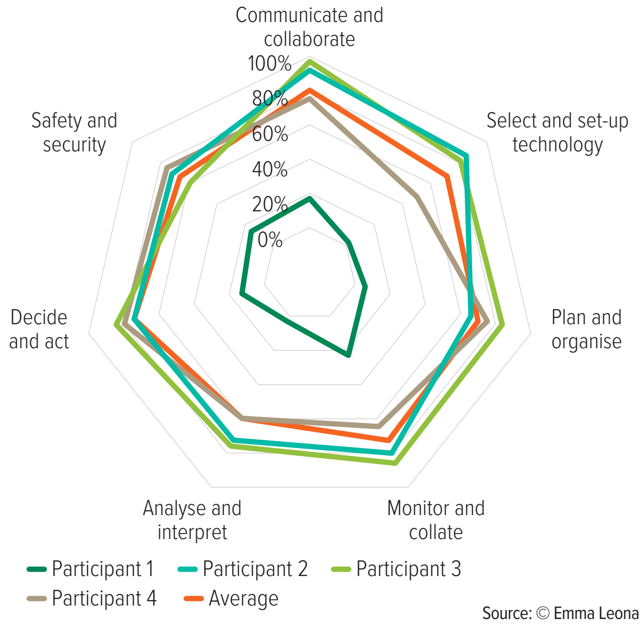
There is no such thing as an unskilled job in agriculture, but different jobs do require different skill sets and different levels of competency. However, irrespective of role or industry sector, there are skill sets deemed vital to operate in the digital workforce. These are the ability to:

- select and set-up digital technology; and
- use digital and digitalised systems safely and securely to:
    - communicate and collaborate;
    - plan and organise activities;
    - monitor and collate data;
    - analyse and interpret data; and
    - achieve decisions and implement actions.

Figure 1.2 illustrates the components of the evaluation tool designed to measure digital know-how. In order to evaluate change in skills it is necessary to be able to measure the starting situation and compare this with the situation after the change is implemented. To achieve this, the skills evaluation tool is designed around a maturity scoring system divided into four categories: minimal (0–24 per cent), directed (25–50 per cent), capable (51–74 per cent) and initiating (greater than 75 per cent). A definition has been created for each category.

The skills evaluation tool has been structured to use digitally specific questions that are relevant to a spectrum of agricultural industry sectors. In addition to scoring individuals against the required digital skill sets, the evaluation is also able to measure an individual's awareness/knowledge, ability and attitude to digital applications and approaches. These three characteristics are key to an individual's openness to change. Consequently, the evaluation tool is called the Digital Knowhow Self-Assessment (DKSA), rather than just a skills assessment.

Figure 1.4: Scores for the same business team and the average for all participants in the study by skill.



Source: © Emma Leonard

Presented on a simple digital interface via a mobile device or website, the DKSA asks users 84 closed, binary questions; that is, most can be answered yes or no. The assessment on average takes 10 minutes and has proved popular, with approximately 1500 users to date. Unlike a survey that just provides data to the researcher, the evaluation tool provides the user with a score and on request a more detailed report and learning resources.

The individual's responses are used to calculate their total digital know-how score, a score for each skill and a score for each characteristic. Based on the literature, a total DKSA result of 50 per cent or more is required to operate in the digital workforce.

Areas of strength and weakness are highlighted by calculating a score for each skill and each characteristic. Depending on an individual's role, these strengths may be used and weaknesses supported with appropriate training. The scores may highlight that someone's strengths are not being used with their current role. Following a change, the use of the tool is repeated. The intention is to measure an increase in the DKSA, but if appropriate training and support are not provided it could decrease due to poorer attitude and, possibly, ability scores.

Figures 1.3 and 1.4 provide an example of the score breakdowns for a four-person business team, together with the average for all participants in the study. The participant with a total score of 30 per cent has good knowledge but lacks ability in the use of digital tools. This is compounded by having a poor attitude towards the use of digital technology. This poor attitude would make this participant unsuited to leading digital change in the business.

Figure 1.4 shows the scores by skill for the same group of participants as in the previous graphic. This highlights all have their lowest score in the safe and secure use of digital systems. It also highlights strengths and weaknesses between participants for specific skill types. The relevance of this will depend on their roles and responsibilities, but this quantification and visualisation of capability can provide a foundation for training and development plans.

The DKSA has a range of uses to evaluate individuals and groups in a business or the success of an extension or training program. In my research, the DKSA was found to be especially valuable when all members of the farm business team took the evaluation and compared scores. Some scores identified team members with little digital responsibility but considerable digital skills and enthusiasm. Others found that those with the poorest digital attitude were in charge of digital change – not a great combination for success. Several older team members gained confidence in their digital skills when they compared scores, strengths and weaknesses with younger team members.

The evaluation tools help clarify if a digital change is appropriate for the current team skills or if training or additional team members are required for successful implementation. By aggregating DKSA results for business teams, of those attending a workshop, or an industry sector, I have been able to quantifiably illustrate agricultural digital capability.

Two areas of weakness are continually identified in the scores (Figure 1.4). These are the ability to analyse and interpret data using digitalised systems and the safe and secure management of digital systems.

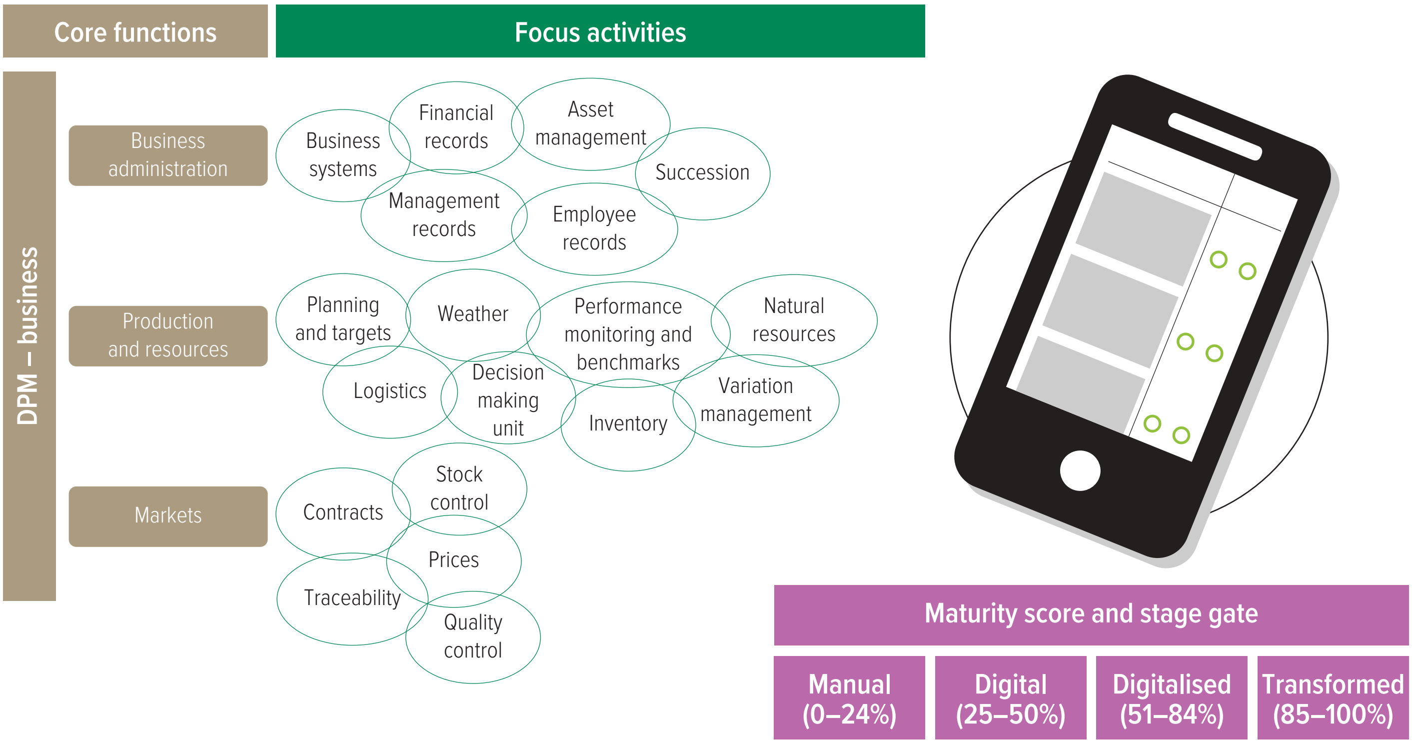
Digital process

Before starting a change journey, it is important to evaluate the current and desired maturity of your processes. That is, how digital do you want that process to become? You might be surprised at the different perceptions and digital desires of those in your team.

The Digital Process Maturity (DPM) tool (Figure 1.5) divides the farming business into three core functions – business administration, production and resource management, and markets. These core functions hold true irrespective of industry sector. Each function is associated with focus activities from which data will be generated and/or used. Multiple activities can require the same data as discussed in the process mapping section of this chapter. The focus activities are at a high level, so again are industry sector agnostic but a focus activity may bridge two or more core functions.

For each focus activity the tool presents four statements. It is these statements that can be designed to meet the needs of specific industry sectors or even to delve more deeply into a process. The statement relates to whether the focus activity is carried out manually, uses digital data, is digitalised, or is digitally transformed (Figure 1.5). These are the four stages of digital maturity (Figure 1.5).

Figure 1.5: The underlying components of the Digital Process Maturity evaluation tool.



DPM = Digital Process Maturity

Source: © Emma Leonard

The DPM tool uses a similar rapid-fire response system as the DKSA, which also aims to achieve speed over precision. The users, who would normally be farm owners/managers and decision makers, are asked to select the statement they consider most closely matches the current level of digital maturity, and the second selection is the desired level of digital maturity for each of 20 focus activities in their farming business.

The results from the DPM tool can help identify if your proposed digital change is a high digital priority for your business. The results also indicate if there are focus activities associated with the process that would also need to be digitised to achieve the desired digital process maturity. When the tool is completed by multiple managers/owners in the same business, it is able to quantify differences between the individual's perceptions of current and desired process maturity. This quantified knowledge is valuable when making change choices and decisions.

Change guide

The results from the evaluation tools are used to support decisions and communication in relation to the first two steps of the change guide (Figure 1.1). The change guide provides the steps and the issues that need to be considered for every digital change. These steps take time and will be influenced by availability of service and support, others' experience of the technology and market demands; for example, of the other for stable and successful progression.

It is important to remember that not every change will be appropriate, hence the traffic lights after the Evaluate Options step (Figure 1.1). Your research and evaluation of your current situation and the relative advantage of the change over current practices may result in negative results and the decision not to implement the change. Reaching such a conclusion based on robust information and evaluation is vital; implementing inappropriate change is wasteful, demotivating and costly.

The DKSA evaluation tool is in the 'People' section of the adoption framework (Figure 1.1). People, your team, will need to implement this change or the change may alter their roles and responsibilities. This evaluation tool and the following steps in the change guide relate to the people that will be affected by the change journey. While the 'People' steps are sequential, they can be revisited and reviewed to ensure all members of the team remain engaged with and supportive of the change and provide positive input to its implementation.

The DPM evaluation tool is in the 'Business' section of the tool. The activities in this half are the responsibility of management, their decisions and the actions that will support operations. The business steps in the change guide must be carried out and completed sequentially before moving to the next step.

Many of the issues identified in the change guide will be common for any change; others are specific to a digital change. Where the change guide differs from other adoption guides is that it brings together the issues that need to be addressed by the management team and in relation to the business and the people in the business. By engaging and guiding both the operators and managers, the change guide will help establish and implement successful digital change.

Conclusion

This article has described a series of approaches and tools initiated as part of my PhD and further developed as part of my business, AgriKnowHow. They are designed to support family farming businesses to take a managed approach to digital change. I am keen to work with farming businesses that are interested in implementing this approach and to be involved with further developing and testing of the DPM tool. Please contact me for more information or to access the evaluation tools.

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Chapter 2: Getting started with PA

Introduction

For most Australian grain growers, adopting guidance, autosteer and auto-boom shut-off technology has been a relatively simple process and the economic returns are easy to measure from day one.

Taking PA to the next step using variable-rate technology (VRT) can potentially be financially rewarding, but investment will not yield returns if growers do not have the basics right first. One question many growers ask is: "Will the benefits outweigh the cost of investing in VRT?"

Some questions to ask yourself before diving into PA include:

- Does the paddock have enough variability to warrant variable-rate applications (VRA)?
- Is the variation distributed in sporadic areas that are hard to manage or larger areas that are manageable with VRA?
- Is the cause manageable with VRA? For example, dispersive soil at depth is a challenge to treat with VRA, but surface pH or dispersion are easier to deal with.

The GRDC publication *Profit from Precision Agriculture* (Southern Region, July 2019) outlines a framework for deciding if PA is a profitable decision. The publication explains how to decide to make an investment in PA technology to improve farm profit.

All about data

Precision agriculture hinges on farm data – collecting, organising, analysing and using it.

Platforms that pull all farm data together and create variable-rate maps are becoming more sophisticated but can still be a challenge to use. In the next section 'Choosing a PA platform', agronomist and grower Beth Humphris looks back at what she wished she knew and had asked when deciding on a platform at the start of her PA journey.

Knowing what data layers are available and how to use them is critical. 'Common spatial layers used in PA (page 19) outlines the main and easily available spatial layers that form the foundation of PA decisions. 'Satellite-based remote sensing for PA' (page 25) has more detail on what growers can expect from satellite imagery.

For a taste of how these layers are put into practice, see how the Dyer family uses a range of data, from satellite images to soil tests, for PA on their farm in Victoria in the grower case study starting on page 29.

GROWER COMMENTS
MIC FELS

Validate, validate, validate

The first step before embarking on variable rate is validation – knowing what to do where. If you don't know, you could end up doing the 'right thing' in the wrong place, actually reducing your profits. Validation can be trials on your own farms or those conducted by R&D bodies. Validations means you are fully confident you're doing the right treatment for the soil types.

Yield maps are a great place to ramp up PA

Yield mapping is the obvious place to start. It's pretty accessible for most people with modern machinery. You can get really good information from a yield map. Even if you don't use it digitally, you can print it out and look at it. You can then do soil tests to understand what it means.

You don't need expensive equipment

You don't have to have complicated, brand-specific equipment; you can do precision ag with your iPad or phone and basic apps. It's about identifying the low-hanging fruit with big gains, hopefully without spending too much money or taking too much time.

It's got to be your thing

Don't just do it because an adviser tells you to if you're not that way inclined. If you don't like computers, screens and analysing data, or if they're not your strengths, you're probably better off avoiding precision ag.

There are lots of people who are remarkably successful without precision ag. They're doing the fundamentals right: timing, rotation, clean paddocks, instinct for farming.

If you are interested in the analytical approach to farming, precision ag is a really useful tool to analyse your business, measure what you're doing, and quantify what's making things better.

Originally published in 'Comparison of variable-rate technologies on Fels family's farms', *Precision Ag News*, Summer 2023, vol. 19, issue 2.

GROWER COMMENTS
NATHAN SIMPSON

Nathan Simpson, NSW grower, says PA has “tremendous potential” for growers through “more efficiently utilising our assets and inputs by zoning paddocks and treating the different zones separately, depending on the needs and yield potential of those zones.”

However, he says knowing where to start and whose help to enlist was an enormous barrier for many looking to start the journey.

“The technologies are out there and have been proven over the past 20 years, but the piece missing is the specialists to do the testing and validation work that goes on behind the scenes that is so crucial to achieve the desired outcomes. Without the soil testing and validation there is no value whatsoever in VR technologies.”

Mr Simpson sympathises with time-poor growers who don’t have the capacity to complete the additional work while continuing to run their businesses.

“Once this gap is filled, I believe that adoption of the technologies will follow suit at a rapid pace.”

Originally published in ‘Turning to technology to combat farming system challenges’, *Precision Ag News*, Winter 2023, vol. 19, issue 4.

AGRONOMIST COMMENTS
BINDI ISBISTER

Start with the basics

Sometimes, the more data, layers and information you collect, the more confusing it actually is. Choose a management issue you want to solve, then look at what data and technology you have first before you invest in more that may not be needed.

Baby steps

Start small and test precision agriculture on one or two issues you want to work on, rather than spending lots of money and doing a whole variable-rate program for the farm, then realising the machinery or the products aren’t quite what you need. When one thing is working well, add in more PA decisions.

Make a plan

We often try and do variable rate when we’re busy, which makes it harder to be patient and troubleshoot. A lot of precision agriculture is about having persistence and perseverance to get it right. This links back to the points above – make a plan, start small and persevere.

Choosing a PA platform

PA platforms are the engine room of PA, collating and analysing farm data and creating prescription input maps. They are advanced programs designed specifically to cover a range of PA activities, rather than tools with one function such as yield mapping.

With multiple potential data sources (sensors, yield maps, soil data), machinery brands and PA platforms, growers can waste months, if not years, finding a platform that:

- is compatible with their equipment;
- is intuitive (enough) to use;
- has decent support; and
- has the features they need.

Even testing out a platform takes time, with growers needing to upload paddock boundaries, order data files correctly and import historical yield maps and farm data.

Save time and effort up-front by considering these things when deciding on a platform.

Compatibility

The software should integrate with your existing farm equipment and systems. Make sure it is compatible with the hardware, sensors, GPS systems, and so on. you already use. It is hard to find a platform that will talk to everything you own but aim for something that does most of the job.

There are many file conversion programs that can help where needed and software dealers often have conversion programs. For example, NEXT Farming’s Wayline converter will convert boundaries or AB lines into different formats.

Does it work in a web browser, or do you need to download software? If you need to download software, check if it works on your operating system, that is Windows or Mac. There are workarounds, such as setting up a system that lets you run a Windows operating system on a Mac, but it adds to the work you need to do.

Can you export maps to your machinery? Sounds simple, but not all tools talk to each other. Sometimes the issue might be file format, with some controllers wanting zipped files and others not, or files named in a specific way. Having decent support helps here.

Mobile access

Does the software have an app? Apps make it easier to check your data or map while you’re in the paddock. Platforms with browser access can still work, but are harder to navigate on a mobile device than a dedicated app.

Features

Look for software that provides the tools and features you need, such as field mapping, yield monitoring, prescription maps, analytics and record keeping.

Essential:

- Satellite or drone/UAV imagery, including NDVI, NDRE.
- Import spatial layers such as soil maps derived from sensors (EM and/or gamma).
- Import point data such as soil test data or tissue test results.
- Generate variable-rate fertiliser and spray seed maps.
- Import yield data, analyse and interrogation.

Nice to have:

- Inventory management – helps track seed, fertiliser, chemical and other input inventory and use.
- Record keeping – stores operation records such as paddock activities, product applications, harvest data, and so on.

For the agronomist:

- Profit mapping – maps estimating the profitability of different paddock areas.
- Crop modelling to plan for next season.
- Analytics and insights – provides analytics tools such as yield variability analysis, comparisons across paddocks, historical trends, multi-year standardised yield analysis.

Ease of use

Can you use the software or is it too hard to perform even a basic task? The ideal situation is a platform that is intuitive and reliable. But as platforms become increasingly (and necessarily) more complex to account for more functionality, it will take some time to learn the ropes. Good support is essential here.

Another way to go about this is by looking at platforms that offer yield map processing behind the scenes through cloud processing. This eliminates a lot of time required for growers.

Customer support

Does the software have responsive customer support? When you need help, you often tend to need it immediately. Local support is ideal, as well as platforms with online knowledge bases and forums.

Also consider the degree of support offered. Some platforms will clean your data and make prescriptions for you. If you need this kind of support, it's worth paying for it as mistakes build on each other. Bad data collection can lead to poor VRT choices, such as the development of wrong zones, over or underapplied fertiliser, and so on.

Data management

The software should make it easy to collect, store, analyse and share farm data across devices and equipment.

Can you send information over the cloud, or do you need to do a manual transfer? Sending data over the cloud is easier, particularly when there are last-minute changes and you are nowhere near the office. Having someone else update or fix the maps without needing to drive back to base with a USB saves a lot of time.

Data cleaning. Can you clean yield maps and do post-yield calibration in the software?

How do you import/export maps? This is a biggie; for example, do you need files zipped or not? Local support helps a lot here.

Proprietary file export formats. Confirm whether you are able to used generic file formats (such as shapefile and/or KML) to export your data, rather than being locked into one service provider.

The National Farmers Federation has published a Farm Data Code, which is intended to inform the policies of service providers that manage data on behalf of growers. It also provides useful guidance to growers to understand how providers are collecting, using and sharing their farm data.

Scalability

Choose software that can expand as your operation grows in size, technology use, data collection capabilities, etc.

Security

The software should have security features to protect farm data. Encryption, access controls and data backups are good to have to keep your data private and secure.

Pricing

Pricing is a big consideration. However, a more expensive platform that does everything you need is cheaper in the long-run than a less expensive (or free) one that wastes hours of your time for no or limited useful output.

Price structure. Some platforms have you pay per hectare to do anything; others require a monthly fee for you to do whatever you need. There are pros and cons to both systems, but consider your own situation.

History and establishment

In a world of constant technology development, company mergers, takeovers and failures, consider the history and feature sets available when selecting a platform and provider. Ensure all data can be exported into generic forms and is regularly backed up externally, so that you always have access to your data regardless of what happens to the platform/provider.

Importing data – start with paddock boundaries

When trying out PA platforms, importing farm data straight away is tempting but can lead to problems later. The best first step is setting accurate paddock boundaries.

1 **Get all the paddock boundaries set**. Paddock boundaries are the foundation of the management tree or data hierarchy – how the data is set up in the platform. When you first start, you need to have all your boundaries as a KML or shapefile to import into the platform. Ultimately, you want to use the same boundary for every layer relevant to the paddock.

2 **Create management tree in the platform.** Import the paddock boundaries into the platform to make the management tree. A management tree sets out how the paddock files are named and organised in the platform. For example:

Farm name
  Properties/blocks
    Paddocks
      Different data for each season in each paddock

Setting up the farm properly first makes using the platform much easier later. Without a management tree, it is hard to quickly view layers relevant to the paddock you want – you will have to scroll through files.

3 **Import historical data.** Then bring in your elevation maps, yield maps, etc.

GROWER FEEDBACK
BETH HUMPHRIS

Beth Humphris, agronomist and grower, spent three years sifting through PA platforms, first to work out which ones would export maps that would 'talk' to the controllers and, second, had all the features she was looking for. Beth's top tips:

1 Get the management tree right first to save yourself pain later.

2 Use a cloud-based platform. It is easier when multiple people need to access the files and said people are dispersed across the farm.

3 Check the platform talks to your tractor. Beth had the pleasure of setting up the farm in a new platform and making VR maps only to find that the maps would not export to her Topcon screen.

4 Think about workarounds while building your PA capabilities. For example, if the tractor does not have VR capability, you can do a manual VR by downloading the VR map into Google Earth, then tracking your location using the GPS and manually changing the input rate when you get to the next zone.

Common spatial layers used in PA

This section is a combination of the article 'Getting down and dirty with data', originally authored by Leighton Wilksch and published in *PA in Practice II* (2012) and the *Proximal Soil Sensing Systems Fact Sheet* published by GRDC in March 2023.

Grain growers often ask: "What is the best layer (type of source) of data for me to use?" The answer is that all layers of information are important if they help formulate a picture of the factors that are affecting production across a paddock.

Colin Hinze of Pinion Advisory said in a GRDC/SPAA variable-rate technology webinar, held on 10 May 2023, that the right data:

- is data you already have, such as farm knowledge and yield maps;
- is related to the problem you are trying to solve, for example, EM maps are useful if mapping salinity (but will still need ground-truthing), less so if mapping acidity; and
- makes sense and is consistent with what you understand about your paddock.

Variations in soil type, fertility and structure are major causes of variability in crop performance. As all growers know, there are many other factors that come into play. These factors include climatic effects (for example, frost in relation to aspect and elevation), surface water impacts (in relation to paddock and block layout and row orientation), biotic factors (weeds, pests and diseases), and most importantly the effects of past management. In many cases, past management effects are a major cause of variability, often more so than variation in soil type.

With advancing technology, growers now have access to a range of useful and low-cost spatial layers to help make PA decisions. Spatial layers are collected from:

- on-farm monitors, for example, yield monitors;
- airborne imagery – satellites, aircraft or drones; and
- proximal soil sensing.

When using any PA tools for information collection and analysis, it is important to ground-truth results and interpretations in relation to all possible factors before making decisions about future management practices.

Yield data

Modern headers come with yield monitors. Generally, it is a simple process of plugging a GPS signal into the monitor to collect yield. Each header brand will have its own procedure to follow to collect good yield data (see 'Harvest data best practices' in Chapter 4 for tips on collecting good yield data).

Yield data is the report card at the end of the season. In some years in some paddocks there may be little variation in yield and in other situations there may be a variation of three to four tonnes per hectare (t/ha).

The main driver behind yield variation is plant-available water content (PAWC) – the amount of moisture in the soil profile that a crop plant can extract to produce grain. Typically, a yield map (for example, Figure 2.1) will identify paddock areas with a high PAWC (higher yields) and areas with a lower PAWC (lower yields). (Remember that other factors such as disease, compaction or salinity can also influence the ability of plants to take up available soil moisture.)

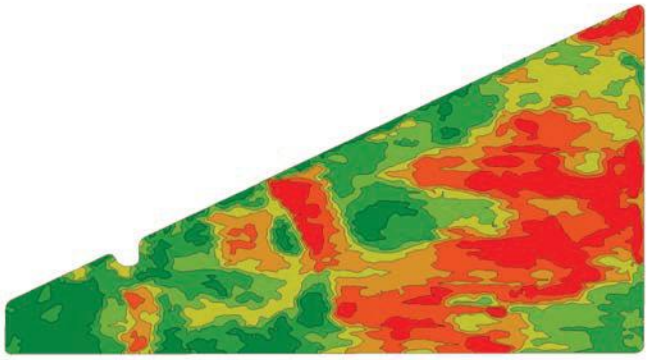
Seasonal conditions can sometimes mean variation in PAWC does not always show up in a yield map; for example, a season with a wet spring finish may mask areas with low PAWC. There are other factors affecting yield that are not necessarily driven by PAWC, such as areas where water pooled following summer rain, mouse damage at sowing or heavy weed infestations that reduced crop yield.

Multiple years of yield data (typically three or more) can be an excellent way of zoning a paddock into areas that consistently produce above-average yield, areas that consistently produce average yield, areas that consistently produce below-average yield and areas that are inconsistent in their yield pattern.

Soil testing within these zones can then be directed to evaluate what is driving yield variation and assess the levels of residual nutrition so a VRA plan can be formulated for soil ameliorants and/or nutrition. On-the-go protein sensors are often used in combination with yield monitors to refine nitrogen applications.

Chapter 4, Yield maps and protein sensing, gives more detail and examples of using yield maps.

Figure 2.1: Yield monitoring provides a snapshot of the variation of yield potential within a single paddock.



Source: James Venning

Airborne imagery

Airborne imagery offers photographs of the ground and crops from a direct-down position. These images are collected by satellites, fixed-wing aircraft and unmanned aerial vehicles (UAVs or drones). Images from drones and aircraft are less affected by cloud cover than satellite images.

'Satellite-based remote sensing for PA' on page 25 gives a more detailed overview of the different satellite imagery options available to growers and how they are used in PA.

Airborne images are usually available in colour and multispectral or non-visible wavelengths, including four-band colour infrared (CIR) or manipulations of the CIR spectrums such as normalised difference vegetative index (NDVI) or standard vegetation index (SVI). These image types can provide good information about crop growth and health. In this case, check that the satellite imagery is up to date.

Full-colour images

Full-colour paddock maps are produced with high-resolution digital cameras. The images produced are often composites of many images stitched together with specialised software. Full-colour maps can be produced from images collected by aircraft or drones.

Four-band images (CIR)

Four-band colour maps are mostly obtained using a specialised two-camera set-up, where one records full-colour spectrum (red, green, blue) and the other records the alpha or near-infrared band. The images are digitally combined and known as colour infrared (CIR).

A natural or full-colour image displays colour as it would appear to human eyes. Conventionally, a CIR image displays the infrared band data with a red tone. Red wavelengths will appear green, and green wavelengths will appear blue. Blue wavelengths are not displayed. Because the healthy green vegetation will appear to be bright red, a CIR image is also known as a 'false colour' image.

CIR images are used to generate vegetation indices, such as NDVI, by manipulating the spectral data. This can give an indicator of plant parameters such as water stress, biomass and chlorophyll content. Chlorophyll in plants reflects green wavelengths; this is why healthy plants appear green. CIR tends to penetrate atmospheric haze better than natural colour and it provides sharper imagery.

Vegetation indices

Vegetation indices or biomass imagery are used to help identify paddock/crop variability at different points in the season. Remote sensed imagery gives a unique look at a farm and enables a grower to get an understanding of crop growth that scouting from a ute will not provide. NDVI is the most commonly used vegetation index, although various other indices have been developed to help gauge crop variability throughout the season.

Normalised difference vegetation index (NDVI)

NDVI is a standard measure of crop greenness. It measures the reflectance of red and near-infrared light by a plant. Photosynthetically active vegetation, in particular, absorbs most of the red light that hits it while reflecting much of the near-infrared light. Vegetation that is dead or stressed reflects more red light and less near-infrared light. NDVI is measured as a figure normally between 0 and 1; the closer to 1, the more 'green' the crop is. Figure 2.2 is an example NDVI image.

A wheat crop at early tillering will typically give a reading of 0.4 and a fully tillered crop that has canopied over the ground will have a reading of about 0.95 when growing conditions are optimal. NDVI can be used to find crop stresses such as:

- a lack of fertility;
- insect infestation;
- soil deficiencies; and
- water stress from over or under-watering.

NDVI can also be used for determining paddock zones for fertiliser application and monitoring fertiliser applications and yield estimates.

A time series over a season or years of NDVI derived from satellite data is a useful tool for monitoring vegetation condition. NDVI can also be obtained from special single-spectrum cameras.

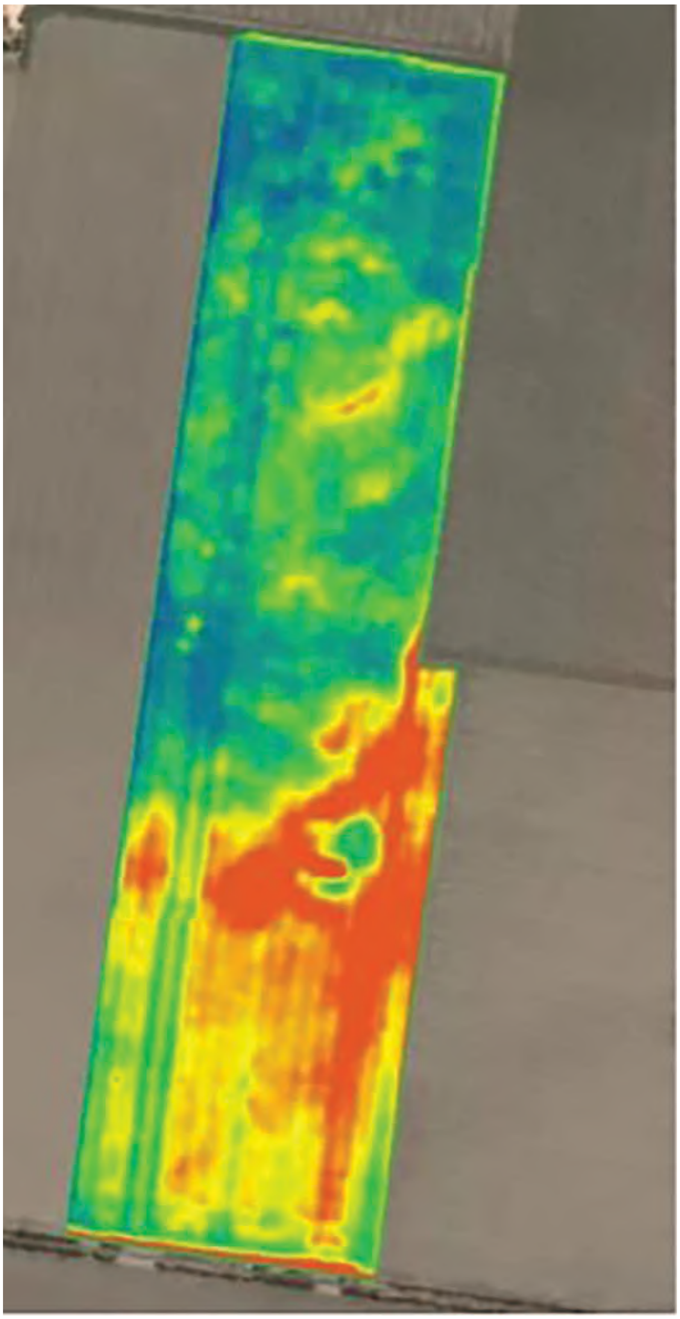
There are pros and cons of fixed wing/drone versus satellite imaging systems, with cloud cover being the main issue with satellite. However, on cloud-free days, a vast amount of imagery can be gathered across a large area. Spatial resolution varies from low resolution (30 metre/pixel) up to high resolution (1 to 5m/pixel). Fixed wing/drone imagery will typically have a more detailed pixel size with imagery to 0.25x0.25m available. Planes can also wait at the airport for a break in the clouds to take images.

NDVI imagery can show an incredible amount of paddock detail and can be readily used (with appropriate software) to formulate a variable-rate plan for top-dressing nitrogen or other nutrients. NDVI imagery can also be used to locate areas of disease, pests or other issues.

Several companies offer a composite of historical NDVI imagery sourced from NASA Landsat satellites. These satellites have been operating since the 1970s and composite images can show where a crop has typically returned a higher NDVI and vice-versa. Such imagery has been useful for zoning paddocks based on crop growth, which is primarily driven by soil type. Users have found this useful in areas that have a dune-swale environment.

NDVI is best used after crop establishment until canopy closure.

Figure 2.2: A NDVI image from September 2022.



Source: Tim Neale, Data Farming

Enhanced vegetation index (EVI)

The EVI is similar to the NDVI but uses more wavelengths of light to correct some of the NDVI inaccuracies. For example, NDVI readings will change based on the time of day (the angle the sun hits the leaves). EVI corrects for this as well as for atmospheric conditions – distortions in the reflected light caused by particles in the air and signals from ground cover.

Normalised difference red edge (NDRE)

NDRE uses the red edge part of the light spectrum. It is more useful for higher plant cover, such as later in the season, or for high biomass crops. It is often used in combination with NDVI.

Modified soil adjusted vegetation index (MSAVI)

The MSAVI has an adjustment figure to differentiate between low vegetation and bare soil. It is best used to monitor crop variation early in the season when seedlings are establishing.

Soil colour

Soil brightness is another product generated by satellite imagery and indicates how intensely the surface of bare soil reflects sunlight. Soil brightness includes the combined effects of soil type (type of clay minerals) and has been shown to be correlated with soil productivity. For example, pale-coloured soil is usually correlated with low organic matter. Growers can use this layer of data to create management zones based on soil type changes. This data should be used in conjunction with ground-truthing using soil tests.

Soil layers

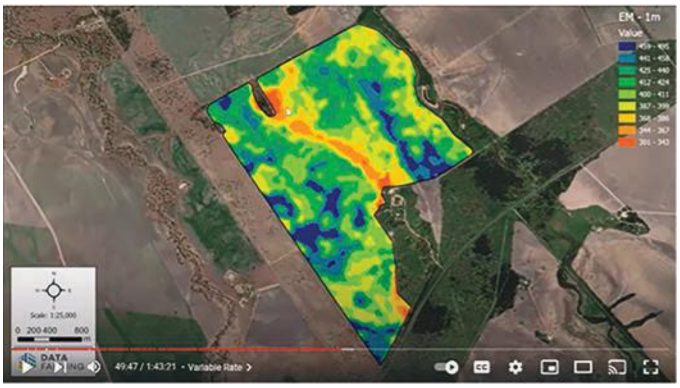
Proximal soil sensing (PSS) involves the on-the-go collection of information related to soil properties, often using one or more soil sensors. These sensors are an expanding set of tools and technologies using paddock-based sensors placed close to (within two metres) or in direct contact with the soil. The depth of soil from which a response is measured depends on the type of sensor used.

Some commercially available soil sensors directly measure agronomically useful soil properties, although the majority measure parameters that are indirectly related to agronomically useful soil properties. If high-accuracy (less than two centimetres) Global Navigation Satellite System (GNSS) units are used (for example, real-time kinematic (RTK) GPS), elevation data as well as longitude and latitude coordinates can be acquired to produce digital terrain maps.

Of the on-the-go PSS systems that are commercially available, the actual properties they measure and the relatable soil properties are shown in Table 2.1. Only the ion-selective on-the-go PSS instruments can directly measure a chemical property (soil pH). The rest of the available on-the-go PSS systems measure properties of the soil that require ground-truthing using laboratory soil testing and calibration if the goal is to map a related agronomically useful soil property.

The maps are either used individually or in combination with other PSS data maps, crop yield maps, terrain maps and remotely sensed images to pinpoint areas of significant soil and crop production difference.

Figure 2.3: Example of an EM survey image.



Source: Christian Capp, Groh Ag

Electromagnetic (EM) conductivity soil surveys

EM surveys measure apparent soil electrical conductivity (ECa), which is an indirect measure of salinity. EM38 is one type of EM conductivity machine along with a DualEM. These machines transmit a pulse of current into the soil and have a receiver sensor that measures the soil's interference on this current.

Higher EM conductivity readings are typically driven by clay soils with higher bulk density, moisture and salt content, whereas a sandier soil type typically shows a lower EM conductivity reading. On sandy soils, readings are mainly influenced by soil moisture and depth to clayey subsoil.

EM surveys are commonly used to map soil type variation and to define zones in the paddock, but always need ground-truthing. Figure 2.3 is an example EM survey image. The readings do not have much meaning until they are tied to the paddock and the readings are relative. High, low and all categories in-between are typically created in mapping software and the categories change with each map. Unless the same high/low categories are used across the whole farm, a low EM reading in one paddock could be a high reading in another.

On large areas of deep sands there might be little variation in EM readings and therefore it is not useful for creating map zones on this soil type.

An EM survey showing significant soil type variation can be used together with yield and other data to zone a paddock for VRA.

In Western Australia, EM surveys are often successfully used to show depth to clay in sand-over-clay soils, which aids in delving and clay-spreading pits.

Using EM even if it does not correlate

Sometimes growers find an EM map does not match up well with their own understanding of the farm, as was the case for Scott and Zoe Starkey (see Chapter 3, 'Strip trials to refine variable-rate phosphorus – grower case study', page 35). In other cases, the EM map correlates well in some years and poorly in others.

This variability in correlation can be useful in itself. There are often stronger correlations between crop production, pasture production and conductivity in lower-rainfall years than there are in higher-rainfall years, because clay content and water-holding capacity are two of the parameters that are most strongly correlated to the conductivity data.

In years of above-average rainfall, there might be no correlation between EM and yield maps because water is not the limiting factor.

Table 2.1: Currently available, and potentially useful, techniques for proximal, on-the-go monitoring of important soil chemical properties.

Soil properties	Limitations to yield	PSS techniques that show potential	Conventional methods for calibration or ground-truthing
Soil nutrients (plant-available)	Deficiency (for example, N, P, K, S and trace elements) or toxicity (for example, Al, B)	Visible/UV/NIR/SWIR/MIR spectroscopy Ion-selective electrodes (ISFET) Electrophoresis Protein maps*	Laboratory-based soil nutrient test Laboratory-based plant tissue nutrient test Crop visual indicators
Soil pH	Nutrient availability and Al and B toxicity	ISFET	Laboratory-based test for soil pH
Organic matter	Low organic matter	Visible/NIR/SWIR/MIR spectroscopy	Laboratory-based test for organic carbon Laboratory-based NIR/MIR spectroscopy
Soil sodicity	High sodium content	EMI Resistivity	Laboratory-based test for soil dispersion Laboratory-based test for cation exchange capacity
Soil salinity	High salt content	EMI Resistivity Ground-penetrating radar	Laboratory-based test for electrical conductivity Crop visual indication of growth patchiness

Note: not all the technologies listed are currently successful and alterations to procedures and sample preparations are part of the exploration process. All techniques would require ground-truthing/calibration as noted.
Key: N (nitrogen), P (phosphorus), K (potassium), S (sulfur), Al (aluminium), B (boron), UV (ultraviolet), MIR (mid-infrared), NIR (near-infrared), SWIR (short-wave infrared), ISFET (ion-selective field effect transistor), EMI (electromagnetic induction).

Source: GRDC fact sheet, *Proximal soil sensing systems*

This makes EM a layer of useful information as part of overall paddock understanding. If an EM map does not correlate well with your own paddock knowledge, compare it with a yield map from a dry year. This might reveal some patterns to help drive further investigations into paddock variability. If there still is not much correlation, EM might not be a useful layer in that paddock.

Overall, remember that correlation does not equal causation. Take care when using indirect measures of variability such as EM as there might not be much of a relationship between the layer and the cause of variability.

Elevation surveys

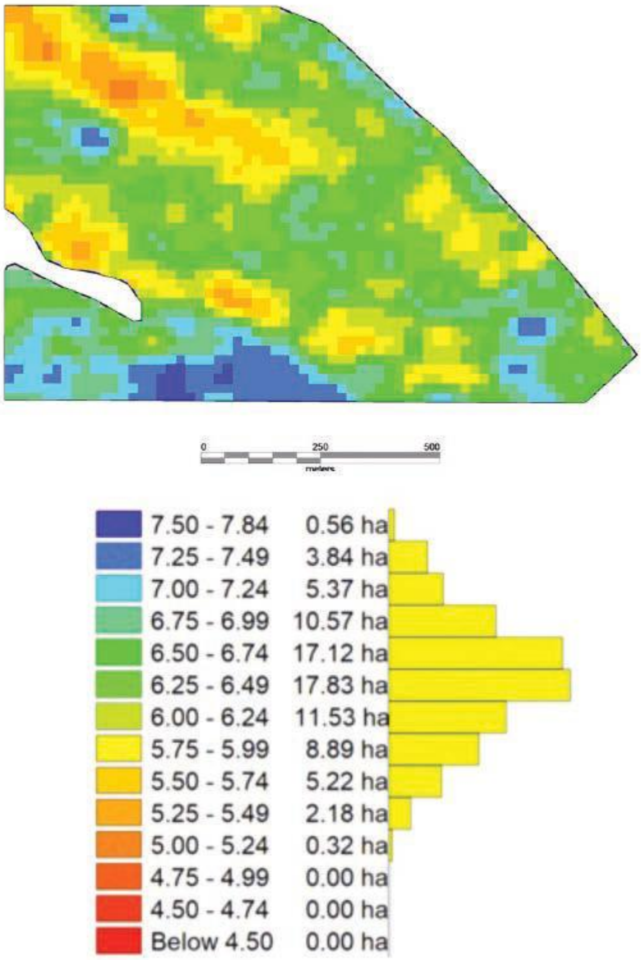
Elevation data is often included as part of EM mapping, although you may have to ask for the data. Free regional elevation data is available for most states, but it might not be of a high enough resolution to use at the paddock scale.

Elevation data collected at planting is usually good enough to use providing that the GPS signal is accurate (that is RTK). Harvester and spray rig data is less reliable as the weight of the machine changes.

As with all spatial data, elevation data will need interpreting with on-farm knowledge. Some data might be measuring wheel-track depth rather than the paddock.

Light detection and ranging (LiDAR) uses a pulsed laser to measure the distance to the Earth and can generate highly detailed 3D maps of the paddock surface. LiDAR is not commonly used but is available at a cost. Jake Hamilton (Chapter 5, grower case study, page 73) uses LiDAR data to develop paddock-levelling plans to treat gilgai.

Figure 2.4: Example of a topsoil pH map generated from Veris® pH mapping.



Source: James Venning

Gamma radiometric (GR) soil surveys

GR soil surveys measure the emissions from the natural radioactive decay of rocks and soils. The isotopes measured are uranium (U), potassium (K) and thorium (Th). The number of gamma ray counts across the whole spectrum is the total count (TC).

There are multiple interpretations for each reading. For example, high thorium could show where ironstone gravels dominate (although it is not perfect) and high potassium might mean higher clay content.

This type of soil survey is more suited to soils in Western Australia where sand and sandy gravel soils typically return a low EM reading, yet soil type change still exists. Much of Australia has had airborne GR survey work done across the countryside on a coarse grid (about 100m swathes), which can often be accessed through lands departments. This information is best used to find broadscale soil type changes.

Ground-based EM and GR surveys can be done at the same time. A survey that measures both costs roughly $10 to $15/hectare, without any ground-truthing or interpretation.

A survey will realistically cover about 50ha an hour, running on approximately 36m transects and collecting a datapoint every 5m. Some companies hire out equipment to do surveys.

pH surveys

On-the-go pH measurements work slightly different to other remotely sensed layers. A vehicle-mounted, ion-selective electrode is pushed into the soil to take pH readings from a set depth, usually about 10 centimetres. These sensors can cover about 250ha per day, taking 10 to 12 readings per hectare. Figure 2.4 is an example topsoil pH map generated with on-the-go pH sensing.

On-farm knowledge

The most important layer of data usually sits in the head of the farm manager. It is the farm manager who often best knows where soil types change, why a crop grows better in one area compared to another, where sheep camps and old fencelines used to be, or where there may have been a weed infestation that reduced yield.

Some growers have zoned their paddocks using simple methods, such as driving on the boundaries of soil type change (such as a dune-swale environment) and logging this on a console in their tractor cab. Free images such as Google Earth™ can help show where soil type changes.

Potential future layers

The ability to remotely measure soil nutrient status would be the holy grail of proximal soil sensing, but at the moment there is no tool that can do this. A range of other sensing technologies continue to be explored for use in proximal, on-the-go soil property measurement.

Tables 2.1 and 2.2 list the available techniques that may be used for on-the-go monitoring of important soil chemical (Table 2.1) and physical properties (Table 2.2).

Table 2.2: Currently available, and potentially useful, techniques for proximal, on-the-go monitoring of important soil physical properties.

Soil properties	Limitations to yield	PSS techniques that show potential	Conventional methods for calibration or ground-truthing
Soil nutrients (plant-available)	Low inherent yield potential due to low CEC, PAWC or inherent fertility	Gamma radiometrics EMI Resistivity Visible/NIR/MIR spectroscopy Ground-penetrating radar Tillage draft Protein maps*	Hand texturing of soil sample Laboratory-based particle size analysis (PSA)
Soil water storage capacity (PAWC)	Low water content	EMI Resistivity Visible/NIR/MIR/thermal infrared spectroscopy Radar	Drained upper limit estimates (DUL) Crop lower limit estimates (CLL)
Soil water in season (PAW)	Low PAW	Thermal infrared Visible/NIR/MIR spectroscopy EMI Resistivity radar Time differential imagery	Laboratory-based mass balance measurements In-situ neutron/capacitance/time domain reflectometer moisture probes Estimate from soil texture
Waterlogging	Reduced oxygen availability	Elevation EMI Resistivity	Piezometers/dip wells Visual observation of crop chlorosis Surface water ponding Soil hydraulic properties
Rooting depth	Shallow rooting depth Abrupt changes to soil texture Subsurface compaction Rocks	EMI Resistivity Ground-penetrating radar	Soil pit profile description Manual push probe

* Protein maps added to this table.

Note: not all the technologies listed are currently successful and alterations to procedures and sample preparations are part of the exploration process. All techniques would require ground-truthing/calibration as noted.

Source: GRDC fact sheet, *Proximal soil sensing systems*

Satellite-based remote sensing for PA

By Mario Fajardo, USYD.

Introduction

Remote sensing in PA is mostly used to observe the spatial (over distance) and temporal (over time) variability in soil and crops by gathering optical reflectance information from the plant or soil surfaces. During the growing season, vegetative growth may be monitored for production variability resulting from nutrient deficiencies, water stress or pest infestation, which may all influence final yield. Imagery is also used to map farm boundaries, watercourses and terrain.

Optical imagery relies on areas with different soil and vegetation cover having distinguishing reflectance signatures in the visible and/or non-visible electromagnetic (EM) spectrum. The amount of energy reflected, transmitted or emitted in these areas of the EM spectrum provides information linked to many vegetation and soil characteristics. Optical remote sensing can provide a useful, low-cost means of assessing variability in these characteristics at a paddock, property and regional scale within and between seasons. In some situations, these images can provide a surrogate production map.

Satellite-based imagery has four properties that are important to their use in PA:

- spatial resolution – the size of the smallest object that can be identified in an image (loosely defined by the picture element (pixel) size of the image);
- spectral resolution – the number of segments (spectral bands) of the EM spectrum that can be measured;
- radiometric resolution – the number of data levels for each band that can be stored; and
- temporal resolution – the minimum time period between two images taken of the same area.

The main satellite systems used in agriculture and their operational characteristics are listed in Table 2.3. The data from most of these systems is archived, creating a potentially powerful historical resource.

Using remotely sensed imagery in PA

It is relatively common knowledge that scientists and growers can make use of satellite imagery. In fact, agriculture has been using satellite imagery for more than 30 years.

One of the most widely used and best-known satellites is Landsat 7, launched on 15 April 1999. This satellite is still in orbit and is planned to be decommissioned by the new Landsat 9 mission, which successfully launched on 27 September 2021 from Vandenberg Space Force Base in California.

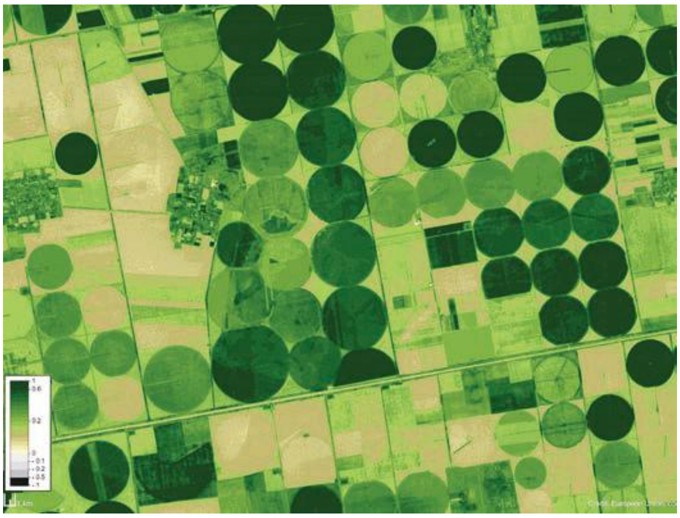
Table 2.3: Basic specifications for the satellite-based remote sensing systems of potential use in PA

Satellite system	Spectral resolution (bands)	Spatial resolution (metres)	Temporal resolution
Sentinel-1	C-band radar at 5.404 gigahertz (GHz) 4 modes of polarisation (HH-HV-VH-VV)	10	6 days
MODIS	36 bands R, NIR B, G, MIR (0.4–14.4 micrometre (µm))	250, 500, 1000	1–2 days
ASTER	14 bands G, R, NIR 6 MIR bands 5 LIR bands	15, 30, 90	On request
Landsat 7 ETM+	Pancromatic B, G, R, NIR, MIR LIR	15, 30, 60	16 days
Landsat 8	Pancromatic B, G, R, NIR, MIR TIR	15 15 and 30, 100	16 days
Landsat 9	Pancromatic B, G, R, NIR, SWIR TIR	15 30, 100	8 days
WorldView-2	Pancromatic B, G, R, NIR Red edge Coastal Yellow NIR2	0.5, 1.8, 1.8, 1.8, 1.8, 1.8	1 day
Sentinel-2	B, G, R, Red edge, SWIR	10 and 20	5 days
PlanetScope	B, G, R Red edge	5, 5, 5	1 day
DESIS	Hyperspectral 235 bands (2.5 nanometre (nm))	0.4, 1.7	On demand

Key: R = red band, G = green band, B = blue band, NIR = near-infrared, MIR = mid-infrared, LIR = long-wave infrared, SWIR = short-wave infrared, TIR = thermal infrared.

Figure 2.5: Landsat 9 real colour image from cropland at 30m spatial resolution.

Figure 2.6: A satellite image example of an NDVI of irrigated paddocks.



Generally, this kind of imagery can be used like normal photography (Figure 2.5), where red, blue and green bands are combined to form a visual representation of reality. However, its power resides in the way the information is collected and stored: in individual bands. The bands can be combined in many different ways to produce new visual and physiological insights. Known as vegetative indices, the more common combinations of bands are shown in Table 2.4.

An example using the European Space Agency's Sentinel-2 satellite is shown in Figure 2.6. This imagery uses a combination of the red and near-infrared bands, commonly known as normalised difference vegetation index (NDVI). The NDVI takes advantage of the natural condition of plants to absorb more or less of the different colours of light. Live green vegetation absorbs red and blue visible light as part of photosynthesis. At the same time, healthy plants refract (or scatter) near-infrared light. NDVI is an index that measures this difference. It is influenced by the fractional cover of vegetation on the ground, the vegetation density and the vegetation greenness.

NDVI provides a measure of vegetation biomass and condition, and it indicates the photosynthetic capacity of the land surface cover.

In Figure 2.6, it is easy to differentiate those paddocks that have higher NDVI (dark green) from the paddocks with low NDVI. The higher the NDVI, the healthier the plants. These healthier plants refract less of the red visible band of light. NDVI decreases as leaves senesce (deteriorate with age or other stress). Bare soil is close to zero on the NDVI, whereas bodies of water have negative values.

Table 2.4: Common indices used in remote crop sensing. Red edge NDVI is calculated from narrow band data with the wavelengths indicated in subscripts.

Index	Bands used	Physiological interpretations
Vegetation (or Simple) Index (VI)	$\frac{\text{IR}}{\text{Red}}$	Crop greenness, vigour, leaf area
Normalised Difference Vegetation Index (NDVI)	$\frac{\text{IR} - \text{Red}}{\text{IR} + \text{Red}}$	Crop greenness, vigour, leaf area
Soil Adjusted Vegetation Index (SAVI(0.5)) (0.5 = correction for soil reflectance)	$\left(\frac{\text{IR} - \text{Red}}{\text{IR} + \text{Red} + 0.5}\right) \text{x} (1 + 0.5)$	Crop greenness, vigour, leaf area when ground cover is sparse
Enhanced Vegetation Index (eNDVI)	$2.5\text{x} \frac{\text{IR} - \text{Red}}{\text{IR} + 6\text{xRed} - 7.5\text{xBlue} + 1}$	Crop greenness, vigour, leaf area in crops with high reflectance
Photosynthetic Vigour Ratio (PVR)	Red	Strong chlorophyll absorption (photosynthetic activity)
Plant Pigment Ratio (PPR)	$\frac{\text{Green}}{\text{Blue}}$	Strongly pigmented crops
Green Normalised Difference Vegetation Index (GNDVI)	$\frac{\text{IR} - \text{Green}}{\text{IR} + \text{Green}}$	Chlorophyll content, cell density and stress
Red edge NDVI	$\frac{\text{IR}_{750} - \text{Red}_{705}}{\text{IR}_{750} + \text{Red}_{705}}$	Crop greenness, chlorophyll content, water stress

Spatial resolution

One of the mantras of precision agriculture is: “Higher spatial resolution leads to a better targeted decision.” However, most of the satellite missions are designed for specific purposes, many of which are not primarily agricultural.

One of the most widely used satellites in natural sciences is NASA’s MODIS Terra (Moderate Resolution Imaging Spectroradiometer). This satellite offers a spectral resolution of 36 discrete spectral bands that cover the visible (red, green and blue), short wave, near-infrared and long wave thermal ranges. This instrument’s characteristics allow scientists to create algorithms to estimate more advanced indices than a simple NDVI. One of these indices is the leaf area index (LAI), which is defined as the one-sided green leaf area per unit ground surface area. It is calculated with the following formula: LAI = leaf area (m^2)/ground area (m^2). Such indices represent a physical phenomenon, in this case the size of the leaf, which can be easily generalised to plant biomass and in other calculations, including yield per hectare. Figure 2.7 shows the world MODIS LAI product for September 2013.

The trade-off with these kinds of satellites is their spatial resolution. Products from MODIS satellites are delivered in 250m to 1000m spatial resolution. This means the user will have one to 16 pixels/ha, which would lead to extreme generalisation if this information were to be used for yield estimation.

If higher resolution is needed, then other satellite constellations should be considered. One of the most popular options is Planet® imagery, which comes with a 3m to 4m resolution, a sub-daily revisiting time, and four bands including red, green, blue and near-infrared. This has been expanded to eight bands in its latest release.

Planet® products can be used in many ways in agriculture. Examples include calculating NDVI and creating a high-resolution picture of any farm, anywhere, on any day (if cloud-free) worldwide. As the focus of these products is to cover as much landscape as possible in the shortest timeframe, their spectral resolution is limited and therefore cannot be used to directly calculate more sophisticated indices such as LAI.

This trade-off has motivated the remote sensing community to create new algorithms, usually employing machine-learning techniques, to link the spectral power of free-to-use satellites, such as MODIS and Landsat, and the better spatial and temporal resolution of other satellites, such as Planet®. Figure 2.8 shows an example of a machine-learning fusion between Landsat 8 (11 bands at 15m, 30m and 100m resolution), MODIS Terra and Planet® CubeSat (four bands at 3m to 4m resolution). This is new research and it will be interesting to see how the technology is taken up.

Temporal (time) resolution

Growers, agronomists and researchers might ask: “What if we need to assess the plant response to a fertilising treatment over time?” For this kind of question, three things are required: high spatial resolution imagery, a good model that can translate information from more spectrally rich satellite imagery, and a high time resolution or revisiting time. It could be argued that satellite constellations such as Sentinel-2, with a revisiting time of about five to six days, are enough for most users.

However, a cloud-free image is never guaranteed, and it is not unusual to end up with no imagery for a full month. This is where commercial constellations such as Planet® come into play.

Again, the remote sensing and modelling community has circumvented this issue by creating time-dependent models applied to satellite imagery. Figure 2.9 shows the evolution over

Figure 2.7: World MODIS LAI (leaf area index) product for September 2013.

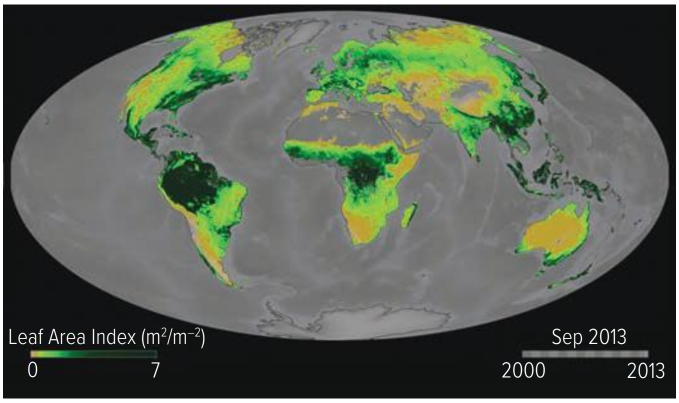
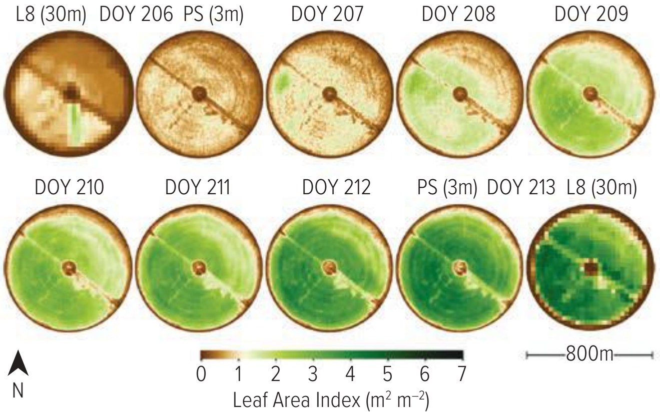
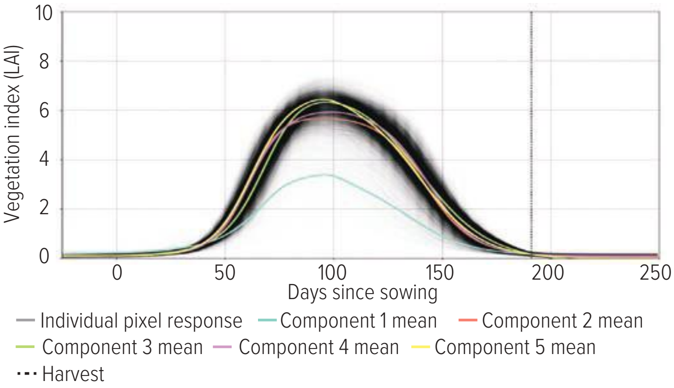


Figure 2.8: Leaf area index (LAI) using MODIS, Landsat 8 and Planet® at 3m resolution.



Source: Extracted from Houborg and McCabe, 2018

Figure 2.9: Time evolution of leaf area index (LAI) in a wheat paddock, Narrabri, NSW, 2020, using Sentinel-2 imagery and a model for estimating LAI.



Source: kindly provided by Future Farm
Phase 2: Intelligent decisions – Improving farmer confidence in targeted N management through automated decisions

time of LAI in a wheat paddock in Narrabri, NSW, for 2020. It uses Sentinel-2 imagery (10m resolution) plus a model for estimating LAI. Each of the black lines corresponds to a single pixel in Figure 2.10. With this kind of information, it is possible to model the LAI in time. Therefore, a complete picture of the evolution of plants in space and time can be produced and used to make informed agronomical decisions along the season.

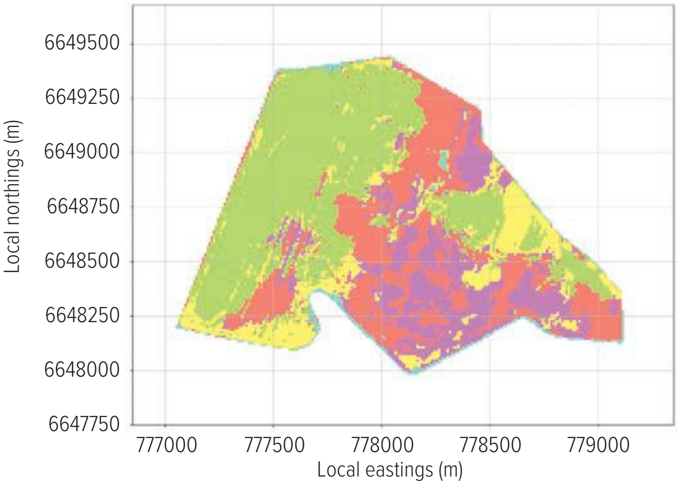
Spectral resolution

There are also some satellites that have high spectral resolution. They may not possess super-high spatial resolution or have a short revisiting time, but they do capture an incredibly accurate spectral picture of the Earth. They are called 'imaging spectrometers' and one example is DESIS (DLR Earth Sensing Imaging Spectrometer).

This satellite has a spatial resolution of 30m and a spectral resolution of 235 bands (covering the visible and near-infrared part of the spectra with a 2.5-nanometre spacing between each band). With this instrument, even more sophisticated agronomic algorithms can be calculated.

Figure 2.11 shows a hyperspectral image captured by DESIS of the wheat paddock shown in Figure 2.10 in Narrabri, NSW, this time for 2021. As so many bands are gathered at each pixel, it is possible to examine a full spectral response at each pixel and compile an average response for each type of land use in a region of interest.

Figure 2.10: Clusters formed by different leaf area index time-patterns in a wheat paddock, Narrabri, NSW, 2020. Relates to data in Figure 2.9.



Source: kindly provided by Future Farm
Phase 2: Intelligent decisions – Improving farmer confidence in targeted N management through automated decisions

Figure 2.11: Hyperspectral imagery captured by DESIS.

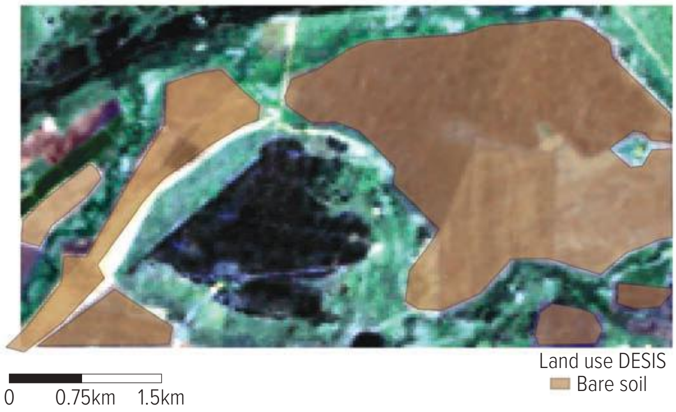


Figure 2.12 shows the average spectral responses across all 235 bands for the pixels in each land use type in Figure 2.11.

Figure 2.12 shows that the soil has a very characteristic spectral shape compared with the spectra of the forest or the roads. With this kind of instrument, the physical characteristics of the landscape can be captured with fine detail and subjected to further analysis. Figure 2.13 presents the results of a spectroscopic model created using DESIS imagery and the results of soil sample analysis taken the same day that the satellite passed. In this example, the higher spectral resolution of DESIS allowed for the calculation of valuable information at a fine scale that can be used to support decision-making, for example, in fertiliser application planning for the season.

Figure 2.12: Spectra of different land uses measured by DESIS.

DESIS spectra segmentation Centroids

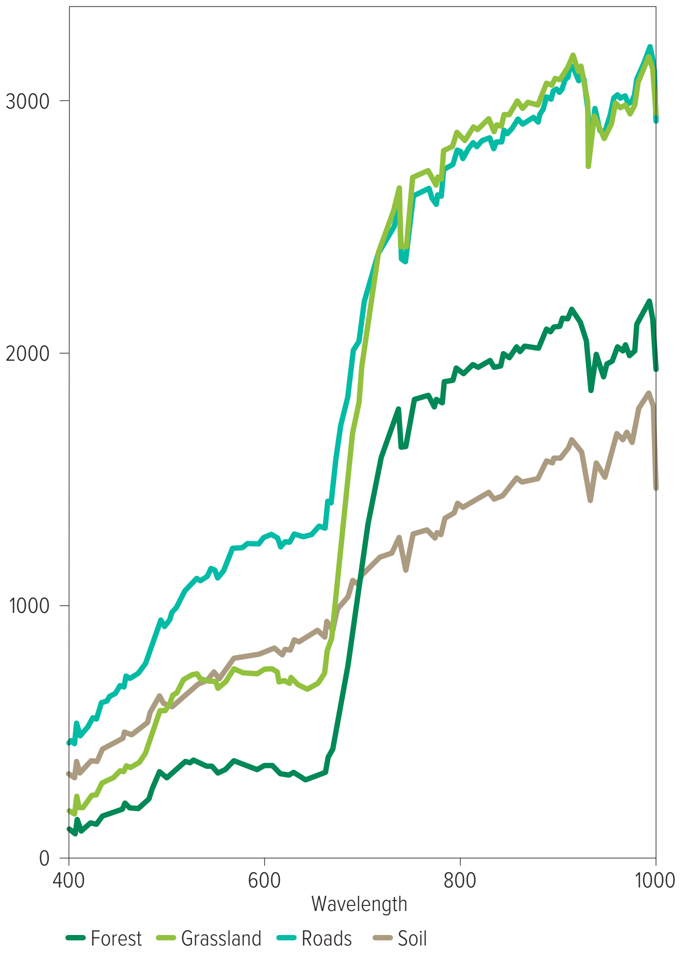
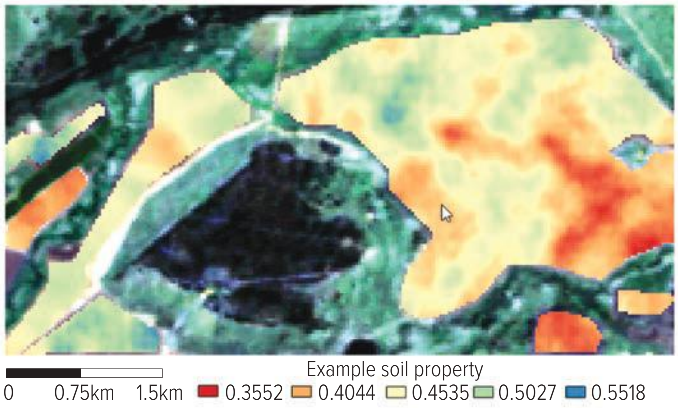


Figure 2.13: Fine-scale predictions of a soil property based on a multivariate spectral model.



Using data to unlock potential on West Wimmera farm

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Jonathan Dyer uses yield maps, protein sensing, soil tests, EM38 surveys and satellite images (NDVI) to make better farming decisions.

Study and work in IT have helped Jonathan Dyer better utilise data on his family's Victorian farm.

Jonathan farms with his parents Alwyn and Kerryn and brother Colin. They employ one full-time worker and seasonal workers at harvest. Their family partnership, Dyer Ag, spans 3000ha in Kaniva, in the West Wimmera. They grow bread and durum wheat, pulses and canola. In 2023, the pulse crops include lentils, faba beans and vetch. Some years they grow chickpeas, too.

While their focus is on broadacre cropping, they do run a small number of sheep on stubbles in summer. Stubble retention is part of their minimum till approach. The normal expected yields for the area are:

- 3.5 to 4.5t/ha for wheat;
- 2 to 2.5t/ha for canola; and
- 2.5t/ha for lentils.

Jonathan said in good years they go above those yields, but they were a good target that the family hoped for at seeding. Heavy cracking Wimmera clays dominate the soil across the farm, but it is dispersed with red clays, particularly on the rises, and about 10 per cent sandy loam.

Precision agriculture has helped the Dyer family manage their soil variability. Their agronomist, Simon Mock from Clovercrest Consulting, provides a range of advice including on precision agriculture techniques. Jonathan said the family had taken a common path to getting started with precision agriculture. They started with autosteer when he was a child and they now use a full controlled-traffic system with inter-row sowing. They have mapped yields since the early 2000s, but took some years to start using that data effectively.

SNAPSHOT

Name: Dyer Ag, a family partnership that includes Alwyn and Kerryn Dyer and their sons Jonathan and Colin

Location: Kaniva, Victoria

Farm size: 3000 hectares

Rainfall: 400mm average annual rainfall

Soil types: predominant heavy cracking Wimmera clays dispersed with red clays (on rises) and about 10 per cent sandy loam

Enterprises: broadacre cropping – 25 per cent bread wheat, 25 per cent durum wheat, 30 per cent pulses and 20 per cent canola

IT experience supports move to PA

Pursuing his interest in computers and digital technologies, Jonathan did an IT degree and worked as a web developer for a couple of years. When he returned to work on the family farm in 2010, he was keen to understand how the family could use data they and many others were capturing.

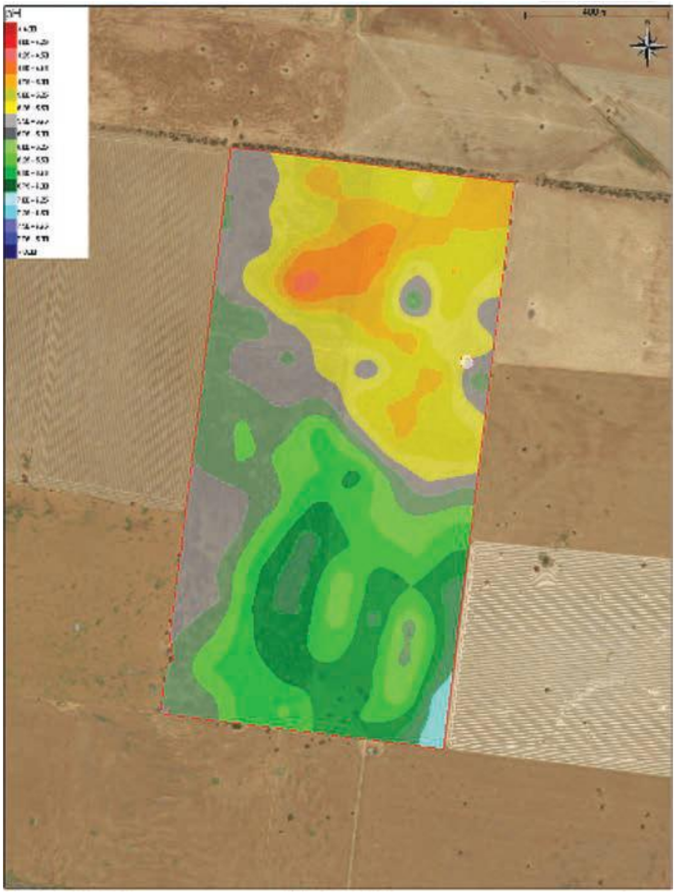
"A good thing about my IT degree is it taught me to solve problems," Jonathan said. "It taught me to think about breaking a big problem down into constituent parts and building a solution from the bottom up. When I came back, I wanted to work out how we could better use the data that so many farmers were collecting. So I did a Nuffield Scholarship on that exact topic in 2015."

He had plenty of time over the summer of 2015-16 to consider how he would apply what he learned while overseas to the family farming operation. "I had a heap of time over summer because we finished harvest the week before Christmas, which only happens in drought years. So, with a bit of advice and encouragement from our agronomist, I started making soil type maps. The drought harvest actually gave us perfect soil moisture availability maps – driven by the differences in soil texture in our paddocks.

"The areas of the paddock that yielded higher in the drought were different than in wetter years. In the data from the drought harvest, you could see very stark lines in the yield maps for different soil types."

He said that 2014 had been quite dry, too, so he then had data to show the wheat yield response to soil type across most of the farm. "So, with those maps and a bit of the old man's intuition, we started doing the soil zone maps. Since then, we've switched away from doing whole paddock management for planning and mapping to doing soil zone management. We're still doing rotations by paddock but also doing deep nutrient management on soil type."

Figure 2.14: pH mapping of the Dyer farm showed some areas of soil had low pH.



Source: Jonathan Dyer

Measuring for management

Jonathan does soil sampling judiciously. "We do soil sampling based on zones of different soil types, which we've determined over years of yield and other mapping. So, for a 100ha paddock we have two or three zones and we do one soil test for each of those zones."

On his travels as part of his Nuffield Scholarship, Jonathan saw growers in the US and Brazil doing one hectare grid soil sampling. He said it was cost prohibitive to do that in Australia and doing soil sampling based on zones was providing the information required.

The family has soil tests done before canola or wheat is planted in the rotation, usually in March or April. "We've been refining the zones as we go and it's been a really helpful tool," Jonathan said. The family has done some EM38 mapping but found yield mapping and soil testing provided enough information for their variable-rate applications.

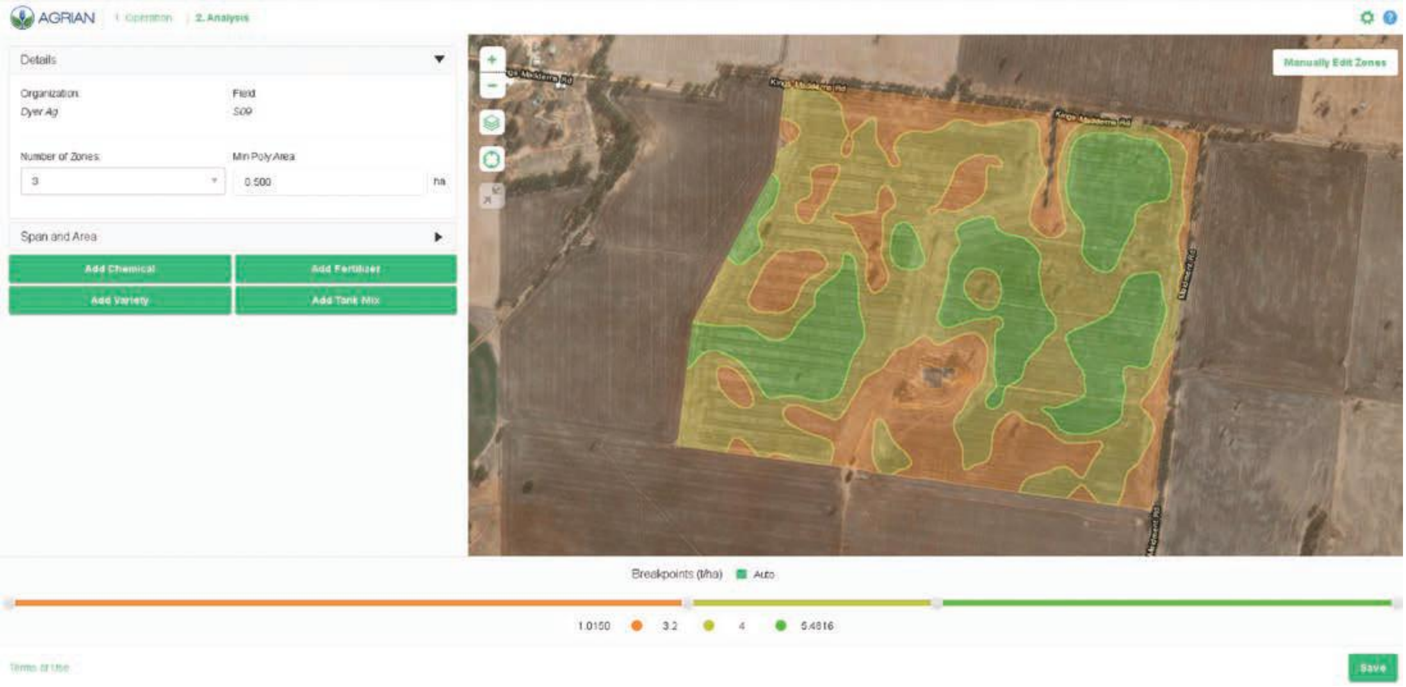
Harnessing the power of data

Jonathan said collecting such data could help growers make better-informed decisions. The data could reinforce growers' intuition and identify new things; for example, on the Dyer farm some areas of soil had low pH. "Once you start collecting information, you find things out. So, every farmer knows that that hill is a bit better, and that other one's a bit worse. And once you can quantify it, put a number to it, you can make economic decisions about it. Is this a big enough problem to address?"

The cost of a protein monitor bought in 2016 was recovered in one year. The real-time protein readings allow them to market wheat at different grades for optimal prices, instead of mixing them all together and selling for the lowest price.

"We were able to get a better financial result straight away, from the first year with that, the power of that live feedback. But the long-term benefit was once you realise how much variability you have on the farm, and you realise all the areas that yield less, you can start to address them." (Read more about this in Chapter 4, 'Protein mapping evens out wheat grades'.)

Figure 2.15: A screenshot as Jonathan Dyer creates soil performance zones.



Organization: Dyer Ag

Field: S09

Number of Zones: 3

Min Poly Area: 0.500 ha

Breakpoints (t/ha) ☑ Auto

1.0150 ● 3.2 ● 4 ● 5.4816

Source: Jonathan Dyer

Jonathan said the main thing they were trying to manage with variable-rate technologies was nutrition, particularly nitrogen. “We can’t control rainfall and that’s our limiting factor for production, basically every year. So we’re trying to fertilise the crops to the potential of the season given the rainfall we’ve had.

“So you have a starting amount of nitrogen. And then you have a target yield in mind based on your rainfall. And then looking at how much is in the soil and how much you’ve added through fertiliser, you ask yourself ‘Do I need to add more? Or do I have enough for the plants to reach their water-limited yields?’ ”

While the family spreads a little bit of nitrogen at seeding with canola, Jonathan estimated about 90 per cent of its applications was now in-crop. “This has been a big change since I returned to the farm,” he said. “Of the nutrients, nitrogen seems to show the most variation on the farm and the one we can more easily address.”

Phosphorus levels also vary across the farm, and the family has done trials to understand how to address it better. “Our heavy clay has a really high phosphorus buffering index. So, often when we get soil test results, you could look at them and think ‘Oh, there’s heaps of P in the soil. That’s great. Don’t need to add any this year’. But we do add a bit anyway and we still get a yield response, because the soil ties it up. So it’s an area we are still trying to understand.”

Figures 2.14 and 2.15 show the images Jonathan created of soil performance zones for a paddock. Figure 2.16 is an example of multiple yield maps put together.

Jonathan said they also used the soil zones for variable-rate gypsum and lime applications. “In addition to the nitrogen variability, another thing that came out of switching to soil zone sampling was that when we tested the different zones, a few came back low pH (Figure 2.14), so we’ve started liming them. This was something you don’t pick up on a paddock scale.

“We did our first liming in 2016. We’ve since used these soil zones to get some soil grid mapping done – just on the areas of concern – and applied VR lime as appropriate,” he said. “We also no longer apply gypsum without a VR prescription. Our self-mulching clays don’t require gypsum; we apply it only ahead of canola for the sulfur component. These areas may get 0.8 to 1t/ha of gypsum, where the red clays in the same paddock that are hard setting are very responsive to gypsum and get up to 3t/ha.”

Where to next?

“We’re dipping our toe in precision ag for weed and pest management,” Jonathan said, explaining that in 2021 they bought a sprayer capable of variable-rate applications and had tried it once. They are also exploring high-resolution satellite imagery and hoping to do more targeted spray jobs using the sprayer. “It will depend on getting better satellite images more frequently,” he said.

They have used satellite imagery to identify insect infestations and used the Satamaps service as a scouting tool. “On two or three occasions now, we’ve noticed low growth areas appearing on imagery on paddocks. When we’ve gone and inspected the spots, we’ve located the infestations. These may well have been missed with a usual crop scouting approach of one or two random spot checks.”

In 2019, the family installed weather stations that record rainfall, temperature, humidity and winds. “We’ve already seen a huge difference in rainfall across our plots this year,” Jonathan said.

Figure 2.16: The completed performance zone map of good (green), average (blue) and red (poor) areas.

Source: Jonathan Dyer

They use information from the weather stations to fine-tune their nitrogen applications according to which paddocks receive more or less rainfall and adjusting yield expectations.

“There are perceptions in the district about which areas are wetter or drier, and these aren’t always true,” Jonathan said. The weather stations show where the rainfall is actually falling.

At Dyer Ag, precision agriculture tools and techniques work hand-in-hand with a minimum-till approach. The family does inter-row sowing using an 18m Horsch Sprinter bar with 72 tynes on 250mm spacing.

“We had started moving towards control-traffic farming many years ago. So we’ve had our spreader and sprayer matched up for nearly as long as I’ve been on the farm, and we’ve been using it for in-crop nitrogen applications and spraying,” Jonathan said. “In 2019, we got the seeder, which was the final step in lining everything up. Now it’s a 12m system, so a 12m harvester, 36m spray spreader, 18m seeder.”

Jonathan said he enjoyed learning and finding ways to optimise the farm’s management. “It is a process of learning and technology developing. The most frustrating thing about farming is you only get to try things one time a year.”

Chapter 3: Trials

Introduction

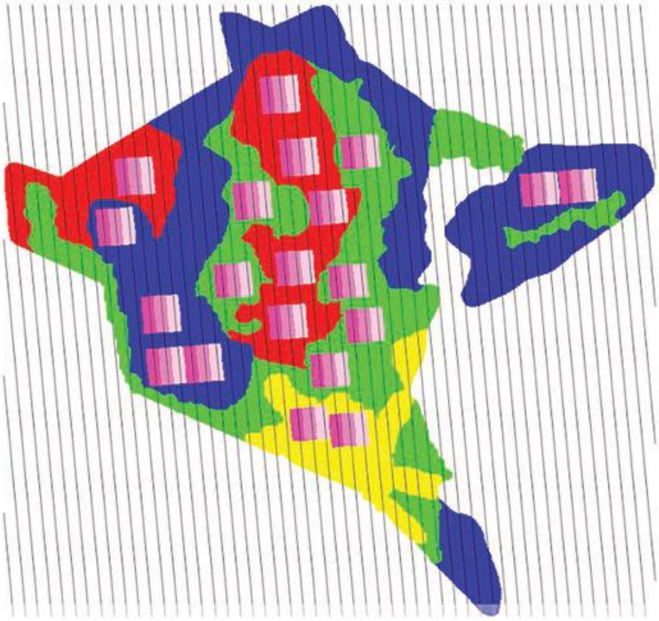
Growers have been experimenting for as long as there has been farming. With the advent of precision agriculture, running trials on-farm became easier. Experimenting on-farm is essential to work out how PA technology is best used.

On-farm trials differ from traditional small plot research trials. As CSIRO project manager Kate Langford writes in this chapter in the section entitled 'Putting farmers at the centre of research to transform agriculture' (page 33), "When you think of agricultural experiments, you might picture a scientist running trials on small plots ...".

On-farm trials flip the process, focusing on farm business improvement rather than discovery science. On-farm trials use the growers' equipment, in their paddocks, at a scale that is consistent with the scale at which farm management decisions are made. Such trials provide useful and credible information to expand practices across the farm.

PA technology makes it easier to vary input rates and lay out experiments automatically. Strip trials – running a strip of different rates alongside the paddock rate – are often the simplest type of trial and can show if input rates are too high, low or spot on.

Figure 3.1: Window trial layout at Vanessa and Darren Cobley's property in Walkaway, WA. The trials are testing various rates of potash and MAP.



Source: Darren Cobley

This chapter showcases some of the simple on-farm trials that growers are using to refine their variable-rate inputs.

In northern New South Wales, Shane Boardman (page 39) is varying seeding and fertiliser rates across different soil types with the aim of finding the rate with the best return on investment (ROI) for that soil type. In-season NDVI maps and end-of-season yield maps will show how effective the trials were.

In South Australia, Zoe and Scott Starkey (page 35) are using strip trials across three soil types with a range of phosphorus buffering index (PBI) numbers to work out the best phosphorus rate. In Western Australia, Ben Cripps (page 38) ran phosphorus trials across two soil types to tease out the economically optimum rate, unexpectedly finding the ideal rates were similar for both soil types.

More complicated trial designs, such as window trials (Figure 3.1), which test multiple strips across the paddock, are also now much easier to implement thanks to PA technology.

For more detail on trial design and tips, including calculating the ROI of various treatments in a trial, see *Calculating return on investment for on-farm trials* at https://grdc.com.au/__data/assets/pdf_file/0026/233945/diy-pa-calculating-roi-for-on-farm-trials.pdf.pdf

Trial design tips

Material in this section was originally published in *The paddock guide to PA trials*, which can be found at https://www.spaa.com.au/public/155/files/pdfs/332_1062_PA_trials_How_to_Brochure.pdf

- Keep it simple! Fewer treatments are generally better. From an analysis approach, one or two treatments present a relatively simple analysis in which yield differences can be easily detected. A simple trial design prevents the trial becoming too big and more prone to the results being affected by paddock variation.
- Build in control strips (a constant or nil treatment). This is a must for comparing variation across the trial.
- Repeat or replicate the trial. By conducting the trial treatments twice or more within the trial or simply repeating the trial in another part of the paddock, you can have greater confidence in your results.
- Make your treatments very different so that the effect on crop yield should be easily detected. For example, double or nothing treatments against the standard paddock rate.
- Trial strips need to be wide enough for at least two (ideally three) header runs for yield data collection. By ensuring three harvester widths for each treatment, there will always be at least two harvester run lines that fall completely within a treatment strip.

Putting farmers at the centre of research to transform agriculture

The material in this section was first published by CSIRO in January 2022 in a website article entitled ‘Putting farmers at the centre of research to transform agriculture’. It was authored by CSIRO project manager Kate Langford.

The article can be accessed at https://www.csiro.au/en/news/all/articles/2022/january/on-farm-experimentation

New global research shows that when farmers and researchers co-create knowledge through on-farm experimentation there can be lasting and meaningful impact to farm profitability and sustainability.

When you think of agricultural experiments, you might picture a scientist running trials on small plots, answering questions they are interested in. But on-farm experimentation (OFE) challenges this model.

OFE supports farmers to conduct their own experiments on their own farms to address the problems they face.

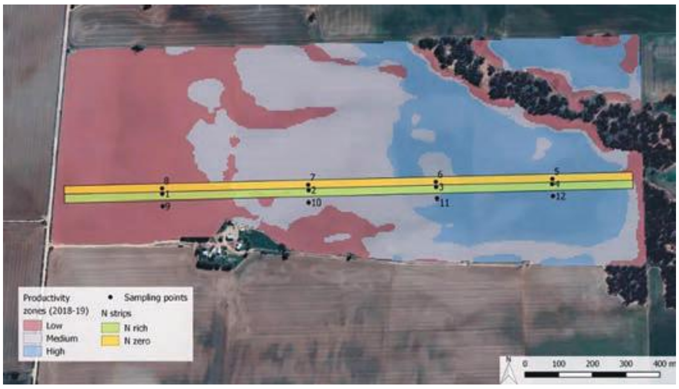
New OFE research has triggered a growing call to overturn traditional methods of agricultural research to solve the challenges facing contemporary agriculture. OFE might involve testing new technologies or practices such as different fertilisers, chemicals, crop varieties or cultivation practices. The farmers observe and measure changes in real farm conditions, with scientists taking on the role of supporter and helping with data analysis and interpretation of results.

Dr Rob Bramley, CSIRO senior principal research scientist (precision agriculture), said success with OFE was driven much more by what farmers saw as effective, combined with spatial analysis, rather than through more classical statistical approaches.

“We’ve found on-farm experimentation to be particularly effective for farmers who use precision agriculture technologies such as variable-rate controllers, yield monitors and crop sensors, because they are able to not only use these to lay out the experiments automatically, but also use them to measure the effects of different management strategies and so derive the optimal approach for their own land and farm businesses,” Dr Bramley said.

“There is also an ‘over-the-fence’ knowledge exchange effect with learnings from one farm helping to inform investigation and decision-making on other farms.”

Figure 3.2: Design of a simple OFE used by farmers Jessica and Joe Koch to inform improved nitrogen fertiliser management in a 101ha wheat paddock at Booleroo Centre, SA.



Source: Jessica Koch

Farmers using on-farm experimentation

OFE recognises that farmers hold local knowledge about their production contexts and practices and are themselves key sources of innovation as they routinely experiment.

Joe and Jessica Koch, cereal and sheep farmers from Booleroo Centre in South Australia, were involved in a OFE nitrogen trial over the 2021 season. For them, OFE meant they could see first-hand how different management regimes affected their yields.

Jessica Koch said: “With the on-farm experimentation approach, we were able to better understand how our in-crop nitrogen management decisions were reflected in protein, yield and therefore profit at the end of the season. We believe that paddock-scale strip trials are the best way to practically assess inputs and better understand how our variable soils respond to different rates and timings.” Figure 3.2 shows a simple OFE trial run by the Kochs to improve nitrogen fertiliser management.

Crop sensors, such as those mounted on this tractor, assist cereal farmers such as Mark Branson in collecting the data needed to assess the effects of different experimental treatments. Photo: Rob Bramley

Hans Loder, supported by PhD student Xinxin Song (University of Tasmania), pruning vines for determination of pruning weight in a vineyard OFE at Penley Estate in Coonawarra, SA. Photo: Rob Bramley

Mark Branson, of Branson Farms in Stockport (mid-north of South Australia), agreed with the Kochs. He has run such trials for several years.

"In-crop nitrogen management is a very hard practice to get right," Mark said. "The OFE approach has allowed us to see how different management affects grain yield and protein. The practical aspects of strip trials have allowed us to see how different soils and slopes respond to different nitrogen management, making optimising N rates and timings so much easier."

Meanwhile, Hans Loder, who is vineyard manager at Penley Estate in the Coonawarra wine region of South Australia, also sees trials as an important part of his business improvement. He conducted strip-based trials to inform fertigation and compost application as means of improving vine vigour and fruit quality, especially in respect of yeast assimilable nitrogen (YAN), which can have a major impact on winemaking.

"Using the strip-based on-farm experimentation approach, results could be assessed in ways which I would not have otherwise considered but which greatly assisted in untangling the effects of vineyard variability. This provided immediate benefit and insight to the whole Penley Estate team beyond just myself and our winemakers," Hans said.

Advantages of on-farm experimentation

Tailored decision-making: On-farm experiments allow farmers to address specific questions and challenges relevant to their individual operations. This targeted approach enables them to make informed decisions that directly impact their business outcomes.

Farm-specific insights: On-farm experiments generate data and insights that are specific to a particular farm's conditions, such as soil type, climate and management practices. This personalised information helps farmers tailor their strategies to maximise productivity and efficiency.

Knowledge sharing: Successful on-farm experiments are often shared with the broader agricultural community, whether as a collection of trials for researchers to draw upon, with the farm agronomist or 'over the fence' with a neighbour, contributing to the collective knowledge base.

Local knowledge utilisation: Farmers possess a wealth of local knowledge and insights about their land and operations. On-farm experimentation allows them to incorporate this knowledge into their decision-making, leading to more effective solutions.

Informed risk management: Farmers can test new techniques, inputs or practices on a smaller scale before implementing them across the entire operation, reducing potential losses.

Continuous improvement: Through repeated experiments, farmers can refine their practices over time.

Data-driven decisions: Experimentation generates data that can inform decisions and strategies. Farmers can use this data to track changes in yield, quality, resource use and other key metrics, helping them make data-driven choices.

Long-term sustainability: On-farm experiments often include investigations into sustainable practices, such as reduced chemical usage, soil health improvement and water conservation. These efforts contribute to long-term environmental sustainability.

Strip trials to refine variable-rate phosphorus

Fifth-generation growers Zoe and Scott Starkey are running phosphorus (P) strip trials with the aim of starting variable-rate fertiliser applications. The trials are part of the project ‘Improving farmer adoption in farm-scale zoning for improved fertiliser decision making’, which is run by Mallee Sustainable Farming (MSF) with assistance from Dr Sean Mason (Agronomy Solutions) and funded by the South Australian Drought Resilience, Adoption and Innovation Hub.

The project aims to help growers create paddock zones, use soil tests and data layers for decision-making, use paddock strips to test optimal nutrient applications in different soil zones, and ultimately use variable-rate fertiliser inputs.

A desire to be more efficient with inputs and trial results from 2022 are key drivers of the Starkeys’ motivation to apply variable-rate fertiliser. These trials, on an adjacent paddock, showed some soils were very responsive to P while others were not. The PBI varied from 45 to 103 on that paddock, with the higher PBI affecting P availability to the crop.

“We’re keen to learn how the tie-up (phosphorus buffering index) affects the crops and how the crop will respond to different rates of P. We want to learn what soil types need more fertiliser and where we can cut back,” Scott Starkey said. “Plus, if the crop isn’t off to a good start because it’s restricted by P, why throw extra nitrogen at it?”

SNAPSHOT

Name: Zoe and Scott Starkey

Location: Sanderston, South Australia

Farm size: 2800ha holding, 2225ha farmed

Rainfall: 330mm long-term average, 110mm growing season rainfall (2023)

Soil types: grey calcareous soils grading to red loams

Enterprises: cropping, sheep

Rotation: typically a three-year grass break rotation that includes vetch, canola, wheat-on-wheat, followed by barley with a little bit of oaten hay

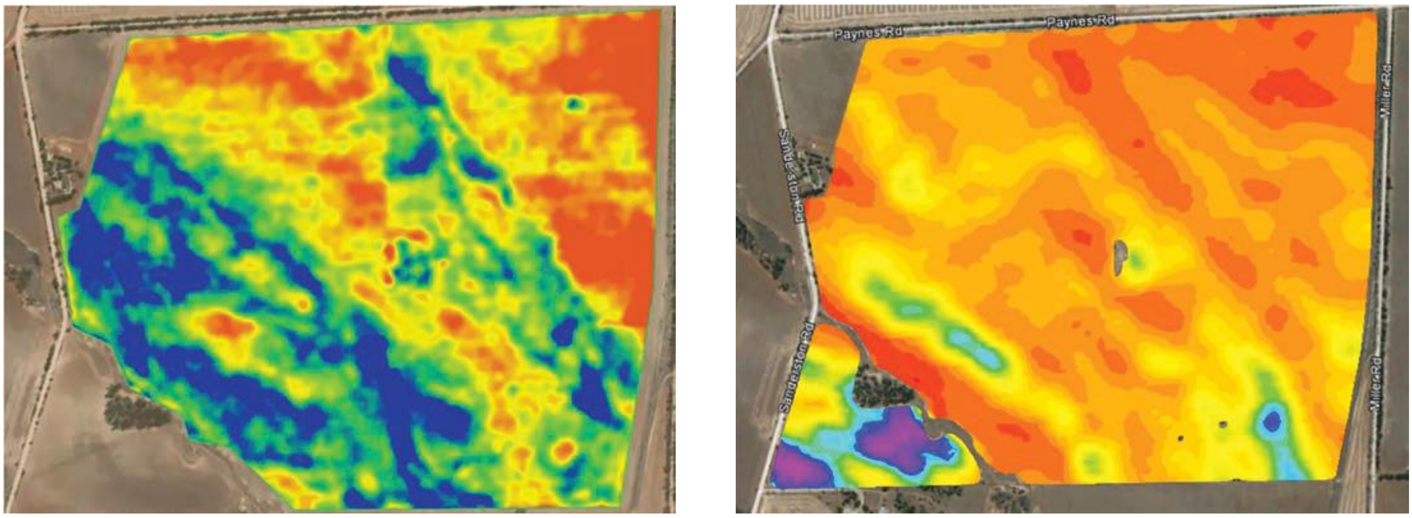
Compatibility issues are one reason the Starkeys have been hesitant to use variable-rate fertiliser. Despite having tech support on-hand during the trial set-up, there were problems.

“The VR map was showing up on the screen, but the seeder wouldn’t pick up on the rate changes, so I had to manually change the rates while applying,” Scott said. They use the same brand of machinery but have two different screens (TopCon and Case).

Zoning the paddock

Although many growers use EM maps as a basis for paddock zones, in this paddock the EM38 map did not correlate well with NDVI maps or the Starkeys’ knowledge of their paddocks. Figure 3.3 compares the EM38 map of the paddock (right) to a 2021 wheat NDVI map (left).

Figure 3.3: 2021 Wheat NDVI (left) and EM38 map (right).

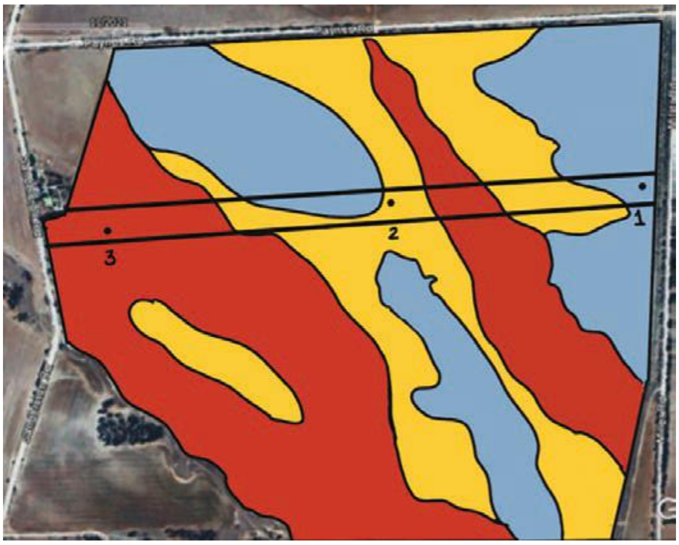


Source: Sean Mason

Figure 3.4: Satellite image of the paddock. The main areas of productive red loam soil are outlined in black.

Source: Sean Mason

Figure 3.5: Zone map – blue = grey, calcareous, rocky soil with higher P requirements; red = red productive loams (replacement P should work and worth feeding with N); yellow = low calcareous intermediary soil.



Source: Sean Mason

Paddock soils include a grey, stony calcareous soil with a high PBI and a productive red loam with a lower PBI. Between these main soil types is an intermediary soil, which tends to be less calcareous and have a lower PBI than the grey soil.

In this paddock, NDVI maps, yield maps and satellite imagery work better to find soil type changes and create zones. The grey, stony calcareous soil and red loams are distinguishable on satellite images (Figure 3.4).

Dr Sean Mason (Agronomy Solutions) is managing the trial and said that the rocky soil zones throughout the paddock and the soil type in the south-west corner with very high EM38 readings (Figure 3.3) might be behind the poor correlation with the EM38 map.

The three paddock zones are based largely on soil properties and were refined with NDVI images and yield maps from the past few years (Figure 3.5).

Although EM is not an overly useful layer in this paddock, the Starkeys have run small strip trials in areas where the EM38 map does vary to see if there are any yield or crop biomass differences that line up with the EM38 map variability.

Setting the P rate

Soil tests in each zone (Figure 3.5, Table 3.1) were based on NDVI readings:

- Sample 1: flat/grey – low early cereal production;
- Sample 2: intermediate grey, flat – intermediate early production; and
- Sample 3: red/darker – high early cereal production.

Results indicated that zones 1 and 2 had a higher PBI (84, 104) and would need more P. Zone 3 on the red loam had a low PBI (40) and less P tie-up was expected. Phosphorus deficiency in the higher PBI zones was likely contributing to differences in early crop growth. Both Colwell P and DGT-P were tested in this paddock. The DGT-P test provides a better guide to P-available stocks in the calcareous soils where Colwell P can overestimate soil-available P and requires the PBI test to assist in the interpretation of the value. The DGT-P test results indicated P levels were low-marginal for wheat in zones 1 and 2.

Based on soil P and PBI results, P strip rates were set at:

- base grower rate – 55kg/ha MAP;
- low rate – 30kg/ha MAP; and
- high rate – 80kg/ha MAP.

The strips were 1.2km long and 36m wide and covered both the

Table 3.1: Selected soil test results.

Zone (sample)		OC (%)	Colwell P (mg/kg)	PBI	Target Colwell P* (mg/kg)	DGT P (ug/L)
1			36	84	26	45
2	Calcareous soil	2.09	44	104	29	49
3	Red loam	1.24	57	40	20	180
Target			**20–25**	**< 70**		**>65**

Note: A large proportion of gravel/stone in zones 1 and 2 might suggest actual plant-available soil P levels are lower than recorded (*Moody 2007).

main soil types and the range of PBIs (Figure 3.5). The paddock had been top-dressed with urea earlier, so any difference in crop growth would be attributed to P.

Trial progression

The Starkeys could see the difference in the strip trials at the beginning of the season. Figure 3.6 shows how the various strips were performing by early August.

“Early on, the difference between P rate was visually evident, and the higher P rate looked better. However, by late August the crop had visually evened-up,” Zoe Starkey said.

Even though the crop appeared even, tissue test results told a different story.

Plant tissue tests at GS30 showed P levels appeared to be driving variation in early season cereal production. Plant tissue P was lower on the grey calcareous soil than the red loam, while the crop on the red loam had higher NDVI readings (Figure 3.7).

“The header will tell the story of if it’s actually worked,” Scott said. “We’re looking forward to seeing how it goes. We’ve got yield and protein monitors in the header, so come harvest time we’re looking forward to seeing how much of a difference it makes.”

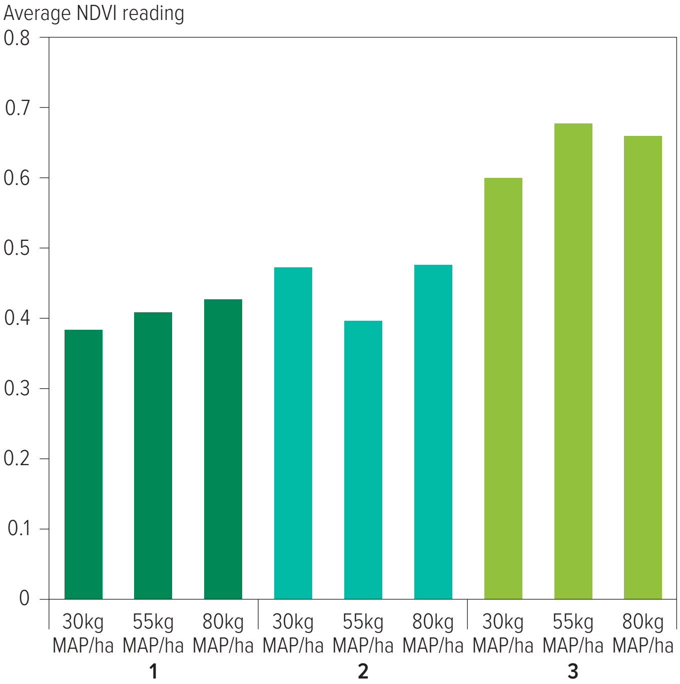
Sean Mason will compare which treatment had the most impact on yield and do a gross margin analysis to work out the most profitable fertiliser rate for each zone. When the trial is done, the Starkeys plan to use what they have learnt to expand variable-rate phosphorus across the farm.

“We use vetch as our main break crop and that’s more P hungry than we first thought. We’re probably going to variable-rate P for vetch as well as cereals.”

Figure 3.6: Drone image of strip trials, taken in the first week of August 2023.

Source: Tanja Morgan

Figure 3.7: Average NDVI readings from zones 1, 2 and 3.



Source: Sean Mason

Reefinating

With limestone at the surface across half the arable land on the farm, the Starkeys have invested in a Reefinator. Zoning where to reefinate has been relatively easy as the limestone is visible on the surface. Some areas are also easily visible on satellite images. They are gradually improving soil depth and root depth by shaving the limestone.

“We want to improve root depth for a more resilient crop, especially during a cut-off spring when it stops raining in August and the crop needs access to residual soil moisture to see it through,” Zoe Starkey said.

It is still early days with reefinating. About a quarter of the arable land has had at least one treatment, but the very stony paddocks are the priority, having multiple passes over the past three cropping seasons.

The 2023 strip trial paddock has not yet been reefinated. Sean Mason said: “An interesting point to watch will be if reefinating the soil changes phosphorus management in the future, because you are potentially opening up previously non-exposed limestone with some soil mixing along the way.”

References

Moody PW (2007) Interpretation of a single-point P buffering index for adjusting critical levels of the Colwell soil P test. *Australian Journal of Soil Research* 45, 55–62. https://doi.org/10.1071/SR06056

Working out the best phosphorus rate for two soil types

Ben and Ange Cripps run Wepowie Farming Co (more on their story in Chapter 6). The main farm is based at Ogilvie, Western Australia, and in 2014 they bought new blocks at Binnu, about 30km to the north-east. Ben believed it required more phosphorus (P) fertiliser than the farm at Ogilvie, but was unsure how much.

He set up a P trial in a paddock with two main soil types – a gravelly sand and a red loam. Ben thought the gravelly soil would have a higher phosphorus buffering index (PBI), requiring more phosphorus to meet crop demand. Three phosphorus rates (0, 30, 60kg/ha) were replicated as strips in the paddock (Figure 3.8).

The trial was implemented as part of a variable-rate application map and results were analysed using yield data collected by standard harvest operation.

In 2014, most of the rain fell in the first half of the year and they experienced a really hot, dry spring. This coincided with flowering, killing many plants and lowering grain fill. Even with an average season, the phosphorus trial still showed a significant result.

Table 3.2 outlines the yields, additional income and ROI on each soil type. Grain price was $300/t. On the red loam the return on investment was 200 per cent for 30kg MAP/ha and 210 per cent for 60kg MAP/ha, compared with no phosphorus. The small increase in response from 30 to 60kg MAP/ha indicated the ideal rate was closer to 30kg/ha, and Ben aimed to apply 30 to 40kg/ha to this soil type. Figure 3.9 shows the wheat yield map after the trial, with the zero P strips clearly visible.

On the sandy gravel, 30kg MAP/ha had a greater ROI (180 per cent) than 60kg MAP/ha (150 per cent), compared with no phosphorus. Ben aimed to apply 30kg/ha to this soil type. Both soil types ended up with a similar optimal MAP rate.

Table 3.2: Selected soil test results.

Treatment	30kg	60kg	Nil
Treatment cost	$15	$30	$0
Red loam			
Yield (t/ha)	1.46	1.62	1.31
Additional income for treatment/ha	$45	$93	$0
ROI*	200%	210%	0%
Sandy gravel			
Yield (t/ha)	0.98	1.09	0.84
Additional income for treatment/ha	$42	$75	$252
ROI*	180%	150%	0%

* ROI calculated as (additional income – treatment cost)/treatment cost.

Source: Ben Cripps

SNAPSHOT

Name: Ben and Ange Cripps

Location: Binnu (40km north-east of Northampton), Western Australia

Farm size: 5400ha (total between Ogilvie and Binnu)

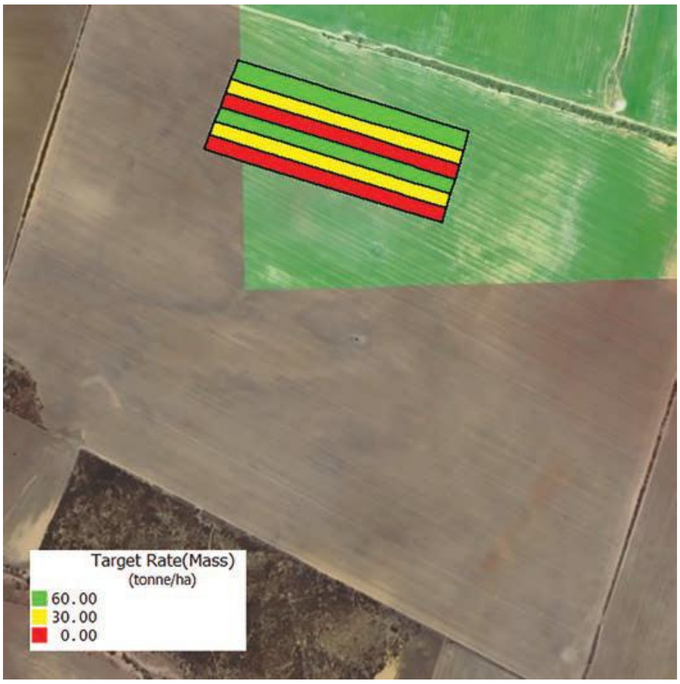
Rainfall: 300mm average annual rainfall

Soil types: a mix of gravels, clay loams and yellow sandplain

Enterprises: cropping

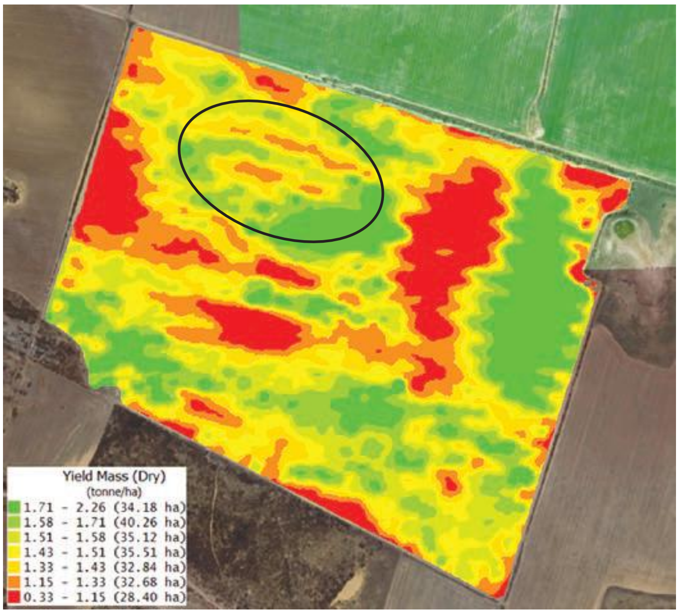
Rotation: wheat/lupins/canola

Figure 3.8: Phosphorus trial layout at Binnu, WA. Red = 0 MAP, yellow = 30kg MAP/ha, green = 60kg MAP/ha.



Source: Ben Cripps

Figure 3.9: 2014 Mace⦶ wheat yield map where the zero P strips are visually evident. The average yield was 1.4t/ha.



Source: Ben Cripps

Strip trials for ideal starter fertiliser and seeding rates

Northern New South Wales grower Shane Boardman is using strip trials across variable soils on a 600ha paddock to work out the optimal seeding and starter fertiliser (Starter Z) rates. Soils in the paddock include black self-mulching clays, red soil rises and a band of sandier soils through the middle of the paddock – shown as a band of red in Figure 3.10. These sandier soils become a creek during floods.

"When we go to plant something it's always a fair struggle with the lighter soils … it's always too wet or too dry," Shane said.

The paddock was divided into four soil zones (poor, poor-medium, medium-good and good) based on an EM survey conducted in May 2021 (Figure 3.10).

Soil tests in 2023 were used to develop new VR fertiliser (Starter Z) rates for the paddock, which was sown to barley. The soil tests were collected from the four different zones in the paddock. The soil test results showed that the poor and poor-medium zones did not need any fertiliser. However, trials in the past had shown that small amounts of fertiliser helped with crop establishment – these areas received 15kg/ha. The medium-good areas received 45kg/ha and the good areas 30kg/ha.

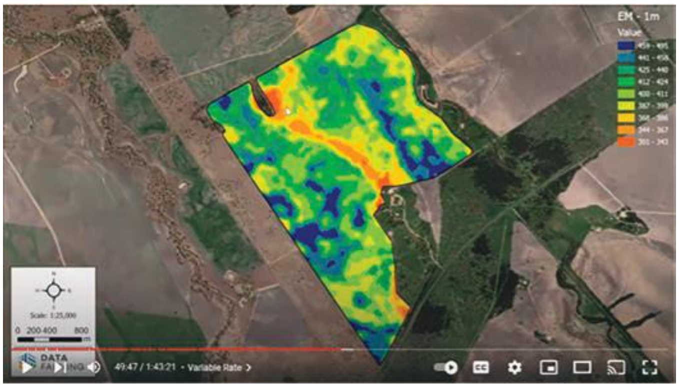
Shane also ran strip trials across the paddocks (Figure 3.11) at:

- variable rates based on the four zones (clear strip);
- 40kg/ha (green strip); and
- 50kg/ha (blue strip).

Barley seeding rates were also varied but in a slightly different way to the fertiliser. Figure 3.12 shows the variable rate seeding rates. Two trial strips matched seeding rates to the zones, putting higher rates (60kg/ha) in the two poorer zones to establish good ground cover and see how these areas yielded come harvest. The medium-good zones were seeded at 50kg/ha, and the good zones at 40kg/ha. These are the two top 'clear' strips in Figure 3.11. The third strip was seeded at 40kg/ha and the rest of the paddock at 50kg/ha.

The trial locations were chosen to ensure strips would cover each of the four soil zones. Strips were 250m wide to allow for the fact that the run direction was north/south and to collect enough meaningful data at the end of the season to compare the results.

Figure 3.10: An electromagnetic survey of the paddock shows great variability, with a significant area of 'light' soils evident in the middle.



Source: Christian Capp

SNAPSHOT

Name: Shane and Annabelle Boardman

Location: Tulloona, New South Wales

Farm size: 4500ha

Rainfall: 600mm

Soil types: largely black self-mulching soils, red soil rises and patches of sandy soil

Enterprises: cropping, cattle

Rotation: wheat/barley/chickpeas/wheat or barley/dryland cotton

Christian Capp of GRoh Ag, the Boardmans' precision agriculture consultant, said: "The overarching goal is higher grain output. We are not necessarily increasing inputs but we are putting them into areas where they will be better utilised. There is no point putting large amounts of fertiliser in an area where the soil type can't use it."

Figure 3.11: Variable fertiliser rates and strip trials on the paddock.

🟧 15kg/ha 🟨 30kg/ha 🟩 40kg/ha 🟩 45kg/ha 🟦 50kg/ha

Source: Christian Capp

Figure 3.12: Variable-rate seeding strip trials were run across the paddock, covering each of the soil zones.

🟥 40kg/ha 🟩 50kg/ha 🟦 60kg/ha

Source: Christian Capp

Chapter 4: Yield maps and protein sensing

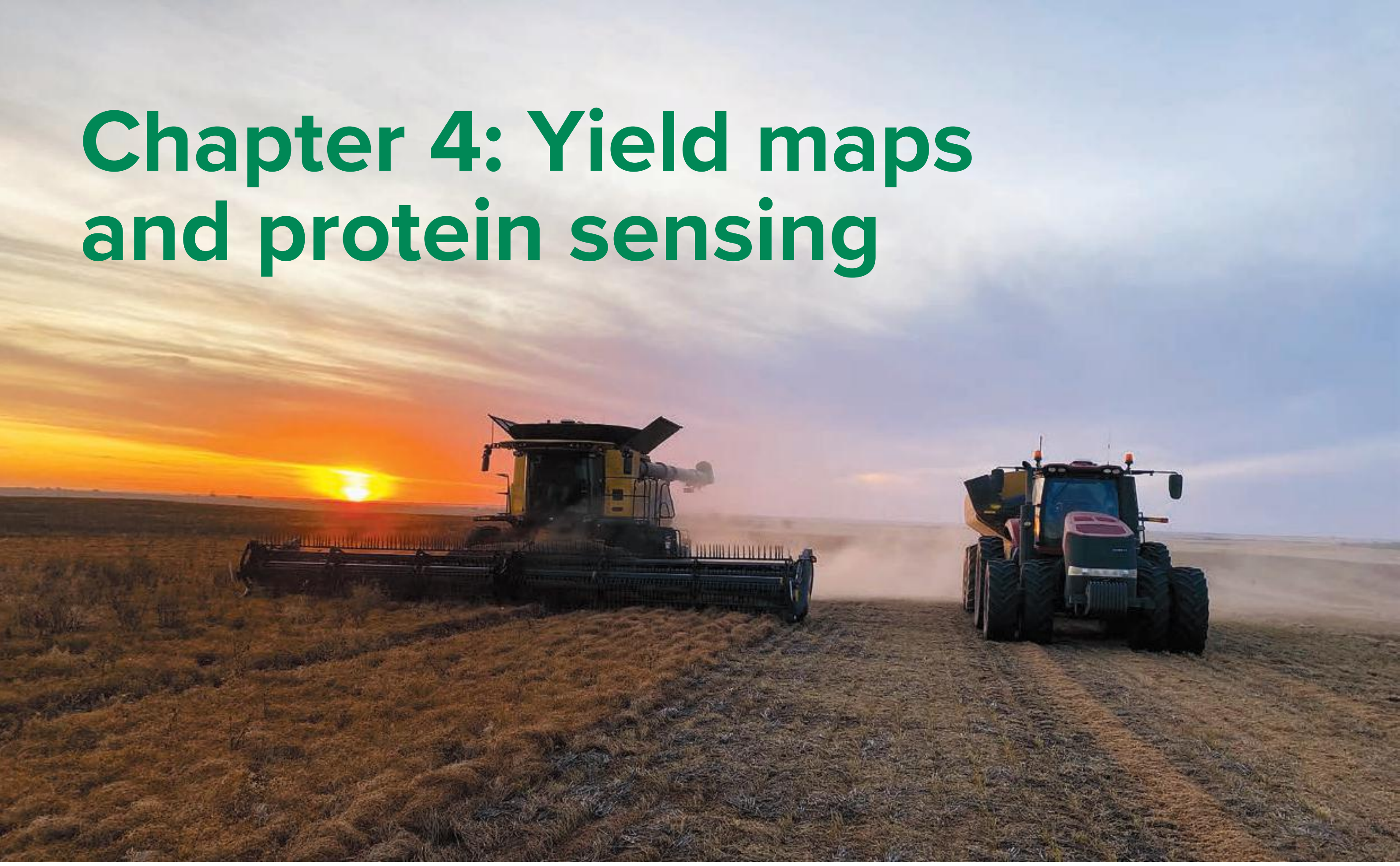


Photo: James Venning

Introduction

Yield maps are the most important data layer to collect as they are the ultimate judge of farming decisions.

For those just dipping their toes into variable-rate applications, yield maps are a great place to start because they quantify the magnitude of variability. If there is a very narrow yield range across 80 per cent of the paddock, there might not be much that needs to be changed from a VRT perspective. If there is a very large variability in yield, there is much to investigate and potentially manage better.

Collecting and managing high-quality data is the first step in driving better decisions for next year's crop. Most modern harvesters already have the ability to map yields. Collecting raw data is easy, but to use it for decision-making the harvester and yield monitor need to be set up correctly. A section in this chapter, 'Harvest data best practices' (page 41), outlines tips for machinery checks and calibrations to undertake before and during harvest to ensure the best-quality data is captured.

Cleaning yield maps post-harvest is often done by an agronomist or PA specialist to remove erroneous datapoints (for example, extremely high or low yields).

Using yield maps

The simplest way to use a yield map is as a starting point to investigate paddock variability or as a problem-solving tool, where comparing low and high-yielding areas (followed by paddock assessment) might reveal the cause of the variability. Other uses include:

- tracking yield over time;
- comparing crop varieties on-farm;
- verify decisions, such as nitrogen zones or application rates; and
- developing PA zones.

Building on yield maps provides even more insights. In this chapter, in the section headed 'Yield maps as phosphorus export maps' (page 42), agronomist Bindi Isbister explains how using yield maps to track phosphorus (P) exports from the paddock can highlighted P run-down. In the section headed 'Turning yield maps into profit-and-loss maps' (pages 44 – 46), two examples are given of using yield maps to create profit-and-loss maps.

In some paddocks, zones 'flip-flop'; yield is good one year and poor the next. In the section headed 'Flip-flop zones', Gus Hogan (page 47) explains how to use yield data in these zones.

Protein sensors

Protein sensors assess grain quality during harvest and are mostly used to blend grain more strategically for higher profit and assess and refine variable-rate nitrogen applications.

The section 'On-the-go protein sensors' in this chapter summarises how protein sensors work and provides more detail on using the data for better management decisions. Growers Jonathan Dyer (page 53) and Neale Postlethwaite (Chapter 6, page 88) describe how they use protein data on their farms to adjust their nitrogen strategies and blend grain.

Harvest data best practices

Note: terminology and requirements may differ between manufacturers and with the age of the machine.

Pre-harvest machine checks

Issues with these will create error codes and/or inaccurate data.

1. Check the deflector/impact plate for wear and tear.
2. Check guard around impact plate for damage.
3. Check for jammed objects or straw and grain build-up behind the plate.
4. The mass flow sensor on the plate records vibration and the force of the grain as it hits the plate, that is the amount of grain entering the bin, or yield. Check the harness off the back of flow sensor is in good condition and connected properly.
5. Clean the front of the moisture meter sensor with clean damp cloth.
6. Check the sensor chamber auger is cleaned of debris.
7. The proximity sensor ensures the moisture sensor fin is completely covered by grain. If any of the sensor plate is exposed, the moisture reading will not be accurate. Clean the proximity sensor with a clean damp cloth.

Pre-harvest calibrations

1. **Temperature calibration.**
   The reading should be an accurate reading of the surrounding air temperature. Temperature calibration should be performed when the sensor has not been in direct sunlight or when the bin is filled with grain. To be performed at the start of the season.
2. **Mass flow vibration calibration.**
   This is to determine what is normal machine vibration without crop going through it. Be certain to select the correct crop in the header set-up prior to completing this calibration. Must be performed with the correct head on the combine and in operational position for harvest. Needs to be completed at the start of each season, for each crop, before entering the paddock.
3. **Moisture sensor correction.**
   Temperature calibration should be completed before this correction. Moisture sensor correction should be done for each crop type and at the beginning of season.
4. **Mass flow sensor calibration (yield/weight calibration).**
   Note that temperature and mass flow vibration calibration need to be completed before weight calibration. This is the most critical part of the yield monitoring system and is vital for accurate yield recording. Perform at the start of each season and for each crop type.
5. **Height/header position sensor.**
   This represents the height of the header below which data will be logged while harvesting. Needs to be adjusted for crops of different heights.

Pre-harvest display/machine set-up

1. **Make sure previous seasons' data is properly stored.**
   Check yield data from previous seasons is stored safely. If the machine has the ability to send data wirelessly, check that all data has been received by the cloud (for example, John Deere Operations Center, Case AFS Connect or New Holland MyPLM). If data is missing, or the ability to send data to the cloud does not exist, export data to a USB and upload it to the relevant platform for storage.
   Note: All new machines have the ability to wirelessly send data to the cloud-based platform of their respective manufacturer. However, this feature relies on mobile coverage; without that, data will be stored on the display and will need to be transferred via USB stick.
2. **Remove old data from display.**
   Delete old data from the display to free up space. Functionality can decrease and displays can stop working properly if they get too full. John Deere 2630s and Gen 4 displays, for example, store all data on the display even if data has been sent via wireless data transfer or exported to USB.
3. **Remove old data from USB.**
   Displays such as the Case Pro 700 and New Holland Intelliview IV use a USB in the side to capture and store data. Remove old data from these before starting harvest.
   Note: it is imperative that during harvest, the USB remains in the display. You cannot transfer data to a USB at a later date if the USB was not plugged in at time of operation.
4. **Software updates.**
   If applicable, update software on displays, receivers or harvest controllers. Out-of-date software can impact performance on all these components. When troubleshooting issues, the first thing tech support will ask is what software version you have installed.
5. **Set-up data.**
   Before harvest, importing up-to-date set-up data (boundaries, guidance lines, paddock names) into each header will ensure a smoother, more efficient start to harvest. This is particularly important if using different machines. The set-up of this data is typically done in the software platform relevant to the display in your machine. Once the set-up is complete in your software, depending on your machine capability, this can be transferred to the machine wirelessly or via USB.
6. **Yield data capture.**
   If using cloud-based storage, these platforms are designed with boundaries being paramount to data capture and viewing. They act as a funnel for the flow of the georeferenced yield data into the correct paddock. As such, some platforms require a boundary to view the data. Ensuring correct client/grower, farm and paddock structure in each machine will also make data collection much easier if multiple machines are working together.

During harvest

Harvest operation

1. Perform required calibrations for each change in crop being harvested.
2. Try to avoid altering settings mid-way through a paddock.
3. Double-check the crop type for each paddock.
4. If possible, record total tonnes from each paddock. This can help with the post calibration of yield data, especially with multiple headers operating.
5. Raise the header front at end of runs to reduce the amount of rubbish data.
6. Where possible, try to keep a full comb. Modern headers with section control will automatically reduce the cut width for yield mapping purposes based on coverage already recorded. This means it will not record zero yield for that area because it knows it has already harvested that part of the paddock.
7. When running numerous headers in the same paddock, if there is an older header without yield monitoring working in a paddock with a header monitoring yield, try to harvest side-by-side. This allows you to interpolate the areas that you do not have data for by averaging the datapoints around that area.
8. If harvesting trial areas, try and use the one header. This will eliminate data variability due to differences in machine setup.

Post-calibrating yield data

If there are differences between recorded and actual yield harvested, the yield data needs to be calibrated. This will often occur when multiple headers that have been calibrated differently (or not at all) are used in the one paddock. An obvious clue that your data needs calibrating is 'striping' in the yield map where each machine has been working.

If you don't know the actual tonnes off a paddock, you can remove 'striping' by simply matching the average tonnes recorded across all headers. This will still allow you to visualise trends and variation across the paddock. However, post calibrating with actual tonnes allows for better record keeping and accurate comparisons across seasons.

MORE INFORMATION

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Yield maps as phosphorus export maps

With some simple assumptions and calculations, yield maps can be used to monitor nutrient exports from the paddock. This was the case for a property in Eradu, about 70km from Geraldton, WA.

In 2022, despite above-average growing season rainfall (346mm), this particular paddock did not perform as well as expected. It had been previously limed and deep-ripped to 550mm in 2020 and the grower was expecting a decent yield as the paddock had performed much better since amelioration.

Due to budget constraints, phosphorus (P) had been dropped back on that paddock for the previous two years. The paddock had three soil management zones (Figure 4.1).

The variable-rate P map (Figure 4.2), yield maps (Figure 4.3) and a simple P balance calculation were used to estimate P extracted from the paddock in the grain each year. In 2022, the paddock had two P rates applied; 8.4kg P/ha in the low zones and 9.8kg P/ha in the medium and high zones (Figure 4.2).
The P balance was calculated as:

Annual P balance = total units P applied – (yield x 3)

For example, where yield = 2.2t/ha in the low P zone:

Applied P (8.4kg P/ha) – (2.2 x 3)

= 1.8kg P/ha remaining

This means that:

- for the low P rate (8.4kg P/ha), any areas yielding above 2.8t/ha were exporting P; and
- for the high P rate (9.8kg P/ha), any areas yielding above 3.2t/ha were exporting P.

With yields up to 4.4t/ha in the paddock, P was being exported in the higher-yielding areas.

Four-year cumulative P balance (2019–22)

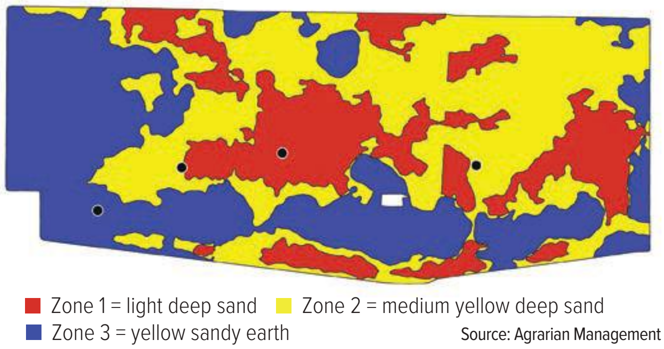
Running the P balance calculation over four years of a canola/wheat/canola rotation showed there was a negative P balance in the high-yielding areas, that is the crop had extracted more P than was applied. This is evident in the lighter-coloured areas in Figure 4.4.

Soil tests in 2023 confirmed that since 2021, subsoil P had declined. At one test site (in the medium sand zone), P had dropped from:

- 14 to 12ppm from 10 to 20cm; and
- 19 to 14ppm from 20 to 30cm.

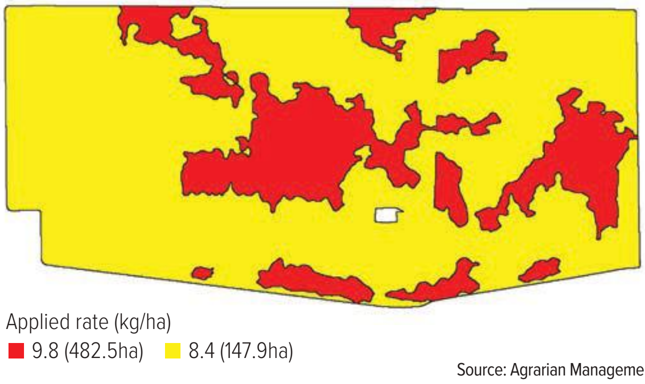
Figure 4.3 shows yield maps from 2019 to 2022. Figure 4.4 shows the P balance over those four years. Note that the yield maps in Figure 4.3 are on different legend scales to highlight low, medium and high-yielding areas.

Figure 4.1: Soil management zones in a paddock on a property at Geraldton, WA, 2022.



Source: Agrarian Management

Figure 4.2: 2022 variable-rate P applications in a Geraldton, WA, paddock. Low P zones = 8.4kg P/ha. Medium and high zones = 9.8kg P/ha. The paddock has three zones, but the medium and high zones are treated together with one P rate.



Source: Agrarian Management

Conclusion

Using yield data and soil tests to review nutrient balances can help better target nutrient decisions. This analysis highlights that there may be a P deficiency in some areas of the paddock and the consistently higher-yielding areas are running down soil P stocks. Reducing P rates can be a strategy to reduce budget pressures but should not be long-term approach. The grower and his agronomist will review the nutrient balance after harvest and adjust P rates if required (in 2023 the yield is likely to be low due to rainfall limitations).

A similar analysis was run to estimate the nutrient balance for nitrogen (N) and potassium (K) in this paddock as there was positive nutrient balance on the medium and low zones, suggesting more is being applied than used by the crop. Soil test levels of K and N are low to 30cm. The sandy soil types are highly leachable and in an above-average season it may be that N and K were leached before roots could use applied N and K. Further investigation is required to confirm the depth of leaching (or loss to the atmosphere) and to assess the economic benefit of different application strategies to improve nutrient efficiency.

MORE INFORMATION:

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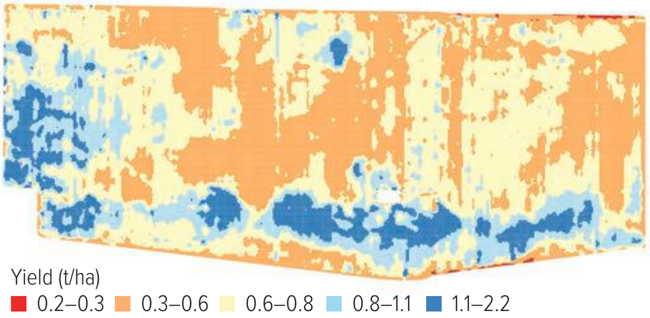
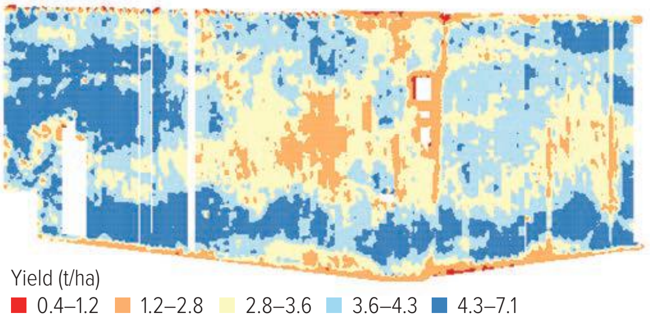
Figure 4.3: In a paddock in Geraldton, WA, canola and wheat yield maps for 2019 to 2022.

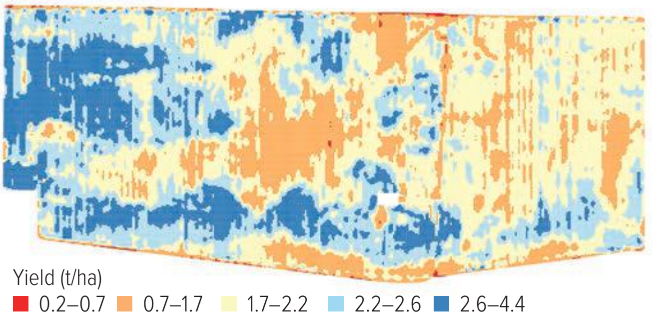
a) 2019 canola yield map



b) 2020 wheat yield map



c) 2021 canola yield map



d) 2022 wheat yield map

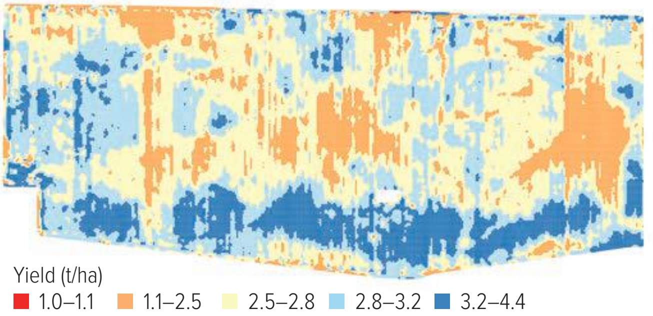
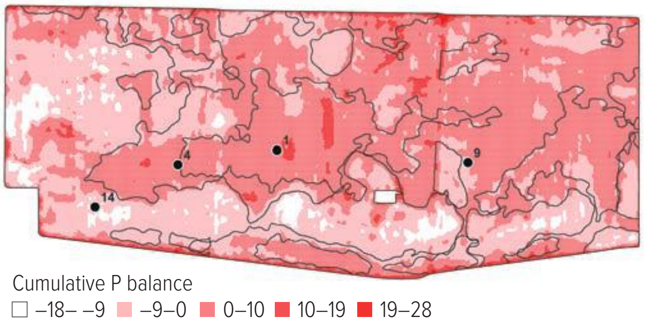


Figure 4.4: In a paddock in Geraldton, WA, the four-year (2019–22) cumulative P balance shows P is being extracted in the higher-yielding areas.



Source: Agrarian Management

Turning yield maps into profit-and-loss maps – two examples

New Zealand

Turning yield maps into profit-and-loss maps helps growers focus on profitability in the paddock and make better management decisions. Allister Holmes from Lincoln Agritech, in New Zealand, has worked with several growers to help them better understand which parts of their paddocks are consistently profitable and which are consistently generating losses.

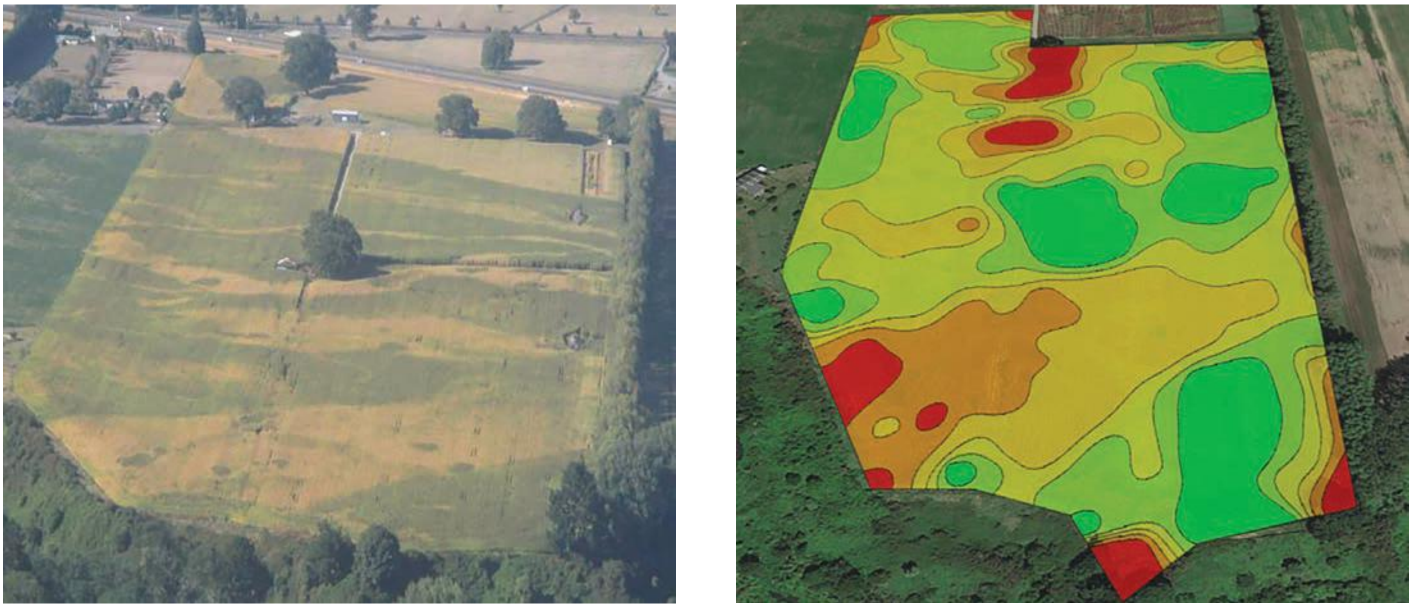
"Agriculture in New Zealand is probably a lot more variable than Australia because of the small landscape scales that we have," Allister Holmes said. "The average cropping farm in New Zealand is around 400 hectares and the average maize paddock would be somewhere in the eight to 10 hectare range.

"Using yield monitors on harvesters gives us the ability to measure this variation in the paddock and analyse the data over multiple years."

In Australia, particularly in grains cropping, most growers already have access to yield data and maps. Using these for an economic look at the paddock involves:

- calculating the gross margin for each yield point, where GM = (yield x crop value) – costs;
- ideally using multiple years of yield maps;
- finding consistently poorly performing areas; and
- considering management options for those areas; for example, reduce inputs, change crops or do not grow a crop in those areas.

Figure 4.5: Maize grain crop during dry down (left) at the Foundation for Arable Research Northern Crop Research Site in the Waikato region of NZ; and yield map of the crop following harvest (right).

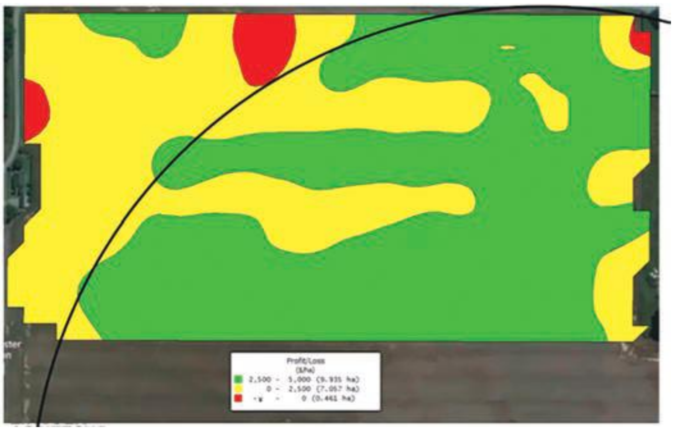


Source: Allister Holmes

Figure 4.6: Mixed arable farm, South Canterbury, NZ, potato yield as measured by harvester yield monitor.

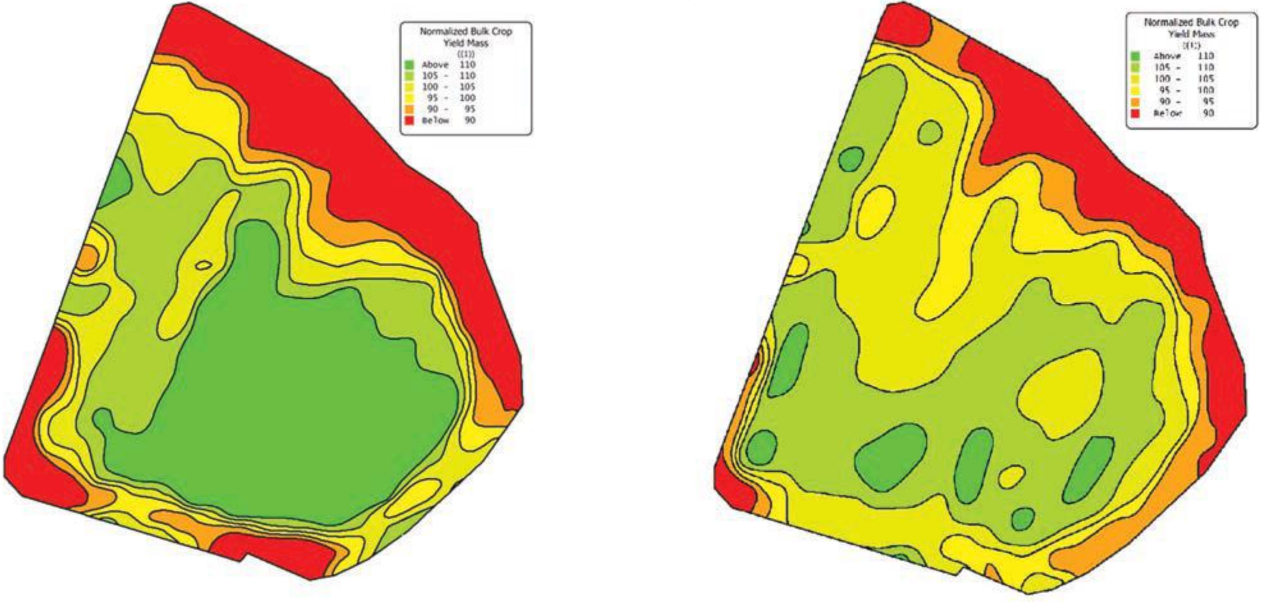
Source: Allister Holmes

Figure 4.7: Mixed arable farm, South Canterbury, NZ, potato crop gross margin map. Black line indicates extent of centre pivot irrigator.



Source: Allister Holmes

Figure 4.8: A paddock at Manawatu, NZ, with normalised yield maps for wheat (left) and maize (right).



a) Wheat

b) Maize

Source: Allister Holmes

Potatoes in South Canterbury, NZ

On this mixed arable farm with annual rainfall of about 800mm, yield maps from the potato crop indicated yields were suffering along the north-western edge (Figure 4.6). Calculating the gross margin for each yield point gave a map showing where profitability could be improved (Figure 4.7). The most profitable areas (green, profit more than $2500/ha) were under the centre pivot irrigator, shown as the black arc. The red areas were operating at a loss, which stemmed from water deficits that were impacting yield. The crop was valued at $253/tonne and costs were $8590/ha (Table 4.1).

The grower chose to keep planting the 13ha under the centre pivot to higher-value crops and the 4.5ha outside the pivot to lower-value crops with a lower need for water such as barley or grass for hay.

Maize grain and wheat

This paddock at Manawatu, NZ, receives on average 1200 to 1400mm of rainfall a year. The soils are a mix of very light sands and heavier loams. The paddock's main crops are maize and wheat. When yield data is available from different crops, the yield of each crop can be 'normalised' so that the average yield of a crop is considered 100 per cent, higher yields are greater than 100 per cent, and lower yields less than 100 per cent. This allows the normalised data to be combined to analyse performance over several years.

Figure 4.8 shows the normalised three-yield-year averages for wheat (Figure 4.8 left) and maize (Figure 4.8 right). Both crops have similar trends, with yields suffering around the headlands.

The six-year combined profit-and-loss map for maize and wheat (Figure 4.9), using the same calculation as in the South Canterbury example, shows a large area of the paddock generating a loss. These yield and profit maps aligned with the grower's knowledge of the paddock's performance – in some cases they could identify why performance was different in parts of the paddock. The lowest-yielding areas were compacted.

MORE INFORMATION:

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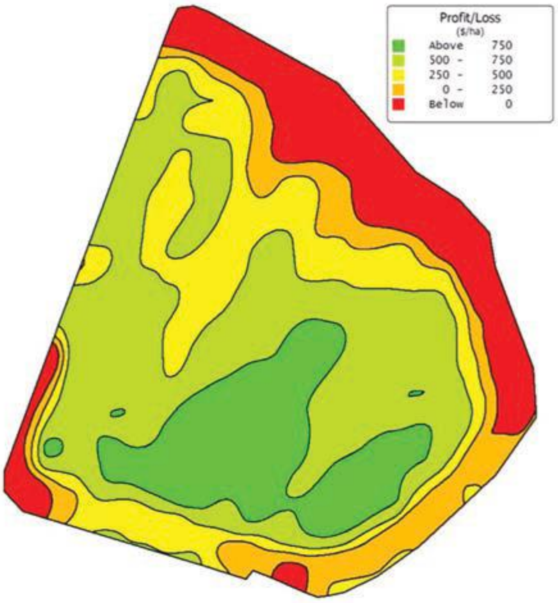
Figure 4.9: A paddock at Manawatu, NZ, profit-and-loss map showing zones with different mean profit or loss over a six-year period in which maize or wheat were cropped.



Source: Allister Holmes

Table 4.1: Mixed arable farm, South Canterbury, NZ, operational costs per hectare of potato crop.

Operation	Cost ($/ha)
Cultivation	1100
Seed and planting	2160
Fertiliser	2860
Pesticides and application	1630
Harvesting	2290
Transport	840
Total cost	8590

Source: Allister Holmes

Australia

In this example, profit and loss is calculated for each yield point or 'pixel', which in this case is 10x10m. Figure 4.10 shows four yield maps, two for wheat (2016, 2019) and two for barley (2017, 2022). The average yield, price and costs for the relevant year are shown in the figure.

Yield data was collected with a John Deere yield monitor and cleaned and calibrated with PCT Agcloud. The grower provided the actual yield obtained in each of these seasons (the yield monitors needed a final calibration against the weighbridge docket).

The maps were made using costs ($/ha), yield (t/ha) and crop value ($/t grain price). A neat colour spectrum was applied to show trends in the data. The same colour spectrum is used in Figure 4.10, where areas with a negative return (less than $0/ha) are in red and areas that broke even are white.

The cumulative map (Figure 4.11) then adds up the $/ha returns for each pixel to calculate a total $/ha profit over the four years.

Some takeaways:

- This is generally a profitable paddock.
- The western half performs better than the eastern half.

Soil testing has revealed alkalinity in the topsoil (carbonate and bicarbonate toxicity) as well as subsoil dispersion, which is a key cause of yield differences.

Creating profit-and-loss maps is a relatively simple process that gives a good idea of long-term yield gap trends and how much money can be spent to recover that yield gap.

MORE INFORMATION:

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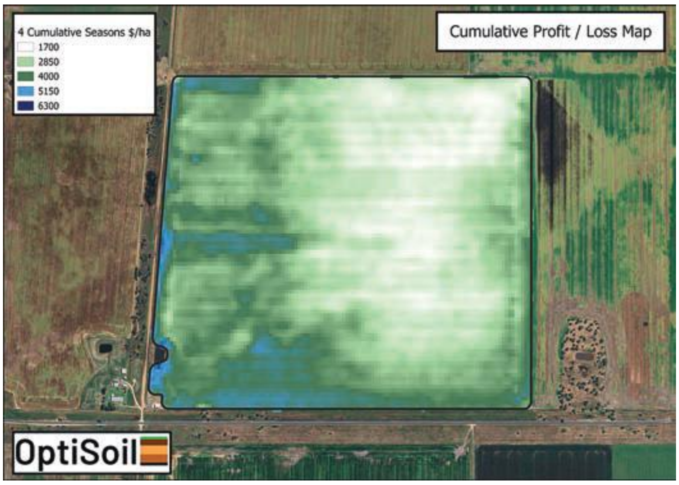
Figure 4.11: Cumulative profit-and-loss map from 2016, 2017, 2019 and 2022.

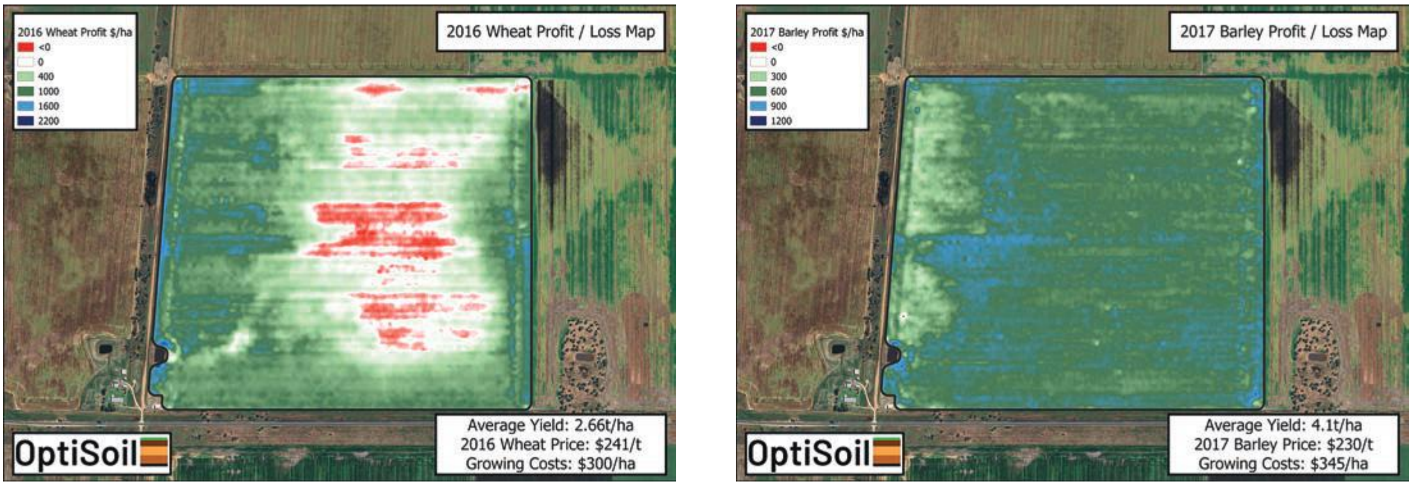


Source: Ned Skehan

Figure 4.10: An Australian paddock, wheat (2016, 2019) and barley (2017, 2022) profit-and-loss maps.

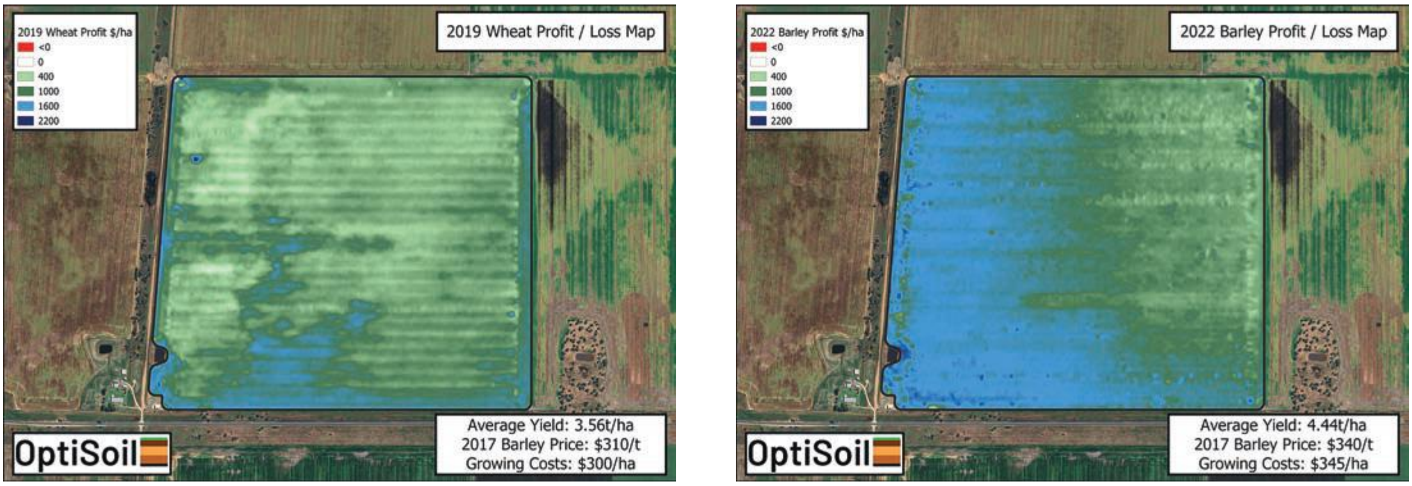
a) 2016 wheat profit-and-loss map

b) 2017 barley profit-and-loss map



c) 2019 wheat profit-and-loss map

d) 2022 barley profit-and-loss map



Source: Ned Skehan

Flip-flop zones

KEY MESSAGES

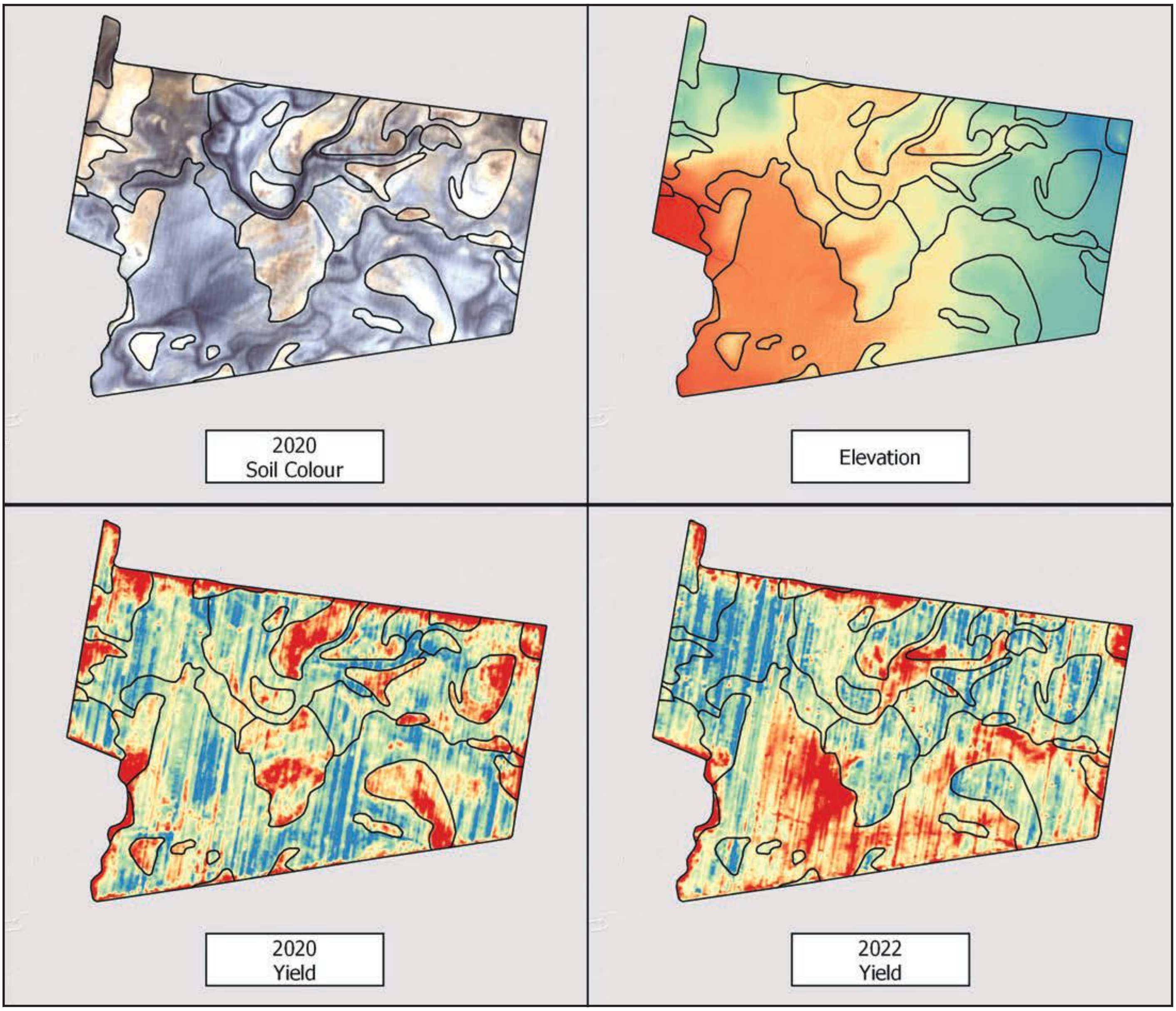
- Flip-flop zones are areas within a paddock that perform well in some years and poorly in others
- The reasons for these fluctuations are complex but topography, plant-available water capacity and rainfall play a big role
- Reliable management zones can be established by identifying and separating different soil types. Various data sources, such as satellite imagery, national soil maps, EM38 data, soil sample results, yield data, elevation and grower knowledge, are used to develop these management zones

'Flip-flop zones' is a term used to describe areas of a paddock that switch between high and low performing in different years. Flip-flop zones can be difficult to manage with confidence due to their seemingly unpredictable and fluctuating production trends.

For a large part of the Australian cropping landscape, reliable management zones can be created through identifying and separating different soil types. Many different data layers are useful to develop management zones – satellite imagery, national soil maps, EM38 data, soil sample results, yield, elevation and the grower's own knowledge.

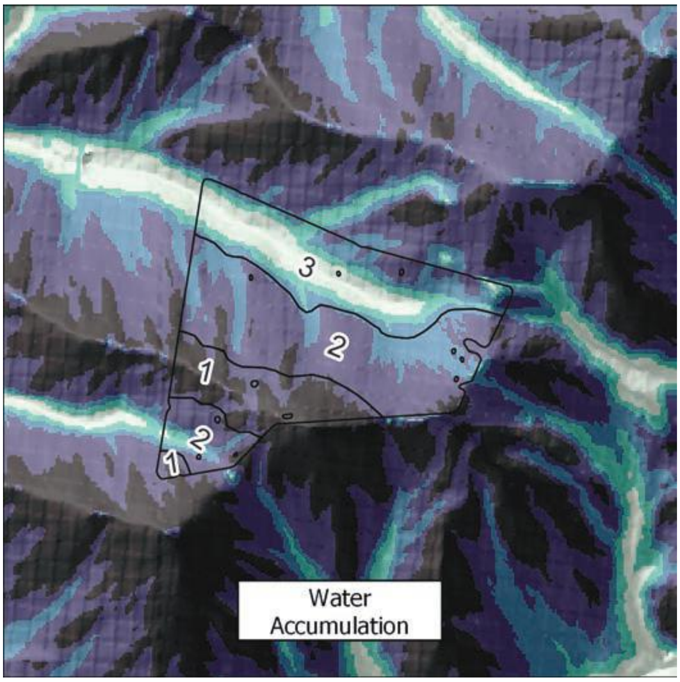
Confidently managing inputs becomes very challenging when a paddock exhibits inconsistent trends in production. In some situations, relative performance between different zones is not always consistent. Flip-flop zones can erode confidence in the decision-making process due to the seemingly unpredictable yield swings shown on a yield map. If it appears that a paddock has flip-flop zones, it is critical to dive deeper into the historical data to link the performance of each individual zone for each season and develop a holistic understanding of the production curve for each zone.

Figure 4.12: Paddock soil types differentiated by soil colour, where grey soil = clay and the lighter soil = sandy topsoil. In the average 2020 season the heavier soils (grey areas) performed well, but in the wet 2022 season yield suffered in these areas.



Source: Delta Agribusiness

Figure 4.13: Water accumulation in a southern NSW paddock showing drier areas in zone 1 (dark colours) and the wetter areas in the water flow line in zones 2 and 3 (bright colours).



Source: Delta Agribusiness

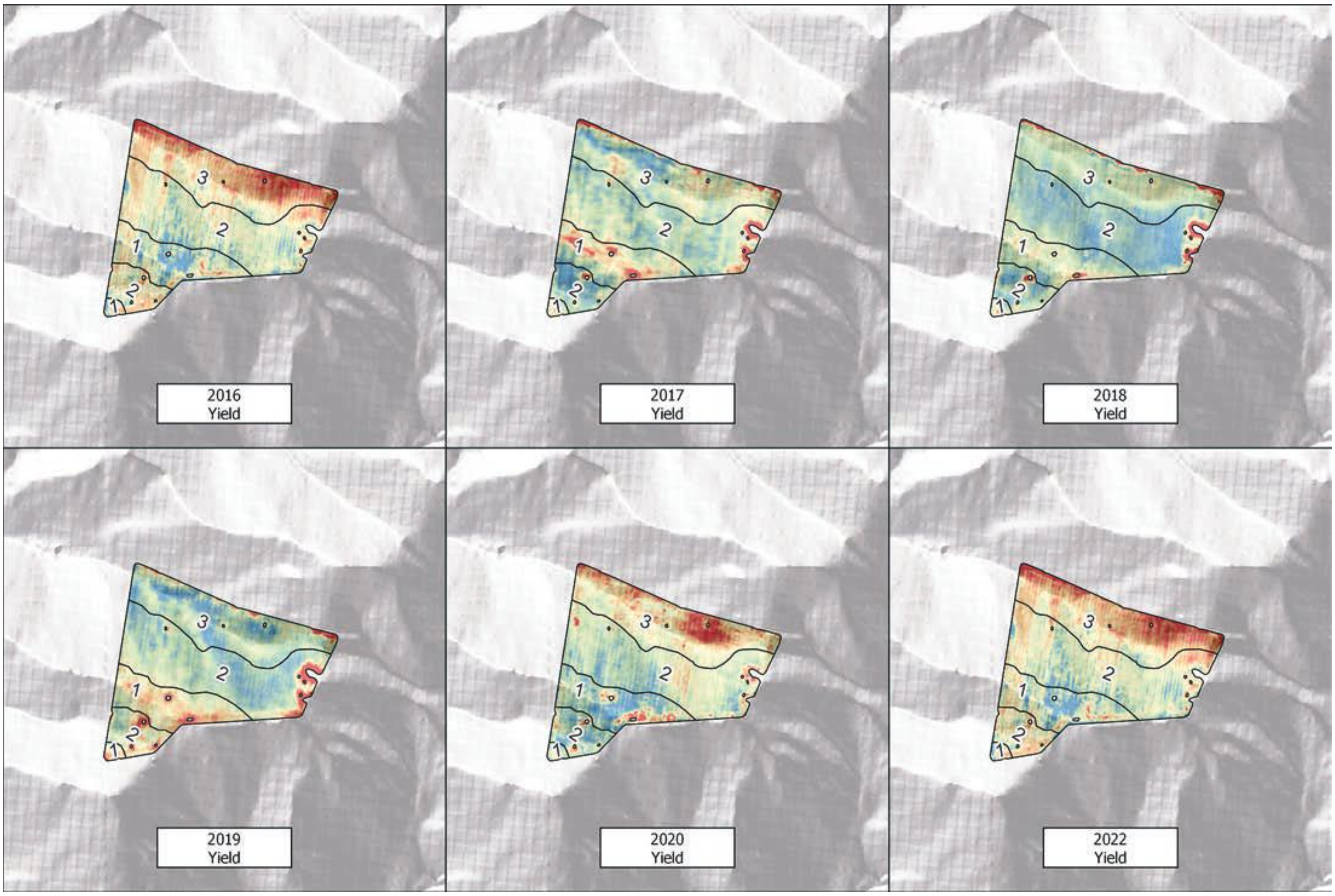
As with any investigation into soil properties, there can be many physical, chemical and biological constraints that will impact on yield, so comprehensive soil testing by zone is always the first step.

However, in our experience, the most common cause leading to flip-flop behaviour is the differing ability of these soil types to collect, store and use moisture. Variation in collection is generally due to the different landscapes, where slopes shed water and flats accumulate moisture. Storage variation is generally due to different soil types with different water-holding capacities. Variation in water use is often due to chemical or physical constraints.

Flip-flop zone behaviour can also occur where there are distinct soil type changes within a paddock. Throughout central and northern NSW, soil types vary considerably and can demonstrate flip-flopping through different plant-available water capacities and the crop lower limit thresholds. This is demonstrated in particular in northern NSW, where deep alluvial soils (Vertosols) high in clay per cent and organic matter are immediately besides lighter-textured chromosols (red soils). This cropping region is critically dependent on the collection, storage and protection of soil moisture during summer rainfall events.

In winter cropping seasons, with good summer rainfall and average in-crop rainfall, the heavier soils perform better due to their storage capacity. However, with an empty soil profile, the heavy soils with a higher crop lower limit have less plant-available water after smaller rain events, potentially leading to the higher performance in the lighter soils. Similarly, in overly wet years the

Figure 4.14: Six years of yield maps from a southern NSW paddock showing better yield performance in the lower areas in dry years (2017–19) and yield penalties in wetter years (2016, 2020, 2022). Note: 2021 yield data is not available.



Source: Delta Agribusiness

heavy soils can become waterlogged and yield can suffer. This is clearly shown in Figure 4.12, where the 2020 season allowed the heavy soils to perform, whereas they suffered yield penalties during a very wet late 2022.

In the slopes of southern NSW, the dominating cause of flip-flop zones is related to the topography, which is the major driver of soil types and water flow across the landscape. Typically, these areas are zoned based on soil type and waterflow modelling, and these landscapes naturally present flip-flop performances during higher and lower-rainfall years.

Logically, the gully areas accumulate water over the years. The soil in gully areas is also deeper compared with the hilltops and mid-slopes as, over time, soil washes off the slopes and into the gullies.

In average or lower-rainfall years, the gullies or flats are generally the highest-performing regions. In high-rainfall years, these areas succumb to waterlogging and nutrient leaching. This can be seen in Figure 4.13, which shows the relative water accumulation layer where zone 1 is the hilltop and is relatively dry (dark colours) compared with zone 3, the flow line (bright colours). In Figure 4.14, in seasons of above-average rainfall (2016, 2020 and 2022), the gully areas accumulate too much water and the crop suffers, while the hilltop and mid-slope are able to shed excess water.

In the below-average rainfall years (2017–19, Figure 4.14) the relative performance of the paddock switches. The lower parts of the paddock where water accumulates perform better.

In addition to waterflow modelling to create soil type zones, in these undulating environments aspect of the slope can also play a significant role in the relative yield performance and can introduce another variable to the flip-flop behaviour.

Consideration of the soil types, characteristics and landscapes in the seasonal conditions (or consecutive seasons in the case of northern NSW) add context to yield data. Collecting data over multiple years and tying it to seasonal conditions is critical in deriving actionable value from long-term yield data. Through linking the spatial and temporal performance characteristics, we begin to understand how the various management zones can perform, giving greater confidence to in-season decisions.

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On-the-go protein sensors

KEY MESSAGES

- Protein sensors assess grain quality during harvest
- Records of how protein quality, yield and moisture vary across the paddock can be used to improve nitrogen management and add value to the crop

This article, ‘On-the-go protein sensors’, was originally published as a GRDC Update Paper in March 2019 on the GRDC website. Author: Brett Whelan, Associate Professor of Precision Agriculture, University of Sydney. Revised late 2023 by Alisa Bryce

The article can be accessed at: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/on-the-go-protein-sensors

Profits from grain crops are not just derived from yield; the quality of the grain delivered is critical to ensuring maximum profits for some grains. For cereals, the quality is largely determined by the grain protein content. For canola, maize and soybeans, the oil content is important.

Protein and oil content in the grain is determined by:

- grain crop type;
- crop variety;
- nitrogen in the soil and applied as fertiliser; and
- moisture availability during the growing season.

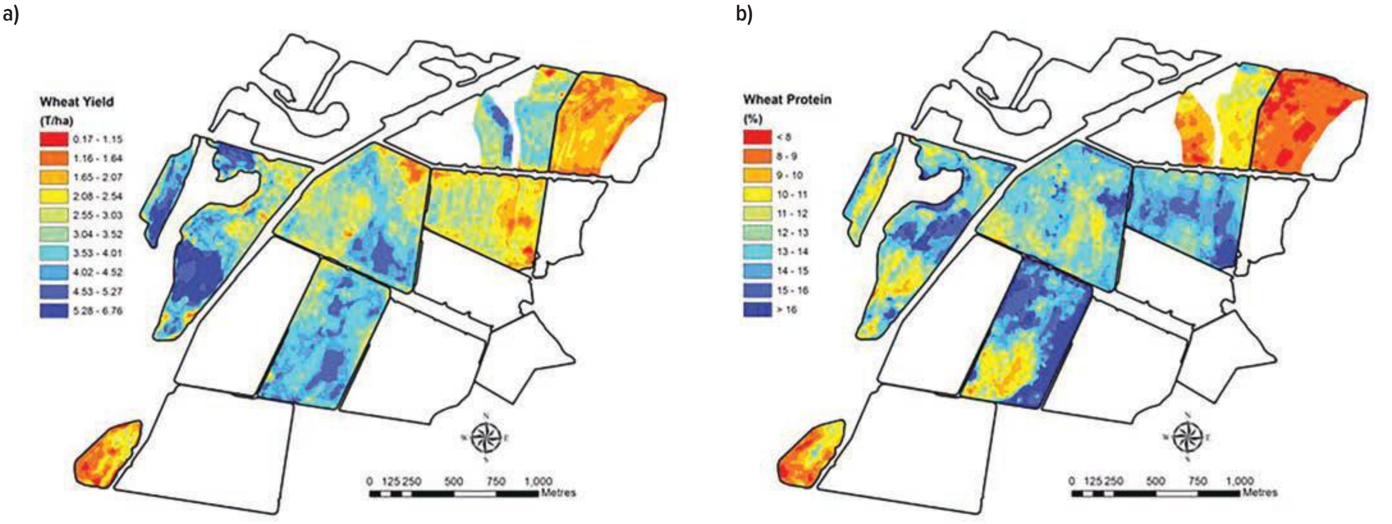
Accurately measured grain quality data has two key uses. The simplest use is to do a more controlled blend at harvest. Knowing how protein varies is an opportunity to segregate out areas of the paddock and blend more strategically for a better financial result. Some loads you might harvest the part of the paddock that is low in protein, store it, then blend it afterwards.

When combined with yield data, protein data can show how well crop nitrogen nutrition was managed in the season and identify areas where management may be altered in the future. If the strategy is changed, the yield plus protein data will show how the change is affecting grain quality.

Grain quality monitors can be mounted on a harvester to measure protein and oil content during harvest operations. Monitors work by passing light through the grain and a near infra-red (NIR) sensor measures the protein, moisture and oil. The light interacts with specific chemical bonds within the grain and is slightly modified because the bonds absorb some of the light energy. The reflected or transmitted light is recorded and when run through a calibration algorithm it provides a measure of grain protein, moisture and oil content. It is the same technology used in grain receival depots.

Instruments that use near-infrared transmittance (NIT) need to capture a stationary sample, so the measurement readings are obtained every seven to 15 seconds (a measurement cycle of 0.14 to 0.07Hz). Using near-infrared reflectance, a continuous grain flow can be used and the measurement taken more frequently.

Figure 4.15: Spatial pattern of wheat grain yield (a) and wheat grain protein content (b) across a farm in northern NSW.



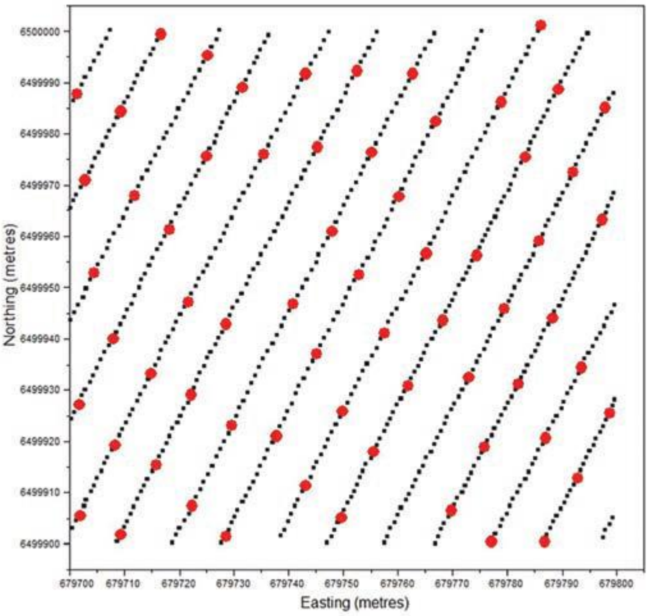
Using grain protein content in PA

Like grain yield, grain protein can vary considerably within paddocks and across the farm (Figure 4.15). Although protein monitors collect fewer datapoints than yield monitors, there is still enough data to produce detailed protein maps of the paddock. For example, Figure 4.16 illustrates the yield monitor collecting about 725 readings/ha, compared with 65 readings/ha for protein.

Post-harvest grain segregation or bulk grain quality control

Monitoring grain quality in real time during harvest provides opportunities to segregate grain based on quality or mix grain based on quality. Neale Postlethwaite (Chapter 6, 'Perfect paddock protein through precision pathways', page 88) has used protein monitoring to even out grain quality in his paddocks, while Jonathan Dyer ('Protein mapping evens out wheat grades', page 53) has used protein monitoring to blend wheat differently for more profit and even out grain quality.

Figure 4.16: Grain yield data gathered on-harvester once every second (smaller black dots) and grain protein content data gathered in the same harvest operation once every 12 seconds (larger red dots).



Identifying areas within a paddock or farm where grain with specific protein levels can be harvested may provide premium marketing and increased profit opportunities.

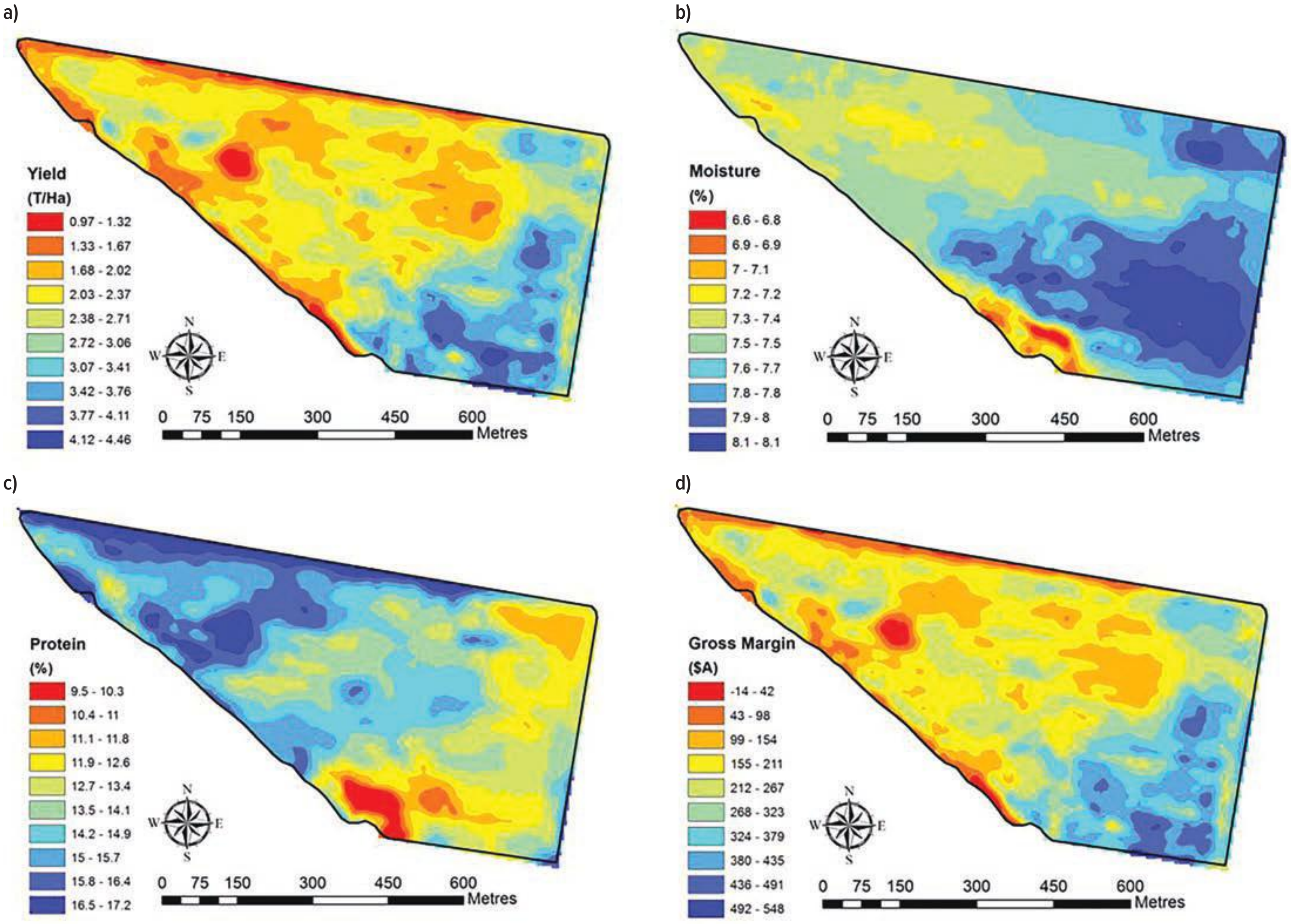
Growers who can provide grain at a consistent quality may be in a better position to obtain premium contracts. In highly variable years, the ability to segregate part of the crop based on protein percentage may allow growers to meet contracts when the average quality of the farm output fails to meet the contract specifications (provided that the entire crop is not under contract). In these scenarios, a protein sensor opens the possibility of strategic harvesting to target grain quality.

It is important to remember that quality monitoring can be done at any stage of the supply chain and should be performed regularly to assure quality levels and to maximise market segregation opportunities. Grain quality monitors have been used successfully off-harvester (for example, on a ground auger) to segregate/manage grain for delivery based on protein content. This does not provide spatial information on protein variability within paddocks but can be very effective as a differential marketing technique. The malting barley market is one example where this technique of off-harvester segregation is being used in Australia to maintain delivered product within a contracted quality window.

Gross margin maps

In Australia, grain protein is an important consideration in quality grading and therefore final grain sale price, particularly wheat and barley varieties. With yield, moisture and protein maps available, it is possible to calculate more accurate revenue figures and produce maps of how the gross margin of production varies within a paddock and across a farm (Figure 4.17). These maps should be very useful to a farm manager, particularly for identifying problem areas for investigation, planning more profitable crop agronomy and rotations, or identifying repeatedly unprofitable areas for alternate uses.

Figure 4.17: Grain yield (a) grain moisture (b) grain protein content (c) and site-specific gross margin (d) maps made by combining all three data layers, applying quality premiums/discounts and subtracting uniform variable costs of production.



Nitrogen agronomy

Conditions that might increase the range of grain protein content found within a paddock include:

- variation in nitrogen availability within a paddock. Where different soil type or soil texture occurs, there may be variation in nitrogen supplies to the crop; and
- variation in moisture availability within a paddock. The interaction between topography, soil type and seasonal climatic conditions will result in spatial variation in the amount of water available to a crop across a paddock. This affects nutrient uptake, grain filling and yield, which all control final grain protein content.

Locations in a paddock where grain protein content is identified as lower provide an opportunity to direct investigations into nitrogen availability and inform options for management intervention. If investigations suggest that a paddock has received adequate nitrogen for the growing season, then in the simplest situation a map of nitrogen removal may become an option to guide variable-rate nitrogen application in the following season. The amount of nitrogen removed from the production system through harvested grain can be calculated by multiplying the mass of grain yield by the percentage of protein in the grain (Figure 4.18).

Generally, there is a negative correlation between grain yield and grain protein in cereal crops. This means that as yield increases, protein is expected to decrease. A positive correlation would mean that as yield increases, protein would also increase. The type of relationship (negative, positive or none) can tell managers something about a crop's access to nitrogen and water. With measurements of yield and protein across a paddock using on-harvester monitors, it is possible to explore whether the relationship between the two is constant or if it changes across a paddock (Figure 4.19). While negative correlations often dominate within a paddock, areas of positive correlations do occur in most paddocks as do areas where there is no definable relationship. These changes in the relationship usually form a pattern as seen in Figure 4.19.

It is speculated here that areas within a paddock where the yield-to-protein relationship is negative could mean that access to N by the crop has been relatively uniform, but the access to moisture has been variably limited by soil/landscape conditions.

Where the relationship is positive, access to available moisture may have been more uniform but the amount of available N was changing. Areas where no relationship is seen (correlations close to 0) could be interpreted as regions where the relationship is changing between positive and negative. Sampling for soil nitrogen and available water-holding capacity within these different regions could provide useful information for building better variable-rate N management plans.

Figure 4.18: Nitrogen removed in grain using both yield and protein monitor data.

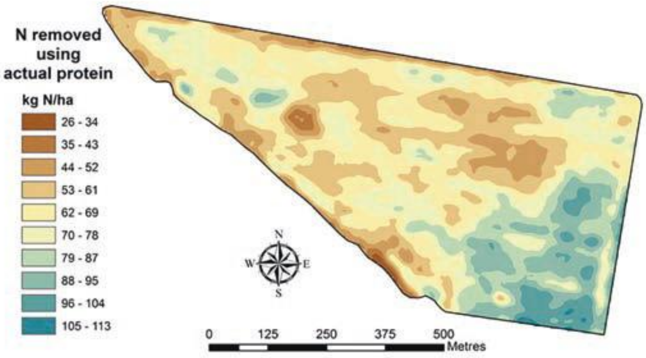
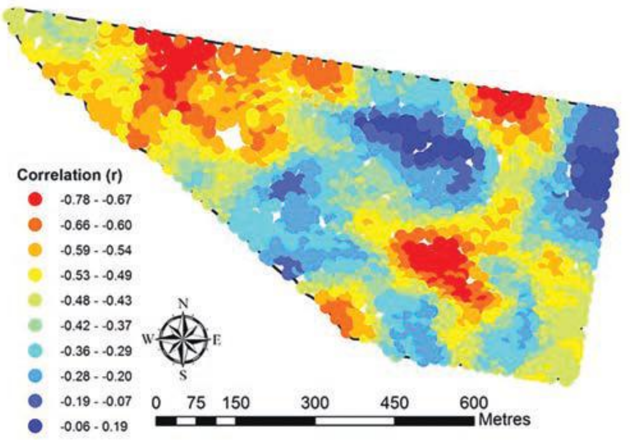


Figure 4.19: Local correlation between grain yield and grain protein within the paddock. The spatial pattern could be used to investigate nitrogen and water supply issues.



Calibration and maintenance of quality sensors

Factory calibrations are supplied with quality sensors; however, a local calibration check is advisable. Several grain samples can be analysed at the local receival silo and then passed through the harvester sensing system, or a set of standard samples can be purchased for use. It is wise to check calibrations for all crop types and varieties to be harvested. Dust and material other than grain will affect the operation of these sensors and efforts should be made to keep the grain sample as clean as possible.

Conclusions

Protein monitors provide useful information by themselves, both at harvest for optimising marketing options and in further analysis to assess the past season's agronomic management. Together with grain yield and moisture monitors, benefits can also be found in improved economic analysis of production, targeting strategic investigative sampling and in aiding future N management decisions. Australian growers are encouraged to explore their use.

Acknowledgements

The research undertaken as part of this project is made possible by the long-term significant contributions of growers through both trial cooperation and the support of GRDC. The author would like to thank them for their continued support.

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GRDC CODE CSP1803

Jonathan Dyer and his girls on the family's farm in Kaniva, Victoria.

Source: Jonathan Dyer

Protein mapping evens out wheat grades

From Jonathan Dyer's experience, the biggest bang for the family's investment in PA tools has been GPS and autosteer, and now protein mapping. (See the Chapter 2 grower case study, 'Using data to unlock potential on West Wimmera farm', for more details on the Dyers' use of PA on their farm.)

In 2016, Jonathan upgraded from a portable protein monitor to a CropScan 3000H On Combine Analyser. The CropScan is mounted on the clean grain elevator and takes readings approximately every 17m, producing about 15 measurements per hectare as the crop is being harvested. This equates to a reading collected every seven to 12 seconds, which is displayed on the touch screen PC in the cab. This also shows bin averages and real-time protein maps. The software sends the data to the cloud where it can be monitored using a PC, tablet or smartphone.

SNAPSHOT

Name: Dyer Ag family partnership, which includes Alwyn and Kerryn Dyer and their sons Jonathan and Colin

Location: Kaniva, Victoria

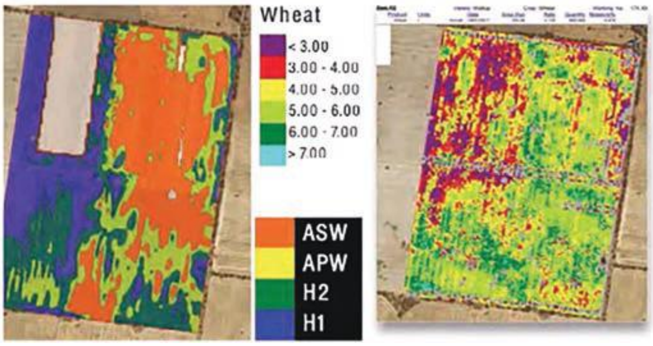
Farm size: 3000 hectares

Rainfall: 400mm

Soil types: predominant heavy cracking Wimmera clays dispersed with red clays (on rises) and about 10 per cent sandy loam

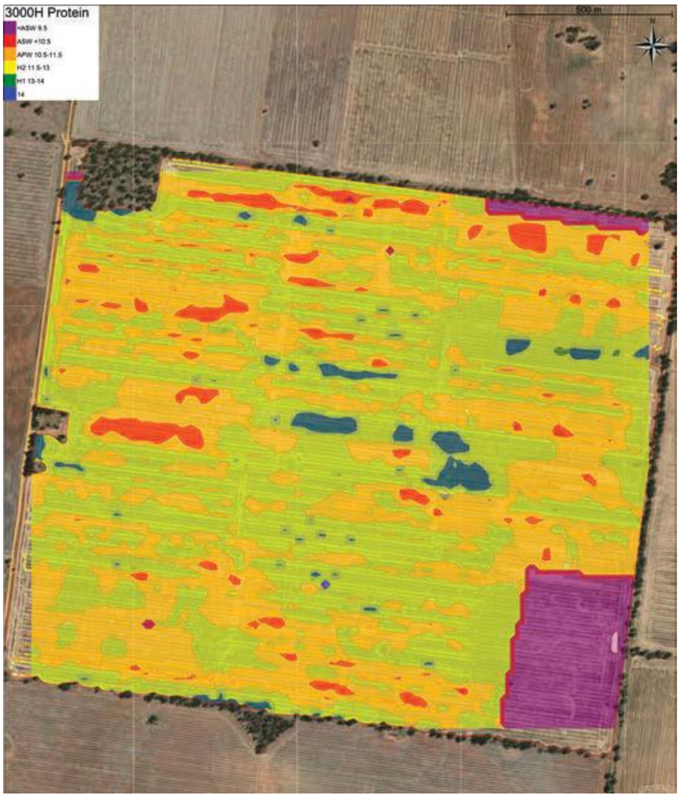
Enterprises: broadacre cropping program: 25 per cent bread wheat, 25 per cent durum wheat, 30 per cent pulses and 20 per cent canola

Figure 4.20: A Dyer Ag paddock in Kaniva, Victoria, showing protein (left) and yield (right) maps for harvest 2016.



Source: Jonathan Dyer

Figure 4.21: A Dyer Ag paddock in Kaniva, Victoria, 2022 protein map. The purple area in the south-west corner represents no data available, despite showing up on the map as low protein.



Source: Jonathan Dyer

The monitor paid for itself in one year. "In 2016, we got a protein monitor for one of our harvesters," Jonathan said. "So we got on-the-fly, real-time protein readings during harvest. That investment actually paid for itself in the first year, because we had one large paddock (Figure 4.20) that had four different protein wheat grades in it, ranging from ASW to H1. We were able to blend the ASW wheat in the paddock in such a way that most of the paddock was H2, and none of it below APW level." This resulted in a $12,500 increase in income (about one-quarter of the cost of the protein sensor), which was repeated across the wheat crops, completely recovering the cost of the sensor.

Now, however, Jonathan does not have to blend. By combining yield data, protein data and soil test information, he has developed variable-rate urea maps and significantly evened-out both yield and protein in the paddock.

In 2016, protein ranged from 9.5 per cent to 14 per cent. The whole paddock had been fertilised for a target yield of 6t/ha, but frost reduced yield to less than 3t/ha in some areas. The high protein wheat was found in the low-yielding areas, as would be expected.

In 2022, the protein range was similar to 2016 (Figure 4.21) but the paddock average was 11.6 per cent and the distribution in protein grades was vastly different. Most of the paddock was APW and H2, compared with 2016 when there were large areas across the range of protein grades. "These are good years to compare as they were both quite wet," Jonathan said.

Since 2016, the Dyers have removed a fence on the western edge of the paddock, but with their zone-based VR approach the consistency of protein holds even across the now larger paddock with different history. "We've evened out the performance of the paddock," Jonathan said.

They can still blend as happened two years ago, when one paddock was badly frosted. Or combine elevation and farm knowledge of frost-prone areas to harvest the frosted areas with the protein monitor and the low protein areas with the second harvester.

"The ability to blend and have real-time data is good. But knowing variation and acting on it to use inputs more effectively and hitting yield targets is better," Jonathan said.

Chapter 5: Soil mapping and management

Photo: James Venning

Introduction

Soil properties vary considerably over most paddocks and farms, often leading to variable crop production. Understanding and managing this variability is what drives variable-rate applications.

In an ideal world, every grower would have detailed soil property maps and be able to match fertiliser, ameliorants, crop varieties and seeding rates to the relevant zones. However, assessing soil variability remains a challenge.

Grid sampling and laboratory tests traditionally have been used to map soils, but are time-consuming and expensive. The result is that fewer soil tests are collected, providing only a snapshot or overall average level of the soil properties of interest in the area sampled. These tests do not provide sufficient information to implement accurate variable-rate application of inputs or amelioration of constraints to productivity.

Using spatial layers such as yield maps or EM maps (covered in Chapter 2, in the section headed 'Common spatial layers used in PA', page 19) as a starting point allows growers and consultants to develop targeted soil sampling plans that tease out soil variability much better than grid sampling can, while working with often-limited soil testing budgets.

In the section in this chapter headed 'Combine data with soil sampling to best manage your soil' (page 56), Drs Rob Bramley (CSIRO) and Patrick Filippi (University of Sydney) explain the benefits and pitfalls of grid soil sampling and how to make use of existing data for targeted soil sampling programs.

Being able to use proximal or remote sensing to map soil properties without have to dig any holes is the holy grail of soil mapping. While work is underway to improve these techniques, it is still necessary to get your hands dirty. In the section in this chapter headed 'Proximal and remote sensing – what makes the best farm digital soil maps?' (page 60), Dr Filippi puts them head-to-head to see which tool makes the best soil maps (hint: they work best together).

Variable soil constraints

Soil constraints such as acidity, salinity and dispersion tend to vary across paddocks, both laterally and at depth. Variable-rate liming programs aim to reduce variability in soil pH across the paddock. Soil tests and VR lime rates have traditionally focused on the topsoil (0 to 10cm). For some growers, this means subsoil acidity is a sleeping giant. It was for South Australian grower James Venning (case study, pg 66), where lentils gave the game away. Although soil pH tests indicated acidity was not an issue, the crop was not performing as expected.

NSW grower Roy Hamilton (case study, page 69) is in the process of developing a subsoil variable-rate lime strategy as deeper soil tests are showing his clay soils are acidifying.

Also check out how SA grower Stephen Paddick (page 72) is using PA to deal with salinity.

Managing drainage

On page 76, read how Tasmanian grower Ben Tait uses spatial layers to develop drainage plans to deal with waterlogging. On page 73, Queensland grower Jake Hamilton tells how he has used LiDAR to map and level gilgai where sodic subsoil is an issue, and shares his future plans to implement variable-rate gypsum post-levelling.

Combine data with soil sampling to best manage your soil

Content for this section has been sourced from two articles previously published in *Precision Ag News* – Autumn 2022, vol 18, issue 3, authored by Laura Jade; and Winter 2022, vol 18, issue 4, authored by Dr Patrick Filippi, University of Sydney. Material updated in late 2023 by Alisa Bryce.

Soil sampling to understand the condition and variation of soil is crucial, particularly if there are any chemical or other constraints that are limiting production. However, it can be an expensive task, which is why it is so important to get it right and do it strategically.

There are many service providers promoting grid sampling as an approach to understand soil variation and to underpin variable-rate prescription maps, but this approach has significant limitations.

"The problem is that often the mapping derived from this grid-based sampling is not robust," Dr Bramley said.

High cost, disregarding spatial variation of soil and crops in selecting sites, and the often poor maps of soil properties that are produced from these grid sampling schemes are just some of the issues.

Because soil analysis is expensive, some service providers collect insufficient samples to develop a robust map and/or use such big grid spacings that potentially important information is missed.

Additionally, some service providers are not using robust techniques to interpolate the soil analysis data into a map (that is, estimating new data values at unsampled points based on the range of known values at the locations where samples were collected).

The preferred method used by geostatisticians to interpolate soil analysis results to a broader map is called Kriging. Dr Bramley said that Kriging enabled the mapping of the issue of interest and gave you an estimate of the error associated with any particular location on the map.

The mathematics of Kriging attaches a weighting to the places where you have collected data in estimating or interpolating data values at unsampled locations. It does this in such a way that the weighting is specific to the separation distance between the sampled and unsampled points.

To do a good job of defining the function from which this weighting is obtained (called the variogram), you need to have some samples that are relatively close together as well as others further apart. With grid-based soil sampling, you do not have any samples closer together than the grid spacing – which may be too large to do a good job of generating the variogram.

As an alternative to Kriging, many commercial providers use a technique called inverse distance weighting in which the value of the weighting (commonly 2) is arbitrary and fixed.

Dr Bramley said: "There has been a lot of work done by geostatisticians in the past, which has established that in order to understand what that weighting should be [to apply the Kriging methodology], you need to have a minimum of 100 samples and desirably a lot more than that. Clearly that's not practical in most commercial settings."

KEY LESSONS FOR SOIL SAMPLING FOR PA

Dr Rob Bramley, leader of CSIRO's Precision Agriculture and Viticulture team, encourages growers to better utilise the information they already have by combining other data with soil sampling. He said there were often more effective regimes for soil sampling than the grid approach.

"Use your other information, whether it be yield maps, EM38 survey, elevation or remotely sensed imagery, to choose where to put those soil samples so that you get the maximum value out of them," he said.

He also reminded growers who had machine guidance or autosteer that the GPS systems in such equipment would allow them to generate accurate elevation data.

Having accurate variable-rate prescription maps enables growers to take full advantage of equipment such as fertiliser or lime spreaders that have continuous variable-rate capability.

Soil sampling can generate useful data for growers, helping them understand if there are any constraints (chemical or other) that are limiting production.

Photo: Rob Bramley

Dr Bramley conceded that grid soil sampling was easy to conceptualise for service providers and growers, but large grid sizes could mean that they lacked accuracy as a basis for underpinning a map. Grid-based sampling largely arose in the US where soil analysis was much cheaper than in Australia, so taking larger numbers of samples and/or on finer grids was more feasible.

But with Australia's relatively expensive soil sampling and analysis, growers will understandably want to make sure that each soil sample provides as much information as possible.

Managing costs while capturing soil variability – management zone sampling

A better option is to use some other available data to identify some management zones and then target a smaller soil sampling and analysis effort to these. Some growers have proximally sensed data such as EM maps. Many growers have yield maps and all growers are able to access remotely sensed imagery of their paddocks with the help of most service providers.

These datasets help growers to understand the variation in soil and yield and can guide the most strategic locations from which to extract samples, which will optimise cost efficiency and help to best understand the variation across paddocks. Soil can be highly variable over very short distances and we must use this knowledge of variability to decide where to sample.

There is essentially only one situation where grid soil sampling is an acceptable approach for growers, and this is when money is no object and sampling on a very fine grid can be performed (that is, hundreds of samples in one paddock).

Dr Bramley gave the example of a 150ha paddock in which a grower had identified two or three management zones. Using a regular grid to generate a robust map, at least 100 to 150 soil samples would need to be taken and preferably many more than that to achieve a good sample density.

However, if a grower could realistically only afford to have 15 soil samples analysed, then the soil samples could be taken from different management zones, defined by this prior information. For example, you might choose to do five samples in each of three management zones.

"You kill a few birds with one stone using this approach," Dr Bramley said. "You have a much cheaper soil analysis bill and you can target your soil samples to the variation in the field based on the management zones."

Dr Bramley said the research community had been using this approach for a long time.

"It's about time the commercial providers caught up and didn't blindly use the grid-based approach," he said.

Management zones – the statistics

Creating paddock zones using a data layer, or combination of data layers, and then sampling within these zones is a more efficient way to choose soil sampling locations. Figure 5.4 is an example using an EM map to define zones.

An approach using a data layer (or layers) typically involves the following:

- Paddocks are split into management zones using an approach such as K-means clustering. K-means is a hard cluster algorithm that partitions paddocks into clusters of similarity based on characteristics of a data layer or several data layers.
- The number of zones can be determined by the algorithm or simply selected based on the understanding of variation by growers or consultants. For example, some paddocks might have four to five zones, but in a paddock with less variability, two zones might be acceptable.
- The number of samples in each zone can be selected based on the area of each zone. For example, if 10 samples are to be taken in a paddock, and a particular management zone takes up 40 per cent of the paddock area, then four samples could be extracted within this zone.

The exact location of samples within a zone can be selected randomly or hand-selected to ensure a nice geographic spread or to account for variability within management zones.

Data layers for unmapped property

If a grower has no prior knowledge of a property, they could use a grid-based approach to soil sampling providing enough samples are collected and at a high enough density, depending on the application. But Dr Bramley suggested including a few extra samples that did not follow the grid formation, so that you ended up with some samples close together. This enables better definition of the variogram and therefore better map interpolation.

"Even if Kriging is not used to generate the map, the 'rules' around sample number should still be used as a guide to what is required. Creating a variable-rate prescription map using as few as 30 sampling points collected on a grid is not okay," Dr Bramley said.

Service providers should also be able to help growers access historical remotely sensed imagery quite easily for free. In the case of a grower who does not have data on hand for zone definition, service providers should be able to acquire this imagery and then do a spatial analysis with that information to identify some management zones and therefore target soil sampling.

Other data sources that can be layered to make a more accurate variable map include yield maps and EM38 or gamma soil survey. Such data allows better targeting of soil sampling, giving growers better information at a lower cost.

Example demonstrating the power of combining data layers with soil sampling

The example is a 7.3ha Coonawarra vineyard where the researchers wanted to identify soil depth. Although this example is a vineyard, the same principles apply to much larger broadacre cereal paddocks.

To get a map with enough detail the researchers did use a grid-based approach, but the grid was very fine with soil measurements taken every 20m or so. This meant there were 190 sampling points underpinning their soil depth map (Figure 5.1a). Of course, collecting this amount of data will never be commercially feasible. But how might enough information of similar value be obtained in a cost-effective manner, realistic for commercial settings?

In vineyards, a common approach to soil surveying has been to use regular grids with a 75m grid spacing, meaning that in this example vineyard there would normally be a maximum of 16 soil samples (Figure 5.1b).

But as can be seen, the map it produces lacks the detail needed for effective decision-making when compared with the more detailed map (Figure 5.1a).

Therefore, Dr Bramley and his team used an EM38 sensor to produce an on-the-go electromagnetic induction soil survey. In this particular example, as can be seen in Figure 5.1a and Figure 5.1c, the pattern of variation in apparent electrical conductivity (ECa) obtained from the EM38 sensor (Figure 5.1c) closely followed that for soil depth (Figure 5.1a). They used the data from the EM38 sensor to assist in directing the locations of the 16 sampling points in such a way that the full range of electromagnetic induction variation was accounted for. Note that these locations were not on a grid.

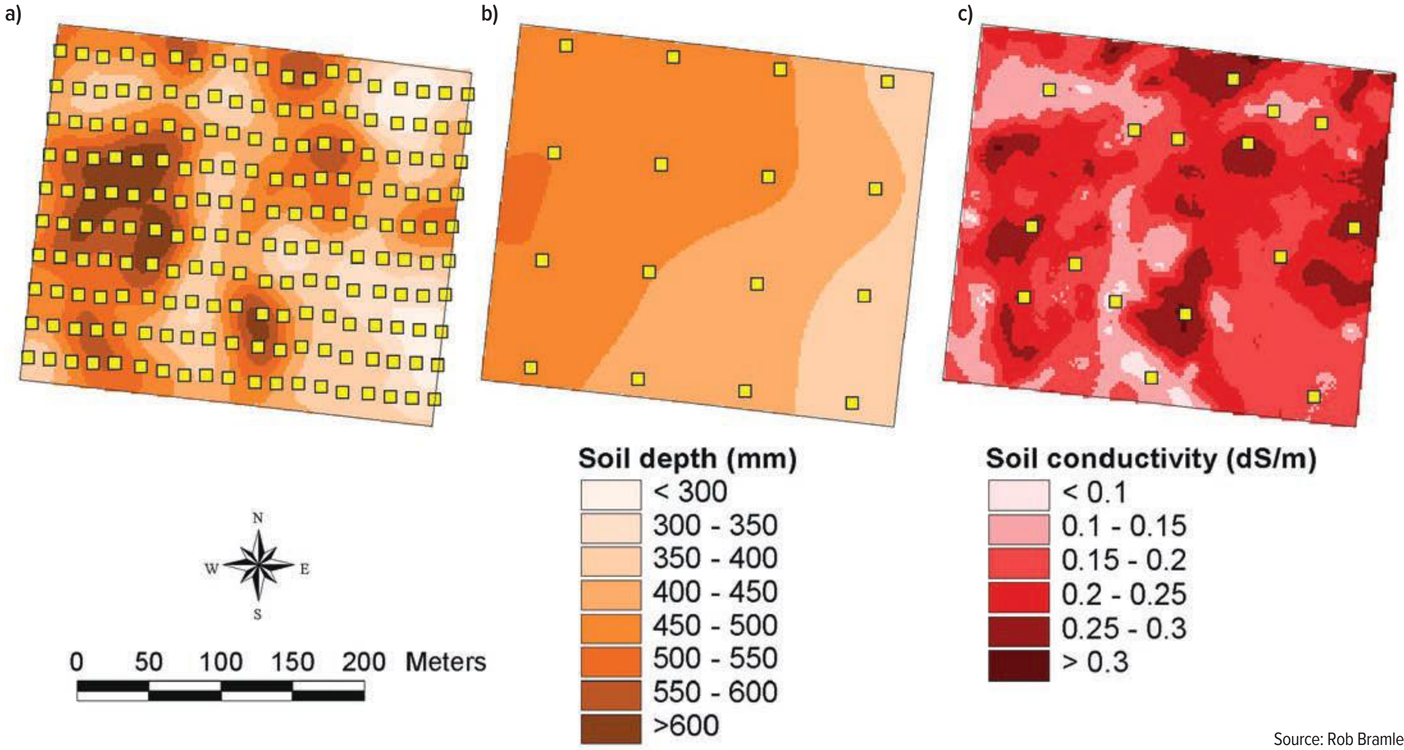
Using the data collected from the 16 targeted sampling points, they generated a relationship between ECa and soil depth and so could use the ECa map to estimate a soil depth map. Because they also measured elevation while doing the EM38 survey, they were able to drape this soil depth map over the elevation model (Figure 5.2). As can be seen, the soil depth map (Figure 5.2) is much closer to the map developed with 190 soil samples (Figure 5.1a), but derived from 16 soil samples, not 190; in other words, this map could be delivered cost-effectively for growers.

"As you see, in Figures 5.1b and 5.1c, there would be exactly the same soil sampling and analysis cost, plus the cost of the EM38 survey, but in 5.1c you're putting those samples in the places where they're more likely to give you good information," Dr Bramley said.

Interestingly, the relationship between soil depth and the EM38 values (Figure 5.3) is fairly weak. Nevertheless, the EM38 dataset enables the production of a map with much better characterisation of soil variation in this vineyard than commercial (that is 75m) grid soil sampling.

Note that it should not be assumed that EM38 gives a prediction of soil depth generally; it does in this particular example due to the characteristics of this Coonawarra soil.

Figure 5.1: Variation in soil depth (a, b) and apparent electrical soil conductivity (c) in a 7.3ha Coonawarra vineyard. The soil depth maps were interpolated from measurements made at either (a) 190 or (b) 16 sampling points (denoted by yellow squares). The sampling points shown in (c) are those from which data was taken for calibration of the EM38 signal with soil depth (Figure 5.3).



Source: Rob Bramley

Conditioned Latin hyper-cube sampling

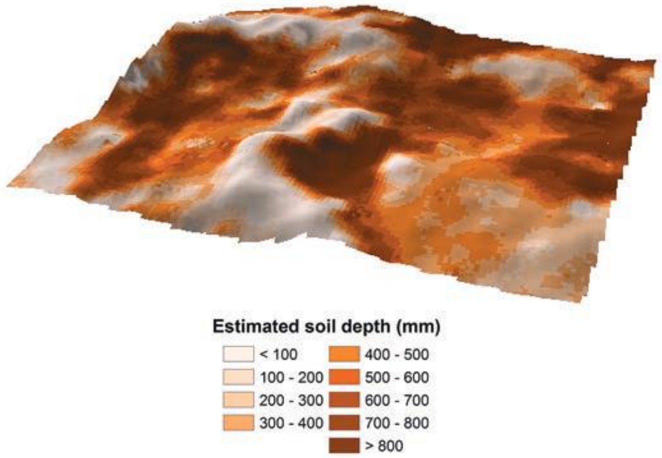
Another effective sampling strategy is conditioned Latin hyper-cube sampling (cLHS).

This approach also makes use of available data layers, such as yield maps, EM soil maps or satellite imagery to generate an optimal sample location plan.

The cLHS method is a stratified random procedure that picks sampling sites based on the numerical distributions of all data layers. For example, if yield and EM maps were used to choose sample locations, the algorithm would ensure that sites were selected in low/medium/high yield zones, as well as low/medium/high EM zones. If there were four layers – slope, land use, NDVI and compound topographic index values – cLHS would choose the sample locations that captured the full range of variability in slope, land use and NDVI.

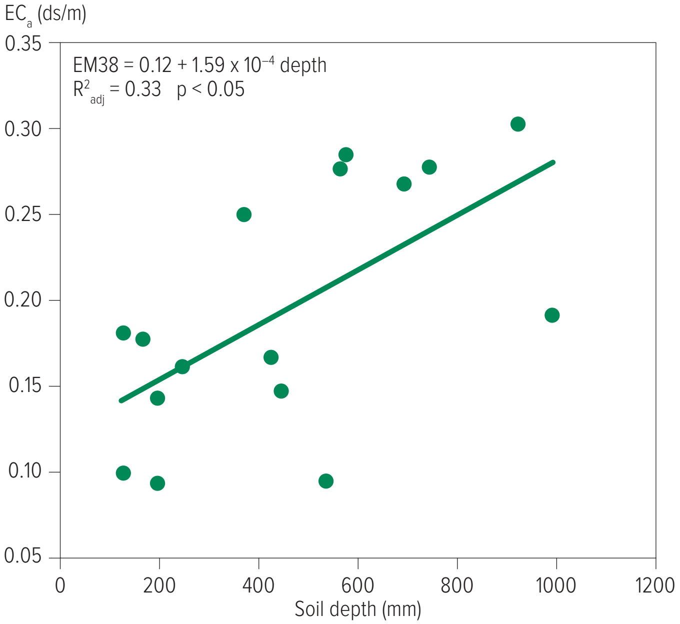
This is achieved using an optimisation routine, which describes how well the sampling sites represent a distribution of all data layers.

Figure 5.2: 3D representation of variation in estimated soil depth and elevation in a 7.3ha Coonawarra vineyard. Note that the map contains some colour distortion due to the shading associated with the 3D display that is not shown in the legend.



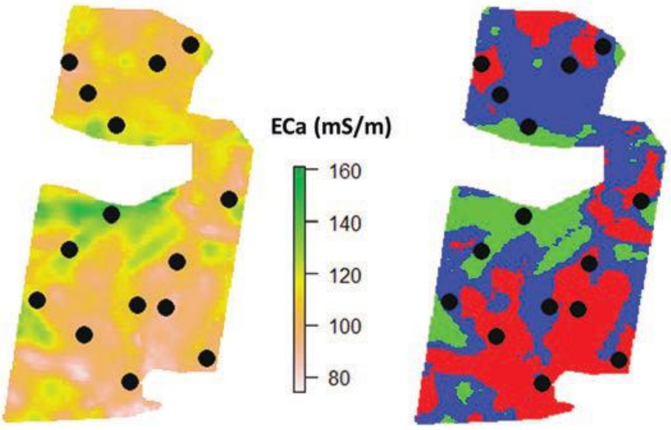
Source: Rob Bramley

Figure 5.3: The relationship between apparent electrical soil conductivity, as measured by EM38 sensing, and soil depth measured at the 16 points shown in Figure 5.1(c).



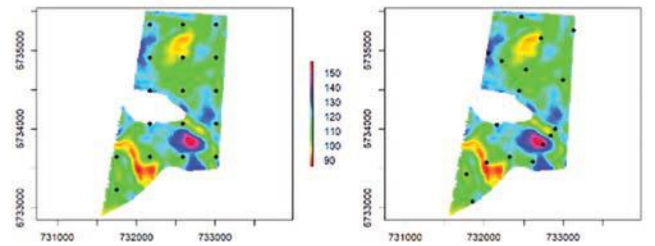
Source: Rob Bramley

Figure 5.4: Sampling sites (black dots) selected from using management zones. The map on the left shows the sampling sites displayed on a map of soil apparent electrical conductivity (ECa) from an EM sensor. The map on the right shows the same sampling points on a map of management zones, which were clustered based on the ECa map.



Source: Patrick Filippi

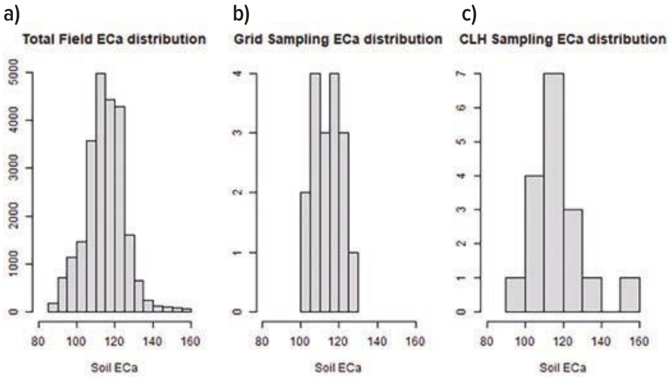
Figure 5.5: Grid sampling (a) versus conditioned Latin hyper-cube sampling (b).



a) Grid sampling **b)** cLHS sampling

Source: Patrick Filippi

Figure 5.6: A histogram of the 1) actual distribution of the field ECa (In Figure 5.5 and 5.6), 2) distribution at grid sampling locations (Figure 5.5 a), and 3) distribution at CLHs locations (Figure 5.5 b).



Source: Patrick Filippi

Figure 5.5 compares a grid sampling plan (left) with cLHS sample locations (right) based on apparent soil electrical conductivity (ECa) from an electromagnetic induction (EMI) sensor. Both plans are based on a budget of 17 sampling sites for this paddock. It is clear that the grid sampling approach misses multiple areas of variation, such as the highest ECa values (pink area in the south-east), and low ECa values (red area in the south-west).

Figure 5.6 compares the distribution of the actual soil ECa values across the whole paddock (left), the ECa values covered by grid sampling (middle) and the wider range of ECa values covered by cLHS (right). Grid sampling misses the lower (<100) and higher (>130) ECa values. cLHS almost covers the full range, with more samples in the most common ECa range (110 to 120, green areas in Figure 5.5). This clearly demonstrates the value of the cLHS approach in selecting areas of the paddock that are truly representative of the spatial variation across the whole paddock.

The cLHS is highly robust, effective and cost-efficient, particularly in comparison to grid sampling.

Conclusions

Using a grid design for soil sampling is often costly and not well suited to mapping and understanding the variation in important soil properties and constraints.

Both management zone sampling and cLHS are cost-efficient and robust and can utilise any kind of data layers to ensure that the variations in soil and crops are taken into account when selecting sites. This leads to more accurate and valuable maps of soil variability in paddocks, and consequently management decisions can be more confidently implemented. Some service providers implement these kinds of strategic soil sampling approaches.

Proximal and remote sensing – what makes the best farm digital soil maps?

Originally published in *Precision Ag News*, Autumn 2023, vol 19, issue 3. Authored by Patrick Filippi, Brett M. Whelan, Thomas F. A. Bishop, Precision Agriculture Laboratory, the University of Sydney, NSW.

KEY MESSAGES

- Using a combination of proximal and remote sensing data gives the best predictions for soil maps
- Considered individually, remote sensing data trumps proximal sensing at this point in time. This is likely because the larger suite of remotely sensed data represents a wider range of factors that relate to these soil properties – for example, terrain, parent material, soil colour and plant biomass

Background

Understanding the spatial variation of important soil properties such as carbon, constraints (e.g. sodicity, salinity, pH) and water-holding capacity throughout the soil profile (for example, 0 to 100cm) is crucial for Australian growers. Soil is generally the largest driver of spatial variation in yields in dryland cropping systems, and information on these at the within-paddock scale can guide critical management decisions.

Digital soil mapping (DSM) has been gaining in popularity over the past few decades, and this has been rapidly increased by the abundance of spatial datasets and computing power now available. A lot of DSM studies are conducted across large areas (for example, regions, countries), but the problem is that these maps do not represent fine-scale variability within paddocks and farms well (Han et al. 2022).

Creating bespoke soil property maps for individual paddocks is relatively uncommon, largely due to the cost and lack of skilled operators. There are two important aspects of this process: 1) the sampling procedure used, and 2) the mapping approach used.

A common sampling approach being used by commercial providers is grid sampling, but this has several downfalls. It can be very expensive and is a crude way of dealing with the variation of soil across space. These approaches also typically map soil using simple interpolation techniques such as inverse distance weighting, disregarding the wealth of spatial data layers now available. An alternative approach is to collect proximally sensed data (for example, electromagnetic induction surveys) and then strategically sample soil based on this information.

This is a more cost-effective approach as often fewer soil samples are required compared with grid sampling. The proximal sensing data is then used in a model to predict soil properties across the paddock, which can more effectively capture the variation of soil compared with the first approach. The downfalls of the grid sampling approach, and the advantages of the strategic sampling method, are discussed in a section earlier in this chapter, 'Combine data with soil sampling to best manage your soil' (page 56).

When the strategic sampling method is adopted, operators generally use very simple approaches, such as using a single spatial variable to create models and maps. Nonetheless, cost can still be a limitation in these scenarios. It could be expected that 10+ samples would be needed to create a simple linear model for a paddock, and a typical grower in Australia can often have more than 10 paddocks. The cost can quickly become daunting if this is the case.

A promising approach to overcome this challenge is to create bespoke soil maps for whole farms, as opposed to individual paddocks. While traditional precision agriculture focuses on single paddocks in isolation, there has recently been a shift to combining data from multiple paddocks for analysis. There are a few reasons for this shift, such as the high cost of sampling and analysing soil, and the fact that more data can be utilised in a prediction model across multiple paddocks.

However, this presents some challenges. For example, differences in management practices between paddocks (for example, crop rotations) can result in differences in the state of soil (for example, moisture), which can then impact on the data collected by proximal sensors. This has the potential to impact the value of proximal sensing when modelling and mapping across multiple paddocks.

Proximal sensing uses a sensor in contact with or within 2m of the soil. Two common examples of proximal sensors are an EMI instrument to collect apparent soil electrical conductivity (ECa) data and a gamma radiometrics sensor (see Chapter 2, the section headed 'Common spatial layers used in PA', page 19, for more information).

Remote sensing uses a sensor greater than 2m from the soil, such as unmanned aerial vehicles (UAVs) and aerial or satellite imagery. There is now an abundance of data collected by various remote sensors that can represent the within-paddock variability of crops and soil, such as the Sentinel and Landsat satellites. This is described in detail in Chapter 2, the section headed 'Satellite-based remote sensing for PA', page 25.

Combining proximal data with remotely sensed data is not a new concept in research, but it is rarely implemented in the industry to create maps of soil variation. There is often a view that if proximal sensing data (for example, EMI/gamma data) is available, there is limited value in adding remotely sensed data.

While the advantage of proximal sensing is that the data is often highly related to several soil properties, there are only a few different sensors commonly available. However, variation of soil properties is driven by, or reflected in, several factors, such as parent material, soil colour, terrain, crop growth and management. There are several remotely sensed spatial variables that may represent these. This, along with the easy and often cost-free access, is a strong advantage of remote sensing products.

This study assessed the value of proximal and remote sensing data individually, as well as the combination of the two for creating maps of important soil properties and constraints. This was assessed for topsoil (0 to 10cm) and subsoil (30 to 60cm) organic carbon, clay and pH at three farms in different biogeographical locations across Australia.

Methods

Study sites and soil datasets

Three different study sites were used in this study: a farm in the wheatbelt of Western Australia (West Farm), a farm in northern NSW (North Farm) and a farm in southern NSW (South Farm). Soil cores were extracted to 1m-depth and subsampled at four depths in the soil profile. Organic carbon, clay content and pH were analysed as they are important properties that represent the biological, physical and chemical components of soil.

The number of sites sampled at each farm varied from 22 to 91 (Table 5.1). Soil sampling is expensive, and realistically growers and land managers are restricted by the cost. Although statistically a larger number of samples would likely be required to produce highly accurate predictions, the reality is that this is just not economically feasible. The soil sampling density for this study ranges from one sample per 80 to 100 hectares, which is something that is realistically implemented by commercial operators for dryland cropping paddocks in Australia (although this can change from region to region).

Table 5.1: The number of sites and proximally sensed data available at each farm.

Farm	Farm size	No. of sites	Proximal EM available	Proximal gamma available
West	7200ha	91	0–50cm, 0–150cm	K, Th, U, TC
North	4900ha	48	0–50cm, 0–150cm	K
South	2000ha	22	0–50cm, 0–150cm	K

K = potassium, Th = thorium, U = uranium, TC= total count

Source: Patrick Filippi

Table 5.2: Proximal and remotely sensed variables used for mapping.

Data type	Category	Data description	Spatial resolution
Proximally sensed data	Electromagnetic induction	ECa 50cm ECa 150cm	10m 10m
	Ground-based gamma radiometrics	Potassium (K) (%) Thorium (Th) (ppm) Uranium (U) (ppm) Total dose	10m 10m 10m 10m
Remotely sensed data	Terrain attributes	DEM (m) TWI	30m 30m
	Airborne gamma radiometrics	Potassium (K) (%) Thorium (Th) (ppm) Uranium (U) (ppm) Total dose	100m 100m 100m 100m
	Landsat NDVI	NDVI 5th percentile NDVI 50th percentile NDVI 95th percentile	30m 30m 30m
	Landsat bare-earth image	Blue band Red band Green band NIR band SWIR1 band SWIR2 band	25m 25m 25m 25m 25m 25m

DEM = digital elevation model, TWI = topographic wetness index

Source: Patrick Filippi

Table 5.3: Lin's concordance correlation coefficient (LCCC) of all models using leave-one-site-out cross-validation (LOSOCV).

Soil property	Model	Depth	West Farm	North Farm	South Farm	Average
Organic carbon (%)	Proximal and remote		0.53	0.54	0.64	0.56
	Proximal only		0.16	0.29	0.13	0.20
	Remote only	0–10cm	0.53	0.54	0.62	0.55
Clay content (%)	Proximal and remote		0.61	0.63	0.78	0.68
	Proximal only		0.41	0.49	0.66	0.52
	Remote only	0–10cm	0.60	0.55	0.72	0.62
	Proximal and remote		0.38	0.34	0.53	0.42
	Proximal only		0.20	0.21	0.46	0.29
	Remote only	30–60cm	0.38	0.12	0.44	0.31
pH	Proximal and remote		0.32	0.37	0.65	0.45
	Proximal only		0.24	0.25	0.37	0.29
	Remote only	0–10cm	0.26	0.12	0.57	0.27
	Proximal and remote		0.72	0.53	0.28	0.51
	Proximal only		0.63	0.42	0.11	0.39
	Remote only	30–60cm	0.67	0.41	0.39	0.46

LCCC values are ranked by colour. 🟩 Green = best 🟧 Orange = middle 🟨 Yellow = worst

Source: Patrick Filippi

Proximally sensed data

A proximal soil sensing survey was conducted to collect high-resolution apparent soil electrical conductivity (ECa) and gamma radiometrics data. Soil ECa was measured via electromagnetic induction using a DUALEM-21S instrument (Dualem Inc., Milton, Ontario, Canada). Gamma radiometric data was recorded using an RSX-1 gamma radiometric detector with a 4 litre sodium-iodine crystal (Radiation Solutions Inc., Mississauga, Ontario, Canada).

The proximal soil sensing survey was conducted on 24m swathes and the position was recorded with differential GPS (DGPS) equipment. Continuous surface layers were obtained by Kriging with local variograms onto a standard 10m grid through the software R (Table 5.2).

Remotely sensed data

All the remotely sensed data used in this study was freely available. A digital elevation model (DEM) at ~30m resolution derived from the Shuttle Radar Topography Mission (SRTM) acquired by NASA was obtained from the ELVIS (ELeVation Information System) platform (https://elevation.fsdf.org.au). A map of topographic wetness index (TWI), which was also derived from the SRTM, was downloaded through CSIRO's Data Access Portal (https://data.csiro.au).

Airborne gamma radiometric potassium, thorium, uranium and total dose data was obtained through the Geophysical Archive Data Delivery System (GADDS), Geoscience Australia (https://portal.ga.gov.au/persona/gadds). This data represents the parent material of the soil and soil types. This data was collected on varying swathe widths across Australia and is provided as a ~100m resolution gridded product.

NDVI imagery from Landsat 7 satellite at a 30m resolution was obtained from 1 January 2000 to 31 December 2020. The 5th, 50th and 95th percentile statistics were then calculated to represent the most common value (50th percentile, or median), and the lower and upper distribution of the imagery (5th and 95th percentile, respectively). This reflects long-term trends in crop biomass and therefore production.

Bare earth imagery was also used from Roberts et al. (2019) and was downloaded from https://nationalmap.gov.au. This bare earth imagery uses 30 years of Landsat data to capture an image of the earth at its barest state at a 25m resolution. Six Landsat bands of blue, green, red, near-infrared (NIR), short-wave infrared 1 (SWIR1) and SWIR2 were used in the modelling. Example maps of data layers at the North Farm site are shown in Figure 5.7. This shows the variation of the different data layers across the farm.

Modelling approach

Multivariate linear models were used to build a predictive model of the soil properties. Although there are many more complex approaches available, such as machine learning, a simple approach is often best when mapping soil across small areas with relatively few samples. A separate model for each soil property, depth and farm was used.

Three different data scenarios were considered:

- using proximal sensing data only;
- using remote sensing data only; and
- using both proximal and remote sensing data.

A stepwise function was then used to find the most optimal combination of variables to include in the final model; these were recorded. The predictive ability of the models was then assessed using leave-one-site-out cross-validation (LOSOCV). The results of the validation at every site were then combined and the Lin's concordance correlation coefficient (LCCC) was used to assess the model quality.

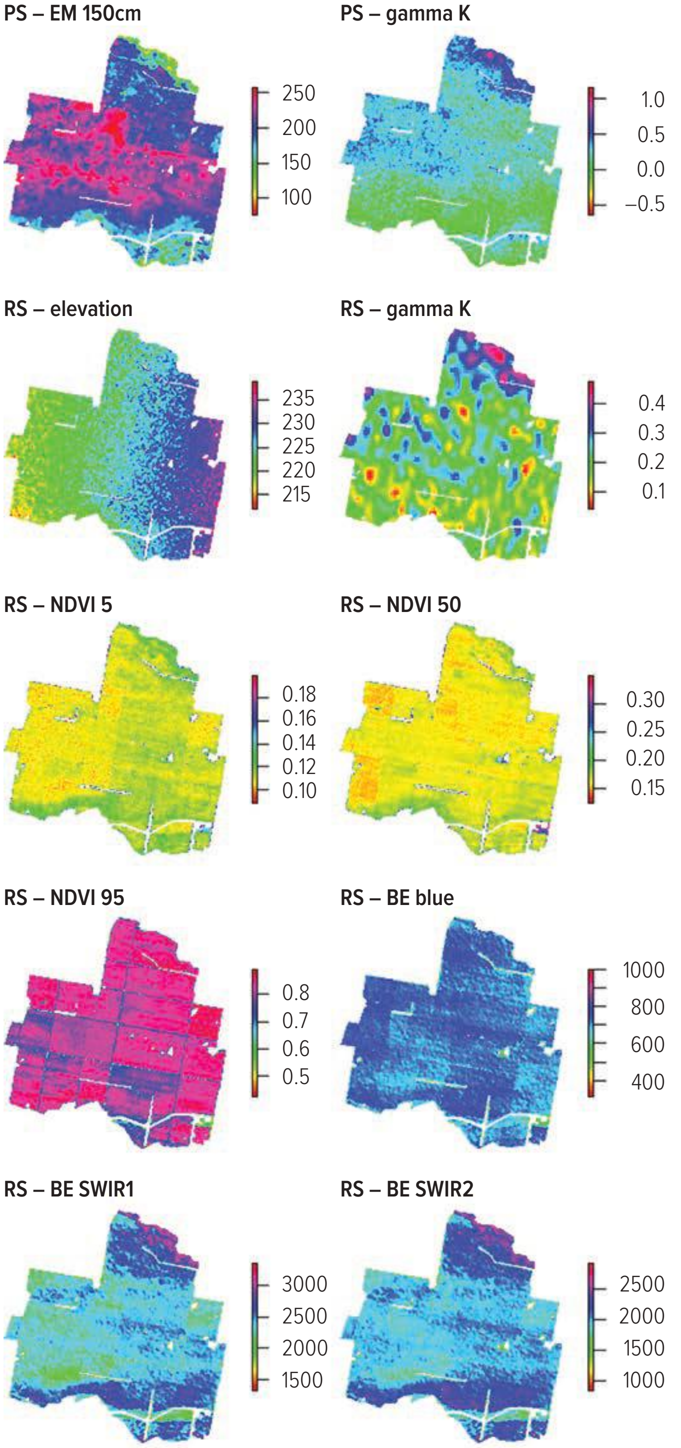
The LCCC is similar in concept to the R2, but is a great way to assess model quality as it assesses the fit of the observed and predicted values to the 1:1 line. It is unit-less, allowing comparison between soil properties with different magnitudes, which we have here – pH, organic carbon and clay. This allowed us to make direct comparisons between the quality of the models for each property. LCCC values can range from –1 to 1, with perfect agreement at 1.

Results

The results showed that using a combination of proximal and remote sensing data always resulted in the best average LCCC value (Table 5.3). This was the case for all three soil properties – organic carbon, clay and pH – in both the topsoil and subsoil. Although it is dependent on many factors, a validated LCCC value greater than 0.5 is generally deemed as acceptable in digital soil mapping studies.

Ideally, higher LCCC values are obtained if the maps are to be used to underpin management decisions. Using remote sensing data only also showed that it predicted these soil properties better than only using proximally sensed data. This is likely because the larger suite of remotely sensed data represents a wider range of factors that relate to these soil properties – for example, terrain, parent material, soil colour and plant biomass.

Figure 5.7: Maps of a subset of covariates for North Farm. PS = proximally sensed, RS = remotely sensed, BE = bare earth. (The straight line artefacts in some of the maps are roads across the property and ultimately do not impact the final soil maps).



Source: Patrick Filippi

Also, proximal sensing data can be impacted by management differences between paddocks, which can reduce the value of this data when aggregating multiple paddocks together as we have done in this study. While some remote sensing variables can also be impacted by these differences in management (for example, NDVI), many are largely unaffected, such as elevation and airborne gamma radiometrics. It could be expected that the proximal sensing data would be more valuable when focusing on single paddocks, or if there were minimal management differences between paddocks. Overall, it is clear that there is an advantage in using a combination of proximal and remote sensing data when creating soil property maps of cropping paddocks and farms.

Table 5.4 shows the variables included in the final model for each farm, soil property and depth. In terms of proximal sensing data, gamma radiometrics potassium was the most included of all variables in the study, being included in 10 of the 15 models. It is known that gamma K is highly correlated to important variables such as clay content.

The EMI data at 150cm was included in six of the 15 models. In terms of the remotely sensed data, it was clear that the variables based on satellite imagery (NDVI and bare earth) were the most useful. In particular, the SWIR1 band from the barest earth Landsat imagery was the variable most included at eight times.

This was followed by the bare earth blue band and NDVI 5th and 95th percentile at seven times each. This suggests that remotely sensed imagery of crop biomass and bare soil can well represent the variation in these important soil properties. Overall, only three of the 15 models used no proximally sensed data, suggesting that proximal sensing provides considerable value when added to remote sensing data.

Discussion and conclusions

- Results clearly showed that using a combination of proximal and remote sensing data always resulted in the best predictions.
- Using remote sensing data only generally led to better predictions than proximal sensing data only. One possible reason for this soil variation is driven by several factors (for example, terrain, parent material, biomass), and there is a larger and more diverse suite of remotely sensed variables that represent these factors. Another thing to consider is that proximal sensing data is often affected by differences in management between paddocks, and combining data across multiple paddocks as we have done in this study may impact the value of this.
- Despite this, the proximally sensed gamma K (potassium) was the most widely used of all the available variables and only three of the 15 models used no proximally sensed data, suggesting that proximal sensing provides considerable value when added to remote sensing data.
- The remote sensing variables based on satellite imagery (NDVI and bare earth) were important predictors for many of the models for predicting soil carbon, clay content and pH. In particular, the bare earth SWIR1 and blue band were standout predictors. This demonstrates that remotely sensed imagery of bare soil can well represent the variation in important soil properties.
- Interested growers should contact their PA specialists/ agronomists or appropriate service providers about possibly getting this implemented on-farm.

Table 5.4: Final variables used in the proximal and remote sensing.

			Proximal sensing data					Remote sensing data											
Soil property	Depth interval	Farm	EM 50cm	EM 150cm	K	Th	U	DEM	TWI	K	Th	U	NDVI 5	NDVI 50	NDVI 95	Blue	Red	SWIR1	SWIR2
Carbon	0–10cm	West		X	X				X		X	X	X		X	X			X
Carbon	0–10cm	North						X				X	X	X	X	X		X	
Carbon	0–10cm	South	X					X	X	X		X			X	X		X	
Clay	0–10cm	West		X		X	X		X		X	X				X			X
Clay	0–10cm	North		X	X						X					X		X	
Clay	0–10cm	South			X										X			X	
pH	0–10cm	West		X	X		X			X			X						
pH	0–10cm	North											X	X	X				
pH	0–10cm	South						X	X						X			X	
Clay	30–60cm	West									X		X			X		X	
Clay	30–60cm	North		X	X				X				X		X	X		X	
Clay	30–60cm	South			X								X						
pH	30–60cm	West		X	X		X			X							X	X	
pH	30–60cm	North			X				X		X								
pH	30–60cm	South								X									
Total occurrence			1	6	10	1	3	3	6	4	5	4	7	2	7	7	1	8	2

DEM = digital elevation model, TWI = topographic wetness index, K = potassium, Th = thorium, U = uranium, NDVI = normalised difference vegetation index, SWIR = short-wave infrared.

Source: Patrick Filippi

Useful tools

Adding these freely available and fine-scale remotely sensed products to your proximally sensed EMI or gamma surveys leads to more accurate soil property maps that could inform important management decisions;

- The bare earth imagery is available as a free downloadable product from https://nationalmap.gov.au and is a great resource for creating soil maps to represent within-paddock variation on farms. This imagery can be easily accessed by anyone and is a great resource for the industry.
- The Sydney Informatics Hub at the University of Sydney has created a Geodata Harvester tool that can be used to easily extract all of the remote-sensed variables used in this project (as well as others). This tool is available for anyone to use and further information can be found at https://www.agrefed.org.au/AgReFedGeodataHarvester.

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Managing acidity – two grower case studies, SA and NSW

Variable-rate liming programs aim to reduce variability in soil pH across the paddock. Soil tests and VR lime rates have traditionally focused on the topsoil (0 to 10cm). For some growers, this means subsoil acidity is a sleeping giant. It was for South Australian grower James Venning of Barunga Grains, where a lentil crop gave the game away. Although soil pH tests indicated acidity was not an issue, the crop did not perform as expected.

NSW grower Roy Hamilton (page 69) is in the process of developing a subsoil variable-rate lime strategy as deeper soil tests are showing his clay soils are acidifying.

Generating variable-rate lime maps has become somewhat easier with the development of on-the-go pH measurement. At the moment, Veris® has the only commercially available on-the-go pH sensor available in Australia.

Photo: Sophie Clayton/GRDC

SNAPSHOT

Name: James Venning

Business name: Barunga Grains

Location: Yorke Peninsula, South Australia

Farm size: 4700 hectares

Rainfall: 400mm

Soil types: sands to loams on a dune-swale landscape

Enterprises: cropping

Rotation: lentils and canola with cereals as the break crop

South Australia

At Barunga Grains, SA, “everything we’re doing is pushing the lentil bandwagon”, according to grower James Venning. A key part of pushing lentils is dealing with soil acidity.

James crops 4700ha on the Yorke Peninsula. The soils are sands to loams on a dune-swale landscape. As the elevation changes, there are very different soil types, with lighter sands on the dunes and loams in the swales. Soil pH is highly variable, ranging from 4.5 to 8.5 with stratification.

Soil pH mapping began in 2018 with two paddocks at either end of the farm. The plan was to extrapolate the results across the farm; however, the two paddocks were completely different and James decided the whole farm needed mapping.

James hired a contractor with a Veris® on-the-go pH sensor to map topsoil pH. The machine was set to test pH at 10cm depth, took roughly 10 measurements per hectare and covered approximately 400ha/day. While speedy, the machine only tested pH at one point in the profile, meaning it was not picking up pH issues above or below where it was set. Figure 5.8 shows an example topsoil pH map generated by the Veris® sensor.

For a more detailed pH investigation, topsoil pH and EC (salinity) (also mapped by the Veris® and a decent map of soil types) were used to create soil zones. pH to depth was assessed by collecting soil cores for laboratory analysis. "Every year we did a bit more, and now the whole farm has been mapped," James said.

James started pH mapping purely to get accurate VR lime rates, but once he had the pH maps of the farm, he started noticing that the slow-growth areas always seemed to be on the higher pH areas, which led to a more sophistical approach to variable rate phosphorus applications (see Chapter 6).

On the dune-swale landscape, the farm has a wide variety of pH profiles (Table 5.5). The flats tend to have a pH >6. The hills have a band of acidity from 5 to 10cm and 10 to 20cm. James said they had to break up the 0 to 10cm soil test because although the average 0 to 10cm test indicated acidity was not an issue, the lentils were not happy.

"Lentils were the canary, and their roots did not like the acid choke," James said. The pH of 4.53, for example, from 5 to 10cm on the mid-hills was an issue for lentil roots.

Varying lime rates

The VR lime strategy targets pH down to 30cm and is based on the topsoil pH map and EM map. To define lime rates and zones:

- If the EM map suggests the soil is a sand and the pH is below 5.5, subsoil acidity is likely a problem.
- If the EM map suggests a loamier soil, even if the topsoil is acidic, assume subsoil acidity is not a problem.

At the moment, subsoil acidity is only evident on sands where the topsoil pH is <5.5. This is then ground-truthed with soil tests, which are used to further refine zones and lime rates. James is targeting a pH of 6 $CaCl_2$.

"The system isn't perfect but it's a starting point and generally if the topsoil on a sand has a pH <5.5, there are acidity issues deeper in the profile," James said.

Using the standard assumption that 2t/ha of lime is needed to lift pH by one unit on the heavier soils, the lime strategy ranges from up to 10t/ha on the worst parts of the paddocks (to treat acidity to 30cm depth) to 0t/ha on the flats. The average lime rate across farm is usually about 2.5t/ha. Figure 5.9 shows a variable-rate lime map.

Getting the lime to depth means ripping, as lime takes many years to treat subsoil acidity when surface applied. The process is:

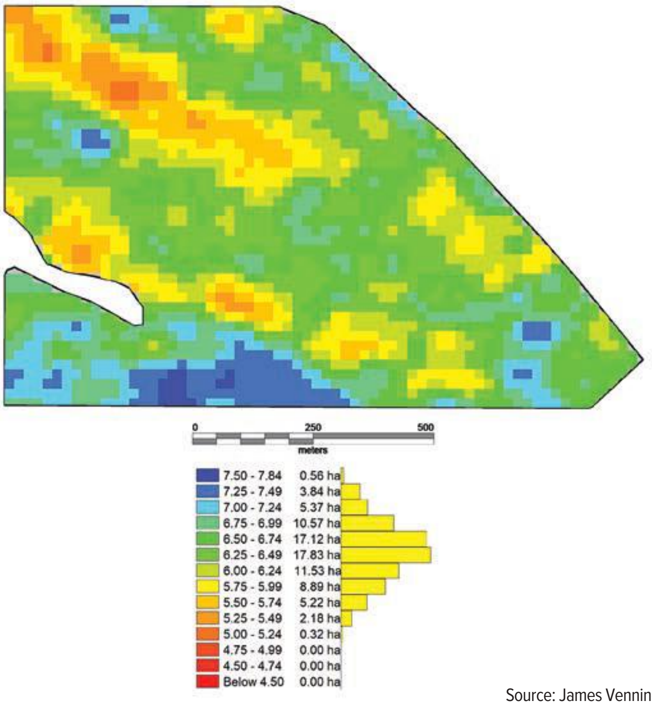
- lime paddock in year one;
- mix lime into topsoil with seeder in that year; and
- deep rip and include the following year with long inclusion plates. Better for high ground speeds and therefore more productive ripping process.

Table 5.5: Example average pH results at Barunga Grains. While the flats have a decent alkaline pH, subsoil acidity is evident on the mid-hill and rises.

Depth (cm)	Top hill (pH)	Mid-hill (pH)	Flat (pH)
0–5	5.22	5.27	6.66
5–10	4.71	4.53	6.93
10–20	5.61	4.82	7.29
20–30	7.62	5.36	7.75

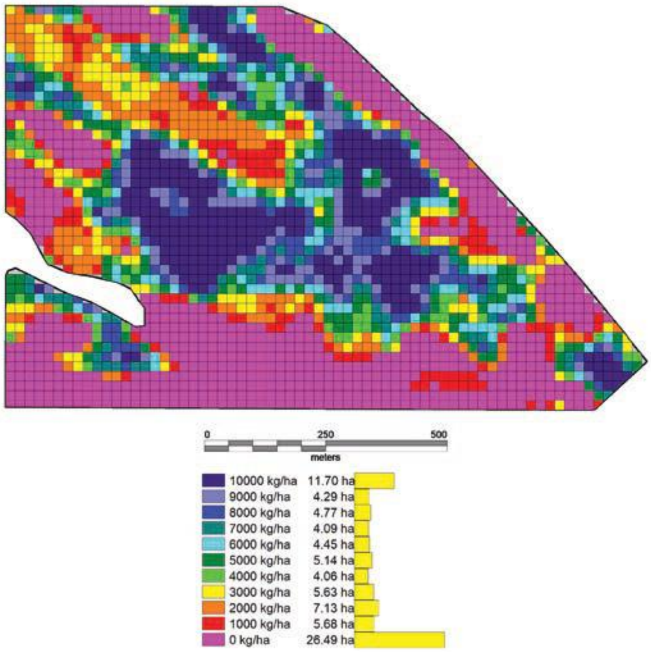
Source: James Venning

Figure 5.8: Topsoil pH map generated from Veris® pH mapping.



Source: James Venning

Figure 5.9: Variable-rate lime map for a paddock on James Venning's farm.



Source: James Venning

Photo: Steve Cowley

SNAPSHOT

Name: Nathan Simpson and Kieran Simpson (brothers) with parents Ross and Michele Simpson

Business name: Binginbar Farms

Location: Gollan, 50km east of Dubbo, NSW

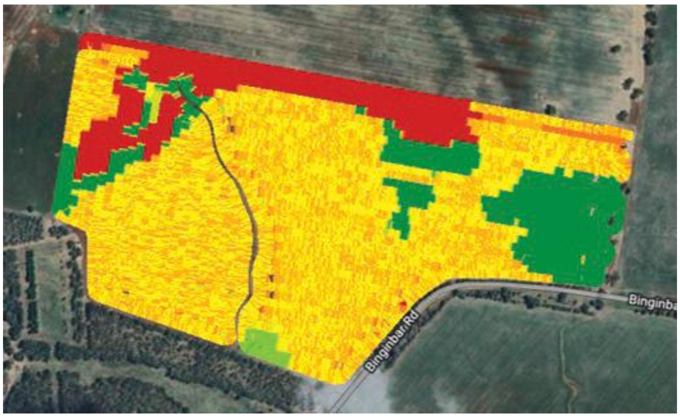
Farm size: 3850 hectares

Rainfall: 550mm

Soil types: red clay to clay loams

Enterprises: cropping rotation wheat/canola/barley; perennial pastures; and a feedlot finishing store lambs

Figure 5.10: Variable-rate lime map (2018) on Nathan Simpson's 45ha paddock.



Source: Nathan Simpson

New South Wales

This case study is extracted from an article, 'Turning to technology to combat farming system challenges', first published in *Precision Ag News*, Winter 2023, vol 19, issue 4, authored by Peter Somerville. Updated in late 2023 by Alisa Bryce.

Nathan Simpson crops just under 3000ha of the family farm near Dubbo, NSW. Soil variability is prevalent across the property's red clay to clay loams, with naturally acidic soils ranging in pH from 4.2 to 6.8. "There's very different soil types in every single paddock on the place, different elevations, different parent material that makes up the soil type," Nathan said.

The Simpsons hired a contractor to undertake Veris® on-the-go sensor soil mapping in 2017 and from this produced a pH map across 186ha of the farm. The Veris® machine collected 10 to 12 samples per hectare and mapped about 30ha an hour.

"We got it zoned up based on the pH map, then went out and ground-truthed with 25 different soil samples to validate what the Veris® was telling us," Nathan said.

He was surprised at the accuracy of the results and how well soil sampling data matched the Veris® data. Each pH zone was allocated a rate of lime and subsequent VR lime applications ranged from 0t/ha to about 5t/ha (Figure 5.10).

He described the resulting consistency in that part of the farm after the lime application as "unbelievable". "It has had a big impact," Nathan said. "Not necessarily a cost saving, but you're putting the lime where it's going to have the best impact over that country."

From follow-up pH testing, topsoil pH now ranges from 6.2 to 6.8, instead the 4.2 to 6.8 prior to the liming.

Tracking subsoil acidification for a pre-emptive VR lime strategy

SNAPSHOT

Name: Roy and Michael Hamilton

Location: Rand, NSW

Farm size: 4400ha total, 3700ha cropped

Rainfall: 425mm, 280mm GSR

Soil types: predominantly red-brown earth to a brown-grey clay interspersed with black cracking clay. A small area of loam

Average dryland yields: wheat 3t/ha, canola 1.5t/ha

Enterprises: wheat, canola, triticale, pulses; 1500 ewes and terminal sires

Roy Hamilton and his son Michael, growers from Rand, NSW, are using PA to improve one of their major assets – the soil. The Hamiltons work with two local soil science specialists, David Hawkey and Dr Cassandra Schefe of AgriSci Pty Ltd, to map the soil into zones and work out where to best invest their money.

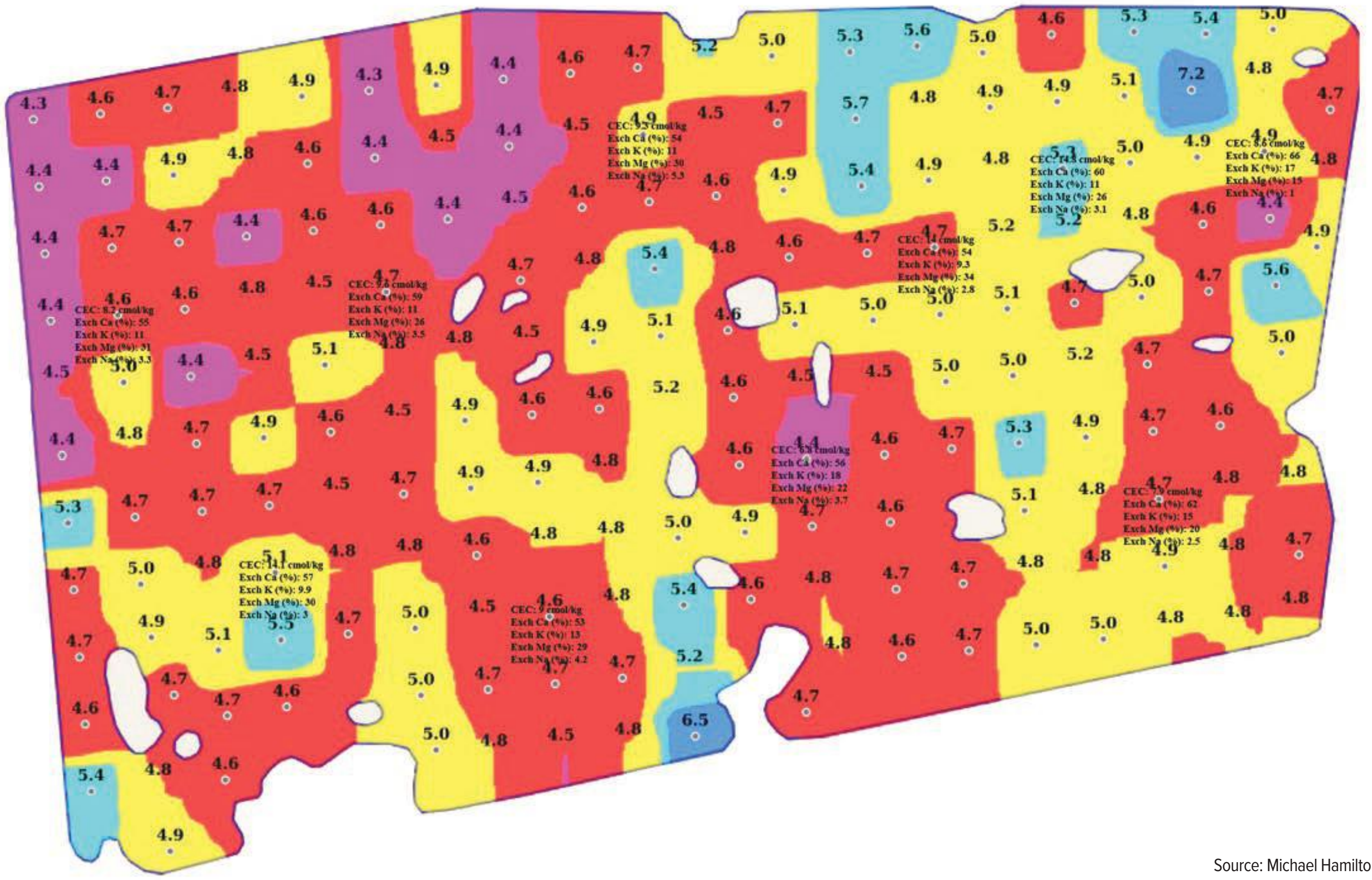
Roy said: “Expanding the farm by buying new land is very difficult and it is hard to make a solid business case for it with land prices and interest rates where they are at present. Can we instead produce more with the land that we manage, while increasing resilience and reducing risk in the business?”

The Hamiltons said that until recently, they had been reactive with soil amendments and wanted to become more strategic. “In a drying climate, we want to enhance the ability of the soil to store water and for crops to access this by minimising constraints,” Roy said. “If we can turn a 0.7t/ha crop into a 1.2t/ha crop in a decile 2 year, this can be the difference between losing money or making a profit.”

Roy has been using precision agriculture since 2002, when he fitted a yield monitor to the header to start zoning their cropping country. In 2004, he had the property EM mapped and calibrated the EM information with soil tests taken over the previous three or four years to refine the paddock zones.

In 2012, Roy was using the zone maps to apply VR gypsum, lime and phosphorus (P). The P applications evened up the zones fairly quickly and they now use VR P on a replacement and maintenance basis.

Figure 5.11: The Hamiltons’ Burrongong paddock 0 to 10cm soil pH ($CaCl_2$) test result.



Source: Michael Hamilton

"We may not have saved on a lot of product but have been far more strategic with how we've used it," Roy said. Now, as the P applications have evened up many of the zones, unless they are varying more than 15 to 20 units of P, they apply blanket rates.

"By using zonal management, if we are consistently taking more [nutrients] off one area we can apply more to maintain the productive potential of the paddock without overspending." For example, in 2019 towards the end of the drought, they could use the minimum amount of P, for example, 15 to 20kg of MAP, because those zones had been evened up over time.

Now the Hamiltons are turning their attention to subsoil acidification. The plan is to pre-emptively lime to catch subsoil acidification before it becomes more of an issue. Although Roy has been using VR lime for about 12 years, the focus has been on combating topsoil acidification. Figures 5.11 and 5.12 show a topsoil pH map and VR lime map.

Recent deeper soil testing has shown that subsoil acidification is emerging as a significant issue, which was not recognised using surface soil mapping and VR lime.

Soil scientist Dr Cassandra Schefe of AgriSci Pty Ltd said: "Because VR lime has been based on the 0 to 10cm zone, lime has been applied at rates required to amend that surface soil. As subsoil pH values were never measured, there was no indication that subsoil acidification was an issue. This means that with high productivity and use of N fertilisers, the subsoil has continued to acidify over time while the surface pH values are addressed. This is emerging as a big problem, not just for Roy and Michael, but across the whole southern cropping zone."

The farm has largely clay soils with a higher cation exchange capacity (CEC), meaning it takes more lime to deal with the acidity compared with a sandy soil. Getting on top of the problem now will prevent yield loss penalties and higher liming costs in the future.

"We don't want to wait for a yield penalty," Dr Schefe said. "We need to be proactive."

The approach

Where possible, AgriSci uses Roy's existing data – 20 years of yield maps, the initial EM maps and zones (Figure 5.13) and years of soil test data. These are supplemented with new soil test results from deep soil cores in increments to 60cm.

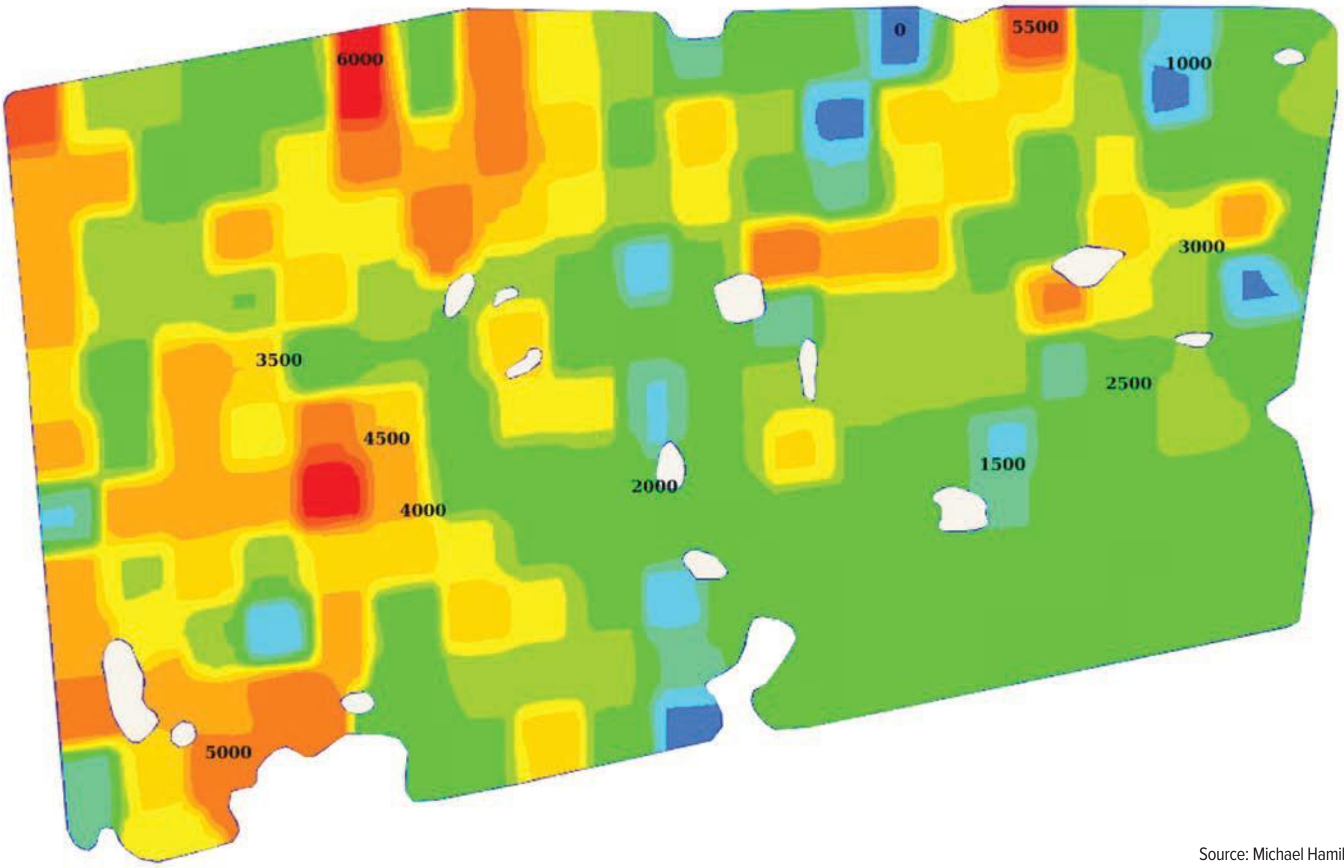
Because intensive grid soil sampling is cost prohibitive, they use the existing mapped zones and soil test at specific GPS locations (Figure 5.14) to check if the mapped zones are appropriate or if zone boundaries need moving. The soil cores from each zone are analysed individually rather than as a composite sample.

"Using the soil sample data, we can ask if each zone makes sense," Dr Schefe said. "If it doesn't, we then look at other layers like yield maps under a legume (a good canary) to see what's happening, to see what we know about historical production."

Tracking subsoil acidity

Deeper soil testing (Table 5.6) showing acidification at 10 to 20cm is a concern in some areas and a pending concern across most of the paddock. For example, compare Green04 and Green12. Both have a 0 to 10cm pH of 4.9, but Green04 has a 10 to 20cm pH of 4.8 (borderline acceptable) while Green12 has a 10 to 20cm pH of 5.2 (acceptable).

Figure 5.12: The VR lime map for the Hamiltons' Burrongong paddock based on topsoil pH map. Lime rates range from 0 (blue) to 8t/ha (red).



Source: Michael Hamilton

Where the soil has a pH <5.0 from 0 to 20cm, soil pH from 20 to 30cm is low compared with the rest of the paddock.

Subsoil acidity is not yet causing a significant yield penalty in this paddock, but it is a concern, particularly because the soils are clay with a high CEC.

"The high CEC in these soils mean they won't show aluminium toxicity until they reach a pH of about 4.5, because the CEC buffering means it takes longer for the aluminium percentage to increase," Dr Schefe said. "This means that clay soils are particularly at risk of being ignored and need to be managed proactively. If you wait until subsoil acidity is an issue, it's a massive deal to fix it."

Dr Schefe also noticed a very strong relationship between the CEC drop at 10 to 20cm and acidification rates. These are the 'red flag' zones. It is not so much the absolute CEC value that is important, but rather when the CEC in the 10 to 20cm zone is less than both the 0 to 10cm and 20 to 30cm depth, which indicates that the 10 to 20cm zone has less capacity to withstand pH change than the surrounding soil and so is at risk of increased acidification.

Knowing where they stand with subsoil acidity means the Hamiltons have a couple of years to develop their liming strategy and budget and to source product. "We're keeping the bucket topped up, rather than waiting for the problem to show itself," Dr Schefe said. "We're also then not needing to order lime when everyone else does."

The new VR lime strategy will address zones that have more issues at depth than others, rather than basing the rates solely on topsoil pH. The next step is to work out the VR lime zones, something that Michael and Roy do themselves. The deeper soil tests equate to about one test per 50ha and are too expensive to do in detail like the topsoil pH testing (Figure 5.11).

As a result, the Hamiltons are in the process of working out the best way to generate VR lime maps to address subsoil acidity.

The EM zones do not align well with pH data or yield maps. The Hamiltons are therefore hesitant about using the EM zones to make new VR lime rates. They are looking at other layers that might help create the zones, including NDVI maps and historical yield maps from faba bean crops as they are more sensitive to acidity.

Lime will be incorporated to depth to ensure effective and timely amelioration. In 2024 they will test different machines to find the best way to apply and incorporate lime and to get the best seedbed after ameliorating.

Michael said: "We will also track the economics of the variable-rate lime and incorporation and hope to see benefit over a few years."

Monitoring

Soil pH will be monitored in the future down to 60cm using the same sample locations (Figure 5.14). This will give the Hamiltons ongoing feedback on how their VR lime strategy is working and where they need to make adjustments.

Learnings

Roy's key learnings after 10 years of VR liming:

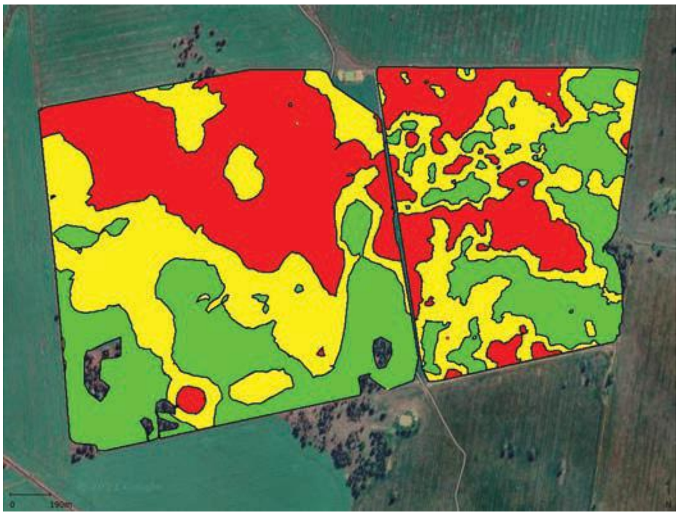
- We need to incorporate lime to get what we want to achieve.
- If you are going to move pH, you're better off getting a big hit and not using maintenance rates. You're also better off spending a reasonable amount and incorporating the lime. Advice in the old days was to get the pH to 5.0; now 5.5 is better.

Table 5.6: Soil pH data from Burrungong paddock.

Depth (cm)	Burr_Green06	Burr_Green04	Burr_Green12	Burr_Yellow02	Burr_Yellow05	Burr_Yellow09	Burr_Red01	Burr_Red05	Burr_Red12
0–10	4.6	4.9	4.9	4.5	4.7	5.1	4.8	4.2	4.8
10–20	4.7	4.8	5.2	5.4	5.1	5.5	5.3	4.9	5.7
20–30	5.0	5.5	6.2	6.2	6.1	6.7	6.1	6.5	6.3
30–40	6.6	6.1	6.8	7.1	6.8	7.6	6.4	6.9	7.3

Source: Cassandra Schefe

Figure 5.13: Three soil zones developed from the EM map of Burrungong and Oaks paddocks.



Source: Michael Hamilton

Figure 5.14: Deeper soil core test locations.

Source: Michael Hamilton

GROWER CASE STUDY

Using PA for saline soil management

Yield maps, satellite images and EM38 maps help the Paddicks find and treat saline soil on their property.

In 2008, Stephen Paddick was ready to retire salty, unproductive areas of the farm. With a typical yield of 0.4t/ha, these areas were just costing money with wasted inputs. However, after a local agronomist and farming group demonstrated that using a thick layer of straw (10t/ha or more) on saline areas could boost their productivity, Stephen turned his attention to trying it out on his own property. On saline land, evaporation draws moisture and salt towards the surface, increasing the level of salt. Covering the soil with crops or mulch reduces evaporation and the associated salt accumulation in the soil.

In 2011, Stephen tried the first round of straw spreading and noticed an improvement in yield that year. The source of straw was 'out-of-spec' oaten hay that did not meet export standards. In 2014, he bought a straw spreader with a group of growers in the area and has been refining treatments on the saline areas ever since.

Mapping the saline areas

Stephen overlays yield map satellite images every year to find the poor-performing areas and see if the affected areas are growing or getting smaller. He also overlays an EM about every five years.

"Ninety-nine per cent of the time they [the three layers] do marry up very well," he said. The worst areas are the salty areas.

"After harvest, we load that map into the tractor on the screen, drive to those areas and spread straw at about 5 to 10t/ha." The straw breaks down fairly quickly so by sowing time, the seeder does not have any trouble getting through it.

By managing the salinity, Stephen has stabilised the problem. The area of unusable saline soil in some paddocks has dropped from about 20 per cent down to less than 5 per cent. Yields have gone from 0.4t/ha in the worse areas up to about 2t/ha.

Stephen has started growing peas again to boost on-farm stubble, even though lentils fetch a higher price.

The current challenge is sourcing the straw. In good years he uses straw from high-performing paddocks but as straw now has a "decent value", it has become hard to source in average years as an economic practice.

SNAPSHOT

Name: Stephen, Shane and Brian Paddick

Location: Wallaroo, South Australia

Farm size: 2000ha

Rainfall: 375mm

Soil types: grey calcareous loams, topography is flat with little undulation

Improvements: saline areas went from yielding 0.4t/ha to 2t/ha

Spreading straw mulch on saline areas. Photo: Stephen Paddick

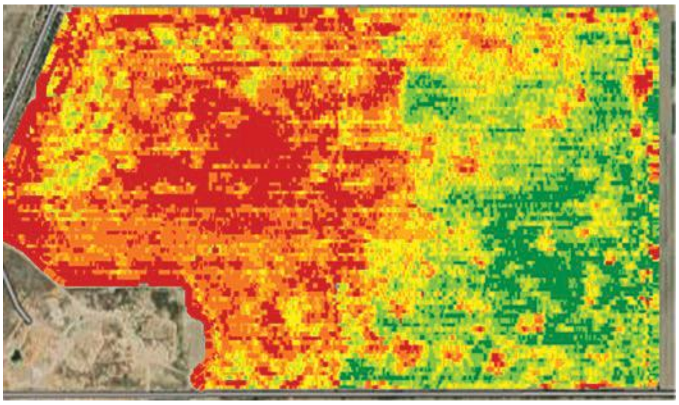
Varying other inputs

Stephen also uses the zone maps to vary fertiliser and seeding rates to match the potential of the zones. "We were halving the fertiliser rates on the saline areas, but through soil tests over time noticed we were depleting soil nutrients. Now we apply about 75 per cent fertiliser compared with the rest of the paddock. We also increase the seeding rate on the saline areas to help counter the number of plant deaths on those areas."

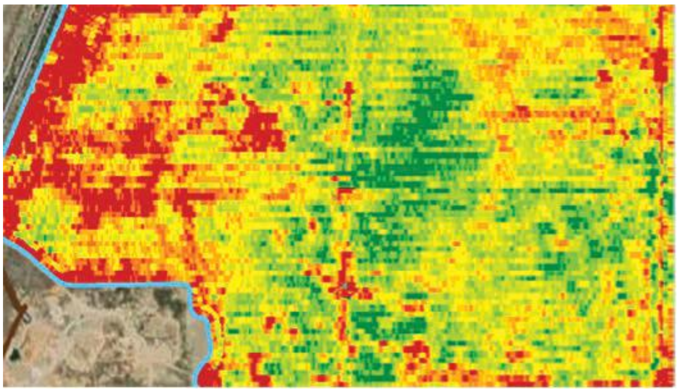
Stephen uses edge-row sowing across the farm to improve crop establishment by using implement guidance with RTK. Seed and fertiliser maps are created using John Deere Operations Center then sent to the tractor. The seed and fertiliser are then applied using the John Deere Dry Rate Controller and Gen 4 Screen through a Bourgault 3310 Paralink seeder.

Figure 5.15: Wheat yields in 2013 and 2022 on a Paddick farm paddock. Regular straw applications have evened out yields across the paddock.

Wheat yield map 2013



Wheat yield map 2022



Source: Stephen Paddick

Precision soil movement

SNAPSHOT

Name: Jake Hamilton, his wife Felicity, father Scott and his wife Janne

Business name: Krui Pastoral Co

Location: Condamine (western Darling Downs), Queensland

Farm size: 5600ha

Rainfall: 573mm

Soil types: grey/brown vertosols, red kandosols, highly sandy creek country

Enterprises: wheat, barley, chickpeas, faba beans, sorghum, mungbeans and, very rarely, dryland cotton

With a few thousand hectares of melon holes (gilgai) covering Jake Hamilton's farm, water management is an issue. The family farm covers 5600ha on the western Darling Downs, with melon holes once dotting 3000ha of the farm. This is now just shy of 2000ha.

Gilgai or melon holes are small mounds and depressions, common in Queensland's Brigalow Belt. On Jake's property they are easily visible on satellite imagery (Figure 5.17). As mini-catchments, wet years are more of an issue than dry years because water sits in the depressions. In very wet years, there is little chance of a crop as water can stay there for up to six months. Waterlogging also leaches nutrients from the rises where they accumulate in the holes, leaving infertile soil on the tops.

"In dry years, the melon holes are usually the best yielding because they collect what little moisture is available," Jake said. Jake's goal is to flood-proof the business, which means removing the melon holes.

Figure 5.16: March 2019 Google Earth image. A 630ha paddock with recently levelled section visible in the eastern half.

Source: Google Earth

Water-filled gilgai at Krui Pastoral Co. Photo: Jake Hamilton

Prioritising the levelling plan

With 3000ha of gilgai to level, Jake prioritises where to start by using a combination of yield maps, NDVI and high-resolution aerial imagery. These highlight where waterlogging is causing the biggest problems. Fuel use data completes the picture, and the highest fuel use plus worst-performing areas are prioritised.

Jake then feeds elevation data collected from a LiDAR survey into T3RRA Design to plan the earthworks. The LiDAR survey was conducted in 2019 during the drought and means Jake has high-resolution elevation maps of the property, including the depths and rises of each of the melon holes. "It's detailed enough to see the planting furrows," Jake said. Before 2019, they collected elevation data using a rover on a 10m grid.

A soil testing program identified exchangeable sodium levels of up to 25 per cent at 60cm depth. Knowing the location of the sodic soil is part of the cut-and-fill planning. To ensure this soil stays buried, the cuts when levelling are limited to 30cm deep. Jake said only in a few cases, about one per cent of the levelling program, do they need to cut deeper than 30cm.

Levelling the gilgai

Jake uses T3RRA Design software to plan the cut and fill, then exports the maps to the dozer. Getting the programs to talk to each other was a challenge and took a lot of trial and error and file translation, but Jake now has a workflow.

"The worst part was that T3RRA uses grid north, and TopCon uses true north, so there was a 1.6 degree rotation I needed to align. It took a long time to work it out."

Levelling means moving on average 300m^3 of soil/hectare, although on the worst areas it is up to 550m^3. The system that is working for Jake is undercutting with a bulldozer, which gives a good spill of blended topsoil and subsoil in each pass. A finished section of paddock has about 100mm of soft seedbed of reasonably blended soil.

The process has evolved from the first levelling trial back in 2006, where 40 hectares were levelled using laser buckets. Although considered a success – as this trial area still outyields other unameliorated areas – it lacked the finesse needed to level his soil. The buckets were scalping too much in each pass, leaving large, bare clay areas and in some cases exposing the dispersive subsoil.

As of September 2023, about 1300ha had been levelled. The ultimate goal is to level the full 3000ha of gilgai country. Figure 5.16 shows a 630ha paddock from 2019 with levelling visible in the eastern half. After rain over summer 2020–21, water was visible in existing gilgai in unlevelled areas (Figure 5.17).

How is it working economically?

"We get an immediate land value increase which is 150 per cent of the costs [of levelling]," Jake said. "For every $100 spent, land value increases by $150." Ongoing land valuations with the bank (and a land valuer experienced with gilgai country) have helped Jake track the value of the works.

"Last year (2022) we planted sorghum into a paddock that was half-levelled. The levelled country yielded 130 per cent of what the melon hole country did. With current grain prices, that increase in yield covered the cost of levelling in one season," Jake said.

This year (2023), the NDVI in the wheat crop planted in May has a noticeable biomass increase and consistency in the levelled section of the paddock compared with the unlevelled western half (Figure 5.18).

Figure 5.17: The same paddock as Figure 5.16 in January 2021 after rain. Note the water in the melon holes on the western side of the paddock (not graded yet).

Source: Google Earth

VR gypsum on ameliorated soil

With high levels of exchangeable sodium now closer to the surface in many areas, the next step is to apply variable-rate gypsum. The cut-and-fill map forms the basis of the VR gypsum map where the deeper cuts have the higher rates of gypsum and the fills have no gypsum. This is because sodic soil is now closer to the surface in areas that were cut and is buried beneath fill areas.

"Only as the crop grows and the roots get into the sodic subsoil you can see the issues, especially with legumes," Jake said. "Faba beans give you a good visual representation of what's underneath the surface."

The economics of gypsum applications are still being worked out. While VR gypsum helps keep costs down by applying gypsum only where it is needed, freight is about three times the cost of the product.

"We have the maps and the gear [to VR spread], but are looking more closely at costs," Jake said. "Our gypsum has to come from either Winton or Burke. It costs about $30/t for gypsum, but $130/t to get here. We're looking to VR gypsum to get the average down."

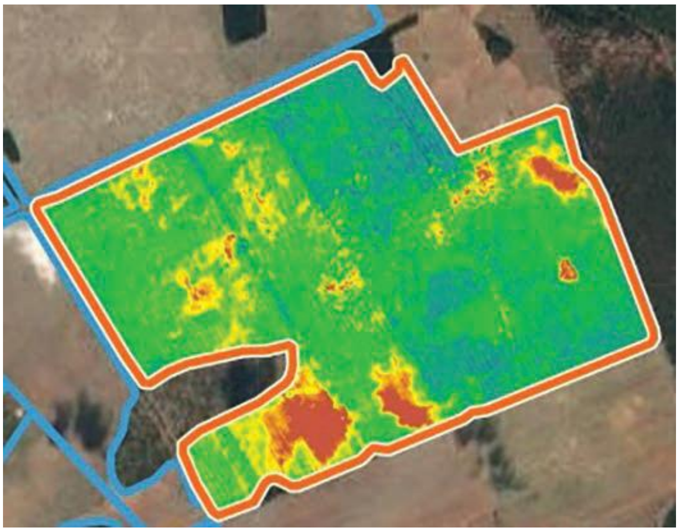
Jake has been using the dry weather in 2023 to deal with more of the melon hole country. The ultimate goal is to level 3000ha of gilgai.

VR fertiliser

Due to the degree of soil mixing after levelling, levelled gilgai areas get blanket fertiliser rates: 10t/ha of feedlot manure straight after levelling, then deep-rip 100kg of MAP (22kg P). The farm had been zero-till since 2000 and phosphorus stratification was a big problem, with 95 per cent of the P in the top 5 to 10cm.

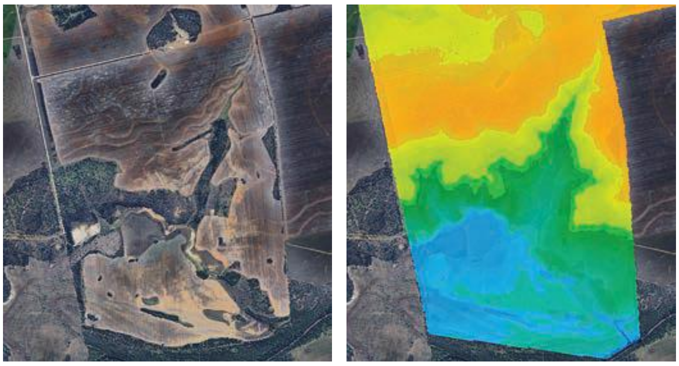
Paddocks without gilgai get VR fertiliser. Zones are mapped based on five-year composite yield maps, soil testing and soil types.

Figure 5.18: The eastern half of this 650ha paddock was levelled with the dozer in 2019 and planted with LRPB Reliant wheat in May.



Source: Jake Hamilton

Figure 5.19: Contour banks on the slope country (left) and elevation map of the same paddock (right).



Source: Jake Hamilton

Soil types vary and include red loam dermosols, grey-brown-self mulching vertosols and sandy country near the creeks.

"We average yield maps over five years as there are always random events such as late frost that will knock the yield maps around, but a composite five-year map is a good place to start."

Contour banks

Jake also uses the LiDAR data and T3RRA Design to design contour banks on the non-gilgai and sloped country. "On the red-loam country, for example, there's a three per cent slope, and those need contour banks to manage surface flows."

The contour banks are graduated, starting small and getting longer and wider across the slope (Figure 5.19). This led to a 60 per cent saving in time and fuel during construction of the banks, by reducing the amount of soil that needed to be shifted. It is a unique approach to contour banks that required Jake to develop a specific formula to use with the design software.

Jake's advice for those considering levelling:

- Save your topsoil if you can – it takes hundreds of years to develop.
- Always soil test before levelling so you know if there are any constraints. Some soil is best left buried. It might seem cost-prohibitive to start, but it is completely worth it.

Using PA to make drainage plans

Parts of this article were originally published in 'The mixed or muddled farmer? Dabbling in precision ag', *Precision Ag News*, Spring 2022, vol 19, issue 1. Updated in late 2023 by Alisa Bryce.

SNAPSHOT

Name: Ben and Stephanie Tait

Business name: Riverlea Farming Co.

Location: 'Fairfield' farm in Epping Forest on the Henrietta Plains, Tasmania

Farm size: 800ha

Rainfall: 580mm

Soil types: alluvial river flats with black soil, duplex soils with shallow clay, sand with quartz

Enterprises: 70:30 crops to livestock. Sheep, beef and agist dairy cows, and ryegrass, canola and chicory for seed production. Barley in marginal seasons. Pastures of clover, chicory and lucerne. Vegetables including peas, broccoli and potatoes

Since arriving from New Zealand, Ben and Stephanie Tait have done a lot of work to develop irrigation and improve the drainage and soil structure of their Tasmanian farm, 'Fairfield'.

The farm is a mixed operation, split roughly 70 per cent to crops and 30 per cent to livestock. They run 3000 composite ewes and finish the lambs and trade lambs opportunistically. They have a small beef enterprise with up to 100 Angus cows and they agist 1000 dairy cows in the winter.

The cropping program is highly varied. Their main crop is ryegrass for seed production, which they have in rotation with lamb-finishing pastures of clover chicory and lucerne. They grow other crops for seed, including canola and chicory. They also produce vegetables in the rotation – including peas, broccoli and potatoes – on smaller areas. In marginal seasons, they grow barley as well as it is a more resilient and less costly crop, which they can stop irrigating if the season requires.

"I get a kick out of mixed farming systems; they work well," Ben said. "For example, our highest paying crop last year [2022] was a chicory seed crop, which we also lambed on in the spring then left the paddock down as perennial pasture post-harvest. I like the balance, and it works well in this climate."

The Taits' improvement program has involved precision agriculture planning and actions on one of their most inconsistent paddocks to see if it can help them unlock its potential. With a river running through the property and highly variable soils, waterlogging is a challenge.

The soil is as varied as the farming operation. Ben thinks of the soils in three tiers:

1. alluvial river flats with black soil (with flood risk);
2. a duplex type with shallow clay that drains poorly; and
3. sand with quartz (furthest from the river).

All of the Taits' lateral move irrigation systems are running with GPS guidance using app-based controls. Photo: Ben Tait

Ben said the sandier soil was "very good for some things and very poor for others.

We try to farm to its advantage. Some parts of the farm with the heavy soil types, the duplex and alluvial, have wet risk. So there's higher risk for root crops, issues with access and these are not suitable for cattle. Whereas the sandy types are safe for root crops and having cattle in winter".

Ben started working with precision agriculture consultant Reuben Wells from Ag Logic soon after moving to Tasmania. "Reuben's got some great technology that helps us. For example, on the duplex soil types, the drainage maps that Reuben has developed in conjunction with land planning have revolutionised how we can farm the land," Ben said.

Reuben Wells said the main objective was to ensure there were no areas sitting wet. The site is flat and erosion is not a problem on the property, but waterlogging is a major cause of crop loss. In some areas there are 'pot-hole zones', with many small depressions, some only 3 to 5cm deep, that waterlog.

Reuben uses EM38 and elevation data to identify the problem areas. The highest readings on the EM maps can show the areas with the worst drainage, but efficacy depends on the soil type and paddock. For example, on ironstone gravel country, waterlogging typically occurs where the gravel transitions to clay. Increasing clay will give a higher reading on the EM38, so a soak will often form just upslope from where EM values increase.

Other ways Reuben develops zones are with grid sampling or based on management expectations, such as a historically poor area. Yield maps are difficult to use to define zones because the rotations are too complex. "You can have a cereal, carrot seed, potatoes, broccoli then pasture," Reuben said. "Systems aren't available to map yield in many of these crops, and those that can be mapped are too infrequent in the rotation to provide the multiple seasons of data needed to get the most out of yield maps. Besides, we were finding that drainage was the driver of the yield variability in the majority of cases anyway, so we have jumped directly to solving that problem."

Detailed paddock investigations including collecting high accuracy (RTK corrected GPS) elevation data are used to create a 3D model of the paddock. Water flow simulations are then run on the model to develop the drainage plan, which needs to consider both water flows and integrate with farm management. The 'best' drainage plan on the model might not be practical on-farm. On some of the pot-holed paddocks, they have used a land plane to reshape the ground.

Both drainage and land planning are done with the same software but use different approaches. Reuben said: "Land plane work is redesigning every square metre and filling in the holes. Drain work is installing a drain – which helps – but at the end of the day you're fixing a hole with another hole."

Reuben uses T3RRA Design to develop the drainage plans, which work in conjunction with T3RRA Cutta, the software on the tractor. "I use the Terra Design program to ensure I get maximum efficiency from the soil movements. It creates a file that translates my design into a prescription that controls how deep the land plane cuts and where it moves soil to."

Ben said: "Before working with Reuben, in the areas where we had poorer drainage, we ended up cultivating whole paddocks just to get rid of ruts which wouldn't have been there if the drainage was better. And so, with better drainage systems, it's more sustainable to go no-till for longer in the rotation, which is better for organic matter and soil structure.

The Taits' children, Isla (top) in a brassica crop and Johnny (bottom) helping move fence posts. Photo: Ben Tait

"We've employed the services of Greenvale Ag Drainage, operated by a local farmer who has invested in land planning and drainage equipment. Greenvale uses the land plane in conjunction with a Wolverine drainer."

Careful topsoil management

'Fairfield' has quite limited topsoils, which require care when moving soil. The best soil is in the top 15cm. Below that is a low cation exchange capacity (CEC), dispersive subsoil with some patches of salinity. Reuben's design work ensures the subsoil is, as much as possible, untouched.

Ben said that pot-holed zones were either gently filled or linked to the drain network.

"The drainer is unique how it disperses the spoil from the drain across the paddock without leaving lumps or ridges."

Greenvale sets up its own base station to communicate with both the tractor and drainer, which are equipped with receivers. An experienced operator is required to execute these desktop plans and common sense prevails. "The systems work," Ben said.

Other PA tools

All of the Taits' lateral move irrigation systems are running with GPS guidance with app-based controls. This saves half a labour unit in the summertime and has proven to be very reliable. They also use moisture probes to refine their irrigation programs.

Chapter 6: Variable-rate fertiliser

Photo: Nathan Simpson

Introduction

Variable-rate applications aim to put crop inputs where they will generate the best return on investment and, where possible, to reduce input and production variability.

As fertiliser prices more than doubled over the past few years, many growers have looked more closely at how to be more efficient with their fertiliser applications. In some cases this means using the soil nutrient bank for a few years with a plan to 'top it up' when prices come down. In others it means critically assessing the production potential of varying soil types and paddocks and matching fertiliser rates to a realistic yield outcome. Either way, the more expensive the inputs, the bigger the opportunity for a more targeted approach.

In a case study in this chapter (page 87), Western Australian grower Tom Longmire explains that in his case variable-rate applications are not necessarily about saving money, but putting every unit of fertiliser where it is most productive.

This chapter explores the many reasons why different growers are varying fertiliser applications on their farms.

Nitrogen, as one of the biggest variable input costs, is the 'holy grail' to get right. The next section, headed 'Improving nitrogen decisions with crop sensing', explores the various tools available to measure crop N and how to use this data to inform N decisions. More detail on research using paddock trials, crop reflectance and other data layers in nitrogen decision-making can be found in the section headed 'Better targeted, more precise fertiliser decisions as a counter to rising fertiliser prices – focusing on three of the six Rs', starting on page 81.

Neale Postlethwaite, in a grower case study in this chapter beginning on page 88, uses VR N and protein maps to even out paddock protein. In the section headed 'Variable-rate nitrogen based on protein maps (page 90), Tim Neale from Data Farming gives a simple example of converting a protein map into a VR urea map, with a trial strip to check the rates.

New South Wales grower Nathan Simpson is using soil maps to avoid waterlogged areas and boost farm profits. By lowering urea rates on waterlogged areas, Nathan broke even when he would have had a negative return if he had applied blanket rates. Read his grower case study on page 91.

For a look at some growers using multiple variable-rate inputs, read about:

- James Venning (page 97), who used a combination of soil pH, P and NDVI data to save $100,000 in fertiliser in 2021;
- Mark Branson (page 94), who has been in the PA game for more than 20 years, using VRT for N, P, gypsum, lime and weed management; and
- Tristan and Graham Baldock (page 93), who have been varying N and P since 2012.

For some growers, VRT is more about a capital investment. Tasmanian grower Ben Tait (page 103) used VRT as capital fertiliser program, aimed at lifting soil nutrient levels to set fertility targets.

Variable soil types are another key reason growers look to VRT, aiming to match inputs to soil and yield potential. WA growers Darren and Vanessa Cobley (page 105) and Ben Cripps (page 107) are successfully refining N, P and K rates on their highly variable soils.

And what about when it does not work? It is 'PA in practice', not 'PA is perfect'. WA growers Mic and Marnie Fels (page 110) successfully implemented VRT at a former property at Three Springs with a $45/ha profit but have found it more challenging on their main property at Wittenoom Hills.

Improving nitrogen decisions with crop sensing

The content in this section was originally published in a GRDC Fact Sheet dated March 2023.

Introduction

After soil moisture, available nitrogen is often the next limiting factor in crop production. Matching nitrogen application to the variation in crop needs within a paddock using variable-rate application (VRA) has the potential to improve profitability through improved average yield and reduced fertiliser wastage.

Making nitrogen application rate decisions

Nitrogen is an essential macronutrient for plant growth. It is highly mobile within the plant and within the soil, and its availability to the plant is tied to soil moisture, soil texture, soil organic matter and soil temperature.

Nitrogen budgeting attempts to account for nitrogen available to the crop in the soil solution as it cycles between the organic and inorganic 'pools'. Soil organic matter and organisms contribute nitrogen from the organic pool, and synthetic nitrogenous fertilisers dominate the inorganic contribution.

Traditional soil nutrient analyses have long been used as the basis for 'mass balance' agronomic prescriptions for nitrogen fertiliser application rates across a paddock or management unit. The application rate is calculated by deducting the amount of nitrogen present in the soil from the rate required to achieve a yield and quality goal, tempered by plant nitrogen uptake.

Historical yield information, soil type maps, and soil and crop sensing data can provide additional information for growers to adjust their nutrient application rates according to likely crop needs. Growers can also use a range of online tools that include rate estimates based on crop growth simulation methods such as Yield Prophet®.

Steps towards site-specific nitrogen management

Crop reflectance data

Actively growing, well-fertilised plants reflect light differently to plants that are under stress. This difference in reflectance can be used to identify areas of a paddock where crop growth is strong/healthy and areas where there is a constraint on production. Information from reflectance sensors mounted on satellite, aerial or ground-based platforms can illustrate these differences in plant growth, allowing growers and their advisers to accurately scout, problem-solve and then plan any input applications to match the needs of the crop.

To gain the most benefit from using these technologies in nitrogen management, there must be a foundation of good general management in place. It is recommended to only use VRA for key nutrients such as nitrogen after any ameliorable soil constraints (topsoil pH, sodicity, compaction), weed and/or disease issues have been addressed.

Sources of crop reflectance data

Crop reflectance data acquired remotely from satellites is available from several commercial sources in Australia, often with a revisit time (length of time between consecutive satellite images taken at the same location) of less than seven days and with a spatial resolution of 30m or less.

Data from the Sentinel-2 satellites (15m spatial resolution) and the Landsat satellites (30m resolution) can be supplied at a relatively low cost. Data from higher resolution sensors (up to 0.4m) on satellites, light aircraft or unmanned aerial vehicles are available, but the cost usually increases proportionally. More information on satellites can be found in Chapter 2 under the section heading 'Satellite-based remote sensing for PA' (page 25).

The commercial ground-based proximal sensor units currently available are Crop Circle™, CropSpec™, GreenSeeker® and N-Sensor™ ALS2. These sensors supply their own light source and are designed to be held approximately one metre above the crop canopy. They can be handheld as individual units or as multiple units and boom-mounted on vehicles to cover greater areas. They each operate slightly differently, although they all emit light of a known wavelength, allowing operation any time of the day or night, and they can all collect multispectral reflectance data from the crop canopy.

Due to the similarities in the reflectance technology used on all platforms, growers can be confident that data from these proximal sensors will be comparable with imagery collected remotely using camera systems mounted on aircraft or satellite platforms. This means that when using these ground-based sensors, growers and their advisers can rely on historical research that has established the relationships between crop reflectance and crop physiology.

With the increased commercial availability of crop reflectance data and onboard yield monitors, growers can collect real-time data and build databases over time to make better-informed decisions about pre-sowing and in-season fertiliser.

Using crop reflectance data for nitrogen management decisions

An important aspect of the use of crop reflectance sensors is the calculation of vegetation indices from the multispectral data. The well-known normalised difference vegetation index (NDVI) uses information from the red and infrared segments of the spectrum to measure the light absorbed as part of photosynthesis and the light reflected from the vegetation's surface. NDVI is unique to live vegetation and provides a way of measuring vegetation density and health.

NDVI values are relatively high in higher biomass crops that are very green, and decrease when plants are lower in biomass, stressed, diseased or senescing. Bare soil and water bodies can be easily distinguished from vegetation using NDVI.

A relatively strong relationship exists between NDVI and the total nitrogen content (kilograms per hectare (kg/ha)) of the crop plant biomass. However, there is a growth stage in most crops at which the reflected light and density of the crop biomass overwhelms the index and it is said to be saturated. At this point, the NDVI ceases to distinguish incremental increases in the total nitrogen status of the crop. Sensor technology has more potential to assist with nitrogen management if it is deployed in situations where the crop canopy has not yet closed, such as early in the season or on less fertile sites where saturation is unlikely to be a problem.

NDVI readings can be influenced by several factors other than nitrogen, including:

- changes in germination/establishment;
- soil nutrition deficiency issues (for example, pH and nutrients other than nitrogen);
- weed patches;
- disease; and
- waterlogging.

These issues need to be ruled out as possible influences before proceeding to use crop reflectance data for nitrogen decisions.

Nitrogen-rich test strips (N-rich strips)

An N-rich strip (Figure 6.1) is an early application of nitrogen fertiliser, usually applied as a strip that is as wide as the width of the farm application machinery. An N-rich strip is best located where it can run across changes in soil type or identified production management zones.

Their length will depend on the characteristics of each paddock and multiple strips may be required in paddocks where the variability cannot be encompassed in a single strip.

N-rich strips are designed to provide an area where the crop response is not limited by nitrogen, which can then be compared with the crop response to the applied fertiliser rate in the rest of a paddock. This can be used to identify whether the fertiliser rate is sufficient in the paddock for the current seasonal conditions and help gauge any top-up application rates if required/feasible.

When conducting a ground-based reflectance survey of a large paddock, it is good to re-scan the N-rich strip/s every two hours or so to account for changes in leaf orientation and environmental conditions during the survey period.

Figure 6.1: N-rich test strip.

Source: Wayne Pluske

Variable-rate nitrogen application decisions

Most nitrogen uptake in cereals occurs between mid-tillering and mid-stem elongation, so this is the time to ensure the crop has access to sufficient nitrogen to reach the target yield. Applying all the expected nitrogen required for the season prior to mid-tillering is one way of managing this process; however, this provides very little flexibility to deal with actual in-season impacts on nitrogen demand/supply. Crop sensing at the end of tillering offers a method to quantify how well the crop nitrogen uptake is going based on actual seasonal conditions.

This method relies on the split application concept where a proportion of the expected nitrogen requirement is applied before/at sowing – sufficient to establish the crop and support early growth. This is commonly about 50 per cent of the expected crop requirement. Obviously, this management option relies on in-season rainfall to be available when secondary fertiliser applications are required or, alternatively, the use of liquid fertiliser.

When using crop reflectance data from any sensing system, higher index levels in sections of a paddock will often indicate a higher biomass and associated higher uptake of nitrogen into the crop canopy. Areas with lower index levels, when no other issues as mentioned above are present, are therefore assumed to be more likely to respond to nitrogen fertiliser applications with improved crop biomass production. A response comparison between the crop in an N-rich strip and the rest of the paddock will provide information of potential responses to increased nitrogen above the paddock-applied rate.

This approach can be applied at several scales. At the whole-paddock scale, input rate changes can be calculated across a continuous range to deal with continuous variability in crop requirements as they are identified by the sensors across a paddock.

At the management zone scale, variability in response can be measured across a whole paddock and averaged over predetermined management zones and an application rate calculated. Variability in response within pre-determined management zones can also be managed by calculating a base rate nitrogen requirement for each management zone prior to the application operation, but the actual input rate is modified by a measure of variability gathered using the sensors within each zone.

All of the ground-based sensor systems come with in-built software that enables calculation of a user-defined crop reflectance index (for example, NDVI) to quantify the response differences. They also have proprietary algorithms that can use this information to prescribe a rate of application.

With the sensors mounted at the front of a vehicle, the decision process can be carried out in real-time as the rate of application can be controlled from onboard or trailing application equipment. Particular care is required when using the in-built application decision system to control VRA nitrogen in the one pass. The algorithms need to be assessed for appropriateness for local conditions before use.

Further detail on the options for, and benefits from, using paddock trials, crop reflectance and other data layers in nitrogen decision-making can be found in this chapter in the next section headed 'Better targeted, more precise fertiliser decisions as a counter to rising fertiliser prices – focusing on three of the six Rs' on page 81.

Better targeted, more precise fertiliser decisions as a counter to rising fertiliser prices – focusing on three of the six Rs

This article in this section was originally published as an Update Paper in February 2022 on the GRDC website: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/better-targeted,-more-precise-fertiliser-decisions-as-a-counter-to-rising-fertiliser-prices-focussing-on-3-of-the-6-rs. Authored by André Colaço, Rob Bramley (CSIRO, Waite Campus), Brett Whelan (Precision Agriculture Laboratory, University of Sydney) and the Future Farm project team

One way to counter the higher fertiliser prices from the past few years is to optimise the efficiency with which fertiliser is used – putting the **right** amount of the **right** product in the **right** place at the **right** time (the traditional '4 Rs') using the **right** equipment and, with the decision as to the **right** amount, underpinned by the **right** data (the '6 Rs').

The Future Farm project was established to re-examine and improve the way in which digital data is used to inform decisions about input management. It aims to automate data acquisition, analysis and input recommendations, with a focus on improving the efficiency and profitability of applied nitrogen (N) use and increasing grower confidence in N decision-making.

KEY MESSAGES

- In past decades, digital and precision agriculture technologies have been developed with the main goal of enabling traditional agronomic decision tools to be implemented at the site-specific scale in an automated fashion
- Traditional N fertiliser recommendation frameworks have not been designed for the accuracy expected for precision nutrient management, leading to limited value of digital approaches underpinned by them
- Novel, data-driven decision support systems based on non-mechanistic frameworks, abundant multivariate data, and on-farm experimentation can improve the accuracy and profitability of N application
- The Future Farm team worked with top-performing growers across the country who, through comparative analyses, are proven to be very good at N-decision making. Even then, a data-driven N model developed by Future Farm resulted in a ~$50/ha improvement in partial profit over the current practices used by these growers

Agronomic advice and digital technologies

The conventional approach to providing advice, such as fertiliser recommendations, has been to use mechanistic agronomic knowledge of crop production to identify important crop and soil parameters and integrate understanding of these to underpin a recommendation or decision. In the case of fertilisation, recommendation charts based on nutrient balances or generalised response curves are examples of such an approach, even though in most instances they translate agronomic knowledge into simplistic 'rules of thumb'.

More advanced decision support systems (DSS) based on crop models, such as Yield Prophet® and its 'parent model' APSIM, are also similarly reliant on mechanistic agronomic knowledge (for example, Figure 6.2a). Again, this approach has limitations. Models are very data-hungry and the inputs needed to run the models can be expensive or difficult to measure. They may also be highly spatially variable, such as soil water availability and soil N status.

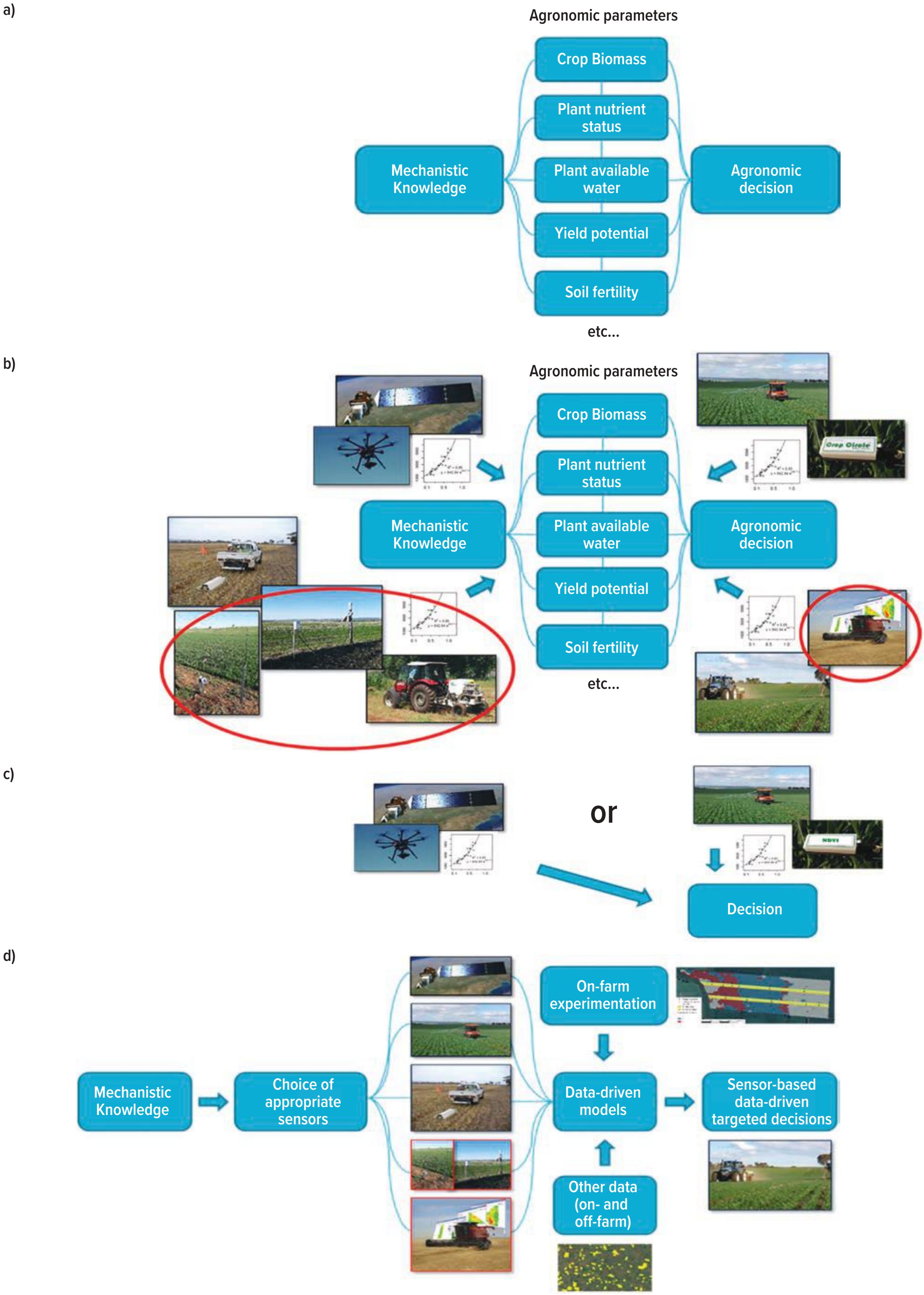
One consequence of this is that such DSS are often used with a 'best guess' set of input parameters; for example, using soil properties from a 'nearby' soil profile, which might be some distance (several kilometres) from the paddock of interest. Is this data actually relevant to the paddock being modelled? Another consequence is that, presumably for reasons of trust, the 26 per cent of growers who make use of a DSS tend, on average, to use more than two of them (Bramley and Ouzman, 2018).

With the invention of new digital technologies, such as proximal and remote soil sensing, attention has been directed to how we can calibrate them to provide more accurate fertiliser recommendations in a local and automated fashion (Figure 6.2b). However, while some sensing technologies (for example, yield monitors, soil pH sensors) are straightforward to calibrate, others (for example, multispectral remote or proximally sensed imagery) are not, which is why to date and to the knowledge of the Future Farm project team, none of the traditional DSS such as Yield Prophet® take sensor data as input.

One reason such calibrations are difficult is that many of the sensors make surrogate (as opposed to direct) measurements. They predict attributes of interest. For example, the commonly used normalised difference vegetation index (NDVI) is a surrogate measure of photosynthetically active biomass, which relates closely to the size and health of the crop canopy. NDVI is not a measure of plant N status, although under some circumstances it might be correlated with it and so can be used to predict it.

So much of the effort put into the integration of sensors into agronomic decision-making has relied on the development of prediction models based on crop sensor data – for example, to provide estimates of yield potential. Fertiliser recommendations can then be based on mass balance (that is, the N rate to apply is equivalent to the difference between nutrient demand [given by the yield potential] and nutrient supply). Of course, such predictions are subject to error. It is also clear that relationships between sensed and target variables (for example, NDVI versus yield potential) may be highly subject to site and seasonal variation (Colaço and Bramley, 2019).

Figure 6.2: Pathways to a digital decision: a) the classical approach to agronomic decision support; b) digital tools and their typical interaction with existing agronomic decision support; c) the simplistic univariate approach commonly used in some commercial offerings; and d) the framework that underpins Future Farm's data-driven approach to decision making. In b) and d), the circled pictures indicate that these sensors are relatively easy to calibrate. Those not circled are used for prediction of crop and soil attributes rather than absolute measurement.



A final key issue is that, by necessity, traditional N recommendation frameworks simplify complex agronomic interactions so that they can be easily implemented at the level of the paddock or farm. As such, most common fertiliser recommendation approaches have not been designed for the accuracy expected for precision nutrient management using variable-rate application (VRA).

Consequently, even if digitally based predictions of yield potential can be made, the resulting N recommendation may not provide much improvement (if any) if the information is implemented via simplistic mechanistic frameworks (Colaço et al., 2021). Accordingly, the common univariate approach (Figure 6.2c) based on a single sensor input as a surrogate estimate of N requirement should be treated with caution. In a recent review study, evidence of this approach providing benefit over grower practice has been equivocal (Colaço and Bramley, 2018).

Clearly, most agronomic decision-making is not a univariate issue. Decisions as to whether to apply N mid-season, and how much to apply, are greatly affected by soil moisture (Colaço and Bramley, 2019; Lawes et al., 2019) in addition to many other factors including yield and protein targets, expectations of future weather, grain prices, grower attitudes to risk, and the cost of fertiliser.

A new way forward with on-farm experimentation

An alternative to the approaches described in Figure 6.2a-c is to use the same mechanistic understanding of crop production to identify sensors that are likely to provide useful information of relevance to agronomic problems (Figure 6.2d).

Instead of focusing on sensor-based prediction of single crop or soil attributes, use the data the sensors provide as input to data-driven models on the basis that their digital signal is providing data of potentially useful predictive value in guiding decisions in different locations.

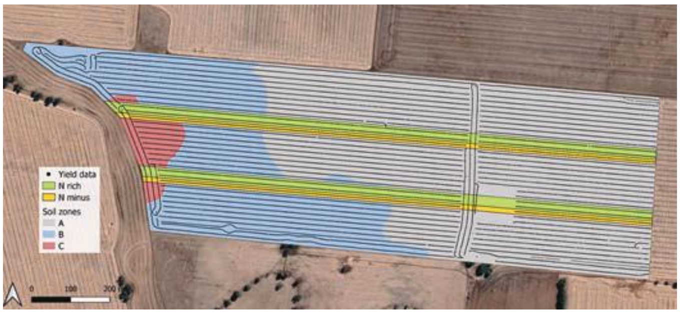
This approach requires multiple data input sources and on-farm experimentation (OFE), such as use of N-rich and N-minus strips, to guide decision-making. There is also potential value of off-farm and publicly available data (for example, data for adjacent areas including historic yield, electromagnetic maps, imagery and weather data) as inputs to the decision (Fajardo and Whelan, 2021).

Growers want more confidence in their N decisions. Accordingly, we evaluated a range of approaches to predict crop N needs, from simple methods using NDVI and NDRE indices up to data-abundant methods that used a range of data sources. Table 6.1 lists these approaches.

Table 6.1: Methods included for in-season prediction of nitrogen requirement.

Label	Description
Grower	Grower decision for application rate (that is, the host grower's chosen rate).
Economic optimal N rate (EONR)	Observed rate that maximised partial profit.
Max yield	Observed rate that maximised grain yield.
Max N removal	Observed rate that maximised grain N removal.
NDVI CC	Inspired by the Crop Circle™ approach, the N rate that maximised the Crop Circle™ NDVI mid-season on the assumption that this maximises end-of-season yield. Note that Crop Circle™ is a proximal sensor that works in a similar way to the Greenseeker®, TopCon CropSpec™ and similar sensors.
NDRE CC	As per NDVI CC but using NDRE instead of NDVI.
NDVI Sent	As per NDVI CC but instead using NDVI sourced from the Sentinel-2 satellite.
NDRE Sent	As per NDVI Sent but using NDRE instead of NDVI.
DD (data abundance)	Data-driven model in which a range of data sources is calibrated against economic optimal N rates (EONR) using random forest regression (Figure 6.4). In essence, this empirical approach provides a recommendation by assessing current site and season characteristics and relating those to past conditions for which optimal N rates are known. In this data abundance scenario, the site and season conditions at which the model is validated are well represented in the data used to build the model.
DD (data limited)	As above, but in a scenario of limited data. The site and season conditions at which the model is validated are not well represented in the data used to build the model, which comes primarily from other paddocks.
N Suff CC	N sufficiency approach based on Crop Circle™ sensor data. This method is based on the N dilution curve, which describes the relationship between plant biomass and plant %N. A target plant %N for fertilisation is set based on estimated crop biomass and an established N dilution model.
N Suff Sentinel	As above but using Sentinel-2 satellite data.
MV (yield)	A machine vision approach based on prediction of optimal N rates for yield maximisation. This uses a tractor-mounted RGB camera coupled with detailed image analytics.
MV (grain N removal)	As above but optimised against grain N removal.
Yield Resp Model	A simplified model of the yield and protein response of APSIM developed by using remote and proximally sensed data and used to predict the EONR.
Simplified mass balance	Simple mass balance calculation targeting local water-limited yield potential (Gobbett et al., 2017) and protein. Three variants are used: (a) deducts initial soil N from total N demand based on soil sampling; (b) assumes an arbitrary amount of starting soil N; (c) does not account for any starting soil N.

Figure 6.3: An example of a Future Farm strip trial, in this case in a 64ha paddock near Tarlee, SA.



N strips were used to test the yield and protein response to applied N. All the Future Farm OFE included three application rates: a zero N rate, a farm decision N rate (that is, the grower's best estimate of requirement) and a high N rate that ensured N should be non-limiting. The N rate treatments were placed adjacent to each other in strips (Figure 6.3) and were applied to run through zones of predetermined potential management zones in each paddock.

In addition to providing key input to the various methods used to develop an N recommendation (Table 6.1), our OFE was also used as the basis for calculating partial profit (harvest income minus expenditure on fertiliser) response functions using the applied N rates, yield and protein data gathered using harvester-mounted yield and protein monitors along the trials, combined with financial information reflecting average grain grade sale prices and average urea fertiliser costs.

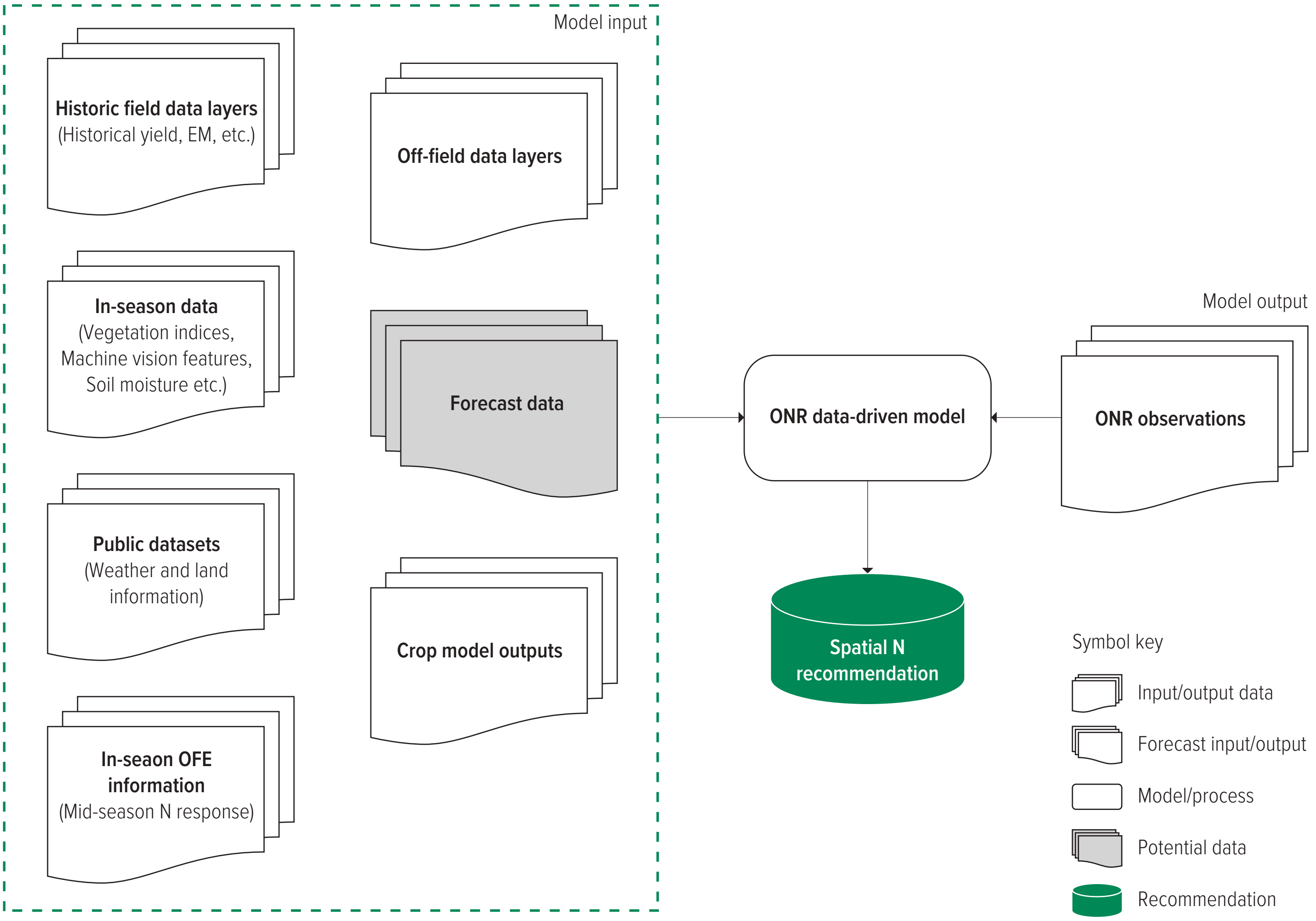
Comparing approaches for N recommendations

We compared the various N recommendation methods at three scales – site, management zone and whole paddock. We completed this analysis through nine large-scale trials held across SA (2018–20), WA (2019-20), Victoria (2018–20) and NSW (2020), generating more than 1500 observations of crop response to N applications. From these functions, the N rate that maximises partial profit – the economic optimum N rate (EONR) – can be identified at the three different management scales. The EONR is regarded here as the ultimate N application rate against which all the recommendation methods were compared.

Figure 6.5 plots the preliminary results (to be updated as data from more Future Farm trial sites becomes available). Each method is plotted based on the average root mean square error (RMSE, that is the prediction error) and a normalised average partial profit (NPP) at each management level across all sites analysed. The partial profit has been normalised because not all the methods were applied across all Future Farm site-years. Nonetheless, costs and prices appropriate to each season (2018–20) were used to generate the results.

The analysis shows that as accuracy in prediction increases (decreasing RMSE), partial profit increases, but the rate of increase diminishes as the methods become more accurate. Such analysis could be used to assess the worth of a new technique or technology that seeks to improve accuracy compared with its cost.

Figure 6.4: Workflow for an N recommendation approach based on the optimal N rate prediction by a data-driven empirical model.



Note that Figure 6.5 includes results from three options of the ‘Simplified mass balance’ approach, similar to the common ‘rules of thumb’ decision-making processes that many growers and agronomists undertake, and that this standard method had similar results to the grower practice. Results also indicate that the mass balance calculation loses performance when the accuracy of soil N information decreases (from a) to b) to c)).

The grower decision approach is on average seven per cent lower in NPP than the optimal recommendation (EONR) at the site-specific level and only about one per cent lower than the EONR at whole paddock level. This result confirms that the growers collaborating in Future Farm, who already utilise aspects of the PA philosophy, are very good at optimising their fertiliser use.

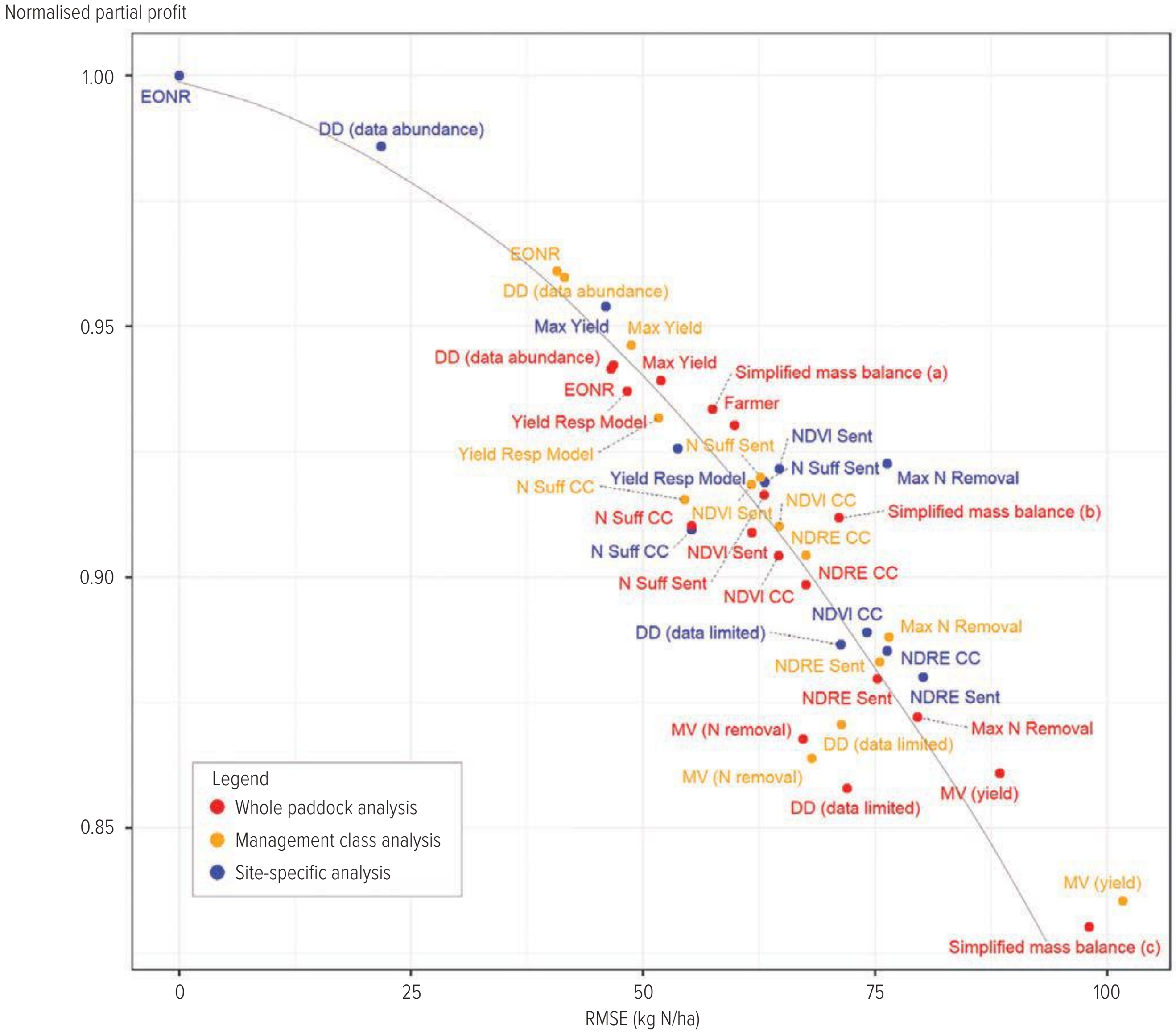
In this connection, we point out that the simplified mass balance approach, which gives a result very similar to that of the grower, assumes that the target yield is the water-limited yield potential. In other words, these growers have very little ‘yield gap’ and they should already have confidence in their N decision-making.

Therefore, a key message from Figure 6.5 is that for these growers to make improvements to NPP, their N decisions need to be made at higher spatial resolution; in other words, using VRA rather than uniform paddock management. The extent to which Future Farm might lead to increased confidence among other growers is unclear. However, it is of note that the decisions of our collaborating growers outperformed all of the single sensor approaches (Figure 6.2c).

The best Future Farm method is the data-driven model with a full dataset (DD data abundance) at the site-specific level. It displays an increase of five per cent over the management of our collaborating growers at paddock scale. Its use at paddock scale leads to a one per cent improvement compared with the grower practice. The site-specific DD data abundance method loses slightly to EONR at the site-specific management level, but essentially matches the EONR at the management zone and whole paddock resolution.

As a simple example to facilitate interpretation, a five per cent improvement can reasonably translate into a $50/ha increase (using a $1000 base line for maximum NPP) which, over a 2000ha cropping program, would mean a $100,000 gain annually. This can be regarded as a conservative number given that it is based on the high-performing growers we have collaborated with in the project.

Figure 6.5: Profitability versus accuracy of in-season methods for N recommendations averaged across trial sites at different management scales. Method labels are defined in Table 6.1. One way to interpret the graph is to multiply the y-axis by $1000 so that the EONR delivers a NPP of $1000/ha. For example, a recommendation derived for the whole paddock from an NDRE measurement using the Crop Circle™ sensor would deliver an NPP of just under $900/ha.



These results point towards relatively low value in a single sensor approach (for example, NDVI or NDRE alone). Many of the methods that rated higher in terms of RMSE and partial profit did, however, use NDVI and/or NDRE in a more thorough analytical approach, so they do have value when combined with other data to give a multivariate input to the decision.

A data-driven approach based only on limited external data is also shown here to be a low-value option for predicting N requirements. This emphasises the fact that the data-driven approach has significant value only when sufficient on-farm data to support it has been acquired. This is also why there is justification during the lead-in to adopting this for using one of the more mechanistic approaches. On the other hand, most common mechanistic approaches may seek to optimise grain yield, which can offer only limited improvement over the grower practice (approximately two per cent). Of course, while grain yield is an important component of profitability, frameworks aimed at yield maximisation do not fully accommodate other important economic considerations.

A profitable future based on OFE and the six Rs

Overall, from this multi-site, multi-method assessment process, it appears that the only way to improve the accuracy and profitability of our good-performing growers is by increasing the spatial resolution of their management from the whole paddock scale – in other words, through the use of management zones or, better still, continuous variable rate. We make this conclusion with the caveat that this move to higher resolution is accompanied by the use of an effective N decision framework such as the DD method.

The data-driven approach relies on data availability to ensure the method performs at its optimum as is evident from the comparison of the DD ‘abundant’ and ‘limited’ results. **Nonetheless, we are certain that a key element for acquiring such large datasets, and indeed improving N decision-making generally, is the use of automated OFE such as the strip trials used here. There is no impediment to these being scaled out across the country and seamlessly implemented by growers every season.**

There is also scope to build the required datasets at paddock or farm scale among groups of neighbours, in local regions and wider to train data-driven decision methods, such as the one proposed here. Its success at all management scales in this assessment provides an important pointer towards a future where farm businesses that collect, maintain and even share relevant production response and resource data will be able to push closer towards season and site-specific economically optimal operation. Against the background of high and rising fertiliser prices, this would be a good thing. Given the broader push towards sustainability and reduced emissions from N fertiliser usage, it is arguably also necessary.

Acknowledgements

The research undertaken as part of this project was made possible by the significant contributions of growers through both trial cooperation and the support of GRDC. The authors would like to thank them for their continued support. In addition to the authors, the Future Farm team comprises Jonathan Richetti, Damian Mowat and Roger Lawes (CSIRO), Mario Fajardo and Asher Bender (University of Sydney), Alison McCarthy, Anand Pothula and Craig Baillie (University of Southern Queensland), Eileen Perry, Alex Clancy and Glenn Fitzgerald (Agriculture Victoria) and Stephen Leo, Daniele De Rosa and Peter Grace (Queensland University of Technology). Their valued input is gratefully acknowledged. We are also most grateful to the various growers who have provided us with paddocks in which to develop and test our methods – Ashley Wakefield, Ben Pratt, Bob Nixon, Ed Hunt, Jessica and Joe Koch, Mark and Sam Branson, Mark Swaffer, Rob Cole, Robin Schaeffer, Stuart Modra, Kieran Shepard and Peter Bell.

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Section control: a game changer for fertiliser savings

SNAPSHOT

Name: Tom, Bindi and Phil Longmire

Business name: Coorong Pastoral Co.

Location: Beaumont, Western Australia

Farm size: 5700ha

Rainfall: 400 to 425mm (GSR 280 to 300mm)

Soil types: circle valley loams and red and grey clays

Enterprises: five-year rotation of field peas, wheat, canola, wheat and barley with the odd opportunistic lentil crop

Sometimes simply reducing fertiliser overlap can have a huge impact on fertiliser spend.

At Beaumont in WA, the Longmire's saved approximately $100,000 in 2022 and the same again in 2023 on liquid nitrogen (N) and starter phosphorus (P) by implementing section control on the air seeder. With the high fertiliser prices, this covered the investment in section control in the first year.

Their farm has many internal salt lakes, drains and other obstacles, meaning machinery needs to take a more complicated route to cover the paddocks. For example, on their largest paddock, doing two headlands around every lake led to a 36 per cent overlap.

Their airseeder has four sections across an 18-metre bar, meaning there is still some minor overlap, but compared to the previous set up the savings are outstanding.

Flexibility with VRT

The Longmire's use variable-rate technology (VRT) selectively, which partly comes down to confidence in the spatial layers behind the VRT decisions, and partly costs.

They use a variety of spatial layers – yield maps, radiometrics potassium and EM maps to name a few – to develop variable rate N and P maps. Which layers get used depend on the paddock and the soil type.

"Some soil types correlate better with EM, some better with radiometrics," said Tom.

Twenty years of ameliorating their sodic grey clays with gypsum (some areas receiving 20t/ha cumulative) has changed how certain layers correlate. Before amelioration, yield maps correlated well with EM maps in some paddocks as the sodic clays didn't have as high a yield potential. However, since improving productivity on these soils, the layers don't correlate as well.

Tom said, "We've got certain soil types and certain paddocks where we're confident in the layers that we're using to create a map such as radiometric, potassium or EM that correlate very well to the production zones and soil types. If we're not confident that the map we're creating is actually maximising both potential production but also not yield limiting other areas, we go with a blanket rate."

"We don't look at VRT as a saving. We have our nitrogen budget and we either blanket or vary the rate. Generally, the higher the fertiliser costs, the more we vary. When urea is cheap, we don't cut back as much on the low or mid zones. But when it was $1200 to 1500/t we had more variation to try and extract as much value."

One way they have been trying to work with the higher fertiliser prices is applying more fertiliser on their loamy sands which produce well in a dry finish but in a wet year need more of a fertiliser boost to reach the yield potential.

Zone sizes a challenge

One ongoing challenge is creating zone sizes that can work with the capability of their machinery to rate change at different speeds.

Tom said, "The airseeder can't change rates very quickly, so some of the maps we're getting from consultants have very small zones throughout the paddock that by the time the airseeder changes its rate to that small zone, you're already through it and not applying enough in the next zone."

Tom is working with consultants and contractors to generate VR maps with zone sizes that suit different machinery.

Perfect paddock protein through precision pathways

This article in this section was originally published as 'Perfect paddock protein through precision pathways' in *Precision Ag News*, Autumn 2022, vol 18, issue 3, by Fiona Myers. Updated in late 2023 by Alisa Bryce.

Neale Postlethwaite has chosen specific precision agriculture technology and variable-rate fertilising to produce more even protein yields in his wheat crops by varying rates during the growing season.

Photo: Neale Postlethwaite

SNAPSHOT

Name: Neale and Trevor Postlethwaite

Location: Gooroc, halfway between Donald and St Arnaud in Victoria's Wimmera region

Farm size: 2000ha

Rainfall: 400mm (270mm GSR)

Soil types: Wimmera grey clays and red loams

Enterprises: wheat, barley, canola, chickpeas and faba beans

PA success: gone from three grades of wheat in a paddock to one to two grades

NEALE'S PROCESS – A SUMMARY

1. Pre-season soil tests to determine blanket fertiliser rates.
2. Sow crop with blanket fertiliser rate and two test strips. The 10th swathe gets zero nitrogen and the 20th gets double the blanket rate.
3. Regularly check satellite images through Satamap to monitor the effects of the different fertiliser regimes.
4. Generate a prescription VR UAN map based on variation in the satellite images, including the test strips, and apply.
5. Yield maps and protein maps generated at harvest feed into next year's fertiliser decisions.

Variable paddock protein levels drove Neale Postlethwaite's decision to try out variable-rate fertiliser. "The main issue we had was too much variation in our grain quality at harvest," Neale said. "In one paddock, we could have three different grades of wheat and when silos used to only take one grade, it could be that you turned up thinking you had that grade only to be tested and found it wasn't the right grade.

"It is a bit better now because silos will often take a few grades, but in the past it meant that we would have to then drive somewhere else to deliver and you would not know from one load to the next what the quality was."

It was this uncertainty that encouraged Neale to explore what could be done with precision agriculture to even up the grain quality in the paddock.

Varying in-season nitrogen

Neale uses satellite imagery, soil tests and variable-rate nitrogen to address the quality challenge. The goal is to ensure each area of the paddock receives the nutrition it needs to produce grain with predictable protein levels.

"We decided to manipulate our nitrogen strategy across the paddock to even out the grain protein," Neale said. Each year, paddocks are soil tested to determine a base layer of fertiliser application. The in-season nitrogen applications are varied to even out grain protein.

Initially, Neale used NDVI cameras mounted on his boomspray to gauge crop growth, which was then utilised to determine variable-rate fertiliser application. The beauty of this, Neale said, was that they could apply in-crop herbicides at the same time as gauging nutrient needs.

"The NDVI gave us a map which we could go back to and variable-rate apply UAN to the crop," he said. "It took about three years, but we did manage to move away from producing three grades of wheat in a paddock to one and occasionally two grades, focusing on a protein level of 10.5 to 11 per cent."

With the evolving technology, the Postlethwaites shifted away from the NDVI camera and subscribed to Satamap Global, a web-based system for viewing and analysing satellite imagery. Satamap can be used to monitor crop health and stress throughout the season.

"The images are produced about once a week, so you are able to look at them regularly throughout the growing season to do everything from finding problems to determining when to harvest," Neale said. "If we see there is an issue from the satellite images, we also have a drone we can fly over to gain more information and can then take action."

The information from the satellite images in the growing season is downloaded into Trimble Connected Farm, which processes the variable-rate fertiliser application maps. The Postlethwaites do this themselves, but acknowledge that it takes time and focus to be able to produce these maps in a timely manner.

Once the variable-rate maps are produced, UAN is applied at rates from 40L to 120L a hectare to produce that sought-after even grade of wheat.

Refining approach over the years

When he first started using variable-rate application, Neale said his variable-rate maps were "sharp" with changes factored in to quickly shift from low to high levels of UAN if the maps determined this was the best outcome. This was difficult to achieve with the Case IH Patriot 4430 sprayer.

With experience, his approach has softened to be more practical. "When you are swapping from a rate of 30L a hectare to 120L a hectare, you need to speed up and slow down to allow this to be accurate," Neale said.

"Sometimes you can have three zones in a paddock (high, medium and low fertiliser application) and then you can have nine sub-paddocks, and then the next year 18 sub-paddocks, all of which can have three different rates.

"It gets more and more complex, and we have pared it back and simplified our variable-rate model to make smooth zones with gradients, so you can keep a more even speed but still be applying what should be applied to what areas but a smoother transition between zones."

It is finding the technology to solve a problem, rather than finding a problem to suit the technology, that drives Neale in his quest to be productive and profitable. This means that while he has had the capacity to use variable-rate fertiliser application at sowing for about eight years, he has not gone down that path.

The variation at harvest, he said, was more due to what happened during the growing season rather than any inherent issues with his country. EM38 surveys have been conducted but show very little variation in soil types, which are mainly Wimmera grey clays and red loams.

"When you look at our EM surveys, you see the same colour in the paddocks with very little variability (in soil type)," Neale said. "Where we get variation is through elevation, frost damage, disease or poor weed control. If a crop has been damaged in these ways, it will result in leftover fertiliser or stored water, adding to the year-on-year variability."

Figure 6.6 compares an EM38 map against wheat yield. Yield is more aligned with topography than EM.

Neale Postlethwaite on the farm. Photo: Neale Postlethwaite

Each year, Neale runs two test strips in each paddock – the only variable-rate fertiliser he does when sowing.

The 10th swathe gets zero nitrogen and the 20th gets double the blanket rate. These strips are used to monitor the effects of different fertiliser regimes, which are picked up using the satellite imagery and the information included in decisions on in-crop applications.

"When you take a soil test, it is just one snapshot of the paddock, whereas multiple NDVI or satellite images throughout the growing season indicate what is happening to that crop and alerting us so we can take action to ensure that we keep that protein level as even as possible across all paddocks," he said.

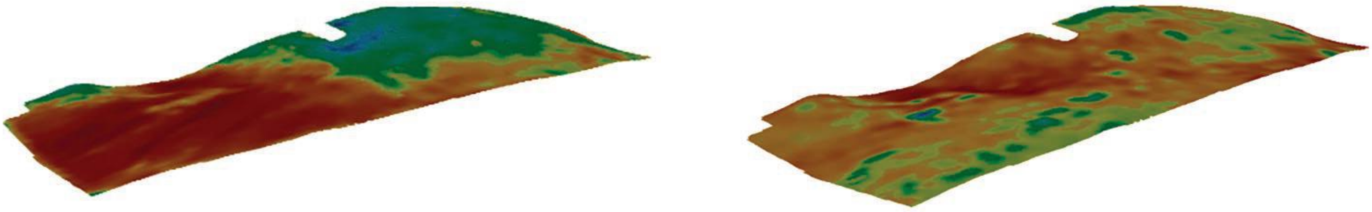
The Postlethwaites run a cereal/legume rotation, with the pulses used as a disease break as well as putting nitrogen into the system. This 'free' nitrogen is another reason they have adopted variable-rate fertiliser spreading. While knowing it will boost nitrogen levels, that boost is not uniform.

"In a chickpea crop, you can get areas affected by Ascochyta blight or weeds and that can affect the level of nitrogen that is put back into the soil in the area that is affected," Neale said. "You get this year-on-year variation within a paddock which is being picked up then addressed to give that more even protein result, all the while ensuring yield does not drop off either."

At the end of the year, Neale produces yield maps that are printed out and studied carefully against what applications were made in the prior season and how they impacted yields/protein levels. This analysis is fed into the next season's decision- making process.

While he watches the yield monitor carefully during harvest and gets feedback from each delivery, the end-of-year process is vital to setting up success for the following season's crops.

Figure 6.6: EM38 map over elevation (left), wheat yield over elevation (right).



Source: Neale Postlethwaite

Photo: Nathan Simpson

Variable-rate N based on protein maps

Nitrogen is one of the biggest input costs into farming systems. Using it more efficiently is every grower's goal, particularly when prices skyrocket like they did in 2021. N fertiliser is also responsible for greenhouse gas emissions that are 265 times more damaging than CO_2.

This short example shows how protein data was converted into a variable-rate urea map on a farm in southern Queensland. The variable-rate maps were developed using CropScan protein data from the 2022 wheat harvest.

Figure 6.7 shows there was a strong correlation between the 2022 NDVI (from satellite imagery), yield and protein data. By September 2022, during peak growth, NDVI imagery (Figure 6.7a) indicated yield might be quite variable across the paddock. Come harvest, the NDVI map correlated quite well with the yield map (Figure 6.7b). Yield ranged from 1 to 5t/ha and protein varied from 6 to 12 per cent, meaning most of the paddock had some protein deficiency resulting in yield penalties. This was caused by considerable flooding over the landscape during the past three years, denitrifying the soil to the point that most of the applied N was lost to the atmosphere.

Tim Neale, from Data Farming, created a variable-rate urea map (Figure 6.7d) based on the protein map (Figure 6.7c). The aim was to even out paddock yield and protein. Soil type is reasonably similar across the paddock.

Pre-planting urea rates ranged from 50 to 300kg/ha (Figure 6.7d), with an average rate of 160kg/ha. This was on top of 100kg/ha blanket rate urea to get a base rate applied earlier on. A large trial strip running up the centre of the paddock had 160kg urea/ha – a simple trial to check how the variable rates fared.

In 2023, the paddock was planted to barley, which was harvested in October 2023. Figure 6.8 compares the September 2022 NDVI map with a late August 2023 NDRE map. NDRE is similar to NDVI but can detect more variation in crop health at later growth stages than NDVI. The trial strip up the middle of the paddock is easily visible, particularly at the southern end of the paddock, indicating 160kg/ha was too low in that area. The higher urea rates (250 to 300kg/ha) led to more even crop growth and a jump in yield in the southern half of the paddock.

At the time of writing, economic analysis data was not available. However, early indications from the yield and protein maps were a four to five times return for every dollar spent on N in some parts of the paddock.

Thanks to Broden Holland (a grower from Young, NSW), who provided invaluable advice and support for this trial.

MORE INFORMATION

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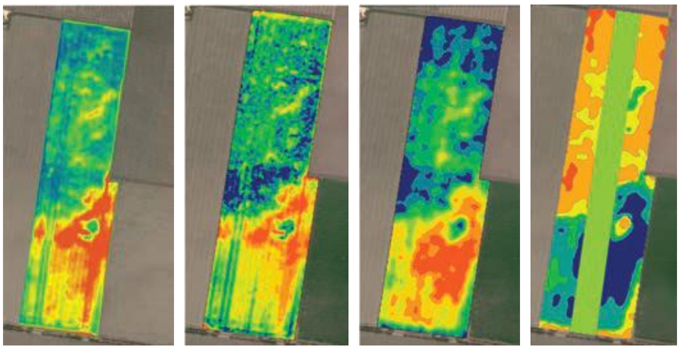
tim@datafarming.com.au

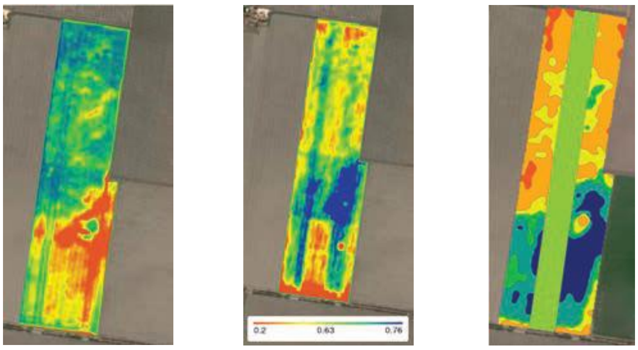
Figure 6.7.



a) NDVI (Sept 2022) **b)** 2022 yield map **c)** 2022 protein map **d)** VR urea map

Source: Tim Neale

Figure 6.8.



a) Sept 2022 NDVI **b)** Late August 2023 NDRE **c)** 2022 VR urea map

Source: Tim Neale

Photo: Nathan Simpson

Limiting urea applications on waterlogged areas

Parts of the article in this section were originally published in 'Turning to technology to combat farming system challenges', *Precision Ag News*, Winter 2023, vol 19, issue 4, by Peter Somerville. Updated in late 2023 by Alisa Bryce.

Over the 2021-22 season, NSW grower Nathan Simpson varied nitrogen applications to maximise yield on high-performing areas and limit fertiliser waste on poorly performing areas. The area's shallow soils range from 10cm to 100cm deep. "We've got a very shallow bucket," Nathan said.

Even in wet years such as 2021 and 2022, the Simpsons need to manage the country carefully and rely on good rains to achieve the greatest yield potential. "We just cannot store moisture like some of the deeper black soils can, so we need to be managing our country differently to be as efficient as possible," Nathan said.

"The soil varies across the property. There's very different soil types in every single paddock on the place, different elevations, different parent material that makes up the soil type."

The incentive for the Simpsons to move to PA was based on a desire to increase input efficiencies and focus on sustainability. The family first invested in collecting yield data in 2009 and started variable-rate fertiliser applications in 2016.

Aligning crop inputs with yield potential

Over the 2021-22 season, the Simpson family relied on variable-rate N applications to maximise returns where yield potential was limited due to different factors.

An airseeder blockage while planting a late winter crop of LRPB Mustang$^{\phi}$ wheat meant poor planting across some areas of the paddock (Figure 6.9). This is evident in the NDVI imagery (Figure 6.9) captured three months post-planting. The red areas at the north and south of the paddock in Figure 6.10 are the areas where the airseeder was blocked.

SNAPSHOT

Name: Nathan Simpson and Kieran Simpson (brothers) with parents Ross and Michele Simpson

Business name: Binginbar Farms

Location: Gollan, 50km east of Dubbo, NSW

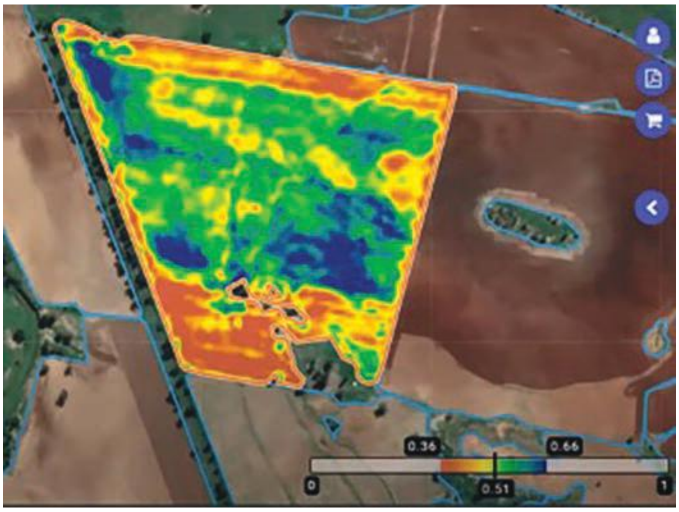
Farm size: 3850ha

Rainfall: 550mm

Soil types: red clay to clay loams

Enterprises: Cropping a rotation of wheat/canola/barley; perennial pastures; and a feedlot finishing store lambs

Figure 6.9: An airseeder blockage caused parts of Nathan Simpson's LRPB Mustang$^{\phi}$ wheat crop to lag behind.



Source: Nathan Simpson

Using the NDVI data, the area was divided into three zones according to potential crop yield. Urea was then applied in three different rates accordingly – 150kg/ha in the areas with most potential, 75kg/ha in the less promising areas, and none at all in areas with least potential. Nathan said that overall they used the same total amount of urea on the block but it was targeted based on yield potential.

Similarly, in-crop VR applications were used to correct obvious variability evident in NDVI of a RGT Planet$^{\text{(}}$ barley crop (Figure 6.11). The crop had been planted using a contract seeder that was unable to apply fertiliser at variable rates. It was instead planted with a blanket rate of 80kg/ha of urea and 80kg/ha of MAP.

Nathan said: "In this particular paddock (Figure 6.11) a lot of the red areas were waterlogged, and the area on the western end had quite a few box trees that make it difficult to grow anything except for perennial pasture. We didn't want to be feeding those areas, we wanted to save fertiliser and put it where the crop had greater potential."

The best-performing areas of the crop (aqua in Figure 6.12) received urea at 100kg/ha, while the more marginal areas of the crop received 50kg/ha and the waterlogged areas (red) did not receive any urea.

Nathan said using the NDVI imagery alone as the basis for a prescription made sense in 2021. "In other years you'd be probably wanting to look at other layers of data as well and combining some stacks from similar seasons in other years, mixed with strategic GPS-marked soil tests so you can validate what sort of nutrient levels are in those areas. By August it's too late to fix any stuff-ups we might have had in terms of nutrient placement, so all you're going to be trying to do is targeting the parts of the crop that have the best yield potential."

Nathan said NDVI data was used in all but six of Binginbar Farms' paddocks. "That was because of the evenness of those paddocks; there were only very small areas where there was difference, so in those cases we applied a blanket rate. But in [the majority of our] paddocks with significant variability we applied nitrogen variably."

Reflecting on the decision to avoid waterlogged areas, Nathan said he was pleased with the approach. As a result, he took the same approach again in 2022.

Was it worth it?

Nathan assessed the value of the work through analysis of profit maps generated after harvest. The maps included data from every fertiliser application and factored in the product cost and application cost, compared with the yield result and the value.

"These maps show that the high-yielding areas (which received the higher urea application) were all in excess of $1200 per ha gross margin, whereas the low areas broke even. In these particular examples, the driver for the poor result was waterlogging, so urea application in those areas would have led to a negative gross margin." Nathan said the prescriptions were very cost-effective, at about 20 cents per hectare.

Figure 6.10: NDVI data shown in Figure 6.9 was used to create a prescription rate for urea application. Areas identified by an aqua colour received the highest application while those in red received the reduced rate.

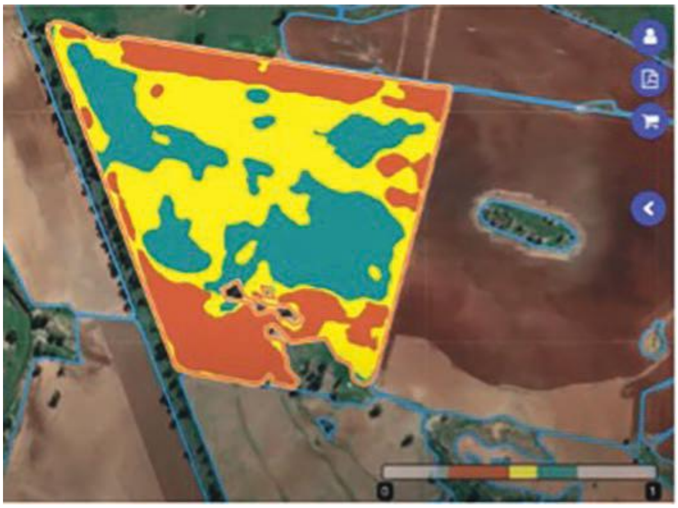
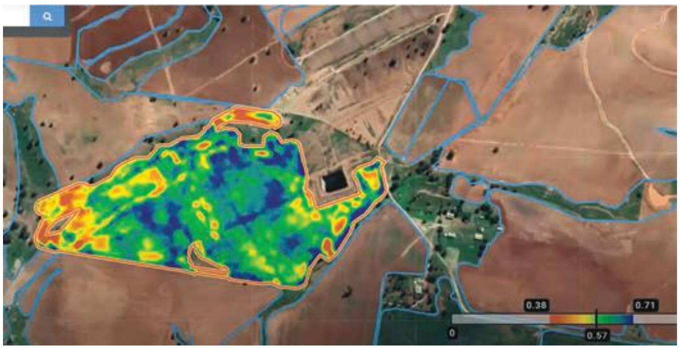
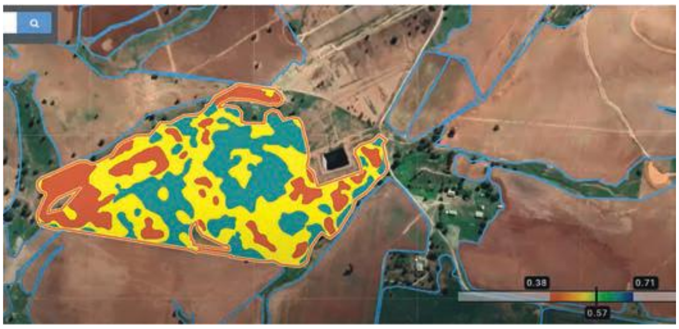


Figure 6.11: Nathan Simpson's RGT Planet$^{\text{(}}$ barley crop, viewed from above in mid-August 2021.



Source: Nathan Simpson

Figure 6.12: The barley crop was divided into three zones for fertiliser application.



Long-term variable-rate nitrogen

The Baldock family were featured in *PA in Practice II (2012).*

Graeme Baldock first entered the world of PA during 2002, investing in a KEE Zynx 10 guidance system to guide his sprayer and reduce chemical overlap. Several years later he bought another KEE Zynx guidance and autosteer system to install in the sowing tractor for increased sowing efficiency.

The Baldocks took a step up with PA in 2004, when Graeme bought a new John Deere header that came with a yield monitor. Graeme has been collecting yield mapping data since 2004, but it was not until the dry years of 2006–08, when blanket rates were proving expensive and nutrients were building up, that he looked at variable-rate fertiliser. His VR fertiliser applications began in 2009.

Most VR fertiliser is nitrogen at sowing, with liquids. This began in 2010 when Graeme bought a Morris 8370 airseeder cart to apply UAN. Back in 2012, Graeme said that variable-rate liquid nitrogen was applied at sowing at rates varying from 20 to 55L/ha. Top-up rates of liquid nitrogen were applied throughout the growing season as required based on the seasonal outlook, with rates varying from 10 to 30L/ha.

Tristan Baldock, Graeme's son, who now manages the farm, said the process had not changed much. For nitrogen fertiliser, the combination of yield and protein maps form the basis of VR decision-making. These maps are then adjusted with farm knowledge.

"Protein maps and yield maps are fantastic to understand where we are leaving yield on the table and where we are over-fertilising," Tristan said. "Through our protein mapping and subsequent variable-rate applications, we are seeing grain protein even up across paddocks. This is telling us that we are better matching the inputs to the yield potential in most years."

In 2022, because of the price of UAN and floods, they did not use any liquid fertiliser or vary their fertiliser application rates. "Because of the floods and full moisture profile we were flat out spreading urea," Tristan said. "Variable-rate became less of an issue because of widespread nitrogen leaching – and the fact we had a once-in-a-generation moisture profile that needed to be capitalised on. Our VR maps went out the door."

The Baldocks now have VR capability on the spreader, but its use is season dependent. "Some years the spreader doesn't come out of the shed," Tristan said. In drier years where the spreader is not used, they often apply foliar UAN to better control N uptake.

Tristan Baldock on the farm.

Photo: Robert Lang

SNAPSHOT

Name: Graeme and Heather, Tristan and Lisa Baldock

Business name: Karinya Ag

Location: Buckleboo, South Australia

Farm size: 10,000ha

Rainfall: GSR 196mm (average)

Enterprises: cropping

Rotation: wheat/wheat/barley/pulse, or in marginal country a pasture or vetch. Occasional canola or oats and vetch mix as a mulch crop

Motivation

The motivation behind variable-rate fertiliser is to better allocate resources. "We might be only varying the rate by 10 units of N. We are spending the same dollar amount but putting it where we get a better response," Tristan said.

Developing the VR maps

"Developing the maps has to be simple," Tristan said. The Baldocks work with Next Instruments (which provides the protein monitor) to develop their VR maps. While they can easily create their own maps, Tristan finds it useful to have someone to help.

"We crop 10,000ha. We need someone to help us create the maps, otherwise you can lose a lot of time trying to sort maps out when you could be doing something else. I like being able to quickly grab the VR map and tweak it with my farm knowledge." The Baldocks try to get maps done in March/April.

The Bransons' tractor is used with autosteer RTK 2cm guidance.

Simple approach key to variable-rate success on Branson Farms

A founding member of SPAA, Mark Branson's journey with PA started with yield mapping the family's farm in Stockport, South Australia, in 1997. Since then, he and his family have honed their overall approach and the technology used to manage variability across their farm, increase productivity and reduce costs.

Today Mark Branson and his son Sam use PA technology to apply variable rates of nutrients, seed and weed management. Across their 1200ha farming operation, the soils range from red-brown earths to dark brown cracking clays. With these different soils plus undulation and creeks, the variability was obvious.

When they first retrofitted a yield monitor to a new harvester in 1997, they could see that the soil and topography variability correlated to differences in yield. They tried to find out how to address that variability and turn data into profit.

To address this knowledge gap, both for his own farm and for the wider industry, Mark Branson became a founding member of SPAA in 2002 and completed a GRDC-sponsored Nuffield Scholarship in 2005. He used the scholarship to research the use of precision and conservation agriculture to improve farm profits and environmental outcomes.

Variable-rate phosphorus and nitrogen

Inspired by his research findings, Mark started to use large-scale variable-rate technology in 2006. On-farm application started with introducing a variable rate for phosphorus. To do that, they took the previous year's yield map and applied a formula accounting for replacement rates for what was lost in yield plus a factor of loss, or a buffer. Figure 6.14 is an example yield map used to calculate phosphorus replacement rates.

The Bransons expanded their use of variable-rate technology to nitrogen and started using N-rich strips. An N-rich strip is an area in the paddock that receives enough nitrogen fertiliser for the whole growing season, regardless of the environmental conditions. The rest of the paddock receives the standard pre-plant rate. Growers can then compare the N-rich strip to the rest of the paddock to see if nitrogen is restricting growth.

For more accurate data on nitrogen levels, Mark also uses a Trimble GreenSeeker® handheld sensor to determine mid-season nitrogen rates. The sensor uses brief bursts of red and infrared light to produce an NDVI reading to indicate the health of the crop.

Mark also uses Topcon CropSpec™ sensors mounted on his tractor. The crop canopy sensor measures plant reflectance to indicate chlorophyll content of the crop. This correlates to the nitrogen concentration in the leaf.

They use data from the N-rich strips, Greenseeker® and CropSpec™ sensors to determine whether crops need nitrogen and how much. They combine this data with visual observations

SNAPSHOT

Name: Mark Branson (general manager), son Sam (operations manager)

Business name: Branson Farms

Location: Stockport, South Australia

Farm size: 1200ha

Rainfall: 425 to 500mm

Soil types: red-brown earths, dark brown cracking clays

Enterprises: dryland cropping: wheat, barley, field peas, faba beans, lentils, canola, oaten hay. Livestock: 1000 Merino ewes (self-replacing flock), prime lambs, 20 cattle of biomass from physically getting out into the paddock but also imagery from a DJI Phantom 4 drone. This is fed into variable-rate nitrogen algorithms.

While Mark said precision agriculture had advanced in the past decades, there were still gaps. “If I were to write a variable-rate wishlist, it would include better algorithms for nitrogen. They’ve got these algorithms working nicely in the US and the UK, but there’s still work to do in the Australian context.

“You need a lot of data, and we got a lot of that through Dr Rob Bramley’s project. We were the strategic site in South Australia for the Future Farm project that ended [collecting data on our farm] last year. And that project showed nitrogen replacing is not easy; you need a lot of data to get it right, but I think I’ve got more right than most others.”

Variable-rate gypsum lime

The Branson Farms team uses a Veris® pH Manager to detect soil pH on-the-go. This machine can produce accurate maps for variable-rate lime application, providing sufficient measurements are made.

“Using a machine to detect soil pH gives us a higher density of data than, say, grid sampling. The reason why we don’t go grid sampling is because the soil varies so much here. So, if you try, and unless you hit the exact the sample site that you did 10 years earlier, then you’re not guaranteed to get the same value.”

They use this data to create variable-rate application maps for applying gypsum on areas with sodic soils (that is those with more sodium than usual), and lime on acidic areas (Figure 6.13). They apply these at different levels depending on each area’s needs.

Variable-rate weed management

Mark said that using a drone also helped with weed management. At Branson Farms, they use a drone to detect areas with extra biomass, which indicates where there are herbicide-resistant ryegrass, wild oats and wild radish. Mark adds that detail to his variable management maps. He manages these areas differently, either cutting them for hay, spraying them or where it is an ongoing problem, using variable-rate seeding to put out more seeds so the desired plants can outcompete the weeds.

Refining the PA approach

Mark was an early adopter of yield maps. “In 1997, our first yield map gave us a nice, coloured map, but so what? We didn’t know how to make use of that data.” He said the family farming operation began to take a different approach based on his research through the Nuffield Scholarship program. He has refined it further since then, including through involvement with GRDC trials.

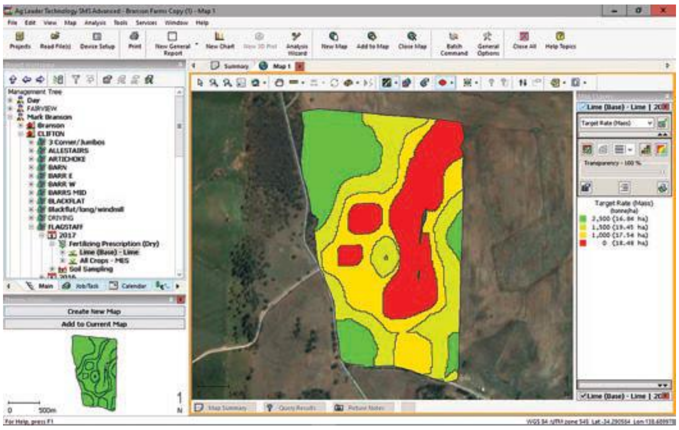
Based on the principle of keeping things simple, Mark has a five-step approach to precision agriculture:

1. identify the problem;
2. fix problems that can be permanently fixed;
3. use variable rate in areas that cannot be permanently fixed;
4. identify whether there is a PA tool to fix the problem and what it is; and
5. decide whether it is economical to implement that PA tool.

Emerging crops planted on the Branson farm with autosteer RTK 2cm guidance.

Photo: Mark Branson

Figure 6.13: Lime application map produced through the use of soil pH mapping on the Bransons’ farm.



Source: Mark Branson

Mark said it was important to start with a problem and look for a solution, rather than creating a reason to buy (or be sold) expensive equipment, machinery or services. “PA is about solving agronomic problems, not buying trendy tools or services,” he said. “But don’t buy in a solution just for the sake that it is good technology and it looks fantastic and the sales have done a really good job on selling. It doesn’t make any money. PA is profitable if you choose the right tools.”

He gave the example of phosphorus management to demonstrate the approach.

“We have a problem in that our grain takes the phosphorus out of the paddock; we’re essentially mining, we’re mining the phosphorus. So I ask, what’s the best way to replace this phosphorus?”

Despite their importance, Mark said that precision agriculture technologies were most effective when used with other tactics that reduced risks, such as pests and disease pressures, and promoted productivity. For example, the family rotates different crops and grazing pastures to help control weeds and diseases. They also apply organic matter to the soils to boost organic carbon levels and overall soil health.

DJI Phantom 4 drone used in weed management on Branson Farms.

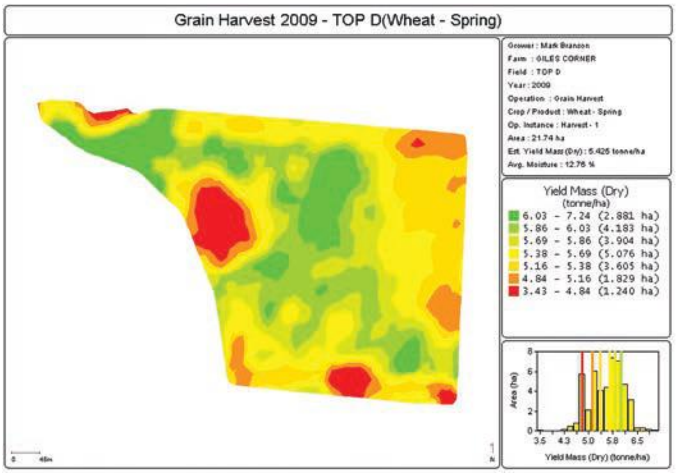
Understanding the economics of PA

Mark received assistance from Associate Professor Christopher Preston and others to do an economic study of controlled-traffic farming (CTF) and PA tools on the farm, which he has presented at conferences.

As of 2020, the economics of CTF and PA on the farm include:

- yield gains averaging $5.95/ha/year;
- overlap savings (for seed, fertiliser and other chemicals) of $7.24/ha/year; and
- nutrient savings (for phosphorus, nitrogen, gypsum/lime, weed control) of $72.31/ha/year.

Figure 6.14: 2009 yield map. The Branson family calculates phosphorus lost through harvested grain by using the previous year's yield maps.



These add up to total savings of $85.50/ha/year, and Mark said that with the rising cost of fertiliser the savings would be even bigger for 2022. He acknowledged that CTF and PA incurred equipment and other costs. Branson Farms has spent approximately $110,000 on this specialised equipment in the past decade. Mark calculated if you divided the cost over time and farmed area, it would come to $12.22/ha/year.

Since Mark creates the maps himself, he calculates his time for managing CTF and PA as $2/ha/year. The other ongoing cost is the RTK GPS signal at 17c/ha/year, which is more accurate than devices such as smartphones and wearables. These take expenses to $14.39/ha/year.

To work out the profit, a simple equation of total savings ($85.50/ha/year) minus total expenses ($14.39/ha/year) equals profit of $71.11/ha/year. This equates to $64,000 a year across the 900ha area of cropped land.

Mark said the benefits of PA went beyond economics. "There are benefits such as using less chemicals and increasing soil health, and also when you increase your profits, it means you can employ more people on-farm, so there are social benefits too.

"I'm not working as many hours in the machines as I used to – that's partly age, but also I had a farm accident five years ago and now I'm an amputee."

The accident has not dulled Mark's passion for PA. He and son Sam provide contracting services to create soil pH maps for variable-rate lime spreading on farms around the local area. Mark is considering expanding these services by going into consulting.

He said precision agriculture was also key to sustainable farming. "The only way we are going to feed the world's population with depleting resources is to adopt PA technologies," he said.

Article produced as part of GRDC project SPA2201-001SAX.

Silo art at Bute Vittera site. Photo: Rick Mohren

Increasing input costs drove PA journey

Increasing input costs was the key driver that started James Venning of Barunga Grains on his PA journey. "We weren't trying to save money or get higher yields, but be more sustainable and efficient with resource allocation," James said. "By putting inputs where they're needed, rather than applying with no science [behind the decision]".

Increasing land prices only cemented the decision, as the economics of buying more land no longer stacked up. "In 2006, we bought a farm for $1600 an acre. In 2015 land was $3500/acre, in 2020 $7000/acre and now it's probably around $9000 an acre. It makes sense to do more with less and fix what we have, rather than expanding," James said.

The Barunga Grains precision agriculture journey started with variable-rate (VR) phosphorus (P) and has expanded to VR lime, in-season urea, seeding and varying crop variety based on elevation for frost-prone zones.

Phosphorus

Historically, the farm received blanket rates of 80 to 100kg/ha MAP. However, despite ongoing applications, some areas of the paddocks were becoming P-deficient, particularly the grey calcareous loam soils.

The first attempt at VR fertiliser was P replacement based on yield maps, using four units of P per tonne of cereals removed and seven units of P per tonne of lentils and canola. This worked well, but there was still variability in the crop that encouraged James to keep refining the VR approach.

He said: "When we were doing blanket rates we weren't even thinking. Once I started paying attention to differences in the paddock and changed the zones or application rates, I'd notice more differences. We would grow a crop with the same fertiliser rate and same rainfall and have such variable results across the paddock, and I started to ask why."

SNAPSHOT

Name: James Venning

Business name: Barunga Grains

Location: near Bute, northern Yorke Peninsula, South Australia

Farm size: 4700ha

Rainfall: 400mm, 70 per cent in growing season

Soil types: sands to loams on a dune-swale landscape

Enterprises: lentils, canola, wheat and some barley

Rotation: lentils and canola with cereals as the break crop

Average yields: 4.5t/ha wheat, 4t/ha barley, 1.5t/ha lentils (pre-ameliorated average, with about 2t/ha on the better country and <1t/ha on the worst) and 2.5t/ha canola

The next evolution in VR P was to base zones on soil pH and the soil's phosphorus buffering index (PBI) – the ability of a soil to 'lock-up' P. The farm was originally pH mapped to develop a VR liming program, but James and his agronomist Sam Trengove (Trengove Consulting) noticed the slow growth areas always seemed to be on the higher pH areas in the paddock.

Soil tests revealed that PBI was well correlated with pH in their landscape. As soon as pH gets more than 6.5, PBI starts to ramp up, meaning the crops need higher P rates in those zones. pH and NDVI are also reasonably well correlated, so Sam developed a formula that used pH and NDVI from a previous year to alter P rates. NDVI is usually taken around late June or early July.

"If, for example, the NDVI is the bottom 20 per cent of the paddock, the program checks the pH of the same spot, and if pH is high, it increases the P rate (as high as 50 units of P)," James said. This system was partly used to keep the cost of soil tests down as it would not be economic to soil test to the same resolution. The Colwell P test was "pretty much useless" at Barunga Grains; the more expensive DGT-P test was more accurate. The pH-NDVI calculation was used as a proxy for DGT-P.

This system was working well, until fertiliser prices soared. "Just before COVID, we thought we were nailing it," James said. "We had found the highly responsive zones and ramped up P rates according to the formula. But when P went from $600 to $1400/t in one year, we realised we were still over-applying in some areas. Where we ground-truthed with trials, there was no response at all in some areas."

Table 6.2: Example optimal P rate sensitivity calculator.

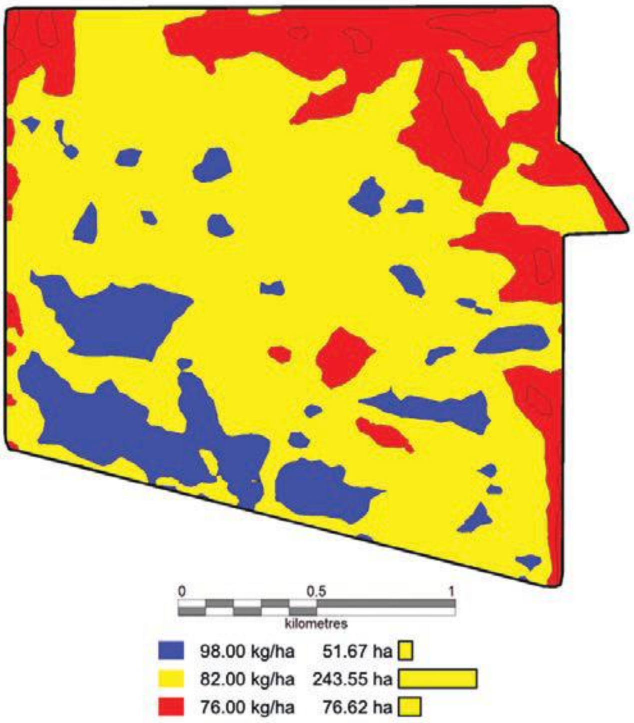
Current grain price

Optimal P rate – price sensitivity calculator kg P/ha
Decile 10 grain prices (current)
Wheat APW1 – $400t, Barley F1 – $350t

	Soil DGT P				
Map ($/t)	>150	100	50	30	<20
$500	0	11	25	39	53
$750	0	6	19	32	45
$1000	0	4	15	27	39
$1250	0	3	13	23	33
$1500	0	3	11	20	29

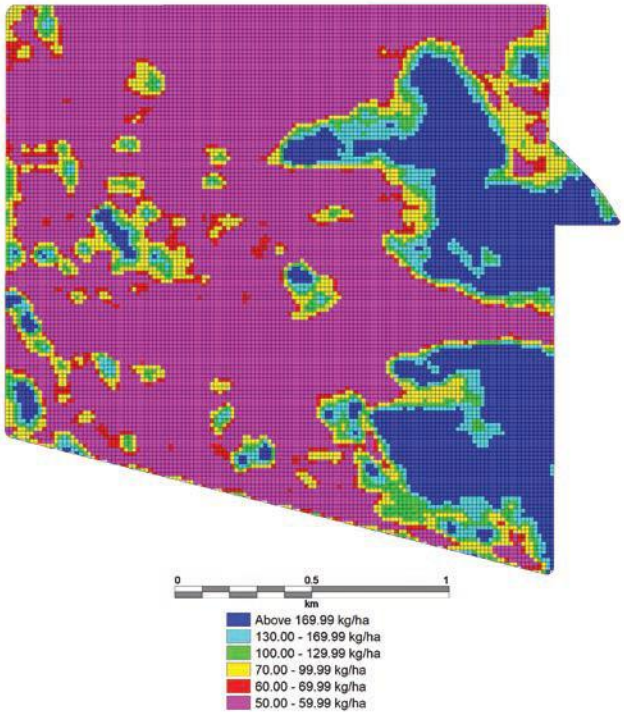
Source: James Venning and Sam Trengove

Figure 6.15: VR P map based on yield export on the Venning farm.



Source: James Venning

Figure 6.16: VR P map derived from the updated P calculation (agronomist Sam Trengove's pH–NDVI formula). Rates range from 50 to >170kg/ha MAP.



Source: James Venning

Figure 6.15 shows a variable-rate P map based on nutrient export in yield, while Figure 6.16 is a variable-rate P map derived from the NDVI-pH formula.

The next step was to develop a price sensitivity calculator and consider where P could be cut back. Table 6.2 is an example of a price sensitivity calculator (one of many) Sam made when teasing out economically optimal fertiliser rates. It compares soil P values with MAP prices to find the optimal P rate. For example, if MAP is $500/t and soil P is 30mg/kg, the optimal P rate is 39 units.

Because of historical blanket P applications, some areas on the farm had a P bank and were not responding to extra P. When fertiliser prices hit $1400/tonne, they used that P bank by reducing rates to six units (30kg/ha of MAP) on non-responsive (acidic) areas. They continued applying 20 to 50 units of P on responsive zones (alkaline areas with a higher PBI).

James said: "We still put some starter P on non-responsive areas, but knew that thanks to years of blanket rates, there was enough of a P bank to see the crop through." This approach saved $100,000 in that first year.

James knows he cannot mine soil P forever, but it was a strategy that helped manage costs while they were very high and made use of existing soil P. "Now that prices are coming back down we can go back to the previous strategy and replace more soil P to refill the bank. This is insurance against higher prices. It's better off to fill the tank while prices are cheap."

Nitrogen (N)

Variable N rates at Barunga Grains are less clear-cut than P rates. Some paddocks receive VR N at seeding and some receive blanket rates. Soil texture plays a big role in the decision.

Areas where there is a greater variation in soil texture tend to receive VR N at seeding, with loamier soils on the flats receiving 0 N and sandier soils receiving N. Time efficiency also plays a role during the busy seeding time. "Urea often runs out first. We like to reduce N rates on the heaver soils that usually have decent nutrient stocks, to get more done in a day," James said.

On other areas of the farm where there is less soil variation the crops receive a blanket N rate at seeding with a VR N rate in-season. The rates are again varied based on soil texture.

In 'normal' dry years the sands perform the best. However, they have the lowest deep N stocks and need more fertiliser. Although it seems counterintuitive, the sands perform better due to larger pore sizes and the mulching effect when the top layer dries out.

James said: "On the heavier soil, an inch of rain only wets up the top 10cm of soil, which is then more prone to evaporation. On the sands, an inch of rain can wet up to 40cm of soil, meaning water is stored deeper in the soil. Then there's the mulch effect – the top will dry out on all soils but with lower capillary action, more moisture stays in the sand for the crop to use. In seven out of 10 years the sand hills perform better than the heavy soils because of better water access.

"Wet years are harder to predict, and the process is usually to blanket urea in the first pass and see what the season does. This year (2023) was a bit different as the sands struggled for emergence (drying profile at seeding). This meant yield potential was capped and therefore rates were scaled back and a blanket rate put out on those paddocks. In other dry years we'd be ramping up the rates on the sands to top them up."

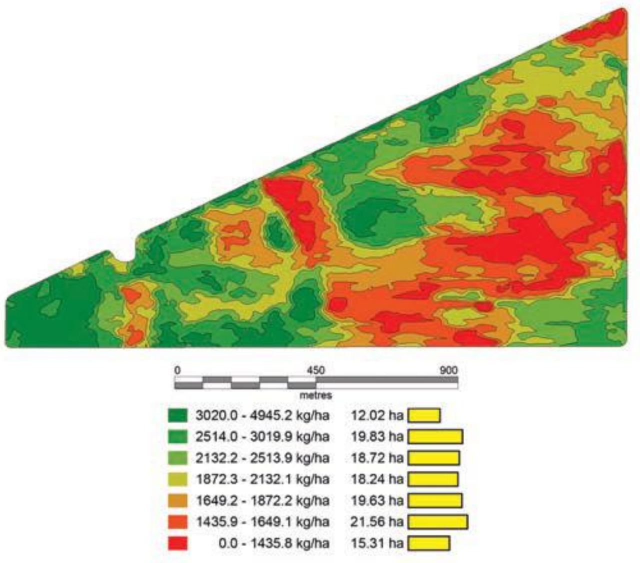
In-season N rates are also partly informed by historical yield maps. "The plant knows more about the soil than we do. You can EM map or do all sorts of mapping, but that data still requires interpretation – and the plant does the interpretation for you, if you get the right season.

"When you've had a hot, dry finish (for example, Figure 6.17), the good sands really show up on the yield map. Anything that yields in the best 30 per cent is high performing, if middle of the range it is middle rate, and if it pinches off and performs poorly in a dry year, best to treat it mean and let it look after itself," James said.

While James tried using a N-sensor mounted to the cab tractor, it made too many assumptions for his liking and he has since stopped using it. He is dabbling with using protein maps to assess N decisions, but has not yet made using protein maps part of normal operations. In 2023, he is mapping grain protein and will test the soil in high and low protein areas to decide if there is enough difference between the results to change current N practices or the yield target. His agronomist Sam Trengove already has one trial with four N rates underway to try and tease out the economically optimal N rate for each zone.

James admitted that urea was a struggle, but it is the one input he is very keen to get right. James said: "Nitrogen is our highest cost on the whole farm, but the biggest profit driver. The stakes are higher if we overuse it as the costs go through the roof, but if we under use it, we sacrifice profit."

Figure 6.17: Yield map from a tight finish on the Venning farm.



Source: James Venning

A canola crop on the Venning farm. Photo: James Venning

Variable-rate phosphorus boosts profit

This article in this section was originally published as 'Increasing yields with variable-rate technology' in *Precision Ag News*, vol 19, issue 2.

SNAPSHOT

Name: Peter Minhard and Tarren Minhard

Location: Cummins, Eyre Peninsula, South Australia

Farm size: 730ha

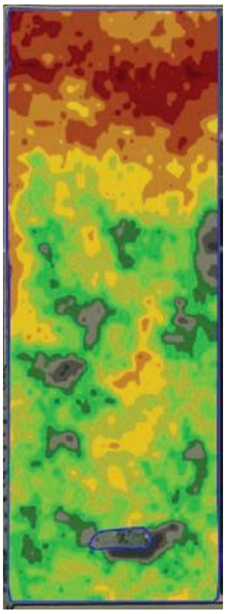
Rainfall: 400mm

Soil types: mostly loam over clay, sand over clay, through to areas of grey cracking clays

Enterprises: broadacre cropping

Crop program: wheat 25 per cent, canola 25 per cent, barley 25 per cent, chickpeas 5 per cent, lentils 20 per cent

Figure 6.18: Radiometric scanning helped Tarren Minhard understand the variation in his soils. This image shows differences in potassium levels across the farm's 'West Paddock'. Higher levels of potassium indicate clays, which means greater phosphorus retention. With the help of agronomist Martin Chandler, the Minhards used this information to come up with the variable-rate phosphorus zones.



Source: Tarren Mindard

Increasing yields inspired Tarren Minhard to embrace variable-rate technology on the family's Eyre Peninsula farm. Tarren manages the 730ha property 'Firthfield', near Cummins in South Australia, with help from his father Peter and casual employees at seeding and harvest.

Tarren said they were fortunate to have good, heavy soils at Firthfield and did not need to apply as much gypsum and lime as some other properties in the area. He applies lime on sandier soils and gypsum only before planting a canola crop and at 0.5t/ha.

Challenges to address and the importance of advice

The family has been working with Martin 'Marty' Chandler, from Nutrien Ag Solutions in Cummins, for many years. In 2015, when Tarren took over management, the two of them went through the property's EM38 and radiometric maps (Figure 6.18) to identify different soil zones, looking for areas that could be improved.

The goal was to optimise yields, getting the most production possible out of the paddocks. Tarren wanted to make sure he was applying enough fertiliser to the high production zones to fulfil their potential, and ensure he was not applying excess to the lower production zones.

Getting started with PA

Tarren worked on farms in the United Kingdom and Canada for several years. Soon after returning to Australia in 2014, he took over the management of Firthfield and was keen to introduce precision agriculture.

Peter had already invested in some seeding equipment – a bar, box and monitor – that enabled the family operation to start doing variable-rate applications. Their current setup includes a Topcon x35 seeding monitor and a Kuhn fertiliser spreader, which is set-up on ISOBUS and runs through an Ag Leader In Command 1200 screen.

The entire property has been mapped using EM38 and radiometrics to detect soil variation. Figure 6.18 is an example radiometrics map.

To complement using PA tools, Tarren has also implemented controlled-traffic farming. Most of the machinery is set up on 3m wheel centres and 12m run-lines, including the boomspray, spreader and header.

"I think rather than having say two or three sets of wheel tracks in your paddock because of different machines on different widths, you can narrow it down to one set," Tarren said. "Then you've got that one compaction zone. When you don't have as much compaction in your paddocks, obviously plants are a lot healthier because they don't have hard pans or wheel tracks to cope with in trying to get their roots deep."

Cost–benefit analysis of VR phosphorus application

A key aspect of developing the VR prescription map for phosphorus has been a cost–benefit analysis. The Minhards considered the potential yield of strips across a paddock, with the results shown in Table 6.3. These strips were determined by similar yield results.

Next, they trialled different phosphorus rate applications on each of the zones: 0kg/ha, 70kg/ha, 100kg/ha, 130kg/ha and 150kg/ha of product (for example, Granlock Z, not of units).

Based on the yield performance for each treatment by zone, they did a cost–benefit analysis. The results are summarised in Table 6.4 for the 2021 cropping season.

The profit/ha is calculated from the yield revenue and treatment cost and does not take into account other costs.

Yield increases resulting from PA

Average yields have increased in the seven years since Tarren took over. The farm now produces:

- 2.5 to 3t/ha canola;
- 5.5 to 6t/ha wheat;
- 5 to 6t/ha barley;
- 2 to 2.5t/ha chickpeas; and
- 2.5 to 3t/ha lentils.

Tarren has found that to achieve such yields, he needed to “pump on the inputs”.

“We used to blanket rate 100kg at seeding of P and we had some good yields in the past. I was kind of thinking when it comes to lower productive zones, we’re probably wasting it, and higher production zones will probably not be getting enough to maximise yield targets.”

Using past results to plan for future P applications

The Minhards have continued the approach of applying enough fertiliser to the high production zones to fulfil their potential, while ensuring that excess was not applied to the lower production zones. For example, they use data from the previous year’s harvest to ensure they apply enough phosphorus to replace what the plants have drawn from the soil (plus a small buffer).

“We apply what we need,” Tarren said. “We look at last year’s crop and then we work out how much phosphorus was taken out and how much then needs to be replaced. We top off more on some soils because they can’t access the phosphorus. In some instances, you can use variable rate to save [on fertiliser costs], but I found I actually have used more phosphorus because I’m obviously pumping it on those areas that we know can really yield well.

“Marty (agronomist) and I talk about rates, and I figure if I’m aiming for 7 to 8t/ha wheat, then I can work backwards to calculate what the plants need.”

Even when fertiliser prices are high, Tarren sticks to this approach. “It’s surprising for some. This year [2022], my phosphorus cost $1560/t and urea at $1350/t. Marty said do you want to cut back and save, or do you want to keep doing what you’re doing? I said, keep doing what I’m doing; I didn’t worry about cutting back because that’s what the plants need to meet those yield requirements.

“They’re talking it’s going to be a wet spring this year (2022), so I don’t want to miss the opportunity if it is a good season. You’re sitting in the header and you’re thinking damn, we should have gone a lot harder.

“I could also be wrong and we could run out of moisture in September or get hammered by frost and the whole show goes down the drain, but you don’t know that when you’re putting it on in June or July.

“In Cummins, we’ve got reliable rainfall most years, and with the soils I have, so I’m one of those guys that looked at high risk, high reward.”

Table 6.3: Wheat yield by zone. Yield performance as wheat t/ha for each zone over five years’ harvests on the Minhard farm.

		Wheat yield (t/ha)				
Zone	Area (ha)	Min	Mean	Max	Std Dev	CV
Zone 1	55.768	0.98	5.91	10.41	0.79	0.13
Zone 2	49.1128	2.15	6.56	10.31	0.57	0.09
Zone 3	53.0696	2.07	6.74	10.75	0.57	0.09
Zone 4	19.224	2.30	6.78	10.21	0.62	0.09

Table 6.4: Comparison of the profit from test strips across paddock zones with optimal phosphorus application rates. Zones 2, 3 and 4 have the same optimal application of P despite having different yield results for 2021. When a different crop is planted in any of the zones, the rates are changed to suit that crop.

Zone	Area (ha)	Optimal treatment (kg/ha of P product)	Profit/ha
Zone 1	55.768	130	$2845.97
Zone 2	49.1128	100	$2554.16
Zone 3	53.0696	100	$2623.63
Zone 4	19.224	100	$2575.44

Additional longer-term benefits

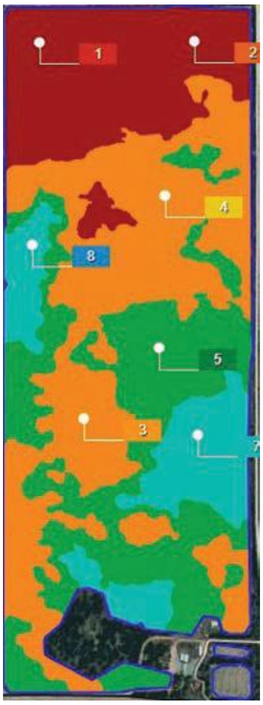
With grain prices where they are [in 2022], Tarren’s approach to purchasing and applying fertiliser is paying off. If a season looks promising, you might not need very much extra fertiliser to generate larger yields and justify additional costs.

“I’ve never seen grain prices so high, and neither has Dad. It doesn’t take that much extra urea or phosphorus to make an extra tonne of grain. Those yields pay off in the long run,” Tarren said.

While there were teething problems with the various technologies, Tarren said it was running smoothly now. He has also found that after a few years working with precision approaches, the labour required has reduced dramatically.

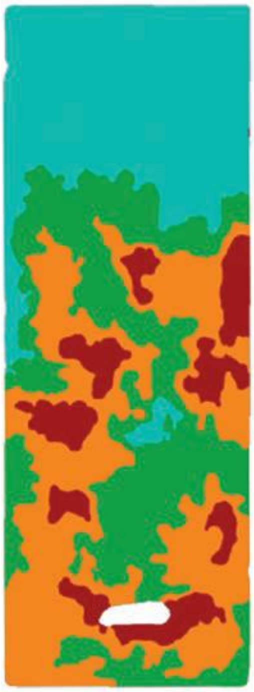
“I’ve done all the hard work creating and sorting the zones. Once these are set up, if you’re a bit savvy with tech, it only takes 10 minutes to produce a variable-rate map.” Tarren makes these maps with Precision Cropping Technologies software, transfers them onto a USB, then plugs it into the tractor, loads the maps, and spreads or sows the paddocks using the PA information.

Figure 6.19: Informed by the radiometric scanning, Tarren Minhard and Martin Chandler developed a plan to do deep soil tests. They aimed to do two soil points for each zone, focusing on understanding the nitrogen levels in the soils. Tarren would like to start doing variable-rate nitrogen.



Source: Tarren Mindard

Figure 6.20: Variable rate map for nitrogen (urea) created with PCT Ag Cloud program, informed by deep N tests the Minhards did in April before seeding to aim for yield potential. The red zones prescribe 25kg/ha, orange 50kg/ha, green 80kg/ha and blue/teal 125kg/ha.



Source: Tarren Mindard

What's next – variable-rate nitrogen application

Tarren plans to start applying nitrogen at variable rates in the next few years. He is confident this next step will improve yields further, making urea application as efficient as possible.

Informed by the radiometric scanning, Tarren and Martin Chandler developed a plan to do deep soil tests (Figure 6.19) at two soil points for each zone, focusing on understanding the nitrogen levels in the soils. Having done the tests, they used the data gained plus the PCT Ag Cloud program to create a variable-rate map for nitrogen (urea) (Figure 6.20) that aimed to meet yield potential.

To gain further insights, last year Tarren purchased a protein monitor to retrofit to their harvester. He planned to use protein data to assess if nitrogen management was working or needed to be improved. "Obviously, rainfall and other seasonal events will affect plants' nitrogen use and yields, but it's pretty exciting to get that additional information to help us assess our management."

Tarren said that while some growers used the protein meter for blending, he planned to use it for nitrogen management only. "I'm hoping in two or three years there will be good data from the paddocks. From that, we can identify some trends, using them to make nitrogen management zones, and start applying nitrogen to the yields we're chasing."

He recently installed three soil moisture probes, each in a different zone in three separate paddocks. "So come September, you know, when in the past I've been worried that the crops are going to run out of moisture because it hasn't rained, and that they say we've got 10mm [of rain] coming and I can have a look at my data and I can say there is enough soil moisture in there to get us through until harvest, so I might go and put more urea out," he said. "I'll also talk to guys that are using similar data and find out how they're making the best use out of it."

Using PA records for potential future international carbon taxes

Tarren thinks it will not be long before Australia implements a carbon tax similar to what is used by Canada. "Whether it's in the next five years or 10, I think fertilisers, fuels and chemicals will be taxed for their impact on the environment. With the data informing rates, zones and yields, growers using these methods will be able to demonstrate that they aren't wasting fertiliser."

Encouragement to other growers to try PA

Tarren encouraged all growers to give precision methods a shot. "You can start small with a couple of test strips or half a paddock. If there's room for improvement, you'll see gains quickly. You just don't know until you try, and most equipment that you buy these days already has the capabilities."

The Taits run a truly mixed operation.

Photo: Ben Tait

Using variable-rate fertiliser as a capital investment

The article in this section was originally published as 'The mixed or muddled farmer? Dabbling in precision ag', *Precision Ag News*, Spring 2022, vol 19, issue 1. Updated in late 2023 by Alisa Bryce.

SNAPSHOT

Name: Ben and Stephanie Tait

Business name: Riverlea Farming Co

Location: 'Fairfield' farm in Epping Forest on the Henrietta Plains, Tasmania

Farm size: 800ha

Rainfall: 400mm

Soil types: duplex soils with a clay subsoil and sand deposits

Enterprises: mixed cropping (mainly ryegrass for seed production) – 30:70 to livestock and crops

Tasmanian growers Ben and Stephanie Tait have largely focused on improving drainage on their 800ha property (Chapter 5, page 76), but in 2021 turned their attention to variable-rate fertiliser on the highly variable parts of their farm. The Taits work with precision agriculture specialist Reuben Wells, from Ag Logic.

Ben was interested in what PA tools could be used to counteract the impact of soil variability on his crops. "The area in question has grown some of our best and some of our poorest crops. And we knew that we couldn't treat it all the same," Ben said.

The Taits run a truly mixed operation, split roughly 30:70 to livestock and crops. On the livestock side, they run 3000 composite ewes and finish the lambs and trade lambs opportunistically. They have a small beef enterprise with up to 100 Angus and they agist 1000 dairy cows in the winter.

Their main crop is ryegrass for seed production, which they have in rotation with lamb-finishing pastures of clover, chicory and lucerne. They grow other crops for seed, including canola and chicory. They also produce vegetables in the rotation but on smaller areas, including peas, broccoli and potatoes. In marginal seasons, they grow barley as well, as it is a more resilient and less costly crop and they can stop irrigating if the season requires.

"We're quite a new farming enterprise here," Ben said. "Since moving from New Zealand in 2018, we've done a lot of development, and we don't have a limitless fertiliser budget. So it's important that we test and place the fertiliser only where it's needed."

They decided that the same data collected to help with the drainage could also help create soil testing zones. The topographic layers and EM38 data were combined with old paddock boundaries to account for historical fertiliser applications, creating practical zones for soil testing in a 50ha area. This area had two main soil types – duplex soils with a clay subsoil and sand deposits. However, flood erosion had created a patchy paddock, exposing the clay subsoil in some areas.

They used these zones to determine 22 sampling locations, with each getting a broad analysis of soil chemistry. The soil tests confirmed the soil variability and "gave us satisfaction that we did the right thing", Ben said.

They used the data and soil testing results to create variable-rate phosphorus (Figure 6.21), lime (Figure 6.22) and potassium maps. The liming program applied lime rates ranging from 3.9 to 12.5t/ha.

"Barley is sensitive to low pH and soil sampling showed some of the pH was as low as 5.1 and required some 10t/ha of lime," Ben said. "Lime takes a while to work, so we didn't expect all the benefits to be in this crop. But testing specific zones and soil types has got to be so much better than random core samples. I'm satisfied that it was good practice."

The phosphorus program was applied as a split application, with half in spring 2021 and the second half in spring 2022. Phosphorus rates, applied as single super phosphate, ranged from 100 to 950kg/ha per application. Some areas did not need any lime or phosphorus, so there was a reasonable saving to Ben by not blanket spreading.

For Ben, this variable-rate application was part of a capital fertiliser program, aimed at lifting soil nutrient levels to set fertility targets.

"I just saw it as an opportunity to top-up to even things out and apply capital fertiliser. I considered it as a one-off to try and level up the paddocks. Generally speaking, if we rule out moisture stress as the limiting factor (with irrigation) and waterlogging (with drainage), then level-out fertility, we can blanket our inputs in line with our yield expectations. It's worth noting that our average paddock size is only 20ha and that any irrigation run-off runs back into farm storage. We aim for best practice and compromise with what's practical."

Ben did not think he would use VR application for the maintenance fertiliser at this stage. "Water and drainage are our biggest limiting factors; our soil fertility is quite good."

Instead, he will concentrate on things that have a bigger impact to his bottom line: irrigation, drainage, crop choice, planting timings, weed management and maximising livestock production.

He also said the potential fertiliser savings from VR applications were not as significant on a smaller farm compared with those typically seen in broadacre or extensive operations.

Ben expected the benefits of the VR applications to persist over many years, although it was difficult to isolate the benefits when different parts of the paddock were irrigated by different systems.

For their maintenance fertiliser program, Ben gets advice from Ben Lomond Agriculture. "And our inputs are well covered by what we remove and what our yield expectations are. So I haven't yet done any herbage tests to see if we're short on anything. But our agronomist is aware of the district and the soil types. He offers great advice and insights into things I might overlook on my own accord."

CTF and PA tools

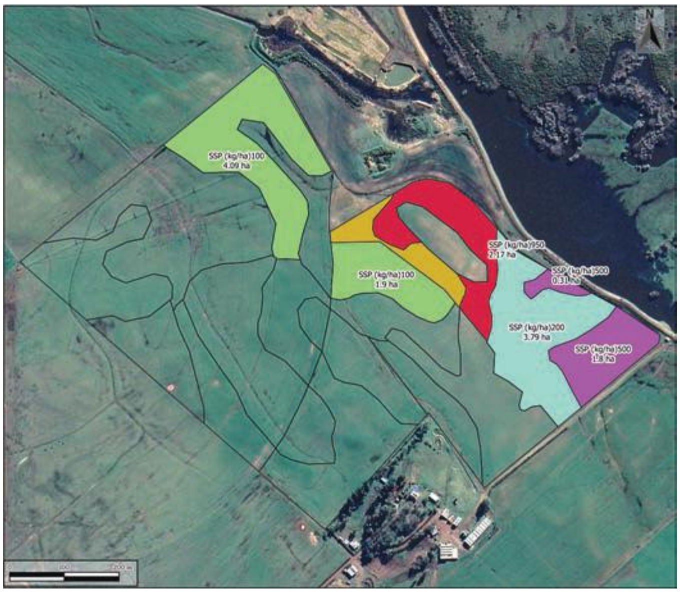
Ben has soil tests done on different paddocks every year and has identified other areas with variable soils. "I'd like to implement this soil type zoning on the rest of the farm in stages, but I'm conscious that I only want to collect information that I can use and put into action, especially when we've got a lot of other development going on at the farm," Ben said. "It was the logical choice to work with the most difficult paddock first."

On their previous property in New Zealand, they did grid soil testing, but did not have the management systems in place to utilise the data generated. In terms of other precision agriculture used on the farm, Ben said RTK grade autosteer and auto shut-off minimised overlap and allowed them to spray in the dark.

Ben said they were "dabbling" with control-traffic farming but compared with broadacre cropping, the equipment Ben and his team used was smaller and caused less compaction.

"With our seed canola, which has male and female rows, we use a strip tillage method there. Tramlines are not cultivated or planted, the equipment doesn't sink and this method leads nicely into a no-till establishment of the next crop. It works well."

Figure 6.21: Variable-rate phosphorus map for a Tait farm paddock. This shows old paddock boundaries with other zones that include soil type and flood-eroded areas. Fertility was quite good but there were significant shortfalls in some zones.



Source: Ben Tait

Figure 6.22: Variable-rate lime map for a Tait farm paddock. It shows old paddock boundaries with other zones that include soil type and flood-eroded areas.

Source: Ben Tait

Variable rate helps WA grower get the best out of range of soils

SNAPSHOT

Name: Darren and Vanessa Cobley

Location: Walkaway, 50km south-east of Geraldon, WA

Farm size: 6800ha

Rainfall: 300mm (average annual)

Soil types: heavy clays on the hills, to loam, yellow sand and then less productive white beach sand

Enterprises: dryland cropping, sheep, cattle

Crop program: canola, wheat, barley and lupins

The article in this section was originally published in *Precision Ag News*, Autumn 2023, vol 19, issue 3. Updated in late 2023 by Alisa Bryce.

The Cobley family's 'Doogalook' farm runs alongside Greenough River at Walkaway, about 50km south-east of Geraldton in Western Australia. Across 6800ha, Darren Cobley and his team (usually three full-time staff) run a mixed enterprise that includes dryland cropping, 4000 sheep and 400 cattle.

About 70 per cent of the farm is sown to canola, wheat, barley and lupins. They use controlled traffic, minimum till and precision agriculture practices in the cropping program. The southern boundary is about 10km of river frontage that is quite hilly. "My farm ranges from very undulating country to flat country and anything in between," Darren said.

Extensive soil variations

Variable-rate applications have helped Darren manage soil types that range from sands to heavy clays. He aims to optimise yields on the different soil types using these practices.

The soil varies as much as the topography – from heavy clays on the hills, to loam, yellow sand and then less productive white beach sand on the flatter areas. The sandy nature of much of the soils make it prone to leaching, Darren said. To help get the most out of these soils, Darren works with Craig Topham from Agrarian Management to develop precision agriculture programs.

"I've always dealt with different soil types," he said. "Before I started with precision agriculture, I managed it by having areas of the farm fenced for livestock and areas fenced for crops. And that's purely just topography and soil type so anything that's poor sands or too hilly is fenced out and is in permanent pasture.

"Despite that, I still have a lot of soil variation within one paddock. I've always thought each soil type needs different inputs, so I was keen on the idea of variable rate for a long time."

Darren started introducing precision agriculture to his farm more than 15 years ago to tackle soil variation and optimise yields. Following Craig Topham's advice, the farm was EM38 mapped. Darren said this helped them understand the different amounts of clay in the soils.

"Where we farm, clay is king. The more clay in the soil the better water-holding capacity it has. But yield doesn't necessarily correlate to soil type, so while we started with EM38, we then used yield data, biomass imagery and soil sampling to get a better understanding."

Different soil types on one run line in one paddock at Doogalook – 'gutless' sand (left), yellow sand (middle) and red sand (right). The red sand shows some protein variation in some years, but protein varies little on the white and yellow sands.

Photo: Darren Cobley

Darren said biomass imagery had helped him refine the categories of soil he had to manage. “I had split my soil types into three: high, medium and low yielding, but since using biomass imagery I’ve added another subgroup that reflects their consistency. So now I think about it as six groups: high yielding consistent, high yielding inconsistent, medium yielding consistent, medium yielding inconsistent, low yielding consistent, low yielding inconsistent.”

This helps Darren to plan late-season fertiliser applications. “For example, when I do biomass imagery of a paddock, sometimes the highest biomass can be in my inconsistent areas. I know from previous years’ data that if we don’t get good finishing rain, those will be the lower-yielding areas of the paddock.

“That understanding helps me make the decision, usually at the end of July, whether I apply more nitrogen for an above-average crop or, if rainfall has tapered off, I just shut the gate.”

Refining fertiliser regime

Darren aims to optimise yields on different soil types with variable rates of fertiliser. “In terms of my approach, I am basically going for yield. I don’t think you necessarily save fertiliser, instead you’re putting it where it can be used. You fertilise for what you think that particular soil type will give you. For example, within one run line of one paddock, I’ll go from it needing no potassium to [a rate of] 40kg/ha.”

At Doogalook, the team applies fertiliser at seeding and in-crop. “We drill as much as we can without causing toxicity with the seed. And then we’ll top it up, post emergent,” Darren said.

In the past three years, Darren has applied more potassium than previously. He said many growers underrated potassium. “Potassium is very important, but it’s the fertiliser that you hardly ever see an immediate response in the plants. On the other hand, when you apply nitrogen, plants respond quickly – they look greener. But you see the results of applying potassium at harvest when yields increase.”

Darren said that the popular wisdom among growers was that phosphorus and nitrogen were the most important, followed by potassium. “But now potassium is as important as the other two macros. I think you get better utilisation of phosphorus and nitrogen with higher rates of potassium, so it’s a win on three fronts.”

Protein monitoring – hit and miss

Darren spent a few years collecting protein data but found the information was not overly useful. “The protein monitor gave me more data, but not more information,” he said. “There were only small sections, about 5 to 10 per cent of the paddock, that had much variation in protein levels. The most interesting results were on the heavier soils, but on the sands the yield monitor picked up the same variation as the protein monitor.” Darren said N-rich strips in the paddock gave better data.

Using variable-rate fertiliser to work with soil variability

The article in this section was originally published as 'Increasing yields with variable-rate technology', *Precision Ag News*, Spring 2022, vol 19, issue 1. Updated in late 2023 by Alisa Bryce.

SNAPSHOT

Name: Ben and Ange Cripps

Business name: Wepowie Ag

Location: Ogilvie, Western Australia

Farm size: 5500ha

Rainfall: 300mm average annual

Soil types: 60 per cent sand plain, 25 per cent red ground, 15 per cent sandy gravels

Enterprises: broadacre cropping – wheat, canola, lupins

Ben Cripps and son. Photo: Ben Cripps

A machinery fire was the catalyst for the Cripps family to start doing precision agriculture on their farm in Western Australia. After the fire, in 2011, they bought a new header to replace the one that was burnt out. The new header was capable of yield mapping and digital record-keeping. More than a decade later, they continue to refine their approach and reap the benefits.

Ben Cripps runs Wepowie Ag in Ogilvie, Western Australia, with support from his wife Ange and their three children Isla, Harry and Max. The farming operation is about 90km north of Geraldton, in the mid-western region of WA, where average rainfall is 300mm.

The soil varies greatly – about 60 per cent sandplain, 25 per cent red ground and 15 per cent sandy gravels. "It is extremely variable where we are," Ben said. "We have everything from flat open sandplain paddocks through to rocky, sandy gravel and shallow red loams."

The farm produces wheat, canola and lupins on 5500ha over five blocks, all of which are within 30km of each other. Wepowie Ag employs two people full-time and Ben said he could not do it without them.

Understanding soil variation

The Cripps wanted to understand how soil variation was driving yield variation so they could target their soil amelioration. The first step was to map the soils using the combination of EM38 and gamma scanning, which had been proven to work in other areas. Ben said originally they were trying to quantify the area to which they needed to apply potash.

"Scanning was really the only option we had, because we had no spatial data at that time," Ben said. Initially, they had 2300ha of the farm scanned. At the time, this represented 80 per cent of the farm, which was owned by Ben's parents Terry and Ros Cripps. They backed Ben on his decision to adopt precision agriculture and variable-rate technologies.

Chris Pinkney of Agrarian Management, who had worked with the Cripps since the early 2000s, helped the Cripps to interpret the data from the scanning program. "Chris is involved in almost every aspect of the agronomic program within our business," Ben said. "On precision ag, we develop the program together. Chris helps me with the ideas and the concepts about the operations, including about the different zones. Then I do the computer work."

Ben said that over a couple of years they refined the PA program with yield and elevation maps and their own knowledge to create the zones. "And then we extrapolated the knowledge that we got from that scanning across the rest of the farm, including as the farm has gotten bigger."

Ben has since added more data sources to further refine the PA approach. "We've used a bit of biomass imagery, even fuel consumption. We overlay all these different layers of data to help us pick different areas. A map may not be used in the final variable-rate map, but we'll overlay it to confirm what we're seeing."

The resulting maps have helped Ben and his team to understand the different soil types. "These are basically water-holding capacity maps of your paddock. You can use these maps any way you want. We use them for seed rate, fertiliser rates, herbicide rates and soil amelioration."

Applications to address soil variation

Ben said they used a lot of variable-rate applications on the farm. But in some cases, when Ben and the team judge it will be worthwhile, they do blanket rates of inputs across paddocks. Most years, the team does variable-rate applications (VRA) of nitrogen, phosphorus, potassium and lime. VRA helps the business respond to the season and get as much from the different zones as the rainfall and other factors permit.

“Variable rate can be used in either a defensive or an offensive role, that’s how I think of it,” Ben said. “What I mean by that is when you get a good year, like 2021, you can use your variable-rate to make more money. For example, I know that a certain area is not going to perform no matter what I do, so I don’t put any more fertiliser there. By then, on the productive parts of the paddock, the final application rate can be as high as 70L/ha of UAN.

“In a year like 2021, we had a 20-unit range in nitrogen application from the lowest to highest-yielding areas within some paddocks. Conversely, in a bad year, like 2019, you start winding back but you still keep in mind those safe areas. So, you leave the fertiliser rate a little bit higher. But then the rest of the paddock you’ll drop off.”

With 2022’s exceptionally high input costs, Ben said variable rate helped him to manage risks. Within any paddock there are high-performing areas and low-performing areas. Given the high prices of fertiliser since 2021, Ben has identified areas within some paddocks that continually perform better than the theoretical maximum water use efficiency. These areas receive higher fertiliser rates while other lower-performing areas receive little or no extra fertiliser because they are not going to give the return on investment.

Adding rain to the equation

Ben monitors the season as it progresses. There are eight rain gauges across the property, with records going back at least five years for most of them and records from 1998 at the main homestead. On one block there are records that go back to 1912.

Ben has digitised these records. He combines this rain data and the yield maps to create water use efficiency (WUE) maps for all crops. Figure 6.23 is an example WUE map. He picks three years with similar rainfall and uses those maps to create an average of those three years to make it somewhat similar to the current year.

“When we’re doing our last nitrogen application, I use the water use efficiency maps to create our last nitrogen application maps.” An example nitrogen map based on a WUE map is shown in Figure 6.24.

Ben said that before the last nitrogen application, he looked at the rain data and calculated total rainfall received and how much could be expected for the rest of the season, based on the averages of those maps. He then estimated the potential yield, and how much nitrogen was needed to achieve that. At present, they average 13.4kg/mm of wheat on growing-season rainfall (GSR).

He also uses the WUE maps to identify the areas that are performing above and below their average. This information is used, along with area-specific rainfall information, to help the team make management decisions.

“It doesn’t work out perfectly,” Ben said. “But I know where our nitrogen levels are for all the zones. You can overlay the two maps [the nitrogen application map and the WUE map] and say based on the water use efficiency map, I can estimate that I need to put another, for example, 40 units of nitrogen on this zone, another five on there, 20 across the rest.

“It’s never going to be exact because we can only deal with and make decisions based on the information at the time. Then we have to accept that Mother Nature will do what she wants.”

Importance of being flexible

In 2022, Ben and his team applied a blanket rate of lime across the cropping country to establish a good foundation. “This summer, we didn’t actually variable-rate lime, we just went blanket rate 3t/ha and went hard. Going forward, when we start going back over those paddocks with soil testing, we will do variable-rate lime again to do it more efficiently. But we’d reached a point where we thought we needed a blanket rate.”

Generally, the team follows a minimum-till approach, but they do cultivate when it is needed. Ahead of the 2022 season’s planting they used a deep ripper with inclusion plates behind it to help get the lime down. They also used a spader.

“Our deep ripper rips to 400mm, our spader to 600mm. And then I’ve also got a speed tiller coming, which will till to about 125mm in heavy country, so we get our lime through that top 12 to 15cm.

Figure 6.23: Water use efficiency map created by Ben Cripps from his locally recorded data.

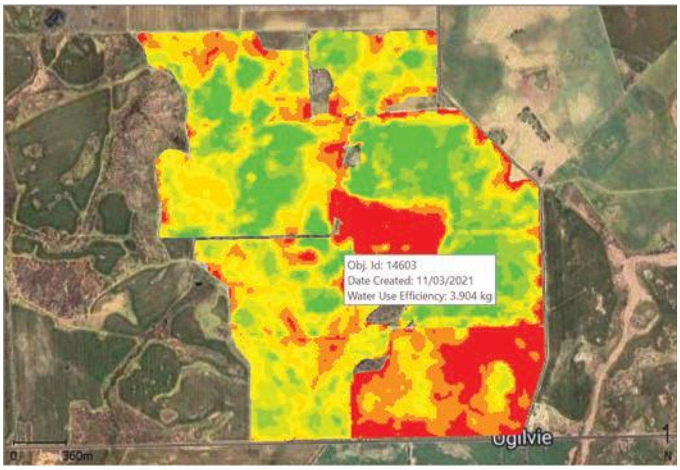
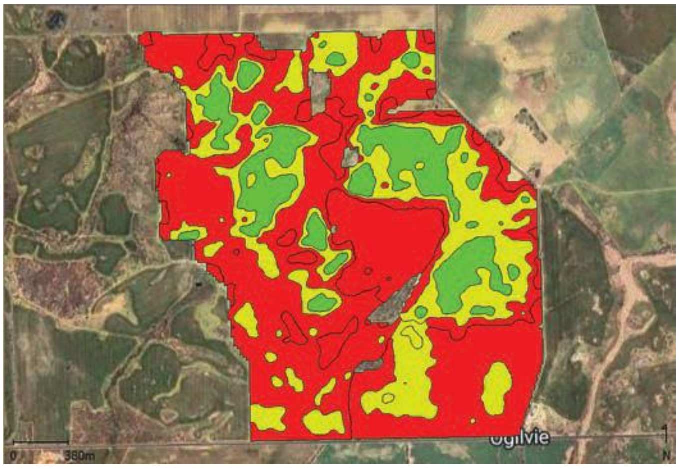


Figure 6.24: Flexi-N prescription map based on the WUE map created by Ben Cripps.



Harvesting on Ben's farm. Photo: Ben Cripps.

"Spading is hopefully a one in 20-year program. Our yellow sand needs deep ripping about every four years because it sets very hard. This yellow sand is very similar to what is used under house pads in WA, and it naturally compacts overtime. Even with controlled-traffic farming we still need to rip. And while we have a bit of a cultivation program going through at the moment, we generally use a minimum-till process. We use tillage in a strategic sense."

Precision agriculture is used alongside control-traffic farming (CTF) to improve the operation's bottom line. All equipment runs on a 13.6m (45 feet) CTF system. Ben uses the rule of thumb that CTF is supposed to save about 30 per cent in fuel, which he said was significant in a year where fuel was nearly $2/L.

VRT success

Despite the high fertiliser prices, 2021 was one of the Cripps' most profitable and high yielding years. Ben said: "What people miss with VRT is that you can go in with a defensive strategy because of high prices but then have to go on the offense and turn it around into a money-making system. This can be hard if you have been conservative all year."

Test strips to validate the results of the VR nitrogen will be put down in 2024 with VRT prescription maps via a trial module within SMS Agleader. "Also, given our current nutrition status and our WUE data, we know we have enough nutrition for what is achievable with an average year from here on in," Ben said.

To assess the effectiveness of PA on the farm, Ben also reflected on their initial goal. "When we started, we were mainly trying to variable-rate potash. We've nailed that. We run potash in a separate bin in our airseeder, we turn it on where it needs to be and turn it off where it doesn't. And equally we're able to vary the rate – we use any rate between zero and 35kg/ha. We put it 2cm from the seed, because you've got to be careful of K toxicity if you get a drying profile." (Too much potassium (K) can impact the way the soil absorbs other critical nutrients.)

Ben said that was a great example of achieving what they set out to do. "We've achieved way more than what we expected with precision agriculture," he said.

He said using the protein meter had also been beneficial. "By having a protein meter in the header we are able to measure where our protein has come from and then verify whether enough nitrogen was applied during the growing season. This in turn can help us improve our decision-making process in future years." The protein meter also helped them optimise grain marketing at harvest, because they used the results to load the trucks to target a better load grade, therefore payment grade, prior to delivery.

Advice to growers considering PA

Ben said software had improved and there was more support available now than when he started with precision agriculture.

Having to work out more things for himself meant Ben developed a good understanding of the SMS Ag Leader software, which gave him the flexibility to try out new things.

For people starting now, he suggested keeping it simple at the start and being flexible. He said he had found it helpful to use the same brand of machinery with consistent monitors.

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One grower, two farms – variable-rate success and challenge

The article in this section was originally published as 'Comparison of variable-rate technologies on Fels family's farms' in *Precision Ag News*, vol 19, issue 2. Updated in late 2023 by Alisa Bryce.

SNAPSHOT

Name: Marnie and Mic Fels

Location: Wittenoom Hills, 50km north of Esperance, WA

Farm size: 6000ha

Rainfall: 450mm average annual

Soil types: transitional mallee, varies from heavy clay loams through to various duplexes, deep sands, gravels

Enterprises: dryland cropping

Crop program: wheat, barley, canola, lupins

Mic and Marnie Fels take an analytical approach to farming, going to great lengths to prove farm management theories before using them across their Western Australian cropping operation.

Their approach to variable-rate technology followed this pattern. They collected data and conducted their own on-farm trials to test whether variable rate (VR) would improve their bottom line. VR proved successful at one property they owned, helping Mic and Marnie transform a sheep property at Three Springs, north of Perth, WA, into a productive continuous cropping operation.

However, they have not been able to apply similar treatment to their main farm near Esperance despite years of scanning, soil testing and trials. The family has since sold the Three Springs farm where VR was so successful, but they learned many valuable lessons through the process.

With agronomist Luke Marquis, Mic Fels and his team deep soil cored and tested representative sites chosen from key zones found on the EM38 maps. Photo: Mic Fels

VRT success at Three Springs

VRT was a ‘no brainer’ at Three Springs. The family bought the 4300ha property in 2014 as part of a plan to diversify. But even with a good manager, the farm being 1000km away from their home base near Esperance was not sustainable.

Over five years, the team improved the land and increased its value by opening it out for broadacre cropping, variable-rate zoning and intensive soil amelioration. “Any way you measured the soils, they were distinctly different, which made it incredibly easy to zone,” Mic said. “Biomass and yield maps even matched up perfectly to what we could see on Google Earth, with the different colours of the soils.”

They used this data to strategically soil test and create four key zones. They set up some simple paddock-scale VR fertiliser trials, applying different combined rates of N, P and K on some paddocks with full-length seeder trial strips. They measured the results with the yield monitor on the harvester.

Mic extracted the data from the yield maps and put it into an Excel spreadsheet to work out the profitability of different fertiliser rates of each nutrient for the four soil zones. “That’s how I devised the fertiliser regime for the next five years on the farm. The data side of it sounds complicated, but it actually wasn’t. It probably took me a couple of days to do it all, and it gave us a validated $45/ha profit gain every year after that.”

Based on trial and test results, Mic broke the farm into four production zones, with zone 1 being the least productive sandy soil through to zone 4 that was the high-performance gravelly soils. “We saw an immediate benefit to variable rate,” Mic said. “So we did that for almost all inputs, even our pre-emergent chemicals.”

On the poorest areas with weak, sandy soils, they were actually able to increase yields by 200kg/ha by lowering fertiliser rates. “Because they don’t have the buffering capacity, too much fertiliser can cause toxicity. So putting less on those areas improved the yield performance while saving a lot of money,” Mic said.

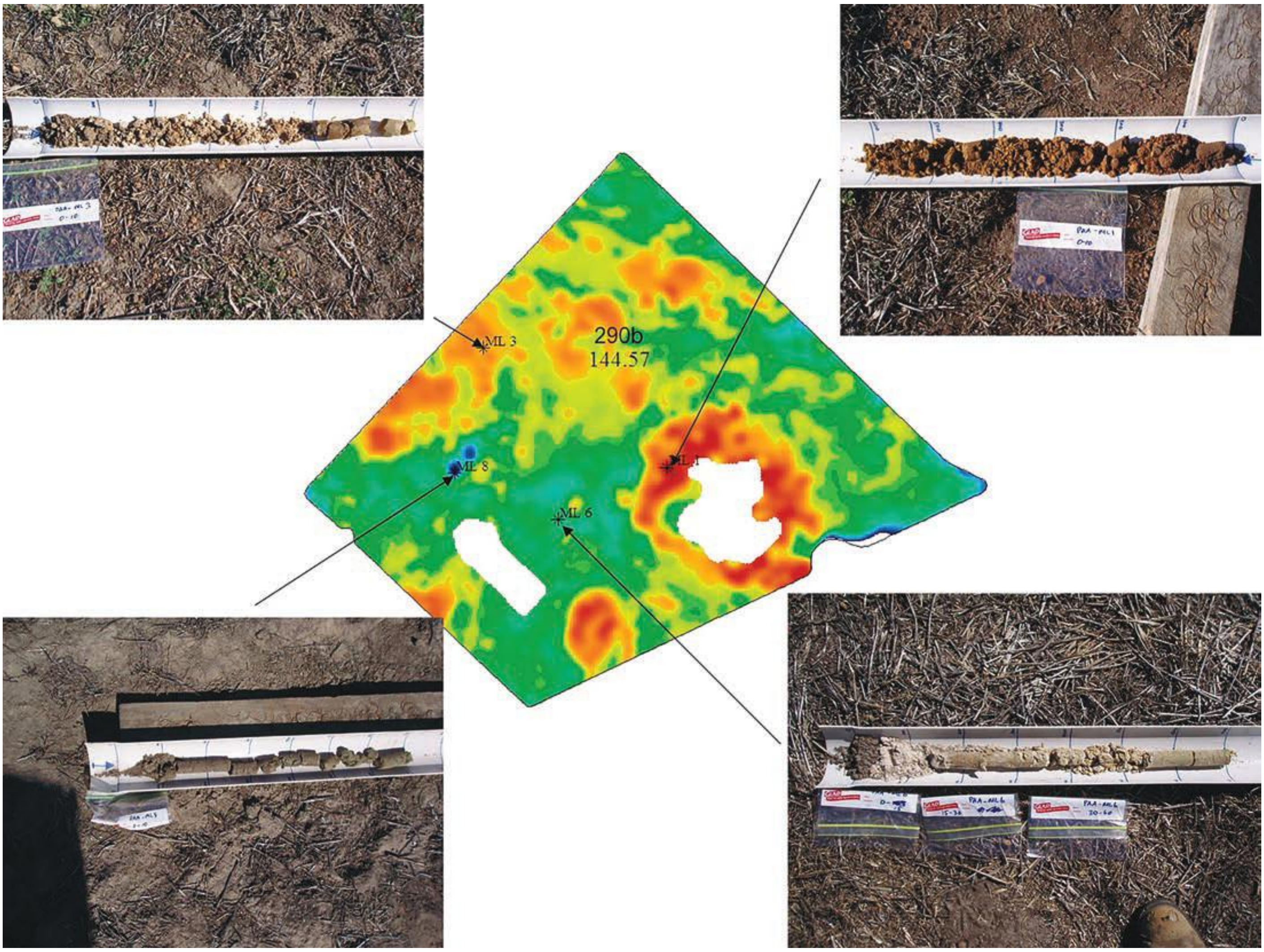
The money they saved was used to increase spend on fertiliser for their best soils, which drove productivity by up to 500kg/ha. “It was a win all the way around, and that’s how variable-rate is supposed to work,” Mic said. “I’d love to get that happening in Esperance [Wittenoom Hills], but I just haven’t hit that ‘Eureka’ moment with how to zone our farms up to achieve it.”

VRT a challenge at Wittenoom Hills

The Fels’ 6000ha farm at Wittenoom Hills, 50km north of Esperance, is used to grow wheat, barley, canola and lupins. The Fels focus on improving drainage, managing weeds and building soil carbon to improve productivity. They have been yield mapping since 1998 to monitor the benefits of these and other activities as well as to plan future activities.

Data collected from EM38 maps and soil testing helped the Fels develop variable-rate application maps for gypsum. Photo: Mic Fels

Figure 6.25: An EM38 map of a paddock at Wittenoom Hills, WA, with four corresponding soil core photos.



Source: Mic Fels

For drainage, they have RTK elevation maps from the seeder (with an accuracy of 2cm), from which Mic develops maps that direct how they improve drainage.

For managing weeds, particularly rye grass, they follow the WeedSmart Big 6, which involves rotating crops, double knocking to preserve glyphosate, mixing and rotating herbicides, stopping weed seed-set, increasing crop competition, and implementing harvest weed seed control.

One of the ways they increase crop competition is narrow row spaces (7.5 inches [19cm] compared with 10 or 12 inches [25.4 to 30.5cm] more common in the region) boosted by high seeding rates. They do this with the iPaddock Alpha Disc, invented and commercialised by Mic. The Alpha Disc is a narrow row disc seeder that can operate very effectively in stubble. Like all heavy machinery, the 24m seeder is run on a 12m-based control-traffic system. The disc seeder is part of their no-till approach. This is also helping to build soil carbon for improved soil quality, which has been supported by a trial that WA company Carbon Ag is running on the farm.

One aspect of precision agriculture that Mic has explored extensively, but not been able to implement effectively on his farm, is VRT. Mic said that soils varied in transitional mallee country, although not as distinctly as at their Three Springs farm. The northern end of the Wittenoom Hills farm has heavy clay loams, then traverses through different duplexes (gravel on top of clay, then sand over clay). Towards the southern end, closest to the coast, it has deep sand, sand clay, deep gravel and a gravel duplex.

“It’s a real mixed bag, so you would think it’d be obvious how to do variable rate, but it hasn’t been,” Mic said. But it is not through lack of trying. In 2007 and 2008, the Fels had EM38 surveys conducted across the farm. Based on the electrical conductivity (EC) results, they identified 40 sites across the farm to do deep core soil tests in 2008.

Mic used results from the EM38 scanning and soil tests to develop a variable-rate prescription map to apply gypsum across the farm. Figure 6.25 shows an EM38 map and corresponding soil core photos. The very high EM tended to be sodic, wet, saline areas.

“With our agronomist Luke Marquis, we deep soil cored and tested 40 representative sites chosen from key zones found on the EM maps. Luke then created a spreadsheet to correlate the EM data with soil sodicity and pH,’ Mic said.

“Then we were able to set the rates based on the EM maps. Our main use was for gypsum, as we had solid correlations between the EM data and the sodicity and used from 0 to 4t/ha [of gypsum] based on the maps. We also put down several trial strips for monitoring, with 0 and 6t/ha rates.

“Interestingly, we still don’t see any differences on those strips, which we still monitor, which confirms for me that our full residue disc farming system is effectively improving the soil structure on its own.”

Mic said the results from the EM38 scanning correlated to salinity – generally where they had very high EM, it tended to be their sodic, wet, saline areas. However, the EM38 results alone did not differentiate salinity from high sodicity or even from just wet soils.

Mic and his team also used the EM maps to apply lime, but it was a slightly more complicated activity. "With gypsum we literally zoned from the EM maps and used them directly for the VRT gypsum, because the sodicity correlation was very solid. With the lime though, there was more of a manual process of interpreting the maps on top of our own knowledge of the soils across the farm, and then creating simple two-rate maps," Mic said.

This knowledge of soils across the farm includes Mic's insight that their heavier clay soils have increasing pH at depth, whereas their sandy and gravel soils tend to decrease at depth, so have been their first priority for lime.

Following the EM38 survey, Mic did VR fertiliser trials on the farm for seven years. "We picked a paddock with a long run that incorporated a range of different soil types. We used the EM maps, gamma radiation maps, biomass and yield maps as the key layers to try to zone those soils up.

"We applied different combinations of high and low N and P on different strips of the paddock, and repeated the same treatment annually for seven years straight. We used the yield monitor to capture results. We hoped it would show which was the best treatment on which soil type. But what we found is, even though the yield performance of each zone was different, the response to nutrients was much the same. So whether it was bad gravel or a good clay didn't seem to matter. They both needed similar amounts of nitrogen and phosphorus, but applying marginally more of either led to yield results that were offset by the cost of the fertiliser. So the conclusion I drew out of all that work was the best thing I can do is a blanket treatment."

Mic admitted it was frustrating for him, especially because he saw the benefits of VR on the Three Springs property.

Diving deeper on the benefits at Wittenoom Hills

Mic said the work they had done over the years to continually improve soil health was definitely making their soils more resilient. "For example, it's been a dry year here [in 2022] and water is likely to be our major restraint, but you wouldn't know it, looking at the plants. And that's a mark of a resilient system."

At seeding this year, they modified a Veris® Technology iScan to run on their seeder to map organic carbon, soil moisture, soil temperature and EC. "It worked really well; we still need to work out the optimal process but the data that's coming through is really interesting, particularly the soil carbon," Mic said.

In the future, Mic hopes to measure soil pH with the iScan unit and redo the deep core soil tests on the same sites as in 2008. "Right down to 60cm, I want to see what changes have occurred in our soils over the last 15 years. We've been using discs for the last 11 years and before that we were doing no-till with tynes. I'm convinced the increased biomass from using our discs with narrow spacings is basically really building organic matter. And it's going to be really interesting going back to those sites and just seeing what has changed."

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Chapter 7: Sowing

Precision sowing with autosteer RTK 2cm guidance. Photo: Nathan Simpson

Introduction

For many Australian grain growers, adopting GPS guidance and autosteer have led to more efficient farming by minimising seeding overlap and – perhaps more importantly – underlap. Guided-row sowing optimises crop establishment and yield by allowing growers to plant exactly where they want to, whether on last year's row, within a few centimetres of it, or between rows. The section in this chapter headed 'Tracking straight to success with precision seeding' offers some tips for choosing between on-row and inter-row sowing, the technology required for precise seeding and machinery set-up.

Many growers are now also using variable-rate seeding to increase or decrease seeding rates in different paddock zones. Soil type, constraints (for example, salinity) and productivity potential can drive different seeding rates. The section headed 'Variable-rate seeding' (page 118) presents three grower experiences using variable-rate seeding in different soil types.

Tracking straight to success with precision seeding

Katherine Hollaway, Astute Ag

Guided-row sowing enables growers to precisely plant into the preferred seeding position regardless of terrain, year after year, optimising crop establishment and yield. Getting the system set up correctly is essential to ensure accurate placement relative to the existing stubble rows.

The right equipment relies on a 2cm-accuracy autosteer and increasingly implement guidance systems to ensure a consistent and repeatable sowing position along the length of the paddock. Commercially available guidance technologies have many varying capabilities, but ensuring the stability of implement tracking is a key starting point.

Making the choice between on-row, near-row and inter-row sowing

The choice between on-row (or near-row) and inter-row seeding depends on the situation. Factors that will influence this decision are summarised in Table 7.1. Near-row can be a good alternative to on-row seeding where trash management is a concern.

For most farming systems, inter-row sowing will be the preferred option to improve stubble flow and the speed of the sowing operation. Provided there is adequate soil moisture, inter-row sowing promotes good seed-to-soil contact and better crop establishment.

Inter-row sowing supports the benefits of stubble retention such as protecting soil moisture and seedlings while providing a trellis to improve harvestability of pulse crops. It reduces the risk of soil-borne cereal diseases such as crown rot, take-all, common root rot and Rhizoctonia, and pests such as root lesion nematode. Soil-applied herbicides are more efficacious when applied to the bare soil between the rows than when intercepted by retained stubble.

One disadvantage of inter-row sowing is that increased soil disturbance can promote the germination of weeds when seeds left on the soil surface are incorporated into the soil.

On-row or near-row sowing provides better access to moisture in non-wetting soils and low-fertility sands, particularly for canola. Advantages include a longer sowing window and better crop establishment. Crops can easily access old root channels where water infiltrates more easily into these preferred pathways than into the surrounding repellent soil. This advantage is not applicable in seasons or soils with good soil moisture.

Wetter furrows also mean better access to residual fertiliser and greater microbial activity. They can help reduce water repellence by making conditions friendlier for wax-degrading bacteria. On-row or near-row sowing also improves grass weed competition but can increase the risk of soil-borne diseases.

On-row sowing works better when stubble loads are short, brittle and light. Longer, stronger and heavy stubble loads can cause hair-pinning and seed tube blockages, which lead to poor seed placement and establishment.

When stubble loads are too high, near-row or edge-row sowing – sowing within a few centimetres of last year's row – provides the benefits of on-row sowing while overcoming the problems caused by stubble.

Understanding precision tracking and drift

Regardless of the tractor and GPS equipment used, getting the implement to follow directly behind the tractor is often the greatest challenge. Successful guided-row sowing requires the bar to travel straight to ensure that the distance between rows is consistent across the width of the bar.

Accurate tractor guidance increasingly uses sophisticated terrain compensation software to steer the tractor hitch along the guidance path precisely. However, accurate autosteering of the tractor alone may not always be sufficient. Towed seeders are subject to multiple forces and do not always track straight or even consistently crooked.

Drift can be random in response to changing soil conditions or working depths. Random drift is a significant issue when trying to sow accurately.

Systematic drift occurs when the implement is set incorrectly or its weight causes the implement to crab downhill while working along a slope. It may sometimes be managed by following the same seeding pathway every year.

Implement drift is measured by the extent of the skew angle in relation to the travel direction. While at work, forces from the implement's wheels and the furrow openers create restoring forces that stabilise the bar and limit drift within a maximum skew angle.

With large multi-rank bars even a small skew angle, such as on a side slope, quickly becomes incompatible with guided-row sowing because it creates variable row spacings.

A small skew angle with very compact bars (one or two ranks) is generally acceptable and guided-row sowing can be achieved by consistently following the same seeding pathway, season after season.

Minimising drift by optimising equipment

A symmetrical tyne layout is essential to ensure equal loading left and right to balance the machine. This includes symmetrical layouts of both openers and wheels and a uniform distribution of the seeder bar weight, including over the wing sections. For example, the lead tyne on the right-hand side should be in the same position as the lead one on the left-hand side, and so on.

Table 7.1: Suitable conditions for inter-row and on-row seeding.

	Inter-row	On-row
Sowing conditions	Ideal sowing conditions with good soil moisture	Dry sowing or drier sowing conditions
Soil type	Soil types other than water repellent	Water-repellent soils
Weeds	Low grass weed numbers	High grass weed numbers
Diseases	High stubble-borne disease inoculum levels	Low stubble-borne disease inoculum levels
Nutrition	High soil fertility	Poor soil fertility, nutrition or drought in previous season
Stubble management	High stubble loads with poor trash flow (may be an issue in >2.5t/ha yields depending on grazing levels and sowing system)	Lighter standing stubbles (0.5 to 2.5t/ha yields depending on grazing levels and sowing system at higher yields)

Source: EPARF

TIPS FOR INTER-ROW SOWING

In practice, inter-row sowing is easier to achieve than on-row or near-row sowing because of the larger margin for error. Wider rows are better, with 300 to 380mm being a common choice. Wider row spacing can increase trash flow and reduce the risk of seeder blockages. However, wider rows can result in a yield penalty. Row spacing is important to maximise grain yield but will often be driven by the effectiveness of stubble management systems.

With tyne seeders, inter-row sowing can enable direct-drilling into high stubble loads while reducing or eliminating residue clumping and interference over the seed rows.

With disc seeders, inter-row sowing reduces the potential for hair-pinning (where the stubble is bent and pushed into the row) ensuring good seed-to-soil contact, particularly when combined with residue managers.

A common source of implement drift with inter-row sowing is the tendency for the openers to return to last year's row, especially in harder soils. Force imbalances push the openers away from the harder inter-row zone into the weaker furrow side. This problem is more significant with lighter-weight seeders. Stability can be improved with a higher load on the seeder wheels and the use of steering hitches to guide the implement.

TIPS FOR ON-ROW OR NEAR-ROW SOWING

On and near-row sowing are suitable for narrow-row spacing (180 to 200mm) provided accurate guidance and stable tracking are achieved.

There is an increased risk of poor stubble flow and sowing blockages. Another risk is poor seed placement leading to reduced seed–soil contact and lower plant establishment, particularly for small-seeded crops such as canola.

On-row sowing works well where stubble is short, brittle and not too dense. However, near-row sowing is preferred in high stubble loads and stronger stubbles to retain stubble integrity with tyne seeders and to minimise hair-pinning with disc seeders.

With near-row sowing, sow on the foundation row every second year and then nudge to the left or right in alternate years. Canola establishment is usually improved by sowing on the north or west side of cereal stubble to provide better access to the warmth of the sun and improve rainwater harvesting.

Closer is generally better, but nudge distance will depend on the stubble condition and length. Longer stubble needs a wider offset. A 20mm nudge can be achieved with about 150mm stubble and 40mm with about 200mm stubble without disturbing the bulk of the stubble.

In contrast, after a low production season, nutrients are more likely to be available in the old crop row.

GROWER EXPERIENCE
SCOTT AND ZOE STARKEY

Soil texture, the season and ultimately stubble loads dictate whether Zoe and Scott Starkey use edge-row or inter-row sowing. On their more productive soils – red loams – they aim for inter-row sowing to retain standing stubble and limit trash flow issues for the seeder.

"The heavy soils hold on to the moisture and nutrients," Zoe said. "Once those soils are wet they are very productive, but it takes a lot of rain for that to happen."

Low rainfall over the past few seasons has led to lower residue levels, and the Starkeys have moved to edge-row sowing to give the crop access to early moisture. The furrow from the previous year tends to hold more moisture and has more organic matter. It is also an opportunity to access residual nitrogen.

"We haven't had great years, so we probably haven't used all the nitrogen that we've put down. If there's anything left over, we want to access it," Zoe said.

On their stony soils, they have not seen much benefit from inter-row sowing. Here, edge-row sowing is the aim to maintain stubble cover. With edge-row sowing, they nudge a few centimetres either side of the previous crop row.

In some areas there are non-wetting patches in the inter-row. Edge-row sowing again gives the crop access to more moisture and organic matter. Zoe noted that these patches were growing due to the below-average to average seasons over the past six years.

The Starkeys use a Morris C2 Contour with a Morris 9365 Air Cart towed by a Case Steiger 450. A Topcon receiver with the base station improves sowing accuracy.

ROY HAMILTON

The Hamiltons sow inter-row with a tyned seeder for ease of trash flow. "Sometimes it works, sometimes it doesn't," Roy Hamilton said. "It depends on what condition the stubble is in. If the stubble has fallen over it doesn't work as well. If the stubble is standing up and I'm sowing into dry topsoil it works well."

Before moving to controlled-traffic farming, the Hamiltons would cross-seed at 15 degrees to get through the stubble. Roy has autosteer with 2cm RTK and implement steering on the seeder bar.

The same crop row is sown every two years; crop rows are on a 250mm spacing. Each year the row moves 125mm (sowing in between the current year's row), then back again. Roy said: "Inter-row sowing can work really well or it can become a hay rake. There is a coulter in front of each tyne – in good condition – which makes a big difference to how much stubble the seeder can handle."

Even then, moisture on the stubble can be a challenge. Roy has noticed that a shower overnight or dew on the stubble after the sun has gone down can make a big difference in how much the coulter will cut.

Two different varieties of lentils sown at Barunga Grains, SA. Photo: James Venning

Wheels and tyres are also important factors for tracking straight. Tandem wheels are preferred as they are designed to run straight and offer good lateral stability. However, if tandem axles are bent then this will tend to make the system track poorly. Castor (free steering) wheels offer no lateral stability and are not recommended.

Where the wheels are positioned relative to the tynes can improve or worsen tracking. For example, working depths will be affected if wheels ride into the furrow or over soil-throw ridges during skewing. Wide tyres placed on a walking beam are typically the least vulnerable. A longer A-frame gives an advantage by stabilising drift at smaller skew angles.

Longer draw bars give more leverage and better tracking. A common rule of thumb is that the draw-bar length should be half the implement width to give sufficient restoring power to rigid frame wheels. For example, a 12m implement would ideally have a 6m pull.

Implement width influences depth control and contour-following capability. The wider the implement, the worse the tracking, and 12m is the recommended maximum width.

Depth control across the implement is critical, particularly on wider, less-stable bars and undulating land. It is best achieved by using openers with independent depth control, allowing them to follow ground contours.

A poorly set-up bar or inadequate flotation in soft soils can create a constant force imbalance that causes systematic drift to the left or right. You can check the extent of systematic drift by sowing up and back on flat land and checking for alternate closed and open spaces between adjacent passes.

The extent of skewing movements can be assessed during seeding by using a pointer and dial kit – a pointer fitted to the tractor over a dial fitted to the implement. Rigid wheels, either singles or as a walking beam on the bar, act as rudders and provide restoring forces. This can be improved by a greater loading weight, a larger wheel skid angle, and a greater distance behind the tractor's towing point. Larger skid angles can be obtained by positively steering frame wheels to keep the bar on its intended path, either manually or automated with sensor or GPS input (see 'Guidance systems' below).

To maximise the stability of a tyne seeder bar, avoid steep narrow openers because they absorb some of the bar weight by generating an upward soil reaction, especially when dry seeding in hard soils. Conversely, shallow rake angle points (less than 60 degrees) with optimum wear at the cutting edge can both add to the existing frame weight and decrease the seeder draught requirement.

The position of the seeder box and air cart also has an influence on the overall stability and tracking. A fully mounted seeder box placed near the rearmost supporting (rigid) wheels of the seeder bar and openers placed close to the towing tractor can improve tracking by providing a dampening effect.

Placing the air cart between the tractor and the seeder bar increases the distance, which reduces the accuracy of tracking. For this reason, tow-behind carts tend to be marginally better than tow-between. Tow-behind carts can also load weight on the rear wheels of the implement, aiding stability.

Operating on side slopes is particularly tricky. A tow-behind cart can increase the downslope pull on the seeder. Twin-axle carts with steerable wheels can minimise this impact relative to single axle. A tow-between cart can also increase the down-slope drift, especially when the air cart is near empty.

When working on undulating terrain and side slopes, work up and down slopes and try to work in the same direction each time. Undulations and gilgai formations often prevent the implement from maintaining an even depth, leaving the load on the implement unbalanced, causing it to skew. Parallelogram systems with independent individual tynes alleviate this problem. Shorter drawbars are probably better for working on side slopes.

It is a common perception that disc seeders should run straight; however, this is generally far from the truth. The discs act like wheels trying to steer the implement, so any slight misalignment of the discs means the implement will be pulled sideways. Some disc seeders are heavy and travel fast. For example, the tractor may weigh 15t, but the seeder and box can easily weigh 30t and when travelling at 16 to 18km/h the implement itself has a lot of traction that can push the tractor off course. Getting more traction on the soil is essential and steering the implement as well as the tractor is often required.

Working at slower speeds can improve sowing accuracy.

Guidance systems

Guiding implements provide the most accurate implement control. Guidance systems can be either passive or active.

Passive implement guidance systems combine GPS data from mounted receivers on both the tractor and implement to autosteer the tractor in a way that keeps the implement on the intended guidance path. This is the cheapest option but requires the tractor to move on and off track. It is best suited to gradual and systematic drift. It needs to be combined with a stable seeder bar to minimise transient and sudden random drift. Example technologies include John Deere iGuide™ and Trimble® TrueGuide™.

Active implement guidance systems guide the implement independently of the tractor. This type of guidance is more expensive, but the cost can often be offset if better accuracy translates into higher yields.

There are two main types of active guidance based on either hitch correction or an implement steering kit.

Hitch correction is where the tractor draw bar or the implement hitch tongue is hydraulically adjusted side-to-side to guide the implement. A system controller reacts to GPS receiver position data from the implement itself or to data from a stubble row or furrow/ridge tracking sensor fitted to the implement.

This approach adjusts implement position up to a maximum offset but does not correct any skew angle. This approach may not be sufficient to manage a large offset drift, such as on a side slope. Example technologies include SunCo Farm Equipment AcuraTrak®, John Deere hitch-based iSteer™, MBW ProTrakker™ Guidance Systems (GPS, Side-Hill Sensor™ and SonicTrakk™), Seed Hawk SBR technology, SeedMaster Smart Hitch™ and AgriParts i-Till®.

An implement steering kit actively directs the implement frame over the guidance path using steerable wheels or disc blades to generate a corrective force. Their action is controlled by GPS position data from both the implement and the tractor.

This approach corrects an implement skew angle so that it tracks squarely behind the tractor over a common guidance path. Provided they achieve sufficient penetration, piloted disc blades can generate larger restoring forces than steerable, surface-running wheels. Example technologies include John Deere wheel-kit iSteer™, Orthman Agriculture Shadow Tracker® and Tracker® IV.

Variable-rate seeding

As with other inputs, variable-rate seeding aims to more efficiently allocate resources (the seed) for better yields. Soil type is a big driver of variable-rate seeding, with growers sowing at higher rates to get better ground cover on poorer soils, including non-wetting or saline soils. Some growers also increase seeding rates to help suppress weeds.

This section has three examples of how growers are varying seeding rates based on soil types. In Chapter 3 on page 39, read how northern New South Wales grower Shane Boardman is using variable-rate seeding trials to tease out the optimal seeding rate for his soil types.

GROWER EXPERIENCE

DARREN COBLEY

On a 6800ha farm at Walkaway, WA, grower Darren Cobley aims to get the most out of variable soils and a given season's rainfall through variable-rate seeding, which he has been doing for 10 years.

Using many years of yield maps, he has identified areas that are combinations of low-yielding or high-yielding, and consistent and inconsistent. He varies the seeding rate to optimise yields in each category of soils.

In the consistent and high-yielding areas, he reduces seeding a little bit because the plants generally have the ability to hold tillers and keep good grain size. In the inconsistent and high-yielding, he reduces the seeding rate as well, as generally it is the high clay based soils that on a tight rainfall year burn off with small grain.

On the high-yielding areas, he reduces seeding rates for broad-leafed crops as the soil type naturally promotes high plant vigour, which he has found promotes a too heavy crop canopy that exacerbates foliar diseases (for example, Sclerotinia). Generally, canola seeding rates are reduced to 1kg/ha and lupins to 60kg/ha.

In the consistently low-yielding poor soils, he increases the seeding rate as it is generally non-wetting and generally produces fewer tillers. "In those non-wetting areas, even after rain, there might be pockets of dry soil and that can reduce germination. So we have mitigated that by putting more seed on those areas to keep plant numbers up. But with variable seeding, there's a lot to consider: [plant] competition, rain availability. Our approach depends on the season."

Darren's experience was originally published in *Precision Ag News*, Autumn 2023, vol 19, issue 3.

TOM LONGMIRE

When the Longmire's of Coorong Pastoral Co. noticed crops were suffering nitrogen toxicity on their saline grey clays, they opted to reduce starter fertiliser rates by 15% and increase seeding rate by 15% on those soils. The idea came from Phil Longmire's 2004 Nuffield Scholarship tour, when he visited a grower in Manitoba that was increasing his seeding rate by 15% and reducing his fertiliser rate on his saline soils.

The aim was to reduce N toxicity, save money on N as it clearly wasn't needed, and increase plant numbers to be more like the rest of the paddock. Figure 7.1 shows an example paddock with three starter fertiliser zones and two seeding rates. Fertiliser at seeding is split through the seeder, with 50kg/ha at a constant rate going with the seed, and the VR being deep banded below the seed. The lowest VR fertiliser rate (30kg/ha) roughly aligns with higher EM readings (Figure 7.1a). In this example the wheat seeding rate was increased to 65 kg/ha, compared to 56 kg/ha across the rest of the paddock.

"We're finding it pretty successful," said Tom Longmire. "Those lower fertiliser rates corelate to where our highest rates of gypsum are going. With the seeding rates and gypsum, we are reducing variation in the yield map and not noticing the production loss we used to. In a tight year those sodic clays are the first to drought out, but in a good season or an average season with a soft finish, there's limited production loss."

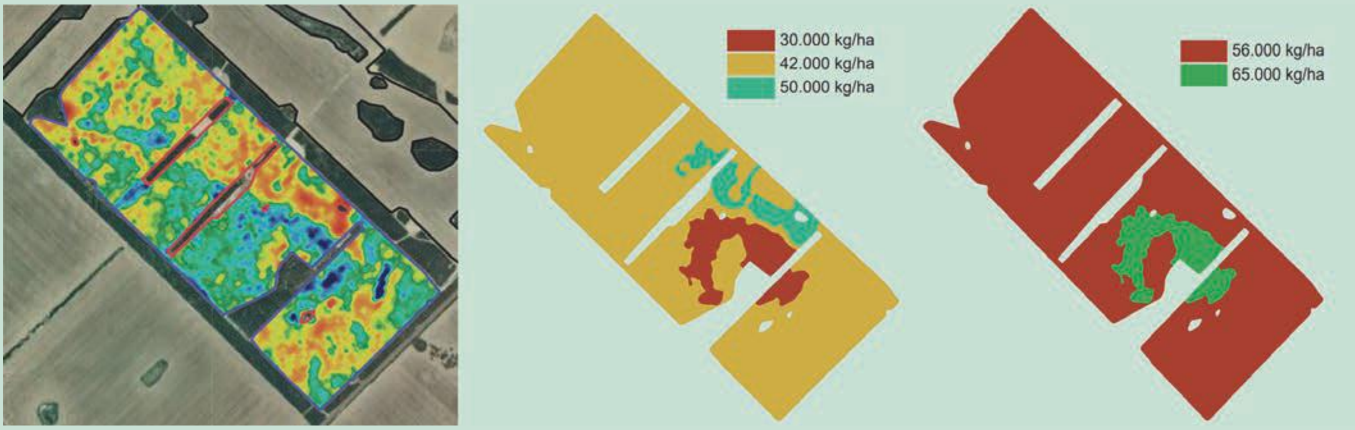
JAMES VENNING

Soil texture dictates lentil seeding rates at Barunga Grains, SA. "Lentils can't be trusted to manage themselves," James Venning said.

On the farm, varying the seeding rate is about managing the lentils to work with the soil types. Lentils and peas are the main crops at the farm, with cereals used as break crops. While wheat does well on the sandy soils, lentils struggle to accumulate biomass, leading to higher risk of wind erosion and lentils being shaken off the plant. James seeds up to 60kg/ha on the sands to get more biomass and help the crop knit together.

On the loamier soils, lentils accumulate too much biomass leading to more disease and poor water use efficiency. "They grow and grow and won't flower because they're so happy," James said. On these soils they seed as low as 25kg/ha, and while the crop looks a bit sparse to start it means more even lentil production over the paddock and helps delay canopy closure and associated problems with disease.

Figure 7.1: a) EM map, b) starter fertiliser rate and c) VR seeding rate at Coorong Pastoral Co., Beaumont, WA.



a) EM map data **b)** Starter fertiliser rate **c)** VR wheat seeding rate

Source: Tom Longmire

Chapter 8: Weeds

Introduction

Automatic optical spot spraying technology is becoming increasingly popular because it requires significantly less chemical and water use and produces less spray drift compared with blanket spraying.

Automatic spot spraying hinges on the technology's ability to recognise weeds, whether by reflection of near infrared light (NIR) from plant chlorophyll to show 'green' (for example, WEED-IT, WeedSeeker®) or use of cameras and machine learning to identify weeds (for example, Bilberry).

Reflectance-based systems work in green-on-brown (GoB) situations, such as in fallow, as they rely on the sensors distinguishing the plant from the surrounding area. The next section, headed 'Weed detection systems', explores some of the pros and cons of reflectance-based weed detection systems, as well as some practicalities including dust management, operating speeds and stubble shading.

Green-on-green (GoG) spraying is the ability to identify a weed in a growing crop and selectively spray the weed. This is not possible with reflectance-based systems and requires the more recent cameras (either hyperspectral or RGB) plus machine learning combination. The section 'Green-on-green spot spraying' (page 122) explains the technology behind systems that can spray weeds in-crop. The machine learning algorithms used in this technology need a very large database of weeds to learn from. On page 127, Michael Walsh from the University of Western Australia describes the open source WeedAI project developed by the University of Sydney, which sought to develop the architecture to create weed image databases.

While GoG technology is commercially available and more companies are developing their own version, there are risks such as exceeding the maximum residue limits (MRLs) that are yet to be addressed by regulatory frameworks. These are explored further in 'Regulatory challenges for GoG spot spraying' (page 123).

Some growers choose to plan herbicide applications by mapping weeds first, then spraying.

This mapping is usually done by drones (for example, Single Shot, Hardi Geoselect) and the maps are then fed into the sprayer. On page 130, Ben Single from Single Shot explains why his family choose to map and spray weeds as separate operations and what drove the family to develop its own weed mapping technology.

In 'Spot spraying delivery systems' (page 133), Brendan Williams gets into the nitty-gritty of actually applying herbicide with spot sprayers. While spot spraying can save considerable amounts of chemical, there are other considerations with nozzle size, spacing and boomspray height that affect chemical waste or under-application.

While chemical weed control technology is advancing rapidly, non-herbicide control options are also in the works. In 'Non-herbicide weed control technologies' on page 135, take a quick look at some of the developments that do not use herbicides.

Weed detection systems – some practicalities

There are two basic types of weed detection systems: those that use real-time sensors for a 'see and spray' approach and those that map weeds before spraying. Map-based systems typically use drones to map weeds. The weed map is then loaded onto the tractor's display as a coverage map and the nozzles are activated accordingly. The pros and cons of this approach are covered in 'Weed mapping with a drone' on page 130.

Real-time weed detection

Growers often refer to these systems as camera sprayers, but there are two types of detection mechanisms – cameras and reflectance-based systems.

Camera systems analyse visual images to determine if there are weeds present. They rely on machine learning and a very large database of weed images to identify weeds. Processing speed is a critical factor. How many frames per second are processed and the depth of view of each frame will determine the maximum travel speed. Projecting the image ahead of the nozzles allows more time to process the image. This is generally done by two methods – mounting the camera on poles well ahead or angling the camera (or a combination of both). The downside of angling is that the more obtuse angle means obstacles such as stubble obscure more of the view.

Camera systems typically experience changed performance at night so strong levels of illumination are required. Some systems are purely looking for green as a detection mechanism; others that have GoG functionality also assess shape and form to determine the presence of weeds.

Sensor-based systems such as WeedSeeker® and WEED-IT do not have cameras and they both use an active light source. WEED-IT has used blue and red light; WeedSeeker® has used red. These systems use the active light source to cause chlorophyll in the plant to emit near infrared (NIR) light. The sensors detect the NIR light to determine if a weed is present. WeedSeeker® calculates an NDVI-type proprietary measurement whereas WEED-IT uses only NIR detection. These systems work equally well in the day or night. The critical difference here is the fact that weeds are emitting NIR so effectively that they are glowing, which is considered critical in the detection process.

Earlier models of WeedSeeker® required background calibration to be performed manually but later models have automatic background calibration, whereas all WEED-IT models have automatic background calibration.

Field of view/detector height

Detection height is critical for all systems as it sets the field of view, which is referenced to the nozzle path. As height increases or decreases, so does the distance to the target; that is, the weed and the width of view. This width of view is critical as it is partitioned to correspond to where each nozzle is located. Basically, if the width of view is too low, weeds or parts of weeds will be missed. Too high and alignment will be changed, resulting in potentially the wrong nozzle being activated. With active light sensors, the distance from the target also influences the strength of signal received by the sensor and therefore affects the capacity to detect weeds. High boom results in lower signal and so small weeds may go undetected.

The bottom line is that the detection height needs to be within a relatively narrow band; otherwise, the system will have suboptimal performance and miss weeds. A stable boom is absolutely critical. This can be very challenging, especially in more undulating terrain. If you cannot keep a stable height, these systems simply will not work well. This will be true for every system.

As a fail-safe, some systems have automatic height sensing that turns nozzles on if the boom is above or below a set height, regardless of whether a weed is present or not. This is to avoid missing weeds because they were out of the field of view.

Power management

Running solenoids consumes power so having a good power supply is critical. With WEED-IT and WeedSeeker®, the active light source consumes power, too. In the case of camera sprayers, if they are being operated at night they require a high level of light illumination that has high power demand.

In the case of WEED-IT, the system runs at 48 volts so the current draw and losses are reduced. Computing is done in each sensor to minimise delays in response. Most of us think of our PC as being a low-powered piece of equipment; however, processing a lot of information very quickly consumes a lot of power. This means that users must be acutely aware of power management for camera sprayers. Heat dissipation from computing components is critical, too. Heat sinks are an integral part of many systems and their effectiveness needs to be verified.

Dust

Dust can accumulate on the lenses of the sensors, inhibiting weed detection. This is generally a problem around the wheels of the sprayer, irrespective of the type of system being used. The WEED-IT monitoring system uses a histogram of individual nozzle firing to enable operators to gauge when it is necessary to clean the sensors by observing a sensor has reduced activity. In dusty conditions this may occur after two to three hours of operation, but more typically once a day is sufficient and represents good practice.

Stubble shading

Stubble can obscure the view of weeds as well as shield the weed from the spray. With camera-style sensors, this is determined by line-of-sight to the camera as each frame is captured. With NIR sensors, the issue is a little different as they rely on an active light source to activate chlorophyll to emit NIR. The weeds are an emitting source and the sensors are continuously detecting for the presence of NIR.

With regard to shielding the weed from spray, all systems are pretty much the same. However, a higher boom with narrow nozzle spacing and narrow angle nozzles will reduce stubble interception.

Speed measurement

Speed measurement is another critical feature for spot sprayers, because this affects the timing with which the solenoids hit the weed. Only a slightly incorrect measurement will mean the weed is missed. More than this, it is important that each sensor knows the speed it is travelling to avoid missing weeds when moving around obstacles. When turning a corner, for example, the inner boom is moving very slowly while the outer boom is moving much faster. Compensating for these differing speeds along the boom helps ensure weeds are not missed.

WEED-IT accomplishes this by fitting two speed sensors, one on either side wheel or in the case of SPs using two GPS speed sensors on either side boom. The system is programmed with the distance between speed sensors and then models the arrangement so that each sensor knows its position relative to the speed sensors and therefore knows its speed and adjusts timing accordingly. This is a very important feature.

Monitoring

There is a massive amount of technology on a spot sprayer – multiple sensors and often more than 100 solenoids. This is quite a lot to get right and to keep right. The quality of wiring harnesses is a key feature to look out for and there needs to be a good warning/monitoring system. The WEED-IT will monitor and sound an alarm for all sensor and solenoid issues, and alert when boom pressure is too high or too low (so you know when the tank is empty) as well as sun intensity. The solenoid activity log (histogram) also monitors for dust accumulation.

ISOBUS compatibility

ISOBUS compatibility is a buzz word in the agtech industry as it allows systems to be operated with the displays that growers are already using. ISOBUS is simple and it unlocks features such as mapping and boom section control. In the case of WEED-IT, it unlocks the capability to use WEED-IT in blanket mode with section control at 1m spacing so the system can be used all year round. A WEED-IT in blanket mode gives the benefit of pulse width modulation nozzle control with turn compensation so it can be used as a high-spec blanket sprayer as well as a spot sprayer.

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Bilberry's green-on-green solution harnesses artificial intelligence, which uses algorithms that detect and spray weeds in real time. Photo: Josh Johnson

Green-on-green spot spraying

Green-on-green (GoG) is a precision farming technology that utilises artificial intelligence (AI) to identify weeds in real time and isolate herbicide spraying on the individual weed/plant level. In this respect, GoG builds upon the beneficial principles that have been developed in GoB spraying by only applying the herbicides where they are needed.

The difference is that due to the AI component, the spot spraying is not limited to just fallow but can be extended to in-crop situations. This technology has been made available by the increase in computer processing power and the investment into AI algorithms for agricultural use. At present, there are only a handful of commercially available GoG systems for broadacre farming, with the most prominent and widely adapted being Bilberry's offering.

Many of the same issues with GoB apply to the GoG cameras, such as boom stability, stubble/crop shading, dust and speed. The RGB camera in some GoG systems is similar to the one in a smartphone, so they must be able to see the weed to identify and spray it. One user of a Bilberry system has noted that if they could not see the weed from the sprayer cab then there was a lower chance of the cameras detecting the weed. Data suggests that detection of weeds is higher once the weeds are more than five centimetres in diameter.

The main driver of uptake for GoG spraying is the reduction in chemical usage, which for commercial users is routinely between 80 to 90 per cent. Traditional broadcast spraying often results in over-application and chemical being applied in areas of the paddock where it is not required. With GoG spraying, only the target areas receive treatment, significantly reducing the quantity of chemicals used. This not only saves money but also decreases the impact on crop yield and the overall environmental impact of agriculture.

At present, herbicide labels do not account for the use of targeted application in-crop such as GoG spraying. Therefore, users must still adhere to current label application rates so as to not exceed the maximum residue limits set by regulatory authorities. Combining robust rates and multiple tank mixtures for the crop that it is being treated will ensure a high level of weed control and a reduced risk of herbicide resistance. It will also reduce the overall weed seedbank within the farming system.

Another benefit of GoG spraying is precision. By using the cameras to detect weeds and combining it with other precision technology such as GPS, the user has the ability to produce an accurate map of weed infestation in-crop. Weed maps enable the user to quantify areas of weed infestation and subsequently make data-based management decisions for current and future crops or crop rotations.

There is a variation between crops that is not primarily due to the camera systems themselves but is influenced by the growth habits and characteristics of the specific crops. For instance, once a canola canopy starts to close, the herbicide hit rate on weeds is significantly reduced regardless of whether a blanket spray application or camera-based spot application is used.

Cameras can be affected by high stubble loads, crop shading and canopy closure. This is a limitation of all optical sprayers (GoB or GoG). If they cannot see the weeds, they cannot spray them. A camera system will never have a 100 per cent hit rate, and for this reason a two-spray strategy is highly recommended. We are seeing Bilberry users successfully deploying two-spray strategies with large savings.

The first spray should target weeds before canopy closure, while the second spray should focus on weeds that have emerged above the canopy later in the season. This strategy allows for better weed control during different growth stages and reduces survivors as well as any later emerging weeds that were not present at the first spray timing.

As technology continues to advance, GoG spraying is likely to become an even more integral part of the agricultural farming system, supporting the goals of sustainable and environmentally responsible farming while saving money in the process.

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GROWER EXPERIENCE
BRODEN HOLLAND

Broden Holland, who farms 5000ha near Young in NSW, has acquired a 36m Goldacres G6 boomspray fitted with a Weedetect system. It can spray both GoG and GoB. Overall, Broden said the machine had improved efficiency when summer spraying. Over the past few wet years the benefits had been less obvious (due to a higher weed burden), but he had still seen some savings and less chemical use.

Broden said the GoB capabilities were excellent, but the value of GoG depended on your use case. For him, GoG worked where there were very low weed numbers. One issue was when crop canopy closure affected the ability of the cameras to 'see' the weeds. He found the system worked best just before canopy closure, but thought that adding additional lighting to the boom or having wider row spacings (the farm works on 7.5 or 9-inch [19 or 23cm] spacings) would help.

Having automatic height control had been critical as it kept the boom level and the nozzles at the right height to spray.

Regulatory challenges for GoG spot spraying

Dr Rohan Rainbow, Crop Protection Australia

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Origins of GoB spot spraying and permits for use

Optical camera spot spray systems for use in fallow have been widely adopted by Australia's agriculture industry. Today the technology is considered industry best practice for fallow weed management, both in reducing herbicide costs and in ensuring there are no weed escapees, which result in the increased risk of herbicide-resistant weed patches in paddocks.

The origins of optical camera spot spray technologies using NIR reflectance for fallow weed management actually started in Australia in the mid-1980s (Felton and McCloy, 1992) but were commercialised following North American investment. Grains Research and Development Corporation (GRDC) invested in a project with the New South Wales Department of Primary Industries (NSW DPI) more than 10 years ago to establish an industry permit via the Australian Pesticides and Veterinary Medicines Authority (APVMA) for legal use of a range of herbicide products with optical camera spot sprayers. This permit was held by Crop Optics Australia, the then Australian agent for WeedSeeker® spraying systems. This APVMA permit PER11163 expired in February 2019.

Grain Producers Australia (GPA) holds an APVMA permit ('Industry Pesticide Minor Use Permits' page, GPA website) for the legal use of optical green-on-brown (GoB) camera spot spray technologies for a range of herbicides for summer weed control. This includes WeedSeeker®, WEED-IT, John Deere See & Spray®, Bilberry and other emerging GoB optical camera spray systems (PER90223 – Permit to allow minor use of a registered agvet chemical product for control of various weeds in fallow in conjunction with optical spot spray technology. In force from 1 December 2021 to 31 December 2026).

In addition, Nufarm Australia has registered several herbicide products for use with GoB optical camera spot spray technologies (Nufarm, year of publication unknown). The GPA permit (PER90223) products will also need to be registered by the time the permit expires. Towards this end, there are ongoing industry discussions to deliver outcomes for growers.

Most of these new optical camera spray sensor technologies are being developed in conjunction with tractor CAN Bus connectivity and communications systems, including ISO 11783 (International Standards Organization, 2017) and the emerging autonomy standard ISO 18497 (International Standards Organization, 2018). In addition, drone solutions such as Single Shot (see singleagriculture.com.au) for aerial weed detection have been developed. These allow growers and advisers to plan weed control before spraying.

KEY MESSAGES

- Green-on-green (GoG) spot spray technology is a valuable tool for crop protection, offering economic and environmental benefits through reduced pesticide use and improved weed management
- GoG also poses risks, such as off-label chemical use (through higher rates, in different crops and different timings), exceeding maximum residue limits, and presenting challenges for regulators in defining crop safety
- The industry needs a risk assessment framework to address these issues and facilitate the commercialisation of GoG technology

Commercial GoG weed ID technology

Technology development of crop sensors, including optical weed sensors, is accelerating. It is a busy space for intellectual property and commercial protection using patents is becoming complex for new entrants. There is a significant commercial focus on GoG optical camera technologies for spot spraying of weeds within a growing crop, combined with the existing GoB capability (Table 8.1).

The European company Bilberry has been first to market with GoG detection of broadleaf weeds such as radish, turnip, blue lupin, thistle and capeweed in wheat, barley and oat crops. This technology has already proven useful in Australia. It has been used on more than 20,000 hectares to manage wild radish and blue lupin infestations in wheat paddocks with up to 97.5 per cent chemical savings. Bilberry claims users have witnessed significant improvements using this technology and chemical cost savings have paid for the system in just one year.

The development of GoG optical spot spraying technologies also provides commercial opportunities for the development of patented new pesticides and formulations using specific targeting and application technologies. Producers are likely to see these technologies, particularly for herbicides, become available in the coming years.

There has been significant investment, both in Australia and overseas, in artificial intelligence (AI) weed identification (ID) systems, mainly for commercial use in agricultural production. There have been tens of millions of dollars invested in camera-based real-time weed ID systems by John Deere, Bilberry, Bosch and others, noting that much of this investment has been focused on detecting European and North American weeds.

This highlights considerable opportunity for accelerating weed ID systems in Australia through potential future national and international collaborations specifically targeting Australian weeds. In Australia, however, there is also an increasing number of dispersed weed ID datasets emerging. This presents a significant opportunity for a single aggregated weed dataset to be developed to improve consistency and user experience with AI-driven weed ID systems. This becomes particularly important in identifying invasive or exotic weeds and other pest species. There is a role for potential coordination in delivering Australian datasets.

Table 8.1: Green-on-brown and green-on-green optical spot sprayer sensors. Based on publicly available information at the time of initial article publication (Spring 2022).

	Availability	Green on Brown	Green on Green
Weed Seeker & Weed Seeker 2 (Owned by Trimble)	🟩	🟩	
WeedIt & Weed-It Quadro (Licenced by Nufarm-Croplands in Aust/NZ)	🟩	🟩	
SenseSpray (AgTechnic)	🟩	🟩	
Bilberry (Licenced to Agrifac, Dammann, Miller and Goldacres Australia)	🟩	🟩	🟩
Bosch – SmartSprayer (Investment by BASF – licenced to Amazone, Stara & AGCO)	🟩	🟩	🟩
Carbon Bee –SmartStriker (licenced to Kuhn, Berthoud)	🟩	🟩	🟩
Greeneye Technology (Investment by Syngenta)	🟩 *Availability in Australia unknown*	🟩	🟩
John Deere - See and Spray (Includes IP from John Deere owned Blue River Technologies, plus includes University of Southern Queensland IP with previous investment by SRA, CRDC & HIA)	🟩	🟩	🟩 *See & Spray Ultimate* Limited USA Release 2023
AutoWeed (James Cook University IP - Previous investment by Sugar Research Australia)	🟩 *Limited availability*	🟩	🟩
Agerris- VIIPA (University of Sydney IP – Previous investment by Hort Innovation Australia)	🟨 *In development*	🟨	🟨
Agrointelli (incorporating RoboWeedMaPS fitted to Robotti platform)	🟨 *In development*	🟨	🟨
Ecorobotics (Investment by BASF)	🟨 *In development*	🟨	🟨

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It is likely that into the near future, producers will have camera-based weed and pest surveillance technologies fitted to utility vehicles, tractors and all-terrain vehicles conducting active real-time surveillance of agricultural pests and weeds that already exist in Australia. It is likely that these sensors will also be used for biosecurity surveillance and detection of other new crop diseases and pests in the future.

Potential benefits of GoG spray technology

GoG spray technology will be a significant advance as a crop protection tool for growers. In some situations, growers may be prepared to sacrifice part of the crop for the benefit of the whole crop using a product that may have inadequate crop safety for blanket paddock use.

GoG technology also provides the opportunity for commercial pesticide companies to develop and formulate products that would not necessarily be commercially viable or safe for widespread use in crops. However, they may become financially viable or have acceptable crop losses if used for selective spot spraying. This includes the opportunity for use of new modes of action or products that have previously been shelved due to cost or potential crop damage. There are potentially economic and environmental benefits from a reduced volume of pesticide use in crop production.

A successful strategy that has been widely adopted by grain growers is using as many weed control tools as possible to reduce weed seed-set. The adoption of weed management strategies over many years, highlighted by the WeedSmart program (see weedsmart.org.au), points to the benefits of aiming for complete weed control and keeping weed populations low in order to reduce the selection pressure that causes herbicide resistance to develop. GoB and GoG optical spot sprayer technologies have been demonstrated as being effective tools to support these practices.

There is also the argument that in the pursuit of near 100 per cent weed control, sacrificing small areas of a crop (which would potentially yield poorly anyway due to weed competition) may be a good economic and crop management decision. The balance of resulting crop losses and low costs of weed control potentially warrants the use of GoG technology in-crop. Improved weed control, adding another tool for tackling herbicide resistance, reduced herbicide cost and the ability to cost-effectively repeat a treatment are all very appealing benefits of GoG spot spray technology.

Optical spot spraying technology has also demonstrated improved management of herbicide-resistant and hard-to-kill weeds by making it economically viable to use more expensive herbicides and at higher registered label rates . Bilberry has reported that GoG trials have shown an average weed target and efficacy rate of 80 per cent, as well as chemical savings of up to 90 per cent. Several GoB and GoG spot sprayer sensors also have the capability to map weed populations, which helps to monitor and manage herbicide resistance. However, this is highly dependent on the sensor and supporting artificial intelligence for accuracy in identifying a wide range of weed species.

Potential risks of GoG spot spray technology

Only products registered for use in the correct crop and growth stage can legally be used with GoG spraying. However, the potential of GoG sprayers to use existing registered pesticide products at higher registered label rates or different timings to kill weeds in-crop opens up the risk of off-label chemical use, as the specific technology use is not yet specified on pesticide labels.

One of the options being discussed by some optical sprayer developers and users of GoG technology is using existing registered herbicides at higher than registered rates, or, in some cases, using currently unregistered broader spectrum herbicide products in-crop. This concept has also been previously trialled by several groups using GoB sprayers but with mixed results.

A very real potential industry risk posed by GoG spraying in this way is exceeding maximum residue limits (MRLs) in resulting grain or fodder products, or residues being detected in crops the following season.

Today, as international trade and pesticide MRL compliance becomes more complex, there is a need for increased industry efficiency in managing pesticide access and trade risks. There is a need for a broad industry discussion about options as to how this can be best managed in the future, particularly with the new risks presented from the introduction of technologies such as GoG optical spot sprayers.

APVMA regulates crop, animal and human safety, plus risks to the environment, to the point-of-sale. GoG spot spraying will require a reconsideration of absolute crop safety requirements due to the opportunity for new models of herbicide application in-crop. This becomes a difficult consideration for the regulator as to what constitutes crop safety and acceptable risks of crop loss. In addition, the risks from herbicide product use at higher rates when using GoG sprayers could result in a difficult quantification of cumulative or concentrated plant and grain residue levels, depending on what percentage of a crop field is sprayed.

The current GPA permit PER90223 for GoB fallow weed control considers these risks through restricting the use of optical spot spray technologies with the requirement to survey the area to be sprayed and estimate the percentage weed cover prior to application. In practice, however, this is a manual observational estimate by growers. For example, the current GPA permit can only be used for weed cover between 0 and 10 per cent, or 0 and 30 per cent, depending on the herbicide product used. If the percentage of weed cover exceeds 30 per cent, only currently registered herbicide label rates can be used. GoG spraying will require a similar evidence-based approach to restricted in-crop use, depending on the product used. How weeds are dispersed will affect managing crop safety, plant-back and trade risks (Figure 8.1). Visual observation by the spray operator only sees a green field if objective sensor surveillance tools before optical spraying are not used.

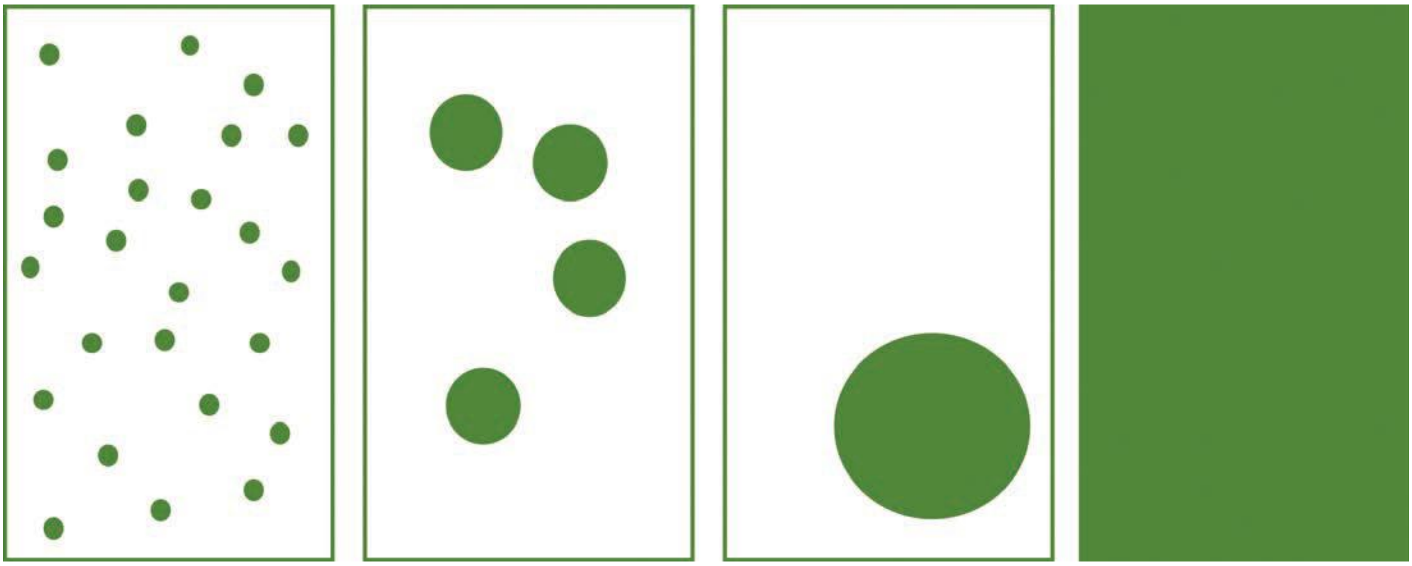
Need for future risk assessment framework

GoG spray technology is on the precipice of widespread commercialisation, but will growers be able to realise its potential without significant investment and delivery of official pesticide label registrations? Crop phytotoxicity, environmental and residue studies will potentially need to be assessed under different criteria from traditional ‘good agricultural practice’ (GAP) studies, which is what is currently reflected on pesticide labels.

The Australian plant and animal production industry has a robust and independent chemical registration framework through the APVMA, which is a significant trade advantage when it comes to market confidence that Australia can deliver a clean and green agricultural product. The current process for chemical label extensions to maximise the efficacy and efficiency of GoG technology is time consuming and costly, which will discourage many pesticide manufacturers, particularly for older generic herbicide products.

A lack of a clear regulatory pathway for GoG spot sprayer technologies will likely stifle investment and commercialisation of new technology in the small Australian market. There has been considerable discussion around the potential role of the cross agricultural industry body, the National Working Party for Pesticide Applications (NWPPA), in facilitating industry coordination to guide the introduction of GoG technologies and producing science-based evidence for risk management that meets APVMA’s requirements.

Figure 8.1: Five to 10 per cent field coverage of weeds; how they are located changes crop safety, plant-back and trade risks.



a) Dispersed risk **b)** Clustered risk **c)** Concentrated risk **d)** What we see

Source: © Crop Protection Australia. Used with permission

While pesticide companies are well aware of the opportunity that GoG technology presents, the challenge is the cost of closing the regulatory gaps and delivering a legally registered label outcome. It will take industry cooperation to address regulatory requirements to enable the potential widespread use of GoG spot spraying while protecting Australia's trade markets.

For this to be successful, industry producers, their respective research and development corporations, machinery manufacturers and pesticide companies will need to work together to deliver an effective outcome to support APVMA in delivering effective GoG technology regulation determinations.

Conclusion and future needs

GoG spray technology is a significant advancement in crop protection, offering reduced volumes of pesticide use in crop production with both economic and environmental benefits.

However, there is much to tease out from a regulatory standpoint to ensure growers meet label requirements and minimise trade risks from pesticide residues in crops. Off-label chemical use is a key risk, as growers may experiment with higher-than-registered herbicide rates or use unregistered herbicide products within the crop. Off-label use may result in exceeding MRLs in crop grain or fodder products or residues being detected in crops in subsequent seasons. The industry faces the challenge of closing regulatory gaps and delivering legally registered label outcomes for growers.

APVMA faces challenges in determining what constitutes crop safety and acceptable risks of crop loss when using GoG technology, especially when higher herbicide rates are involved. While existing permits consider weed cover percentage as a basis for application restrictions, GoG spot spraying will require a more evidence-based approach to restricted in-crop use, depending on the specific product used. There are multiple pesticide x application technology x geospatial area combinations to consider, and opportunities for new patented pesticides and formulations using new specific targeting and application technologies.

The industry needs:

- a GoG optical spot spraying technology permit to manage trade risks and provide industry guidance on use, especially for generic pesticide products;
- a geospatial optical spot spraying technology risk assessment model for APVMA's risk assessment; that is, a risk model that not only takes into account the specific risk at a given site (what is done currently), but also considers the spatial location and concentration of that risk; and
- a clear regulatory pathway for GoG optical spot sprayer technologies to avoid stifling investment and commercialisation. A lack of such a pathway may deter pesticide manufacturers from pursuing these technologies, particularly for older generic herbicide products.

Cooperation between producers, research and development organisations, machinery manufacturers and pesticide companies is necessary to support APVMA in effectively regulating GoG technology while safeguarding Australia's trade markets and ensuring the continued production of clean and green agricultural products.

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WeedAI: database of weed images for the development of recognition algorithms

Commercially, the two sensing technologies used for weed detection are spectral reflectance sensors – used to detect 'green' weeds in GoB situations – and digital cameras that are taught to recognise weeds. The latter are being used for both GoB and GoG weed detection in-crop.

Weed detection that uses cameras and machine learning has three key stages:

1. collecting digital imagery;
2. annotating digital imagery and establishing a training dataset; and
3. training a weed detection algorithm.

Training a weed detection algorithm requires between hundreds and many thousands of images, with more needed for complex detection challenges. The images need to be labelled according to the required training of an algorithm for a detection task. Once trained, the algorithm can run in real-time using imagery collected as a platform (for example, boomspray) moves across the paddock. Figures 8.2 and 8.3 compare labelled images used to train the algorithm (left) and the algorithm weed detection (right).

Weed recognition algorithms can be more accurate when using more precise as well as larger datasets. The database established in WeedAI, developed by the University of Sydney, enables the use of more focused datasets for algorithm development. WeedAI is a database of more than 20,000 images (including annual ryegrass and turnip weed growing in chickpea and wheat crops) with a range of datasets of other weed and crop combinations in different situations. The WeedAI database is structured in a way that enables datasets of specific crop and weed growth stages to be used in developing more specific weed recognition capabilities. For example, it is possible to train an algorithm that specifically recognises a three to four-leaf stage weed in 10-leaf stage wheat crops.

Because weed detection is a rapidly changing space, new machine learning architectures are regularly being released. One challenge is keeping up with the progress, as recognition algorithms tested 12 months ago are now out of date.

WeedAI is an open-source platform, meaning anyone can upload or download images. This is good in theory, but the images need to be appropriately annotated for effective algorithm development. At this stage, users uploading images still have to do quite a bit of work to make them suitable for the platform. It is hoped that in the future – if there is the opportunity for more website development – that the uploading process will be more streamlined and include automated image classification and annotation options.

Next steps

While the project that developed WeedAI officially finished in 2021, the site remains active and is being managed by the University of Sydney, which continues to curate uploaded images. The ideal outcome would be large amounts of data on WeedAI for all weed species across all crop production systems.

The aim is to keep the information freely available as an open source database for growers, advisers and businesses to use. This is in line with the wider object recognition community that develops the open source recognition architectures that are used for weed recognition algorithm development.

MORE INFORMATION

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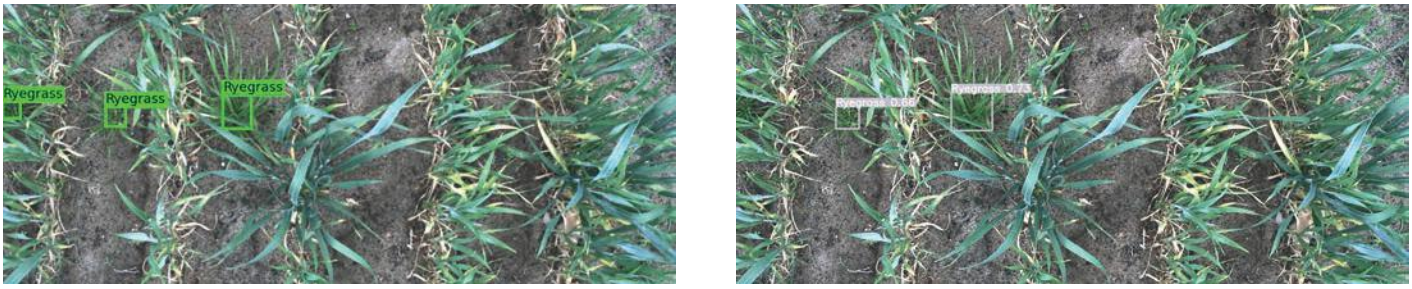
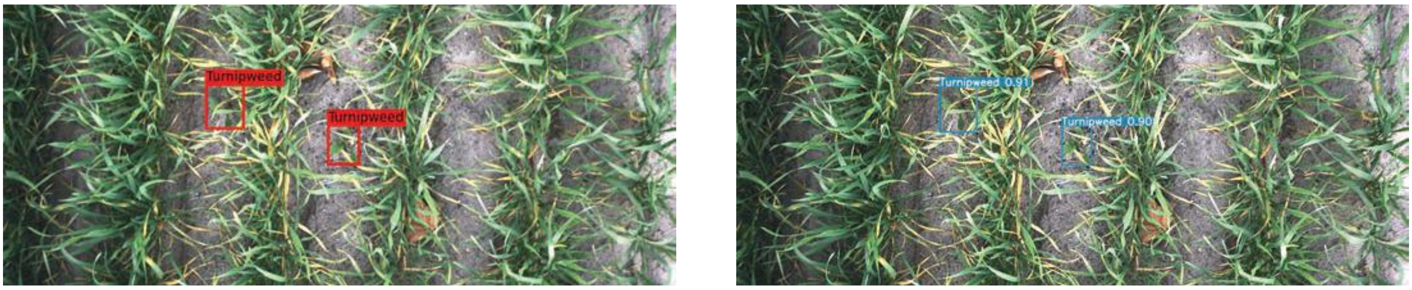
Figure 8.2: Ryegrass labelled (left) versus predicted (right) by machine weed recognition.



Source: Michael Walsh

Figure 8.3: Turnip weed labelled (left) versus predicted (right) by machine weed recognition.



Source: Michael Walsh

SNAPSHOT

Name: Tom, Phil and Bindi Longmire

Business: Coorong Pastoral Co.

Location: Beaumont, Western Australia

Farm size: 5700ha

Rainfall: 450mm

Soil types: circle valley loams, red and grey clays

Enterprises: cropping

Rotation: five-year rotation of field peas, wheat, canola, wheat and barley with the odd opportunistic lentil crop

Autonomous weed management

Weed management on the Longmire family's 5700ha farm at Beaumont, WA, is an ongoing challenge. To help manage such a large area while cutting down chemical use, in February 2023 the Longmires leased a SwarmBot (an autonomous robot) and attached a Hayes WEED-IT spray boom. The WEED-IT uses near infrared light (NIR) reflection from plant chlorophyll to show 'green', which then activates the relevant nozzles to spot-spray the weeds.

Mapping critical

Boundary mapping has been critical for the SwarmBot to work effectively. The farm's paddocks range in size from 31 to 900ha and many are not square or contain internal headlands due to dams, salt lakes and trees (see Figure 8.4). The Longmires have mapped the entire farm with John Deere RTK (both the paddock boundaries and internal headlands) set at 1.3m off the paddock boundary.

Figure 8.4: Salt lakes and drains in paddocks on the Longmire farm required detailed boundary mapping to enable a SwarmBot to work effectively.

Source: Phil Longmire

This was initially done partly to reduce overlap with fertiliser and seed rates applied on the headlands. Variable-rate maps were developed for the headlands based on the level of overlap and obstacles.

The SwarmBot needs a 1.5m buffer from paddock fences. Tom Longmire used the existing 1.3m internal boundary maps and buffered them by an extra 0.2m to make the necessary 1.5m geofence, without having to re-map the boundaries. The next step was mapping the roads and fill points.

Tom said, "You can queue paddocks in the software so that once it finishes a paddock, it will drive itself down the road to the next paddock and keep going. Getting that part of the system fully working is the next goal."

Internal issues a problem

Tom is finding the SwarmBot needs some tweaking to cope with the second headland lap of internal boundaries, necessary to ensure there is 100 per cent coverage of the paddock when spraying. In the short term, Tom is adjusting the curves manually in the software to ensure there are no misses until the software can draw a second lap. Figure 8.5 shows an example SwarmFarm plan path.

Although the SwarmBot normally averages 10 to 12ha/hr, the number of internal paddock obstacles makes the working rate slower. The other issue is that the obstacle detection is too good.

"It's very sensitive, probably more sensitive than I was expecting. We have a lot of trees that are overhanging fencelines at two-and-a-half to three metres off the ground which are picked up by the bot," Tom said. The plan is to cut off any branches that hang below 3m height.

Savings

The first-year saving from using the SwarmBot was about $85,000 (Table 8.2). However, Tom was cautious with this number. The robot arrived in early February, limiting the time to use it before seeding. The costs do not include the SwarmBot lease and have not yet been converted to a per hectare number. "I want to run it for a full year before I try attaching a cost to that to see how many hectares we can get done."

Compared with blanket spraying, the savings are:

- $22,214 for the double knock, by spraying only 4.2 per cent of the farm;
- $65,667 for the summer spray, by spraying only 10.2 per cent of the farm (2181ha); and
- $20,085 in operational costs, from $8/ha using the boomspray versus $1.50/ha for the SwarmBot.

Can we leave the weeds to the robots?

"I couldn't purely rely on it," said Tom, who based this statement on weed prevalence.

"In drier years with less weeds it might keep up quite well, but it won't keep up if there's a summer storm."

Tom suggested a hybrid approach. If a lot of self-sown weeds came up after summer rain, he would blanket spray then use the SwarmBot a week later to double knock the hard-to-kill weeds such as marshmallow and fleabane.

"When it's busy we treat the dirtiest paddocks with the blanket sprayer so the SwarmBot gets the best payback. And times in summer when we don't get rain, the SwarmBot can keep cruising around."

One planned use is to have the SwarmBot follow the header at harvest to get the first round of spraying done. The farm tends to get coastal rain and weed germination at harvest. "Normally we don't have the labour availability to stay on top of that spraying. The plan is once that first paddock is off, the SwarmBot will follow our headers around and by the time we finish harvest, we've done the first round of spraying."

Figure 8.5: SwarmFarm path plan.

Source: Tom Longmire

Table 8.2: Chemical and dollar savings comparing a blanket spray to using the SwarmBot.

Chemical			
Double knock			
	Hectares sprayed	Cost ($/ha)	Total cost
Blanket	909	27	$24,543
Coverage	4.20%	61	$2328.86
Savings			**$22,214.14**
Summer spray			
	Hectares sprayed	Cost ($/ha)	Total cost
Blanket	2181	24.04	$52,431
Coverage	10.23%	40.24	$8978.20
Savings			**$43,453.04**
TOTAL	**3090**		**$65,667.18**
Operation			
	Cost/ha	Hectares sprayed	Cost
SP cost	$8.00	3090	$24,720.00
Swarm	$1.50	3090	$4635.00
Savings			**$20,085.00**
TOTAL			**$85,752.18**

Source: Tom Longmire

The Single Shot drone in action. Photo: Ben Single

SNAPSHOT

Name: John, Mary, Tony, Sharon and Ben Single

Location: Coonamble, NSW

Farm size: 4500ha cropped (5500ha in total)

Rainfall: 520mm

Soil types: heavy clay

Enterprises: wheat, canola, faba beans, chickpeas for winter and sorghum for summer

Weed mapping with a drone

Herbicide resistance and increasing chemical costs spurred the Single family to look for better weed management options. "Even more than a decade ago, chemical resistance was a massive concern for us," Ben Single said. Glyphosate-resistant ryegrass was confirmed on the property in 2005 and there were patches of glyphosate-resistant barnyard grass.

The family started looking at the existing spot sprayers, but the cost of the new equipment (sensors and sprayer) and not-quite-perfect detection rates pushed Ben into looking for other options. "Detection rates weren't quite good enough," he said. "We wanted elimination, not just control. A 98 per cent hit rate isn't good enough when targeting chemical resistance."

Armed with an aerospace engineering degree, Ben started looking at possibilities with cameras and machine learning, but in 2015 turned his attention to drones. After many years of experimentation on the family farm he created Single Shot, a weed mapping drone.

How it works

Single Shot uses imaging sensors combined with other sensors in a dedicated sensor to map green (that is, weeds) during fallow or just after planting. As it flies, every section of the paddock is imaged at least twice from different angles. This improves detection accuracy, particularly for weeds in heavy stubble.

The drone flies at 80m altitude on an 80m swathe at about 12.5m/second. At this height, the drone can map weeds as small as 4cm. While it could fly lower to recognise smaller weeds (about 3cm in diameter), it would need to do more passes of the paddock.

The system works on all weeds in GoB situations. Ben said some weeds could be harder to detect if they had started flowering or had some dead matter. Fleabane was a particular challenge, but the drone can now easily pick it up.

The drone can realistically map about 250ha an hour, which accounts for battery changes (each battery lasts about 40 minutes). Once the paddocks are mapped, the software generates a shape file to upload to the sprayer. Single Shot has built-in buffers to deal with the inaccuracies of the system and the sprayer.

The Singles' own struggles with complex data and PA systems meant Ben wanted Single Shot to be intuitive. "We are very cognisant of making it easy to use," he said.

The drone comes with the flight software. "You click the corners of the paddock to set the boundary. The software works out the flight path, which is uploaded to the drone, then you push a button for the drone take off. Push another button and the drone will return."

Two-step process is a benefit

While some growers prefer a system that identifies and treats weeds in one pass, Ben preferred the flexibility that two steps – mapping then spraying – offered. "Anything that is boom mounted you can't use as a management tool because you don't know what's there before you start."

What partially drove the Single family down the drone route was they sometimes found after the fact that there were more weeds than expected, and a blanket application would have been better.

In their experience, decoupling mapping from spraying has several advantages, including:

- planning herbicide rates and options (see below);
- flying the drone afterwards to scout for surviving weeds, as surviving weeds have a higher probability of being resistant. In this case, a new plan is made to deal with the survivors; and
- mapping with the drone is not limited by light conditions.

The Singles prefer knowing how much of the paddock needs spraying before-the-fact to make detailed herbicide plans, which helps to keep track of costs and decrease product waste.

"For example, if it's a 10 per cent spot spray, I'm happier to use a higher label rate to make sure I get the kill, but with a blanket rate I'm often walking the line between getting a kill and reducing the overall rate to reduce chemical costs," Ben said.

The Singles can also tailor spray programs to weed size. If there are lots of little weeds that are easy to kill they might use a cheaper herbicide. Or they might need to target bigger weeds that were missed, resistant or just stressed with higher label rates or more expensive herbicides.

Making the herbicide plan also ensures they are meeting regulatory requirements and label rates, with some herbicides having a higher spot spray rate but an associated maximum spray area percentage.

Cost and time savings

Typical herbicide savings are 80 to 90 per cent compared with blanket spraying, although it does depend on weed density.

Table 8.3 compares the cost of blanket rates to spot spraying using the Singles' existing unmodified 36m Goldacres trailed sprayer. These booms only have seven sections and require significant lead time to ensure the section is fully open when it passes over the weed. Other users with more advanced booms have reported significantly higher savings.

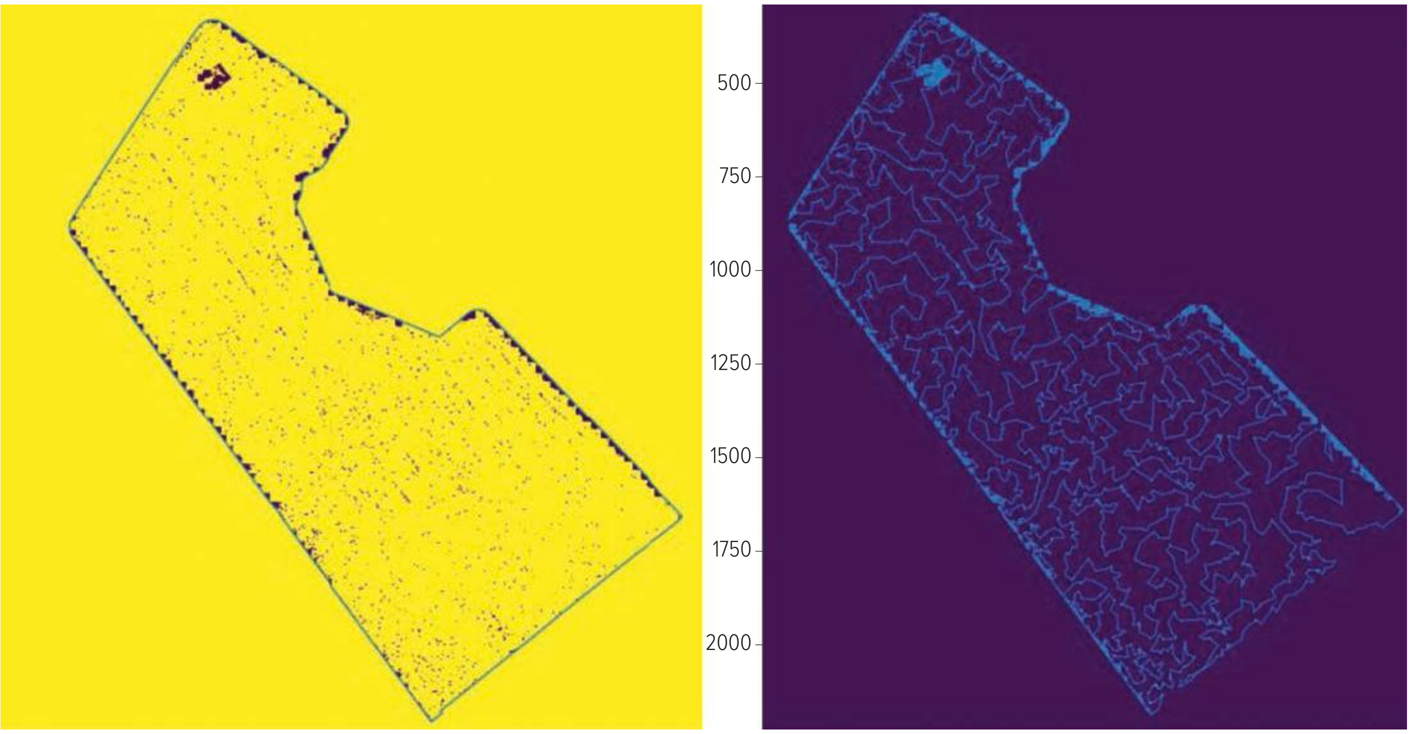
Table 8.3: Cost comparison of blanket rates versus pre-mapping weeds with the Single Shot drone then spraying.

Total area covered	Total area sprayed	Percentage spot sprayed	Average herbicide cost if blanket per hectare	Average herbicide cost saved per hectare	Total savings before drone costs
4837ha	1018ha	21%	$15.95	$12.20	$58,197

Note: The table is not completely valid in that the Singles potentially would have chosen different herbicide mixtures if they were making blanket applications, but it does give an idea of the savings that can be achieved without making any modifications to the boom.

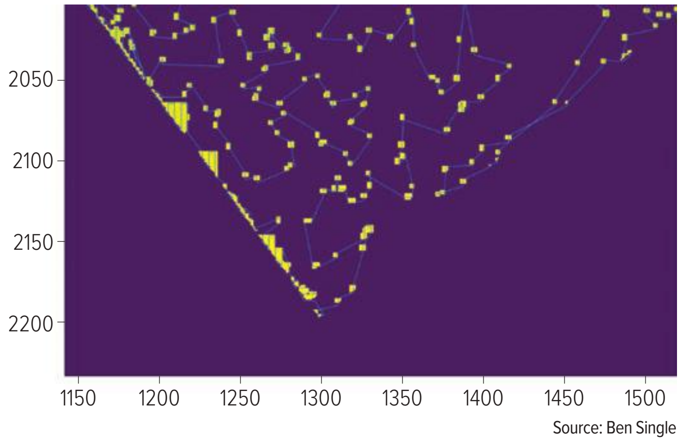
Data first published: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/08/drone-weed-mapping-for-spot-spraying

Figure 8.6: Left: actual weed coverage in a 125ha paddock (blue line is the boundary and purple is the weeds). Right: the path that the UAV would travel using the shortest route.



Source: Ben Single

Figure 8.7: A zoomed image of the bottom left-hand corner of the paddock to show the path the UAV takes over bigger weed areas, which could be further improved by refining the computations.



Source: Ben Single

Although having to map and spray separately seems more time consuming, Ben said it was less time intensive than most people thought because:

- the drone can map weeds much faster than an all-in-one;
- you can operate the sprayer at normal speeds (compared with going slower when sensing and spraying in one operation); and
- having a pre-made spray map means two or more sprayers can operate at once.

The other time saver is the ability to map in suboptimal conditions, such as the middle of the day in summer or if the ground is boggy.

Next steps

On-board real-time processing, green-on-green detection and drone spraying are all on the horizon. “The fundamental problem with the spray drone is carrying capacity,” Ben said. “Spray drones can typically carry about 70L compared to 10,000L for boomsprayers. But when you only need five to 10 per cent for spot spraying, a drone becomes more feasible. For example, if a 100ha paddock only needs five per cent sprayed, that’s five hectares. At a typical rate of 40L/ha, you only need 200L for that whole paddock. With a typical carrying capacity of 70L, it would take only three flights to spray the paddock.”

Being able to fly point to point, or weed to weed, rather than covering the whole paddock is particularly attractive to spray weeds in the shortest time possible. The ‘travelling salesman’ algorithm calculates the shortest route between weeds.

Ben ran a scenario across a 125ha paddock, comparing a blanket spray with an unmanned aerial vehicle (UAV) to spot spray using the travelling salesman algorithm (Figures 8.6 and 8.7). The drone mapped 1896 weeds.

To cover the 125ha with a UAV equipped with a 4m wide boom would require the UAV to travel 312.5km. Using his custom-built ‘door-to-door salesman’ computation, the travel distance for shortest route for one drone was reduced to 53.6km. The sprayer would only need to apply herbicide on 16km of the 53.6km flight path.

MORE INFORMATION

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The Single Shot drone at work in a paddock. Photo: Ben Single

Spot spraying delivery systems – some practicalities

Most growers know a lot about spraying; it is a centrepiece of most broadacre cropping enterprises. However, spot spraying fundamentals are quite different. Sure, there are obvious differences in relation to detection, but there are also key differences when it comes to the liquid delivery too.

Growers need to know the key differences to optimise their spot spraying. In normal spraying, nozzle size and spacing, travel speed and operating pressure determine the application rate. The boom height and nozzle fan angle do not influence application rate, whereas in spot spraying they do. It takes a little to get your head around this difference. A wider fan angle nozzle spreads the liquid further and so reduces the rate applied. Similarly, increasing boom height allows the liquid coming from the nozzle to spread out further and so reduces the application rate.

If we are trying to minimise waste and target weeds precisely, we need to carefully consider the nozzle selection as it depends on nozzle spacing, nozzle fan angle and boom height. If the name of the game is to minimise herbicide use, this will be largely determined by how precisely we target the application.

Spray band width to nozzle spacing ratio

The spray band width to nozzle spacing ratio determines how precisely the application is targeted. A ratio of less than one (that is, spray band narrower than nozzle spacing) would mean weeds are missed. A very large ratio means a lot of chemical is wasted, so chemical use would be substantially increased. The spray band width is calculated from the boom height and nozzle fan angle (Table 8.4). For example, a boom height of 50cm and a nozzle fan angle of 30 degrees gives band width of 27cm. If nozzles are every 25cm, this is a ratio of 107 per cent – close to one so not high enough to reliably provide good spray coverage. If the boom height is 60cm and the fan angle is 40 degrees the spray band width is 44cm, indicating a nozzle spacing of 25cm is ideal (ratio of 175 per cent). Figure 8.8 compares the spray band width to nozzle spacing ratio of a 50cm and 80cm boom height, with 25cm nozzle spacings and a 40 degree fan nozzle. At a 50cm boom height the ratio is 146% (good), but at an 80cm boom height the ratio is 233% (too high). The red triangles show where the ground is receiving spray from 3 nozzles.

This information is then used to calculate the overlap in herbicide from nozzles when spraying. Tables 8.5 and 8.6 show the spray band to nozzle spacing ratio at various boom heights and nozzle fan angles for a 25cm nozzle spacing (Table 8.5) and 50cm nozzle spacing (Table 8.6). The ideal overlap is approximately 150 to 200 per cent. For example, if the boom height is 80cm and nozzles are spaced every 25cm, the ideal nozzle fan angle is 30 degrees. A nozzle fan angle of 40 degrees and higher will create too much overlap and waste chemical.

Nozzle spacing is important as a system with 50cm nozzle spacing will typically use twice as much chemical as a 25cm system in a sparse weed population, and less than twice the chemical in a dense weed situation.

Table 8.4: Application spray band width in centimetres based on boom height (cm) and nozzle fan angle (°).

Nozzle fan angle (°)	Boom height (cm)				
	50	60	70	80	90
30	27	32	38	43	48
40	36	44	51	58	66
65	64	76	89	102	115
80	84	101	118	134	151
110	143	172	200	229	257

Table 8.5: Sprayer band to nozzle spacing ratio as a percentage for 25cm nozzle spacing.

Nozzle fan angle (°)	Boom height (cm)				
	50	60	70	80	90
30	107%	129%	150%	172%	193%
40	146%	175%	204%	233%	262%
65	255%	306%	357%	408%	459%
80	336%	403%	470%	537%	604%
110	572%	686%	800%	915%	1029%

Table 8.6: Sprayer band to nozzle ratio as a percentage for 50cm nozzle spacing.

Nozzle fan angle (°)	Boom height (cm)				
	50	60	70	80	90
30	54%	64%	75%	86%	97%
40	73%	87%	102%	117%	131%
65	127%	153%	178%	204%	229%
80	168%	201%	235%	269%	302%
110	286%	343%	400%	457%	515%

Table 8.7: Pattern intersection height (maximum weed height coverage in cm) for 25cm nozzle spacing.

Nozzle fan angle (°)	Boom height (cm)				
	50	60	70	80	90
30	3.4	13.4	23.4	33.4	43.4
40	15.7	25.7	35.7	45.7	55.7
65	30.4	40.4	50.4	60.4	70.4
80	35.1	45.1	55.1	65.1	75.1
110	41.3	51.3	61.3	71.3	81.3

Table 8.8: Pattern intersection height (maximum weed height coverage in cm) for 50cm nozzle spacing.

Nozzle fan angle (°)	Boom height (cm)				
	50	60	70	80	90
30	-43.3	-33.3	-23.3	-13.3	-3.3
40	-18.7	-8.7	1.3	11.3	21.3
65	10.8	20.8	30.8	40.8	50.8
80	20.2	30.2	40.2	50.2	60.2
110	32.5	42.5	52.5	62.5	72.5

Source: Brendan Williams

Pattern intersection height

Another factor that should be considered is the coverage of tall weeds. Fleabane is notoriously hard to kill, is often the key target and quickly runs up a tall head. Referred to as pattern intersection height (PIH), this is the height where the adjacent patterns intersect. This relates directly to the height of the weed that will be sprayed if located directly between nozzles. Closer nozzle spacing, wider nozzle fan angle and greater boom height increase the PIH. Tables 8.7 and 8.8 list the PIH – or how tall the weed can be for full coverage if it is located directly between the nozzles. For example, with a boom height of 50cm and a nozzle fan angle of 30 degrees with a 25cm nozzle spacing, a weed located directly between two sprayers needs to be 3.4cm or shorter to be fully covered with herbicide. Figure 8.8 shows an example of PIH for a 25cm nozzle spacing at two different boom heights.

Low boom height, narrow fan angles and wider nozzle spacing can all lead to striping with the top of tall weeds being missed. Typically, nozzle spacing is matched to detection field of view (detection width). For example, WEED-IT has 25cm nozzle spacing and WeedSeeker® 50cm.

Overlap issues

Typically, spot sprayers are set up to deliver a set rate when a single nozzle is fired. If adjacent nozzles are fired (in the case of larger weeds or a weed that dissects the field of view) then the rate applied will be increased. With spot sprayers, growers often aim to use very robust rates to get good kills. If the weeds are large, then adjacent nozzles will be fired resulting in an increased application rate.

In the case of WEED-IT, weeds greater than 25cm wide are assured of getting adjacent nozzles fired and therefore receive an increased rate. This is an excellent feature where large weeds get an increased rate. However, operators need to be aware of the impact this overlap has on residual activity of the herbicides used. It is not recommended that pre-emergent herbicides be used in spot sprayers and care needs to be taken when using knockdown herbicides that have residual activity. The impact of overlap can be reduced by using tapered flat fan nozzles rather than even flat fan.

Boom height control is critical

Maintaining the boom at the desired height is critical because it determines the rate applied and, more importantly, if you hit the weed. Hitting a weed is a bit like hitting a moving target. You need to know the forward speed, fluid speed from the nozzle and nozzle height to get the timing right. The fluid speed is typically maintained by keeping pressure constant.

The critical importance of maintaining boom height is the same with any spot spraying system. If the boom is unstable then it is likely the target will be missed, so the impact can be profound. Most systems will cater for the uncertainty of boom height by factoring in a band width. For example, with WEED-IT a band length of Xcm before and after the weed can be selected. In a suspended boom that is unstable, band length might be set at 30cm before and after the target whereas for a wheeled or stable boom it could be set at 15cm. The impact of this higher band length is that we use close to double the amount of chemical; therefore the importance of boom stability.

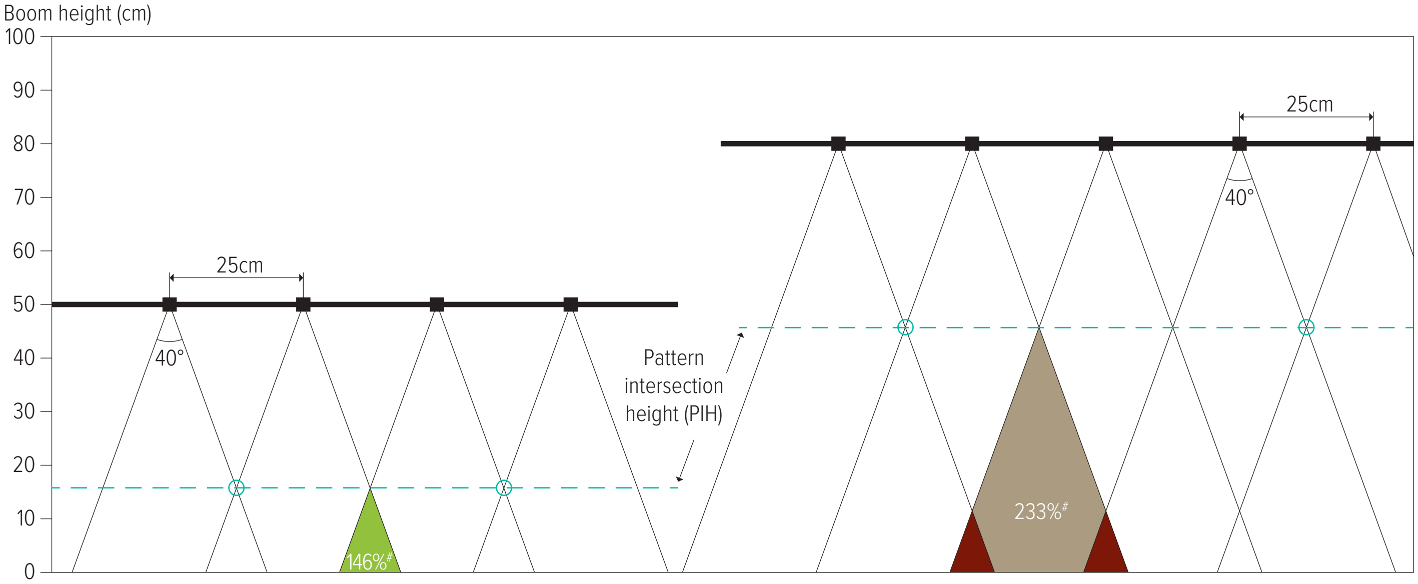
The Hayes suspended mid-mounted boom is a good example of a stable suspended boom option. The Agtronics Chaser is a good example of a hybrid wheeled boom, having a ground following wheel and a suspended tip controlled electronically.

Nozzle type

There seems to be some conjecture about what type of nozzle best fits these types of sprayers – even flat fans, tapered flat fans (this is the type that is typically used on blanket sprayers) and hollow cone nozzles are what have been typically used. The tapered flat fan reduces the spike in application rate when two adjacent nozzles are fired and so is often preferred. Hollow cone nozzles have capacity for greater coverage, but some of the benefit from these nozzles could be attributed to their greater fan angle. As many systems operate pulse width modulation (PWM), then a compatible nozzle will be required.

Drift control, especially when using 2,4-D formulations, requires the use of specific low-drift nozzles. By its very nature, drift from these types of sprayers is far less than normal sprayers purely because the volume being sprayed is often 10 to 20 per cent of what blanket sprayers use.

Figure 8.8: Comparison of a spray band to nozzle spacing ratio at a 50cm and 80cm boom height.



Spray band to nozzle spacing ratio (ref: Table 8.5).

Source: Alisa Bryce

PWM nozzle control

Unlike traditional spraying systems – where application rate is controlled via a motorised pressure valve and flow meter to keep the application rate constant with varying travel speed – this arrangement does not work with spot spraying because the flow is very erratic depending on the weeds present. The only effective way of maintaining the rate for spot sprayers is to use PWM nozzle control.

Pressure control systems

There is some conjecture about the best pressure control system to use on spot sprayers. The task for plumbing on a spot sprayer is quite unusual in that flow rate fluctuates wildly as weeds are detected. Generally, the preference is to use hydraulically driven centrifugal pumps which, by their very nature, respond immediately to pressure drops.

Further improvement can be made by having PWM hydraulic motor control to increase the responsiveness of the system. The other commonly used alternative is to fit what is called a Ramsay valve, which is a special type of pressure control valve that has massive capacity and fast response.

A quick test to determine the performance of a system can be done by monitoring the pressure when you hit the 'flush' mode so all nozzles fire. If the pressure drops significantly, then you know the system needs to be improved.

Boom recirculation

The primary aim of spot spraying is to minimise wastage, so it would seem counterintuitive to have to pump 50 to 100L of chemical to prime the boom. In some cases this might represent 10 to 20ha of spraying. Therefore, boom recirculation is a desired feature as this allows the boom to be primed without spraying.

Ease of use

Depending on your farming location, spot spraying systems are run for very long hours, almost continuously through the summer months in some areas. A key requirement is that the system is simple to use so hired labour can operate it. It is important to assess how easy the system is to operate.

MORE INFORMATION

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Non-herbicide weed control technologies – what is in the works?

In 2016, weeds were estimated to cost Australian grain growers $3.3 billion per year through lost revenue from weed competition and weed control costs. In the past decade there have been significant improvements in weed detection technologies, enabling the targeting and control of individual weed plants. This site-specific approach to weed control now being used by some growers enables a potential 90 per cent reduction in herbicide use.

However, herbicide safety, resistance, spray drift and pressures for certain herbicides to be banned mean researchers are looking at non-chemical control options. These are some of the non-chemical weed control technologies in development.

Blue light plus heat

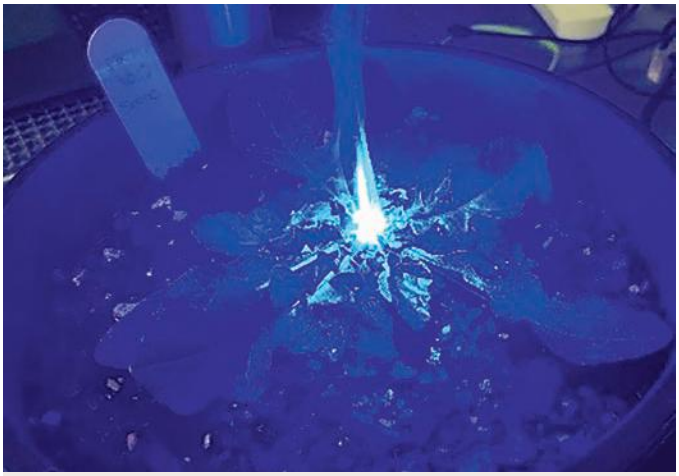
WeedErase™ uses a combination of blue wavelength light (440nm) and heating to kill weeds. There has been limited research into how exactly weeds are being eradicated with this device, but the idea is that, at 30 times the intensity of sunlight, the blue light disrupts photosynthesis by destroying chloroplasts, while the infrared heating (200°C) is believed to have some activity on plant roots. This technology was developed for home garden use and is available commercially in the US as a handheld device. It is effective, fast and targeted, but needs scaling up for use in broadacre farming.

Research is underway in the US with the Weed Seed Destroyer, a unit that bolts onto the harvester to kill weed seeds in chaff. Preliminary testing indicates that it works well in laboratory testing to effectively target weed seeds in chaff material at short durations (10 seconds) of exposure to blue light plus heat combinations.

Electrical weeding

Electrical weeding works by literally zapping weeds with a current often exceeding 10,000V. Electrical weeding is commercially available in Europe and the Americas and is popular with organic growers. The in-crop use of this system relies on the weeds being taller than the crop.

In Australia, Azaneo has developed a pulsed electric field (PEF) low-power electrical weeding method. Unlike the high-voltage weeding systems, this system uses pulsed electric charges of 10 to 15 joules and is non-thermal, meaning that plant death is not due to resistive heating. The exact science behind weed removal using PEF is unclear, but it has been demonstrated to be effective in the laboratory. There are promising results in field evaluations as well.



Laser weeding. Photo: Guy Coleman, University of Sydney

Precision weed control technologies

Precision weed control technologies target specific parts of the weed, such as flowers, seed heads, roots or growing points, and rely on precision weed recognition. At present, the industry uses whole-plant recognition for spot spraying, but there is opportunity to implement weed plant part recognition for precision weed control.

The recognition of plant parts also improves weed plant detection accuracy in partially occluded in-crop situations. For example, recognition of a weed growing point allows the weed to be targeted with a selective control treatment even if much of the plant is hidden by crop leaves. Microjet sprayers are one technology that, while using herbicides, can target areas as small as 10mm. This approach would allow the introduction of new herbicides but does require herbicides to be suitably formulated.

The non-chemical technologies that are being evaluated for precision weed control treatments include laser weeding, waterjet cutting and gametocides.

Laser weeding has been available for a few years with varying levels of success. The first low-powered models were only effective if focused on the plant for a full minute and therefore took too long for broadscale applications. Larger commercially available lasers – such as those on autonomous robots in the US (for example, LaserWeeder™) – were effective and very powerful at 100V but expensive. If laser weeding is to be an option for large-scale cropping systems, a lower cost, more flexible alternative will be needed. At present, research is underway that is producing promising laser weeding results with low-cost lasers (that is, about $100) on weed seedlings.

Waterjet cutting has been used for industrial purposes (for example, cutting steel or masonry) for many years, but has only recently been used for weed control. AquaTill, available in Australia, uses high-pressure waterjets of approximately 50,000 pounds per square inch (PSI) that can be aimed precisely at weed targets. Preliminary evaluations suggest that only a low volume of water is required, for example, 20L/ha of water to control a weed density of five plants/m^2.

As it uses water, this technology can be combined with herbicides to target larger plants. For example, Jetacide (also developed by AquaTill) combines water jets and herbicide to target ratoon cotton.

Gametocides are widely used in the hybrid seed industry to induce male sterility or prevent pollination and are now being used for weed control. A variety of chemicals can serve as gametocides, including plant hormones and ALS (acetolactate synthase, a key plant enzyme) inhibiting herbicides. There is an opportunity to select and refine gametocides to best target a particular crop system or weed species. There is also the opportunity to combine gametocides with precision application systems to better apply the gametocides specifically to the flowers of weed plants.

Waterjet cutting. Photo: AquaTill

Targeted tillage with the Weed Chipper. Photo: Michael Walsh

Weed Chipper

The Weed Chipper began life as a mechanised boot-kicker, inspired by a grower kicking weeds out of the paddock with his boot. It is the first mechanical system capable of site-specific weed control in large-scale cropping systems.

The Weed Chipper combines rapid-response tynes and a WEED-IT camera that spots weeds in a GoB situation. The tynes sit up in a 'stand-by' position, and when the camera detects a weed it moves a tyne to chip the weed out of the soil. Each tyne takes about one-third of a second to chip out a weed and return to the standby position.

The machine is pulled behind a tractor and operates efficiently at 10 to 15km/h, works on weed densities of about one weed per metre squared, and has successfully chipped weeds up to 80cm in diameter.

While the Weed Chipper does disturb the area of soil close to the weed, disturbance is minimal enough for the machine to be suitable for no-till farming. However, at higher weed densities (that is, >1.0/10m^2), there will likely be missed weeds and it may be more efficient to cultivate the entire paddock.

The Weed Chipper requires a large capital investment, but the ongoing costs are much cheaper than spraying as it does not require herbicide.

The next steps are finessing the technology for targeted tillage weed control in row-cropping systems; the Weed Chipper as it stands is designed for fallow systems. Improvements will include more flexibility with row widths, weed sizes and locations.

The Weed Chipper has been developed as a collaboration between the University of Sydney, University of Western Australia, Department of Agriculture and Fisheries Queensland, University of Queensland, hydraulics experts from David Nowland Hydraulics and grain growers in Queensland and Western Australia, with investment from the Grains Research and Development Corporation (GRDC).

MORE INFORMATION

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Glossary

Active light sensor
A light sensor that emits its own light to illuminate the crop and measure the amount of light reflected from it. Active light sensors usually only capture a relatively small number of wavelengths because it is difficult to produce a bright enough light.

Aerial imagery
Photos taken from airplanes, satellites, or UAVs to assist growers to determine variations within an area of interest such as a paddock.

Aerial photography
Remote sensing technique in which either an orbital satellite or aircraft records a photograph of a portion of the Earth's surface.

Autosteering
A system based on GPS signals that steers a vehicle across a paddock without overlapping or underlapping. Autosteering is used on tractors, combines, and forage harvesters, and on self-propelled sprayers, spreaders and mowers.

Band
A discrete interval of the electromagnetic spectrum between two wavelengths measured by remote sensing systems.

Base map
The outline of your field with its proper coordinates is your base map. Data collected within the paddock by your yield monitor will be defined in location by the base map, which is a binary digital map. This simple map shows the boundaries of a paddock or section and information about any unique feature.

Base station
A stationary GPS/GNSS receiver, set-up over a georeferenced point that provides correction data to a GPS/GNSS rover unit. Correction data can be broadcast via radio frequency or the internet. The premise behind the service is simple: a base station receiver is placed on a stable, immobile mount at a known point; the base station continually collects static position information under local or wide-area field conditions and the positioning errors computed at the base station (the differences between "observed" values and "truth") are assumed to be the same errors occurring at the mobile receiver (rover). The base-station errors are transmitted to the mobile receiver on the tractor, allowing the rover unit to use this information to calculate corrected positions.

Biomass imagery
A plan that shows the variation in the crop canopy within a field, based on the data from a biomass sensor. It can indicate differences in soil fertility and therefore crop nutrient requirements, allowing fertiliser to be applied at different rates in different places.

Boom section
A part of a spray boom that can be turned on or off independently from other sections along the boom. Automatic systems control boom sections using a positioning system and precise on-off timing to minimise over-application caused by overlapping or missed areas caused by underlapping.

Boundary
A GPS referenced definition of the exterior of a field. Used to delineate field area (hectares) and provide a basis for map creation. Important in Precision Ag equipment for defining where controllers should 'shutoff' (not apply product).

Compound topographic index (CTI)
A parameter used in terrain analysis to understand topographic characteristics.

Controlled-traffic farming (CTF)
A management system that ensures that all the vehicles used in a paddock keep to the same permanent traffic lanes every year.

Crop sensing
The process of collecting information on crop characteristics such as biomass and chlorophyll content from a distance, by means of satellite, aerial or tractor-mounted remote sensors.

Contour line
A line used to represent the same value of an attribute (elevation or yield).

Digital elevation model (DEM)
A digital representation of the elevation of locations on the land surface. A DEM is often used in reference to a set of elevation values representing the elevations at points in a rectangular grid on the Earth's surface.

Electromagnetic (EM) induction
EM surveys measure apparent soil electrical conductivity (ECa), which is an indirect measure of salinity. EM38 is one type of EM conductivity machine along with a DualEM. These machines transmit a pulse of current into the soil and have a receiver sensor that measures the soil's interference on this current.

Electromagnetic radiation
Radiation in the form of electromagnetic waves such as visible and invisible light rays, gamma rays, X-rays and radio waves.

Electromagnetic spectrum
The full range of electromagnetic radiation from the shortest to the longest waves.

Flow sensor
A sensor that measures the amount of flow through an enclosure (tube, pipe or housing) per unit of time.

Geographic information systems (GIS)
A computerised database designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information.

Global positioning system (GPS)
A network of 24 radio-transmitting satellites developed by the US Department of Defence to provide accurate geographical position fixing.

Ground-based sensor
A sensor mounted on a vehicle or building.

Ground-truth
The collection of information on the Earth's surface at the same place and time as a remote sensor gathers data. This permits the

interpretation and calibration of remotely sensed data sources such as a yield maps.

Guidance system
A system of equipment for automatically guiding the path of a vehicle. Guided steering avoids losses from underlapping or overlapping and allows more accurate working in the dark.

Hyperspectral sensor
A sensor capable of simultaneously measuring hundreds of individual wavelengths of the electromagnetic spectrum.

Interpolation
The process of predicting unknown values between neighbouring known data values.

Inverse distance weighting
A spatial interpolation method that assigns greater influence to known samples closer to a desired location.

Infrared sensor
A device that can detect information about a paddock, soil or crop from a distance, by measuring the amount of infrared light reflected from it.

ISOBUS
An international standard, ISO 11738, for communication between tractors and implements.

Kriging
A method that interpolates data from a known set of sample points to a continuous surface by assigning a set of weights to the samples based a semivariogram model, the locations of the samples relative to each other, and to the point or block being estimated.

Landsat (land satellite)
A series of unmanned earth-orbiting satellites used to study the Earth's surface.

LIDAR (light detection and ranging)
An airborne system that uses height data received from laser beams scanning the ground to provide very accurate maps of the ground surface. It can be used for mapping soils, monitoring erosion, floodplain management, etc.

Lin's concordance correlation coefficient (LCCC)
A measure of the agreement between observed and predicted values.

Management zones
Management zones are created by subdividing a paddock into areas with similar characteristics. Yield maps, soil texture maps, elevation data, EC data, sensor data and grower knowledge can be used to create management zones in GIS software. There are several methods available for creating management zones.

Near infrared (NIR)
Portion of the electromagnetic spectrum lying near the red end of the visible spectrum. Wavelengths of about 700 to 3000nm.

Normalised difference vegetation index (NDVI)
Measures the reflectance of red and near-infrared light by a plant to show crop 'greenness'. Higher NDVI values mean the crop is more green.

Prescription
Refers to the map created in a precision agriculture platform that assigns product application rates for variable rate applications. Prescription information is exported to a precision ag controller for application. Prescription maps are commonly used for variable rate seeding, fertiliser, lime and irrigation.

Proximal sensing
Using sensors or instruments close to the object being measured, but not necessarily in contact with the object.

Rate controller
An electronic device that varies the amount of chemical/plant nutrient applied to a given area.

Real-time kinematic (RTK)
A procedure where carrier-phase corrections are transmitted in real-time from a reference receiver to a user's receivers.

Remote sensing
The act of detection and/or identification of an object, series of objects, or landscape without having the sensor in direct contact with the object. The most common forms include colour and colour infrared aerial photography, satellite imaging and radar sensing. Examples of remote sensing data include satellite imagery, aerial photography and thermal imagery. This data can be used to identify problem areas (such as plant stress and irrigation deficiencies), differentiate bare ground from vegetation and as a tool in the creation of management zones.

Resolution
A way of detecting variation. In remote sensing, one has spatial resolution (the variation caused by distance separating adjacent pixels), spectral resolution (the variation from the range of spectral responses covered by a wavelength band), and temporal resolution (the variation caused by time over the same location).

RTK (real time kinematic) guidance
The highest level of positioning offered by a GPS system, +/– 2cm. This system requires a base station (on a tripod or building), with a GPS receiver and radio transmitter, to get a very local correction signal, accurate to a few centimetres. The base station can transmit to multiple vehicles up to five or six miles away depending on the terrain.

Satellite
A communications vehicle orbiting the Earth. Satellites typically provide a variety of information from weather data to television programming. Satellites send time-stamped signals to GPS receivers to determine the position on the Earth.

Sensor
A device that produces an electrical signal in response to a stimulus such as light or ultrasound.

Sensor-based variable-rate application systems
Systems which create applications maps by processing field data collected from real-time sensors as the implement moves through the field to alter an input, on-the-go.

Spatial resolution
Refers to the size of the smallest object on the ground that an imaging system, such as a satellite sensor, can distinguish.

Spectral resolution
The capability of a sensing system to distinguish between electromagnetic radiation of different wavelengths.

Standard deviation
A statistical term that tells how spread out numbers are from the average, calculated by taking the square root of the average of the squares of the deviations from the mean.

Temporal resolution
The time taken for a satellite to revisit the same location.

Tramlines/traffic lane/wheel track
Parallel lines on the ground created by the wheels or tracks of a vehicle, usually the tracks made by a sprayer or fertiliser spreader.

Unmanned aerial vehicles (UAVs)
An unmanned aerial vehicle (UAV), commonly known as a drone and also referred by several other names, is an aircraft without a

human pilot aboard. The flight of UAVs may be controlled either autonomously by onboard computers or by the remote control of a pilot on the ground or in another vehicle. They can travel along a fixed flight path or be controlled remotely.

Variable-rate application (VRA)
The application of seeds, fertilisers or agrochemicals at different rates as required by the conditions in different parts of a field.

Variable-rate input
The use of different rates of fertilisers or agrochemicals in different parts of a field. For example, fertiliser application can be increased early in the season exactly in those areas where plant density is low in order to build an optimum leaf canopy.

Variance
A measure of dispersion of a set of data points around their mean value. The square root of the variance is the standard deviation.

Variable-rate technology (VRT)
The devices enabling the differential application of fertilisers or agrochemicals in different parts of a field, according to an application map or real-time sensor.

Vegetation index
A scale that indicates relative growth and/or vigour of green vegetation, based on a ratio and/or line and combination of measurements of reflected light in the red and near infrared regions of the spectrum. Examples include NDVI and NDRE.

Wavelength
In Precision Agriculture technology, wavelengths are referenced when talking about radio transmissions for wireless communication or devices that measure/emit light in different parts of the spectrum.

Yield monitor
A system that gathers georeferenced yield data by measuring the mass or volume of a harvested crop per unit area, by location, within a field.

Zone management
A management system in which a paddock is divided into different zones, based on production potential, for the application of agricultural inputs.

Notes

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