Farming in the Zone

Digital Technology and Agronomy

A report for

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Executive Summary

This report investigates the link between plant science research, practical on farm processes and digital tooling to enable better management of defined zones within farmland. It intends to help growers make decisions with a better understanding of how they can utilise relevant farm and climate real time and historical data – overlayed with research agronomy – to gain more profit and reduce emissions.

The aim is to give confidence to farmers when adopting new agricultural technology or system changes within operations and help identify areas that would benefit from new investment, ensuring that time spent using new technology equates to money gained and not just an addition to an already overburdened workload.

Fundamentals that need to be considered when looking at making systems changes or on-farm investments are highlighted. It also provides insight on how to use new tooling to ensure crop production is reaching potential.

It is vital to address all general farm business practices prior to new technology adoption. Current on-farm equipment and management systems should be reviewed to investigate if new goals can be achieved without new technology adoption.

Thoroughly explore agricultural technology options including their accessibility, cost and serviceability and appropriately allocate within the budget for any transition. A well-constructed plan for financial investment is critical.

Employing experience can be difficult when transitioning into precision agriculture and data analytics, and it is dependent on whether the farmer has access to professional services.

There are profitable gains to be made with the application of new ag technology, but plant biology remains the same, so it is important to ensure any changes made will improve profit. Furthermore, it is also vital to understand how changes improve the growing environment for the crop, and the end yield result.

Risk and interest drive the focus of farm budgets, but with more seamless technology systems being introduced – and a critical approach to business observation – digital agriculture and technology adoption can provide new opportunities to maintain long-term business sustainability.

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Foreword

In 2011 I took on a new business venture leasing 5,300 hectares in the Orion farming district on the Central Highlands in Queensland. The region can be defined as rolling to slopping hills marked with contour banks, varying soil types and depths, spotted with areas of sodic soils, accompanied by varying weather patterns and often heavy downpours (270mm overnight).

With no previous experience farming in these soils and topography, it was paramount to build a data that we could use to help us identify and manage these variabilities. Initially starting with financial benchmarking to ensure that the farm was “really” profiting, I began to concentrate on water use efficiency (WUE) and realised that the environment and farming systems adopted played significant parts in the benchmarked WUE.

After spending three years, countless hours and too many app downloads, I began to use only what my machine software provided and our relevant research figures to build my prescription maps and define our management zones, with the goal of maximising production whilst reducing financial and environmental risk, all without outlaying more money.

Whilst I had noble intentions in my quest to improve our farm management, it was the information that our machines had been gathering that gave me the ability to plan our future farming systems. This data, along with our financial benchmarking, helped to outline areas we were doing well and areas that required further attention.

My report highlights the fundamentals that need to be considered when looking at making systems changes or on farm investments. It provides insight on how to use new tooling to ensure crop production is reaching potential.

The Nuffield Scholarship presented an opportunity to explore in depth an emerging industry of new service providers to the farm. It opened doors to researchers, government, farmers, educators and leaders around the world. The experience has broadened my view – not only on the grains industry – but all of agriculture and world trade.

I have visited Brazil, Argentina, Chile, United States of America (USA), Canada, The Netherlands, Italy and New Zealand and was amazed at how vibrant and positive the agriculture community is, as well as poised and ready to meet the challenges of tomorrow.

Acknowledgments

I would like to acknowledge Nuffield Australia for providing me with this once in a lifetime opportunity. The program has truly broadened my understanding of agriculture the world over.

Over a period of 13 months, I spent four-and-a-half months travelling as part of this study and I would like to thank the Grains Research and Development Corporation (GRDC) for their continued investment in Nuffield Australia and me as a scholar.

I think every scholar starts this journey with concerns of how the home fires will stay lit, and the adage is true that 'it takes a village to raise a baby'. My wife Sophie has cared for our children Mackenzie, Georgia, Hunter and Fletcher and all that whilst also being supportive by keeping me focused, organising accommodation, car hire and even checking emails. So thank you Sophie!

I thank my parents and business partners Peter and Kerrie for giving me the space from the business to travel and study. And our staff for stepping up to take on some extra workload.

One of the greatest gifts of Nuffield is the people you connect with on your travels. A special mention to Bob Stewart (Texas, USA), and both Nuffield Brazil and Daniel Schadeck for guiding me and translating through Brazil.

Logistically, comparable to putting people on the moon, Nuffield takes many people behind the scenes to make it happen. I would like to thank the team at Nuffield Australia, as well as Chontell Giannini from itravel Griffith for her efforts.

Abbreviations

API	Application Programming Interface
CAN	Controller Area Network
CTF	Controlled Traffic Farming
GPS	Global Positioning System
GRDC	Grains Research and Development Corporation
Ha	Hectare
MAC	Media Access Control Protocol
MTG	Modular telematic gateway
NUE	Nutrient Use Efficiency
NDVI	Normalized difference vegetation index
PA	Precision Agriculture
PAW	Plant available water
R&D	Research and development
ROI	Return on Investment
SAP	Software- Enterprise Resources Planning (ERP) system
TPML	Total Plant Machinery and Labour
USA	United States of America
WUE	Water Use Efficiency

Objectives

The objectives of this research were to define agricultural technology that would offer valuable return on investment (ROI) within the following criteria:

- The role of water in plant production and how farming systems can benefit from a micro-climate.
- Limitations in plant nutrition and soil condition.
- Possibilities and limitations of current agricultural technologies.
- The simplicity of data transfer to aid farm management decisions.
- Spatial data inputs.

Chapter 1: Introduction

As global food has become cheaper (Table 1), farmers have continuously innovated their farming systems to increase productivity, improve quality, and maintain profit margins.

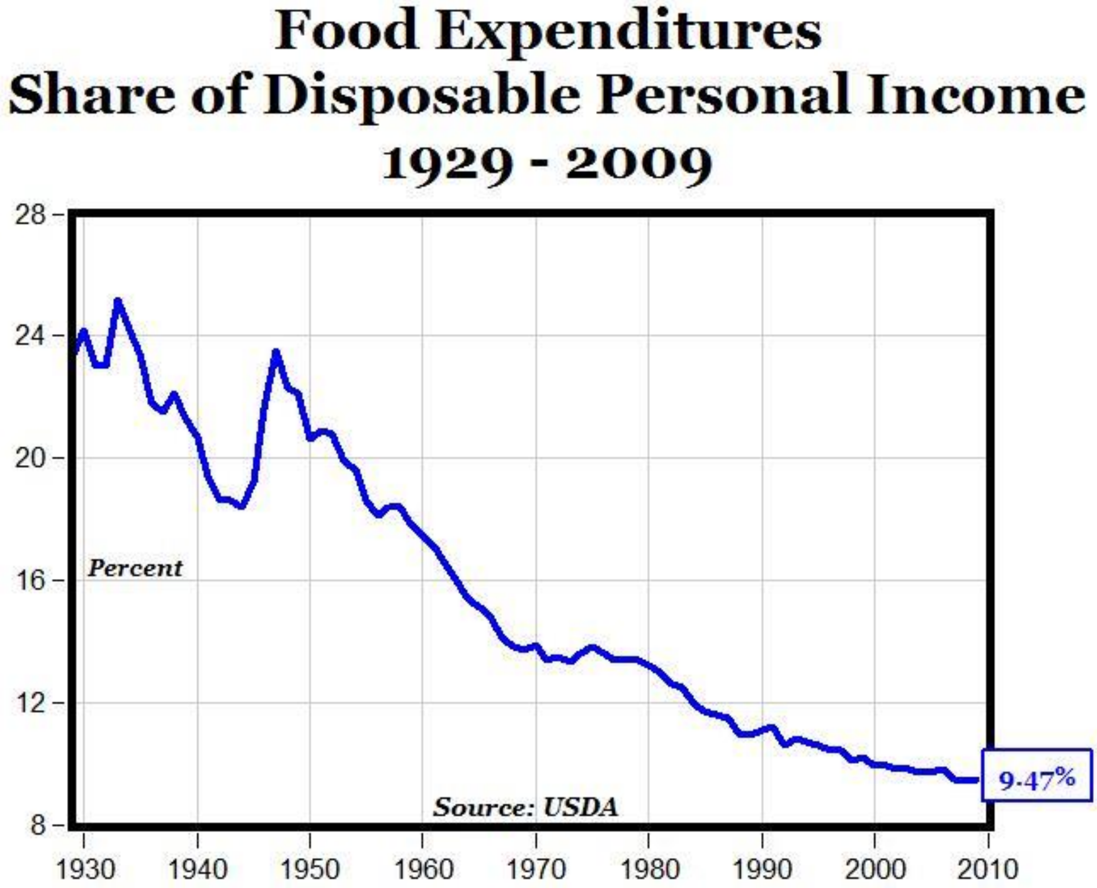

Table 1: 1 Source USA (http://3.bp.blogspot.com/_otfwl2zc6Qc/TC9NcrJvG0I/AAAAAAAAN3Y/S8hwBzi_3uk/s1600/food.jpg)

With the development of spatial referencing, farmers have gained new abilities to monitor analyse and control their farming systems. Despite this, adoption of advanced precision farming has stalled. New machinery purchases come with some level of new gadgetry that makes up the useful side of the ag-tech industry, and with companies like Monsanto, John Deere and AGCO headlining financial papers with acquisitions, the interest in data and information is evident.

With Global Positioning System (GPS) equipment becoming standard farm inclusions in the late 1990's early 2000's it was not until the release of the pocket internet device that attention has been given to what is possible with new technologies.

Silicon Valley has been producing endless new apps from new start-up companies filling the air with excitement that silver bullets will come firing out of every farmers' iPhone and world food security will suddenly be achieved for the next 100 years because computers are more advanced.

Yet the reality is that plants do not need the internet to grow, and phones do not print cash.

Farmers all over the world prioritise cost control as the key to remaining viable. Farm budgets however look very different across the world. Fuel, labour, machinery, agro-chemicals and environmental management expenses vary substantially from region to region and are largely impacted by world trade and government regulation.

Australian farmers operate in one of the most extreme and varying climates in the world. It is an extremely developed society with high employee standards, strict environmental regulations. It is also required to service consumers with a growing choice of products.

1.1 Learning from the Top 20%

The GRDC has published research '*Learning from the 'Top 20%' operators'* (GRDC, 2017) which involved collecting up to five years of benchmarking data from more than 300 cropping businesses nationally. The main take home messages included:

- Top 20% businesses are regularly generating 10% more crop yield from a similar investment into fertiliser costs.
- Replicating Top 20% farm business performance requires developing a low-cost business model in addition to optimising gross margins.
- Strive to keep variable costs less than 40% of business turnover.
- A 0.8 to 1.0:1 machinery investment to income ratio is possible while maintaining excellent operational timeliness.
- Top 20% businesses can keep Total Plant Machinery and Labour (TPML) related costs below 25% of business turnover compared to an average of 35% across the data set.

Whilst this information has been researched from grain and fibre production systems, other aspects of agricultural production operate under similar systems. New tools are giving farmers greater opportunities to manage their businesses in new ways including greater transparency for cost control and new marketing opportunities. Australian agriculture should lead the world to new standards in production, environmental stewardship and food safety.

Chapter 2: Farming Systems

Australian farmers produce food and fibre in one of the harshest and most variable locations in the world. With intense heat, strong winds and historic rainfall charts to rival Ricky Ponting's test batting scores, a large proportion of research and development (R&D) has gone into managing variable climatic conditions and breeding genetics to withstand the unpredictable weather.

To grow any plant requires three key components - water, light and a median for the plant to live in to support and feed itself. As a farmer, the task of raising plants is distributing its requirements and not limit its ability to use the water it can access, but to also manage the financial risk of this investment. In both dryland and irrigation systems, water – and its management – are key to having a profitable and sustainable farming system.

2.1 Water in grain production

When water falls to the ground five things can happen:

1. It can run off.
2. It can evaporate.
3. It can drain beneath the root zone.
4. It can remain in the root zone.
5. In can be used by the plant for transpiration.

Water run off can be managed but should be reduced to ensure maximum water storage capacity of the soil. The retention of stubbles has been a big driver in the adoption of zero-tillage and minimum-till operations, and more recently strip-till and deep ripping in certain soil types has indicated farmers looking to manage precipitation further.

Any form of tillage used in this fashion is being used to target compaction or a soil condition ailment that may be affecting healthy root development and nutrient and water availability.

To go further than this Controlled Traffic Farming (CTF) has been implemented into many farming systems to avoid compaction from machinery frequenting the paddock, and to direct water in paddocks at times of excess, aiding in the reduction of waterlogging. Crop rotations help to keep stubbles in the system without build-up of pest and disease.

Evaporation can also be managed with similar techniques. For example, ground cover over the fallow period shades and cools the soil surface. Narrowing rows up in the growing crop has the same affect by obtaining canopy closure faster. Any subsequent water increases the canopy humidity reducing the opening of the cuticular on the leaf aiding to improved transpiration activity.

Water lost beneath the root zone can be difficult to manage, requiring the storage of plant available water (PAW) in the profile. But with cover cropping or short fallow plantings it is possible to gain better use of this water to improve cover of the soil. (B.A Stewart, West Texas A&M University, 2017)

In the northern grain region of Australia, keeping water in the plant root zone is what gives plants the ability to perform in climates with high heat units and variable rainfall patterns. "*An extra 20mm of soil stored water could add 400kg/ha to yield – enough to double the profit in some situations!"* (P. Wylie, 2014).

The planning for the storing of water starts with systems adopted on farm. Methods of applicating fertiliser to aid infiltration, planter row configuration to maximise stubble cover, tyre configurations across machines and implements to travel on the inter-row and reduce compaction affecting root development and water infiltration.

Transpiration increases yield!

"*The goal of a dryland farmer is to use all the water but "ration" its use so there is some available for grain filling.*

GY = ET x T/ET x 1/TR x HI

When any one factor is changed, the others are also changed but not always in the same direction. Big yield increases can only occur when they are all changed in the positive direction and ET is the first limiting factor." (B.A Stewart, West Texas A&M, University, 2017)

ET: Evapotranspiration is the amount of water used by the crop between when it is planted and when it is harvested.
T/ET: Is the portion of ET used for Transpiration.
1/TR: Is the kilograms of water transpired to produce a kilogram of above ground biomass.
HI: Is the harvest Index.

All components are expressed as dry weight.

Much of what farmers have built into their farming systems has focused on HI. For example:

- Wider row configurations enable moisture to be rationed over the growing period.
- Reduced plant populations ration higher amounts of water per plant.

However, both actions have a negative effect on the other parts of the equation:

- Wider rows take longer to establish canopy closure which increases evaporation loss, and the stubble left over reduces ground cover.
- Reduced plant populations reduce biomass which affects canopy climate.

With these fundamentals, it becomes increasingly important to evaluate how the farming system influences the climate in the crop whilst well developed systems are reducing risk and returning well. Constant crop monitoring of water use efficiency (WUE) is needed.

Research has been done to establish baseline WUE and NUE budgeting figures by GRDC funded programs. The use of this data can be implemented into any farm planning budget.

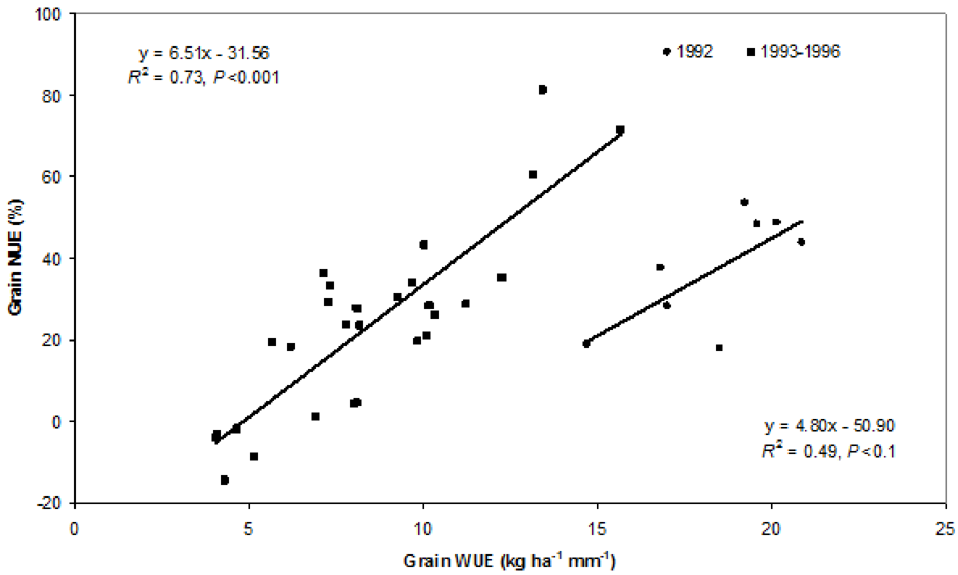

Figure 1: GRDC, Northern Updates July 2014

Figure 1 shows that not only does the plants ability to transpire more efficiently positively effect yield, but this graph shows increasing WUE is directly proportional to the plants NUE. In field trials can be done to study the effect of population and row spacing within a season (Figure 2).

Figure 2: Cluster plants grown in Texas. Source B, A, Stewart, 2017

By grouping plants, it is possible to check the performance of the selected plant spacing in a Row-by-Population trial without changing the planting configuration. The cluster leaves more space around the plants on the end of the cluster row to allow for observational differences of the plant. With even numbers of the seed holes on the meter discs covered over in quarters of the discs and alternated by 90 degrees across the machine, it gives the same effect on the plants as doubling the row spacing (Figure 3). For accurate comparison, another lot of discs can have every second seed hole covered to replicate the same population and yield comparisons can be made.

Figure 3: Cluster trial seed meter discs. Source B, A, Stewart, 2017

2.2 Nutrition and condition

In 1840, the German scientist Justus von Liebig formulated the "Law of the Minimum," (Figure 4) which states that:

> "*The rate of growth of a plant, the size to which it grows, and its overall health depend on the amount of the scarcest of its essential nutrients that is available to it*." (Oxford Plant Dictionary, 2nd edition, 2006).

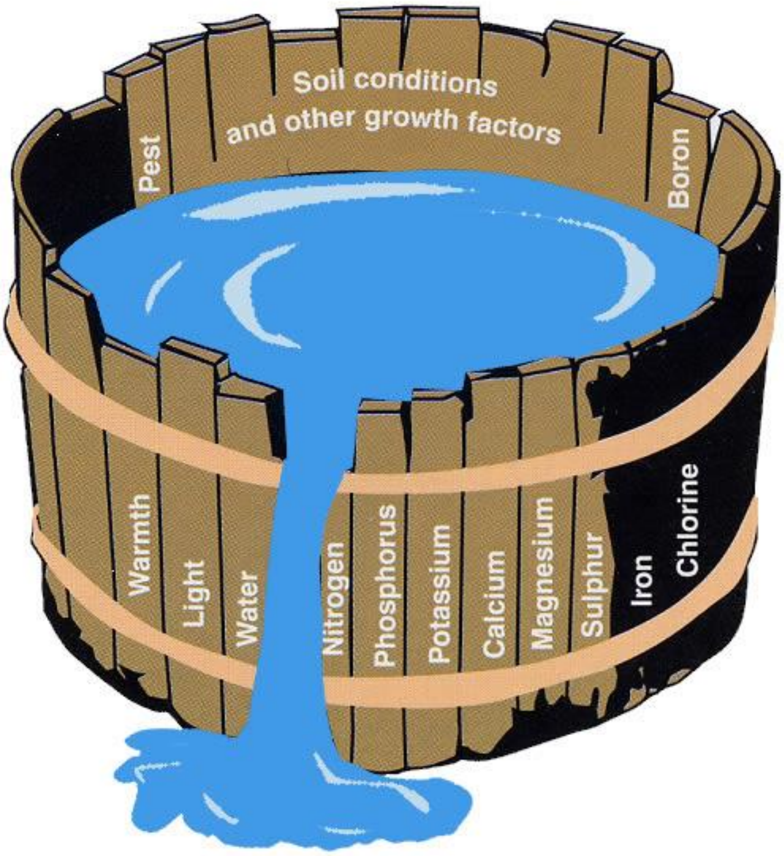

Figure 4: Liebig's Law of Minimum Source

Water is often the limiting factor of crop production in Australia. Nutrition and plant care will command a significant portion of the farm budget.

Nutrition budgets are designed around expected yield potential and key drivers for this assessment are:

- Crop type
- Variety traits
- Paddock history
- Soil testing
- Cost of fertiliser source
- Application equipment
- Contract services available
- Risk profile of the business

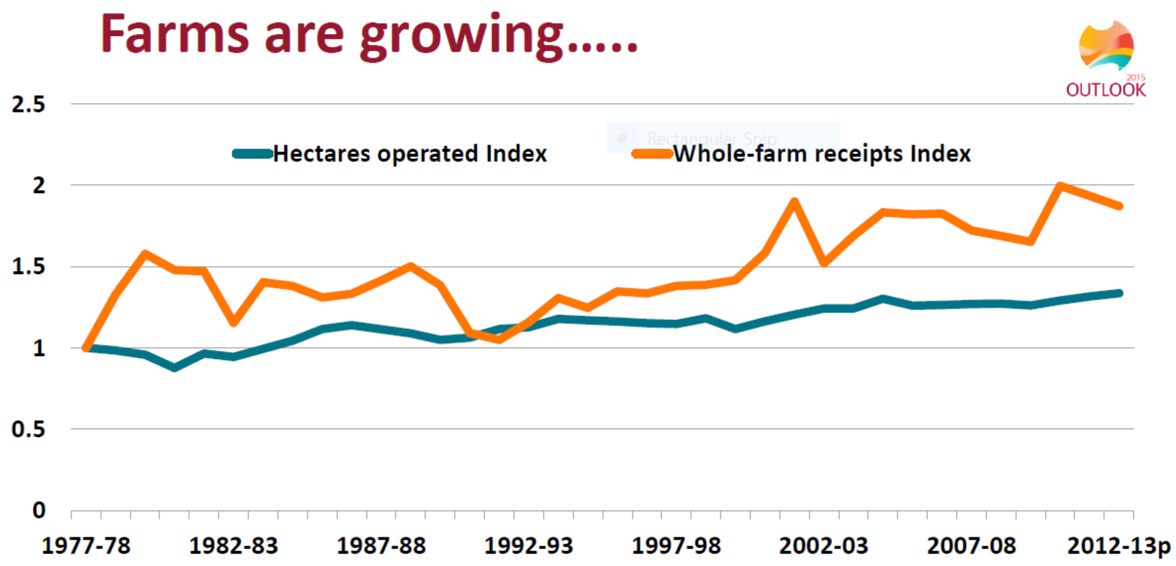

Figure 5: Farms are growing. Source: Peter Gooday, ABARES (2015)

It is easy to blame a lack of rainfall for less than expected yields. With so many factors to consider, improved nutrition within cropping systems is likely to remain a major constraint in Australian production. According to ABARES, the overall scale of the average farm and farm business in Australia has continued to grow in recent years (Figure 5) and so does the risk and onus on a manager's ability to make sound financial decisions.

Good nutrition management is essential to a farm business. Many farmers use rotation in a way to help maintain nutrient levels. For example, pulse crops are now widely used to help form a mutually beneficial relationship with rhizobia to help fix atmospheric nitrogen. But with years of continuous cropping and naturally occurring denitrification sequences such as flooding and severe soil water saturations events, the inherit levels of soil nitrogen are being depleted, even in the best soils.

Each year farmers in the GRDC northern region make decisions on the amount of nitrogen fertiliser they will apply across approximately four million hectares of paddock, with most of decisions made without the benefit of soil testing (GRDC, 2012). Budget allocation of nitrogen fertiliser in the northern cropping region can be up to 40% of variable inputs (GRDC, 2014). This is expected to continue whilst soil organic matter declines, along with other macro nutrients, and the need for fertilisers increases.

Baseline data needs to be collected through various forms, such as:

- Soil maps to consider soil starting and finishing nutrient levels
- Harvest yield maps to consider nutrient removal
- Grain protein levels to consider nitrogen removal

The expense of large soil sampling operations such as grid sampling can often be a hurdle in providing more accurate analysis, particularly fields with varying soil types, sub-soil constraints, and topography. Having a sampling strategy and using geo referenced recording of sampling sights can reduce the number of plots required to give a more accurate distribution of soil nutrition. A single sample within a varying field is not likely to give a concise picture of the fields' nutrition status.

Figure 6: Zone Map, generated from Filedview. Source, L.P Bradley, 2018

Figure 6 shows a field separated into seven zones for better economic management of a 526-ha field. By having this type of reference data, the farmer can better ensure their investment in nutrition sampling.

The goal of the nutrition strategy is to ensure that crop productivity is not limited by any one specific nutrient or subsoil constraint and may also impact a farmers' decision on crop type. Also, sodic fields may require a different crop rotation or management strategy for example. If the impacting zone's area is precisely known, it may not be significant enough to alter the rotation.

Increasing fertiliser inputs by volume and investment can often be limited by a farm business risk capacity, but many options exist to improve ROI:

- Placement
- Variable rate application
- Source of nutrient
- Timing

New methods of adoption offer multiple solutions, and compounding effects can give exponential gains.

Case Study: Francis Farms, Texas USA

On the high planes of Texas, Andrew and Marka Francis of Francis Farms have improved yields by 25% whilst maintaining the same applied rate of fertiliser. Andrew has been banding fertiliser in his cotton, corn row crop rotation using strip-till at depth and banding with his planter at seeding. The system was focusing on improving his return on inputs instead of increasing his application rates.

Figure 7: Francis Farms, Texas Source: Author, 2017

The on-planter liquid application allows for late season changes of fertiliser inputs. It creates flexibility of timing, an alternative source, and variable application without requiring another field operation.

Figure 8: Francis Farms, Texas Source: Author, 2017

The strip-till has enabled Francis Farms to directly band nutrition directly into the root zone while preparing a seed bed in the sandy, duplex soils on the high plains. The machine has also helped to retain valuable stubbles by inter-rowing the crop sequences.

Case Study: EMBRAPA, Brasilia, Brazil

The author visited EMBRAPA, The Brazilian Agricultural Research Corporation, which was founded in 1973 and is under the aegis of the Brazilian Ministry of Agriculture, Livestock, and Food Supply. Their role is to overcome barriers that limit the production of food, fibre and fuel in Brazil.

Figure 9: EMBRAPA P trial site, Brazil Source Author, 2017

Figure 9 Is a phosphorus trial site at Embrapa Cerrados. The site has been treated for PH, the soil conditioned, and nutrition corrected with all but phosphorus. Varying rates have been applied in different plots and it shows a clear deficiency in the 0P control with an average annual rainfall of 1,200mm this represents the impact of an extreme deficiency.

Amelioration programs are often expensive and logistically challenging, but subsoil constraints can also be catastrophic to plant production systems. In many growing regions the addition of ameliorants is essential to have and form of plant production.

Newly adopted EMBRAPA research in Brazil has led to the opening of new farmland that would otherwise be unused due to poor soil conditions and low natural fertility.

Figure 10: Cerrado Natural vegetation, West Bahia, Brazil Source Author, 2018

The Cerrado region has enormous potential if the correct steps are taken. Liming and gypsum applications, cover cropping and stubble retention is the key to farming productively in this region (D, Schadeck 2018).

Figure 11: Corn crop with Bracaria grass inter-sowed and banded nutrition. Source Author 2018

An integrated approach to a farming system is putting steps in place to manage the natural existing limitations within a farm site. Good crop yields are a result of good planning and implementation of crop production considering all factors, starting with crop choice, the rotation program and how moisture is stored and used on the farm.

Every mistake, delay or oversight on inputs can cost 10 or 15% in yield. Correct these problems and average grain yields can be doubled in the GRDC's northern grains region. Profits could lift five to ten times! (GRDC, 2016).

Chapter 3: Technology

Technology exists in every facet of modern-day life. People are connected 24-hours-a-day through mobile phones, Google is storing search preferences, and cars can customise the automatic gear shift. Many are happy to receive notifications on their phone any time of day and enjoy the way a new gearbox works in their Mazda 3. Yet Google providing an improved searching experience, particularly as you scroll through Facebook, is often met with scepticism and conspiracy theories.

The point is that technology exists in many layers. Not just the device but technologies leverage off one another to improve the original concept and people use them continually.

In crop production the layers of technology are extensive, including:

- Seed genetic tooling e.g. (GMO, CRISPR)
- Seed genetic proofing e.g. (LGC Hydrocycler)
- Agro Chemical Distribution e.g. (SAP software)
- Machinery Telematic Communication e.g. (JD Link)
- IOT, IOF e.g. (Spectrum Technologies, Climate Field View)
- Optic and Satellite Imagery e.g. (Weed-It, Weedseeker, Planet Labs)

These platforms and systems have become daily tools used by farmers that are not directly required to operate a farm business but used to improve its management and deliver targeted outcomes, reducing time, cash and human error.

> *"Have I fully exhausted the internal opportunities within my business to increase gross margins and net profit through crop rotation, crop agronomy and operational timeliness?"* (S. Vogt, Rural Directions 2018)

To ensure that adopted technologies are a profit driver, it is essential to seek technology that can deliver return on capital and time invested. For example, in the last ten years the humble harvester has become a monumental cash debt chasm, with added tech and a never-ending cycle of ratcheting increases, but most importantly, productivity increases aside it creates the base platform with geo-referenced real time yield maps which creates the foundation for prescription development.

Figure 12: Data inside the harvester. Source L.P Bradley 2017

Along with the production increase also came a set of tools such as header front height and return control, automated setting adjustments, in cab function of all parts adjustments from a button, so much equipment added to the cab, that due to not needing to leave the seat, manufacturers decided to install a fridge to occupy the operator during long shifts and assist with their ability to function the machine at optimum capacity for longer (Figure 12).

Modern equipment can greatly improve the ability to transfer knowledge, observe production variabilities and execute a cropping program, all the while maintaining the parameters that are put in place by the manager. For example, the harvester generates a yield map which then gets calibrated by the manager. Soil tests are undertaken, cross referenced with the geo reference site on the yield map before generating a prescription map for applied nutrient after establishing the financial budget allocation. In summary, the manager does not create the map, instead the manager sets the parameters for the job using knowledge of crop production and the risk profile of the business.

3.1 Precision Agriculture (PA)

> *"With increased globalisation occurring in every sector of our economy, today's farmer needs to produce better, greater, cheaper, and faster to remain viable. Precision Farming can help today's farmer meet these new challenges by applying the right input, in the right amount, to the right place, at the right time, and in the right manner. The importance and success of precision farming lies in these five "R's"."* (Raj Khosler, Colorado State University.)

PA seeks to exert more control over a production system and can manage different areas of land differently, Tools exist to meet PA needs but each tool must be well considered, and the farmer should have a good understanding of its advantages and limitations.

PA technologies can be sub-grouped into inputs and outputs. Inputs contain information received to enable an action in the field. Sometimes these inputs are direct and sometimes they are indirect or require modelling to enable the action.

3.2 Agronomic knowledge

Agronomic knowledge is often overlooked in discussions surrounding PA and ag-tech. It is more challenging to digitise knowledge into a useable format for PA purposes, but the development of new agronomy platforms such as Farmers Edge, Echelon, and Climate Fieldview are going a long way to bridging this gap.

> *"Climate are very focused on return on investment, not looking to replace experience rather to enable managers to make better informed decisions around variability with a Collecting, Describing, Prescribing approach*" (Verona Montone, Climate, SP, Brazil).

These platforms can replicate an agronomic decision invariably throughout a paddock. Through geo-referenced collection of field data, new layers can be generated being guided by the agronomist or manager parameters. These platforms chronologically collect and file operational data also for future reference and create the conduit between GPS and machinery operations. Offering customisable inputs such as climate data, (precipitation, radiation, evapotranspiration), can also build new layers previously not available.

Media Access Control (MAC) protocols such as Sigfox, LoRoWan, and MESH networks, provide channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multiple access network that incorporates a shared medium.

Figure 13: Watchdog Weather Station Source L.P Bradley 2017

Whilst many of these companies were founded producing sensor products, market growth and consumer demand has seen them transferring into applied uses from research which enables users without being educated in their sensors to utilize the product and to make better decisions (David Lau, Spectrum Technologies, Aurora, IL, USA) (Figure 13).

With the cost of this type of infrastructure coming down, it creates opportunities for farmers to collect climate, soil reference and insect data in real time and much more site-specific to the current government infrastructure and data sets provided. Having an open-source focus on these products can also open new options.

Leaf wetness sensors placed in fields can help guide new management decisions on fungicide applications with better climate indicators than pre-determined experience. Instead of adhering to rules of thumb around weather predictions, a manager can begin to map in field indicators to calculate accurate thresholds for application operations. It can also aid with retailers to position stock where it is required faster instead of the farmer having to pre-purchase products at the start of a season.

Insect traps work in the same way to extend the eye of the scout to make better use of their time in tight season windows. Hot spots and migrations can be more quickly and accurately identified, to optimise the workload of the scout and to speed up the lapsed time to applicate.

CSV file generation from using these types of sensors along with collected imagery has the potential to produce RX files for fungicide and insecticide applications, but speed of image collection and optics are still a major limitation in this process being broadly adopted.

3.3 Technology from fertiliser

Fertiliser products are also helping to assist in the accuracy of PA. Not only to placement but the right amount, and at the right time, can be a big challenge in Australian farming systems, most notably due to unpredictable weather. Nitrogen is still considered to be a major limiting factor in Australian grain production, but often this is the result of not being able to add more nitrogen particularly to dryland crops. Spreading can have severe losses if climate conditions are unsuitable at the time of application, resulting in reduced rates of nitrogen begin accessed by the crop or the timing of the operation being less than ideal for the growth stage. However, the cost of liquid nitrogen in many regions provides a clear cost and operational advantage over other methods for application.

Benchmarking of WUE and NUE after crop sequences aids future nutrition strategies. Despite a season showing good profits, benchmarking ensures farmers are optimising ROI on resources. Urease inhibitors such as Incitec Pivot green urea NV and Impact Fertilizers black urea contain urease inhibitors, which not only reduce ammonia losses but can also aid in targeting nitrogen availability at a more desirable time with greater flexibility on application timing.

Research has shown wheat yield increases of 7.5% with a 70% positive result and Corn yield increases of 7% with a 90-93% Positive result using urease inhibitors, on spread applications. (Nico Vario, ASP, BA, Argentina.)

3.4 Seed production

Seed production is the first step in a plant production system but interestingly, with operating systems modernising and such a large variation in farm practices, each farmer has a different preference to what type of genetics they are looking to bring into production. Many seed companies have claimed responsibility for historical production gains whether it be GMO technologies, new disease packages or Flex attributes.

Considering the impact a farm system has on the growth of a crop and its phenology, it is also more relevant than ever that breeders have a good understanding of the client they are producing for, in particular levy funded public breeding programs.

Case Study: Pioneer Dupont, Des Moines, USA

The author visited DuPont Pioneer in Des Moines, Iowa, in 2017. They are a world leader, developer and supplier of advanced plant genetics to farmers in approximately 90 countries.

Plant breading is a slow and arduous job, taking significant time and investment to bring new traits and products to market. GMO and CRISPR have been monumental in accelerating these programs, able to bring crosses over in a single function irrelevant to crop growth cycles (M. Owens 2017) but have however had their critics and access is still debated worldwide.

Figure 14: Pioneer Dupont, Des Moines, showing the change in corn cultivars through history. Source Author, 2017

Case Study: Louisiana State University, Rayne, USA

Hydrocyclers like seen here at Louisiana State University of Rayne in Louisiana (Figure 15), help breeder's proof genetic type from fields by loading multiple samples, in this case up to 145,000 samples in an eight-hour day. This ability speeds up plot analysis enabling accurate monitoring of individual plants within plots. Non-compliant plants can then be removed from the plot to maintain purity.

Figure 15: LGC Hydrocycler at LSU. Source Author 2017

The 8c/sack rice levies at this site are focused on varietal gains and speed of development to keep pace with 'Red Rice Induced Mutation'. Clearfield rice was developed here mid 1990's. This technology allowed for the chemical control of red rice in a rice production field for the first time. (A, Famosa, 2017)'

Andrew Farquharson, Director at Toowoomba Engineering has been in the agronomy industry for 25 years. He has penned the term "*Plot to Plot to Paddock to Plate!"* In other words, with current computing systems it is possible to have total production transparency from the lab to the table, giving consumers an accurate picture of what goes into growing the products they purchase, and allowing them the choice at the shelf.

3.5 Optics and imagery

This area of technology is one of the most talked about, not only in agriculture but in all industries, with similar uses overlapping industries. These forms of imagery give both observers and operators enormous insight into crop performance and enables direct decision making through such equipment as spot sprayers Weedit and Weedseeker.

Optic technology has been keenly adopted in the spraying industry, setting a new benchmark for fallow weed control. With huge reductions in a single pass herbicide knockdown control, it is easy to quantify if this technology has a fit in a farm system. Furthermore, imagery gives insights into trends and crop production at any stage of the growing season.

Case Study: Stanford University, USA

Figure 16 is an image from Planet Labs providing 3m to 5m resolution representing the average corn yields across the USA states of Iowa, Illinois and Indiana between 2000 and 2015. David Lobel PhD is a Director at the Center on Food Security and the Environment and his research focuses on agriculture and food security, specifically on generating and using unique datasets to study rural areas. He states that when the distribution of these yields by year is considered against density, it shows that yields are increasing in the higher yielding areas of fields whilst lower yielding areas are remaining similar over time (David Lobel, USA). This clear focus on improving yields in higher potential zones has proven to have increased overall production.

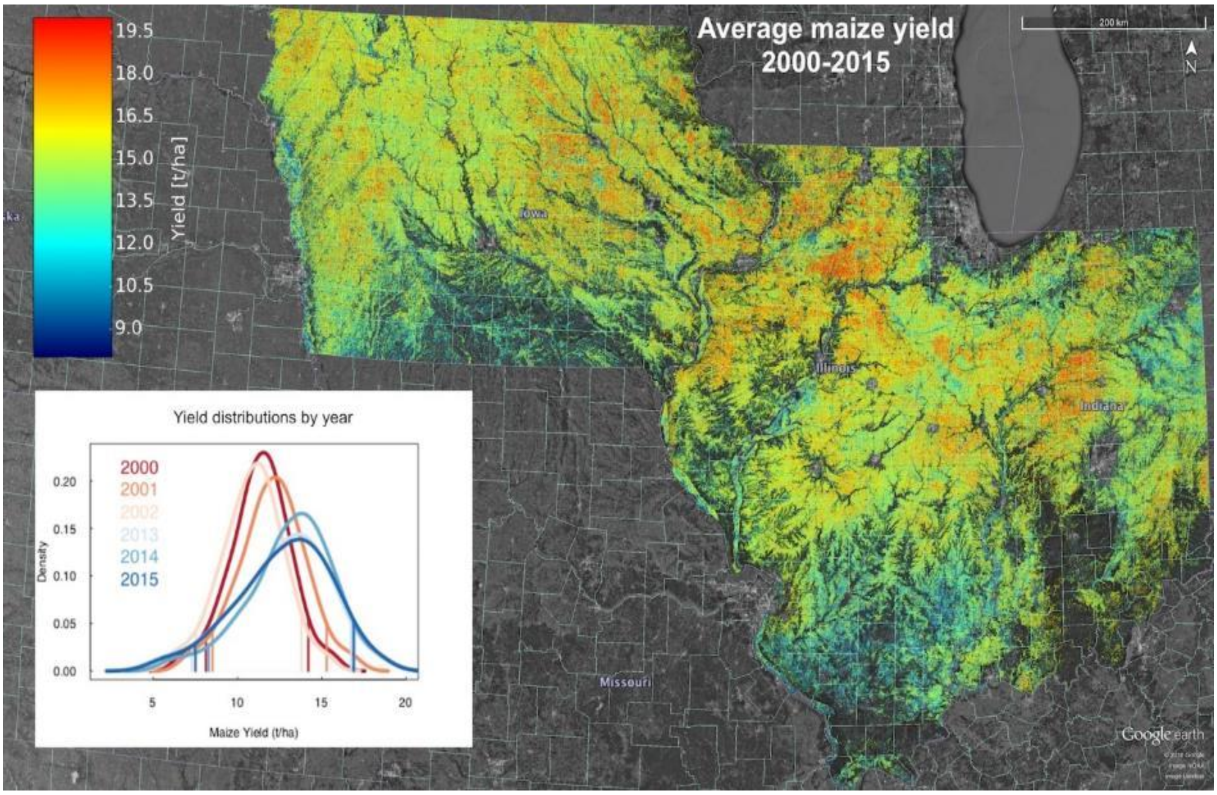

Figure 16: Source D. Lobel, Stanford University, USA 2017

The cost of providing this information is getting cheaper, more accurate, and with greater frequency, with clear benefits to the farming community to increase flexibility and monitoring of systems developments over long term. Planet Labs are now providing image data included in several farm management software platforms.

3.6 Subsoil imagery

Sub-soil Imagery provides farmers with spatial data at depth across the field otherwise not possible with soil sampling.

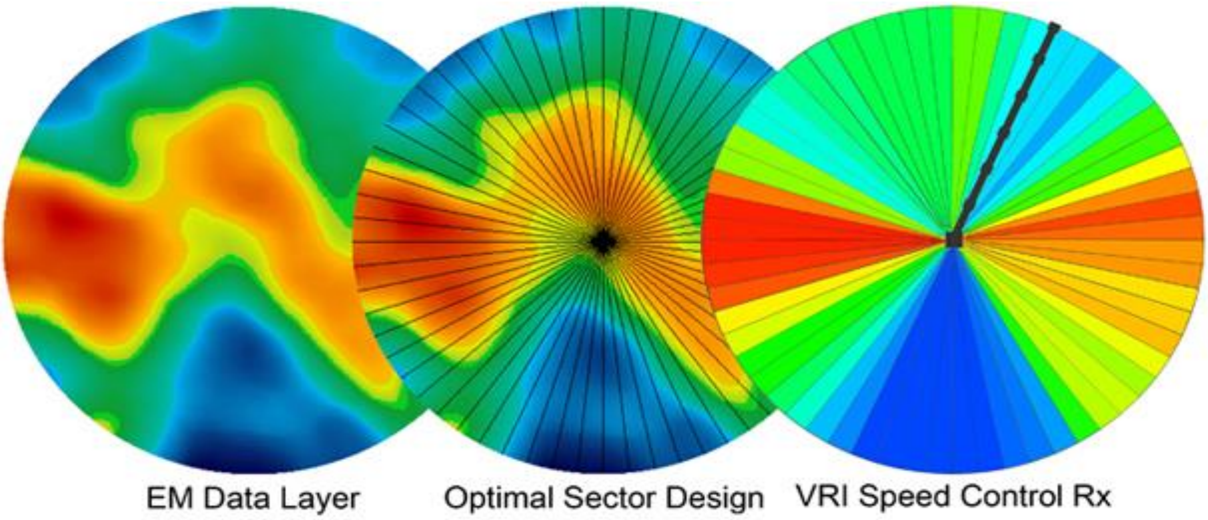

Figure 17: Source VNET, Australia 2017

EM38, Gamma Radiation, EC mapping are becoming common place in data layers for zone management development. Many environmental government funded programs are providing incentives to capture this data. This type of imagery is fundamental in developing sampling strategies to build amelioration prescriptions and with:

- Soil sodicity: affecting 8.1 million ha and costing growers $433 million/ year
- Soil acidity: affecting 1.5 million ha and costing growers $61 million/ year
- Soil salinity: affecting 2.6 million ha and costing growers $47 million/ year
- Compaction (one form of Physical soil structure decline) – affecting 0.8 million ha and costing growers $37 million/ year

(GRDC, 2017)

These tools have limitations but like all data collection, care needs to be taken that field conditions such as moisture content is even across the field to avoid developing a water map. The cost of these sensors is also becoming cheaper with medium to large farms most likely affording to purchase the equipment against to paying a contractor, but it is important to consider the labour capacity before doing regarding experience and time constraints. There may also be expenses to reformat data to be used in management software and equipment.

Case Study: NATIVA, Brazil

NATIVA, Brazil have centred their prescription development around their major limiting soil conditions, using a penetrometer to map compaction, and have between 50 and 60% of their client's fields mapped using EC and grid sampling (Amorim, R 2018). To improve the cost effectiveness of the process the company purchased their own equipment and built their own testing lab at a cost of approx. $800,000AUD.

Figure 18: NATIVA testing equipment, Formosa Brazil Source L.P. Bradley 2018

Under performing zones in extreme cases are used for other land uses such as eucalyptus production to provide a heat source for grain driers.

Figure 19: Produtiva Farm, Formosa Brazil. Source L.P. Bradley 2018

3.7 Equipment capacity and connectivity

Equipment capacity and connectivity has improved dramatically recently with manufacturing companies recognising software as stand-alone equipment and providing integration through data sharing from planting input data, harvesting data and application coverage.

There are several options to transfer this data:

- Manual input setup data
- Use of USB or SD cards
- Use of internet/ telemetry

Manual input setup data

Manual input setups provide the most inaccurate transfer of data, due to an estimation being made on numbers (GPS Headings) and spelling mistakes requiring editing after the job completion to have data to overlay and compare. Inaccurate inputs of guidance lines reduce the performance of banding operations, increases the impact of wheel tracks on soil compaction and can affect overlap performance if multiple machines are being used in the same field.

USB or SD cards

The use of USB's and SD cards is an accurate way to transfer data but relatively time inefficient. SLC Agricola in Brazil are still using this method despite farming over 400,000 Ha and having huge on farm labour levels. But with poor connectivity and despite machinery having the capability to transfer through an internet network, this gives the managers the ability to ensure the machines are setup correctly and the data transferred is accurate (Menezes, 2018).

Internet/telemetry

The use of the internet to transfer data is the fastest method, provides absolute accuracy and avoids having to travel to the machine to input data, or back to the office to download it. This can be done from anywhere in the world. It does have the highest associated cost though, requiring access to network via yearly subscriptions which fluctuate based on the size of the fleet. Most new equipment come equipped with the MTG (modular telematic gateway) that enables this transfer, but older machinery can also have them installed.

Telemetry is also used in a range of sensor equipment, from weather stations to blockage monitors. It enables wireless connection of information transfer and reduces the stress on the main CAN (controller area network) wiring system for data not relevant to the main operation begin undertaken. Telemetry can operate closed systems like MAC protocols to transfer the data.

Farmers have always managed inputs and outputs but traditionally had to manage this via pen and paper with only paddock referencing, diaries, and spreadsheets to store data. It is not possible to transfer memory between brains but with current platforms available farmers can transfer and utilize data forever into the future, with the past begin a search word away (Sonka, 2018).

Approaching PA should be met with a 'SWAT' strategy e.g strengths, weaknesses, opportunities and threats. Often assumptions around technology can confuse opportunities and threats so a Strategic plan needs to be developed to succeed.

Case Study: Lindley Downs, Queensland

All cropping seasons provide different and variable data sets, however focusing on WUE, and NUE benchmarks helps to determine the success of the season in relation to available resources i.e. rainfall/precipitation management, fertiliser strategies and integrated pest management strategies.

The 2017 central Queensland winter crop cycle created many opportunities to map PAW via harvest yield data due to very low in crop rainfall. The aim of this case study was to improve variable rate management and to assess the viability of certain crop sequences for future management decisions. The first step was to benchmark KG/MM/HA for the crop type.

Measured rainfall was observed at 29.5mm for the growing season. With such a low rainfall event it reduces the effect of on field rain variability and redistributed precipitation through overland flow.

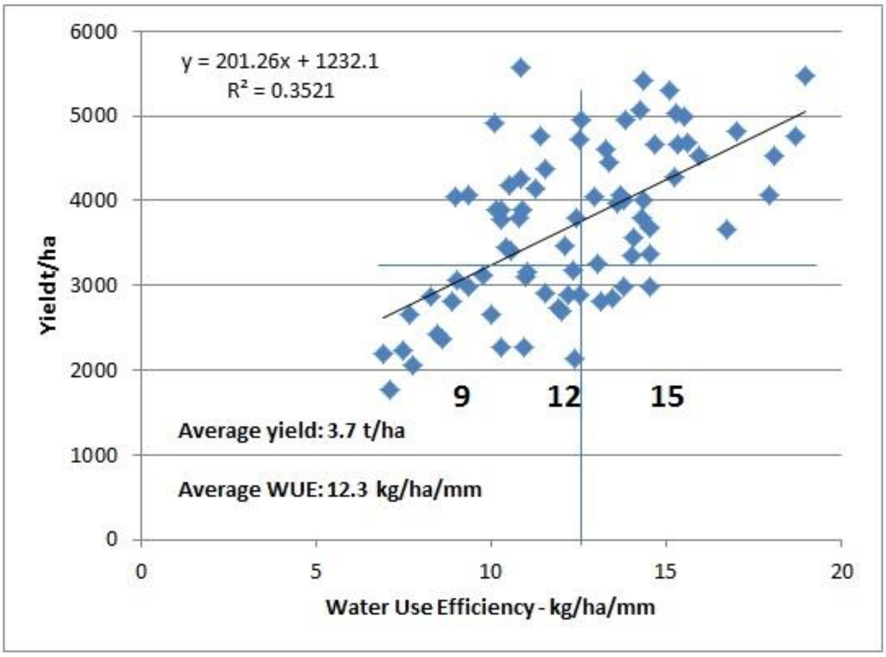

Table 2: WUE of wheat; north-east NSW and south-east Qld (2007-2012). Source: Fritsch & Wylie, Agripath 2017

Utilising researched average WUE, a fields average PAW can be defined against a corresponding crop type.

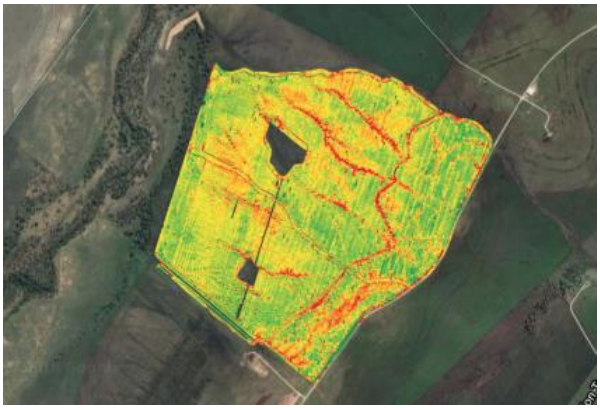

Figure 20: Chickpea. Source Author 2016

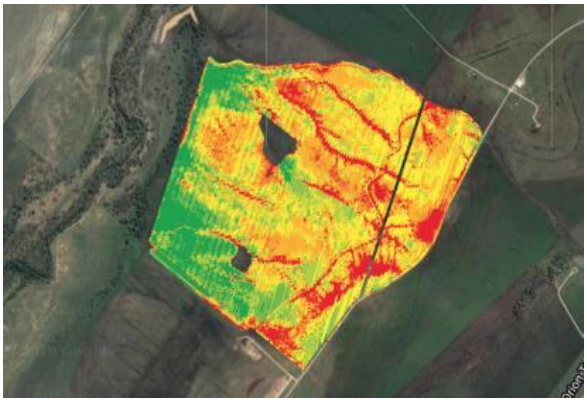

Figure 21: Wheat. Source: Author 2017

Effort needs to be made to ensure raw data is interpreted correctly. To achieve useable yield layers, calibrations need to be made on equipment at the beginning of the field to capture the field variability accurately without adjusting as the field is harvested.

The contrast in Figures 20 and 21 shows that in 2016 with decile 10 winter rainfall, the variation in yield is not as determined by stored moisture. Whereas with a Decile 1 season such as 2017, shows more exasperated detail of the lower performing management zones, but the zones remain relatively the same.

The wheat tonnes harvested in the field totalled 815.87 metric tonnes. Total area equates to 389 Ha. Using the collected layers and agronomic research data, it is possible to build management zones relevant to PAW and to maximise NUE through better distribution.

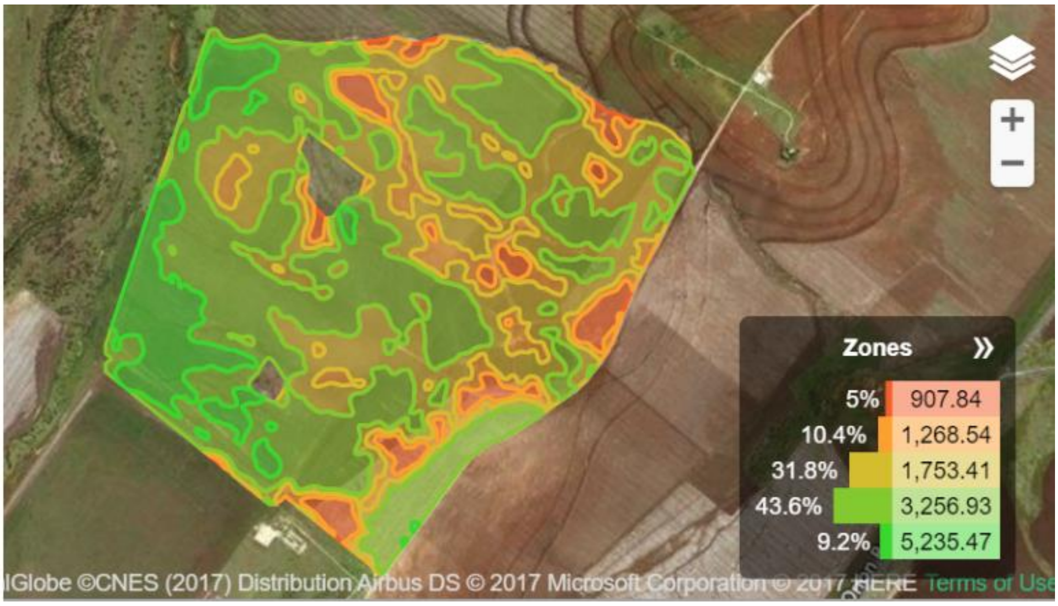

Figure 22: PAW Zoned Layer Source: Author 2017

After the management zones were defined by their water holding capacity, it was scrutinised against an average operation to ensure the management strategy was showing a positive ROI.

Taking into consideration a 10% deviation, it shows only 31.8 % of the field represents the average, and that 52.8% of the field is above average. It could be assumed that in this case variable rate would be a benefit, but robust economic analysis needs to demonstrate a positive net benefit (Simon Vogt, Rural Directions, 2018).

The data is used to forward plan the following year fertiliser program to maintain soil nutrition and eliminate possibly limiting production via reduced application in the higher yielding zones, whilst reducing environmental and financial risk from losses in the lower performing zones. Consideration is given to long term weather and price data.

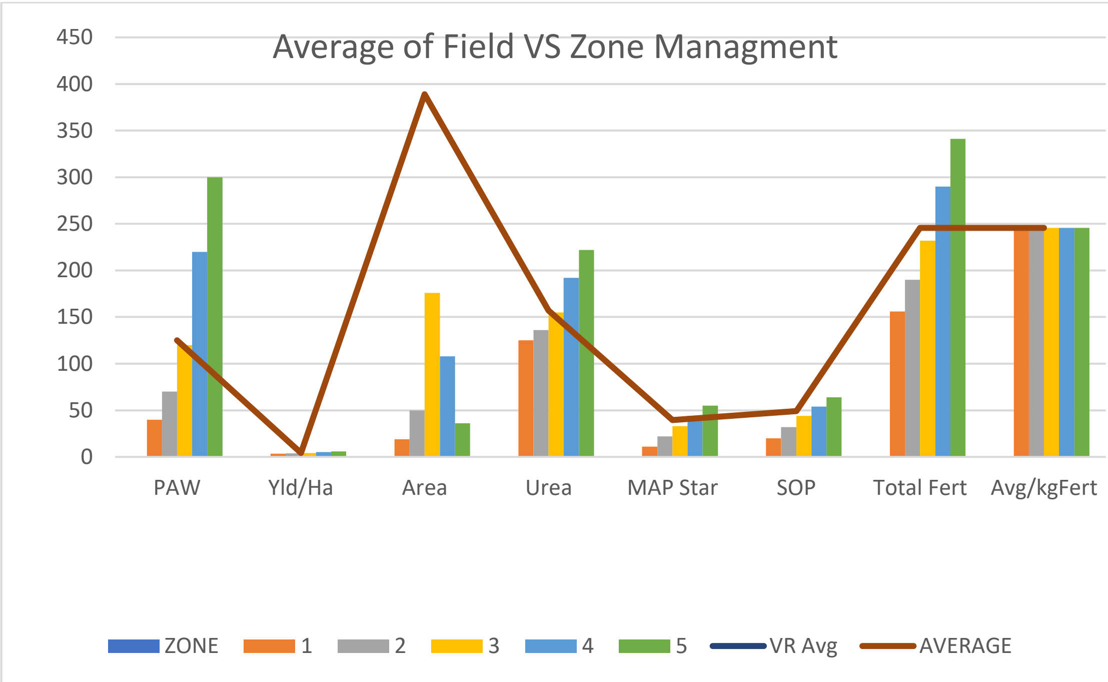

Table 3: Av of field versus zone management. Source: Author, 2017

Table 3 shows that in the two lower performing zones 1 & 2, PAW is limiting to the applied average fertiliser, and in the two higher performing zones a lack of nutrition can lead to underutilisation of available water, leading to reduced total field tonnes.

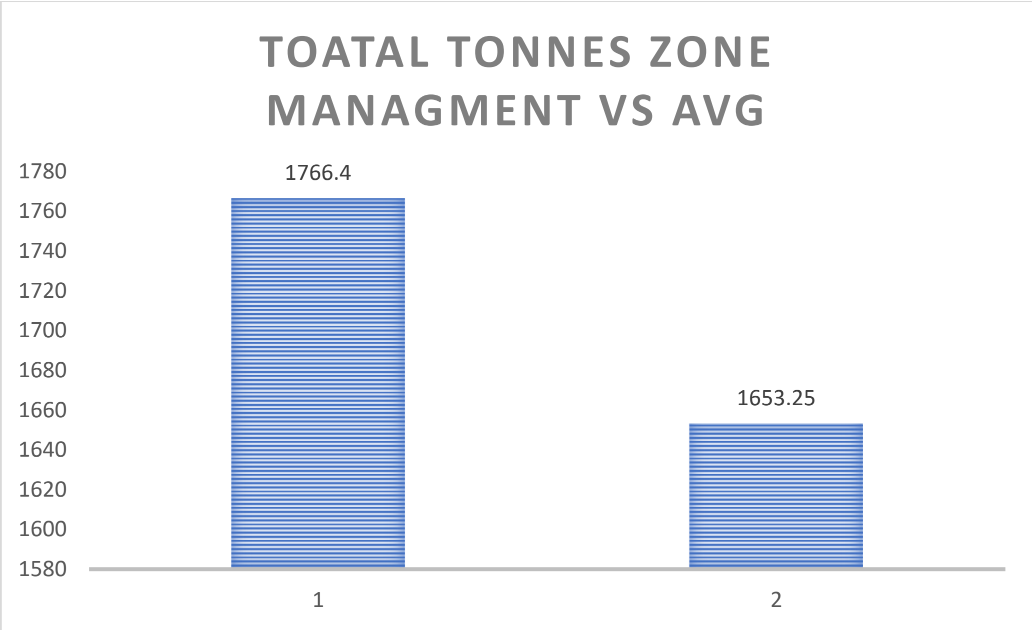

Table 4: Whole Field Tonnes. Source Author, 2017

Based on a Sorghum Price of AUD $250, this difference totals $28,287.5 or 6.4%.

After financial and environmental analysis has been undertaken, further layers to help establish long-term variability can be added to define margins.

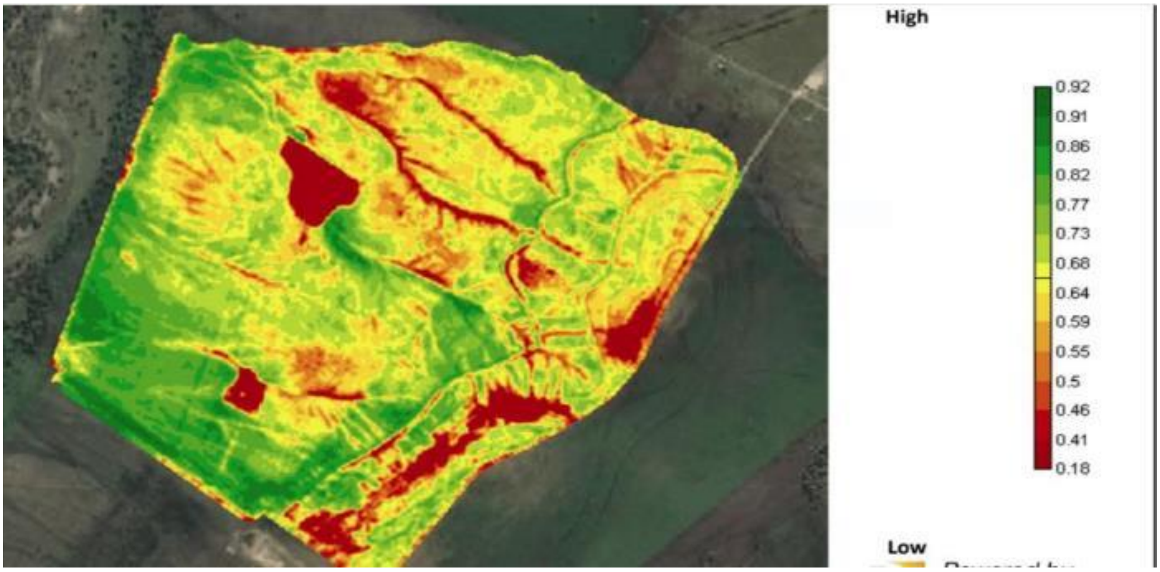

Figure 23: NDVI Image June-2017. Source Precision Agriculture 2017

NDVI (normalized difference vegetation index) provides data relevant to biomass health of the growing crop and references crop potential before end of season water deficiencies and can aid with in crop nutrition corrections. As well as this service providers can back date data to help establish variable rate management for farmers with little or no harvest yield data layers.

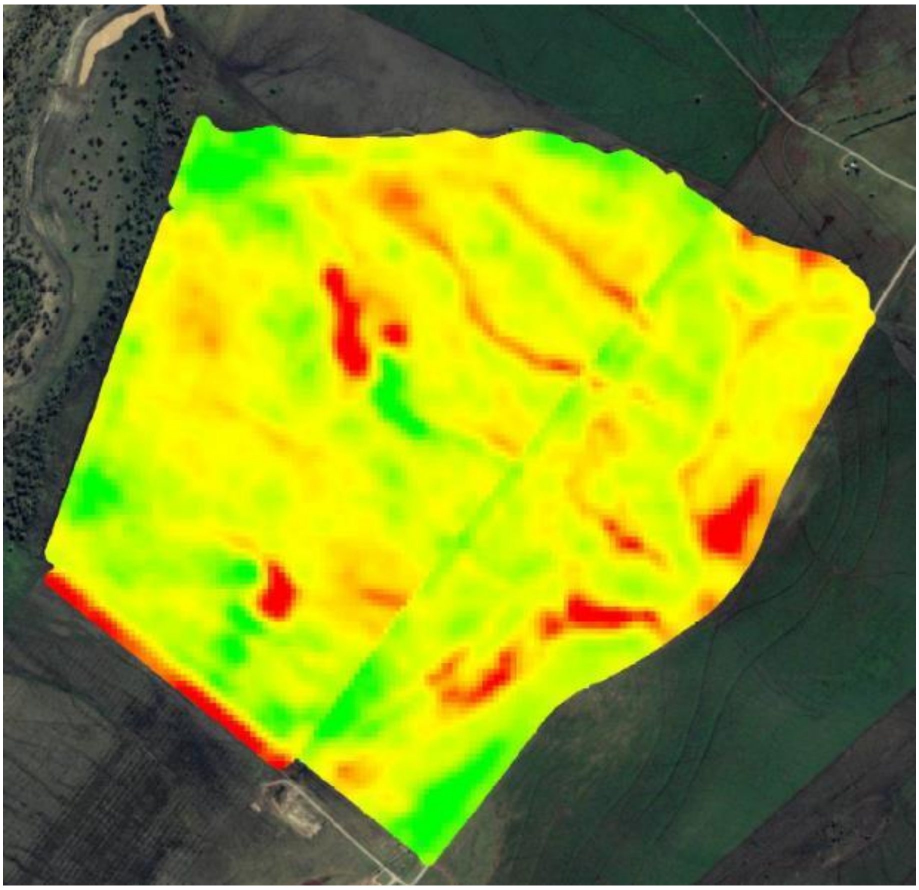

Figure 24: Prescribed Urea Layer. Source Echelon, 2018

Figure 24 represents the prescribed urea layer for the field derived from overlaying years of yield layers and NDVI maximum index layers to create the RX file to upload directly back to the fertiliser applicator.

Conclusion

Managing farm profitability provides stability and sustainability of farming businesses. Consideration of adopting new agricultural technologies to manage variability can increase profit margins and aid in cost control. With farm expenditure increasing, treating variability opens new production opportunities whilst reducing financial and environmental risk.

This report has detailed how technologies are being used to manage variability and provide new methods to reduce time with consideration to the fundamentals of crop production. It has shown:

- How microclimates impact farming systems.
- Soil nutrition and condition limitations can affect crop production.
- Technologies provide new opportunities but also have limitations that need to be considered.
- Data transfer can simplify management decisions and spatial data can be used to manage this.

Much of this technology already exists within farming systems but as margins get tighter, farmers are looking to manage new problems and ensure that data collection is managed precisely and accurately and relevant to the farm. Technology will provide the farm manager with a blueprint to aid with flexibility and avoid vulnerability.

Risk and interest drive focus in farming budgets but with more seamless technology systems and a critical approach to business observation, digital agriculture and technology adoption can provide new opportunities to maintain sustainability.

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Recommendations

- Farmers should make every effort to address all general farm business practices having a negative impact on their production prior to new technology adoption.
- Current on-farm equipment and management systems should be reviewed to investigate if any new goals can be achieved without new technology adoption.
- When considering investing in new agricultural technology, management and staff capacity and skills need to be considered. Upskilling staff is critical to success.
- Consider how any new agricultural technology processes will affect current farm practices and if there are any risks to the overall farm production system.
- Research the serviceability or customer support mechanisms that are available for new agricultural technology. Timely customer support is critical to problem solve and correct early faults in any new electronic system.
- Will the new agricultural technology save time, make the job easier, save expense in the longer-term, or even generate income? Ponder these questions by undertaking a SWOT analysis (strengths, weaknesses, opportunities and threats).
- Gather feedback from other farmers, grower groups, researchers, agricultural consultants and research and development corporations prior to making decisions about investment in new technologies.

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Plain English Compendium Summary

Project Title:	Farming in the Zone Digital Technology and Agronomy
Nuffield Australia Project No.:	1712
Scholar:	Luke Bradley
Organisation:	Wool-A-Roo pty ltd 1355 Orion Ten chain rd. Springsure QLD 4722
Phone:	0400 324 441
Email:	woolaroo5@bigpond.com
Objectives	The objectives of this research were to define agricultural technology that would offer valuable return on investment within the following criteria: • The role of water in plant production and how farming systems can benefit from a micro-climate. • Limitations in plant nutrition and soil condition. • Possibilities and limitations of current agricultural technologies. • The simplicity of data transfer to aid farm management decisions. • Spatial data inputs.
Backgroun	With the development of spatial referencing, farmers have gained new abilities to monitor analyse and control their farm systems. Despite this, adoption of advanced precision farming has stalled. New machinery comes with new gadgetry that makes up the useful side of the ag-tech industry, and with companies like Monsanto, John Deere and AGCO headlining financial papers with acquisitions, the interest in data and information is evident.
Research	This scholarship explored in depth an emerging industry of new service providers to the farm. It opened doors to researchers, government, farmers, educators and leaders. The author visited Brazil, Argentina, Chile, USA, Canada, The Netherlands, Italy and New Zealand.
Outcomes	Managing farm profitability provides stability and sustainability of farming businesses. Consideration of adopting new agricultural technologies to manage variability can increase profit margins and aid in cost control. With farm expenditure increasing, treating variability opens new production opportunities whilst reducing financial and environmental risk.
Implications	Much of this new technology already exists within farming systems but as margins get tighter, farmers are looking to manage new problems and ensure that data collection is managed precisely and accurately and relevant to the farm. Technology will provide the farm manager with a blueprint to aid with flexibility and avoid vulnerability. Risk and interest drive focus in farming budgets but with more seamless technology systems and a critical approach to business observation, digital agriculture and technology adoption can provide new opportunities to maintain sustainability.
Publications	2018 Nuffield National Conference, Melbourne, Victoria (September 2018)