Variable Rate Fertiliser Use in the Livestock Sector

A report for

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By Jack England

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Executive Summary

Precision agriculture and VRT have been applied in cropping and horticultural industries to maximise plant biomass and quality parameters for many years, but are not yet widespread across pasture and livestock systems. There is little doubt that benefits exist for nutrient use and pasture growth efficiencies by deploying PA and VR tools in grazing systems (Trotter, 2010). Where header yield monitors provide a simple cost/benefit measure of applied PA and VR techniques in the cropping sector, analytic tools and advances in spatial monitoring are now enabling the livestock sector to follow suit.

The challenge for farmers worldwide is best summed up by the "cost price squeeze" concept where the price of inputs is ever increasing disproportionately to the price received for commodities sold. Arguably there is little farmers can do to influence prices received but there is a lot that can be done on the cost side of the equation. One of the largest overheads for a livestock business is the fertiliser bill. Yet despite fertiliser's finite resource status and extrapolation of future price increases based on historic price trends, it is generally applied in a grossly inefficient manner where agronomic potential is left unrealised. Little has been done to investigate the spatial variability of soil nutrients in grazing systems and even less in quantifying the benefits of making management decisions aimed at taking advantage of this variability.

Visiting livestock farmers throughout the world revealed a dramatic knowledge gap on Variable Rate Technology (VRT), Precision Agriculture (PA) and the finer points of soil fertility and associated profit drivers. Livestock managers need to ensure that the current pasture base is being utilised for optimal profitability and sustainability. In most cases this requires matching peak seasonal stocking rate with peak pasture growth rates. Livestock production depends on yield, quality, pasture utilisation and feed conversion, all factors that are a challenge to measure.

The efficiency with which graziers' harvest or utilise pastures grown is often indicative of gross margins achieved. Diagnostic soil testing can be better targeted to understand both high and

low yielding zones to identify both physical and nutrient constraints to be addressed (McLaughlin et al, 1999). Pasture biomass measurements record only what is in the paddock but not what has been eaten by livestock or left behind as seasonal organic matter carryover. There is a need for pasture yield maps at a sub-paddock scale that quantify actual pasture productivity that consider animal intake and nutrient re-distribution. Recent developments in global positioning system (GPS) collars attached to livestock have helped to overcome these challenges.

Developing a variable rate fertiliser program for livestock systems requires the use of multiple technologies to avoid conflicting scenarios. For instance, obtaining an NDVI (Normalised difference vegetation index) pasture yield map of a paddock after sheep were removed and prior to their return would logically provide insights into which areas were the most productive, thereby validating an increase in nutrient replacement. This technique is valid to a certain degree but misses the opportunity to increase yields in lower NDVI zones that have not received adequate fertiliser to suit agronomic potential. Preferential over-grazing and subsequent growth suppression of zone specific pasture species that were either more nutritious, palatable, or both, is another missed opportunity that NDVI measurements alone cannot detect. Integration of NDVI, soil fertility testing and electro-magnetic surveys, together with understanding the spatial utilization of pastures by livestock, will assist farmers to have a far better understanding of the flux of nutrients across a landscape. This can then be used to formulate a variable rate input strategy (Trotter, 2010). For the sake of making better use of our resources, we can also minimise inadvertent off-site nutrient contamination that damages the environment. Growing more with less is an obvious progression and evolution for farmers.

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Foreword

Why do graziers acknowledge that the cropping sector has enjoyed enormous efficiency and productivity gains using precision agriculture (PA) and variable rate technology (VRT) yet refuse to use the same technology on their pastures? Both sectors abide by the same agronomic principles of soil, water, sunshine and inputs, yet the livestock management sector generally deem the current level of progress acceptable. Does the lack of a combine yield monitor, inherent seasonal variability and diverse livestock systems make many PA benefits unquantifiable and therefore too difficult to implement?

For a long time now the Australian livestock sector has been consolidating its efficiencies by lowering the cost of production. Most examples of profitable businesses demonstrate the ability to maintain a low-cost structure, maximise pasture utilisation and adjust to seasonal and market variability before others. While cost of production is central to a business's competitiveness, I certainly do not find chasing labour efficiencies as exciting as research and development

I have an agricultural science background and am a fifth-generation farmer. Our property consists of sheep (wool, meat, feedlot), cattle (Angus/Murray Grey maternal herd), forestry and cropping enterprises. Building on skills learnt from my father, adoption of innovative technology and profitable management techniques are at the forefront of my mind. What can we do that will yield greater returns, increase job satisfaction, be easy and interesting to adopt, and that will not cost much to trial?

Grappling with the lack of objective tools, pseudo-science and assessment undertaken on livestock farms throughout the world, a simple comment from a fellow scholar had a profound effect on the shape of my study topic. His words were "*you know what is more interesting, but what will have the greatest effect on profitability and sustainability on your farm?*".

To explore the suite of PA and VRT tools potentially adaptable to livestock systems I began visiting cropping and horticultural specialists and the researchers behind development and deployment in the field. Throughout the journey to Ireland, Scotland, England, Wales, Australia, Israel and New Zealand, I constantly used livestock farmers as a sounding board. Despite the many challenges, the majority were very enthusiastic. Most promising of all was the excitement generated by technological change, that I hope can provide job opportunities and draw young people back into agriculture.

We have plenty of room to improve! Let us explore, measure, and quantify the costs and benefits from implementing PA and VRT in grazing systems.

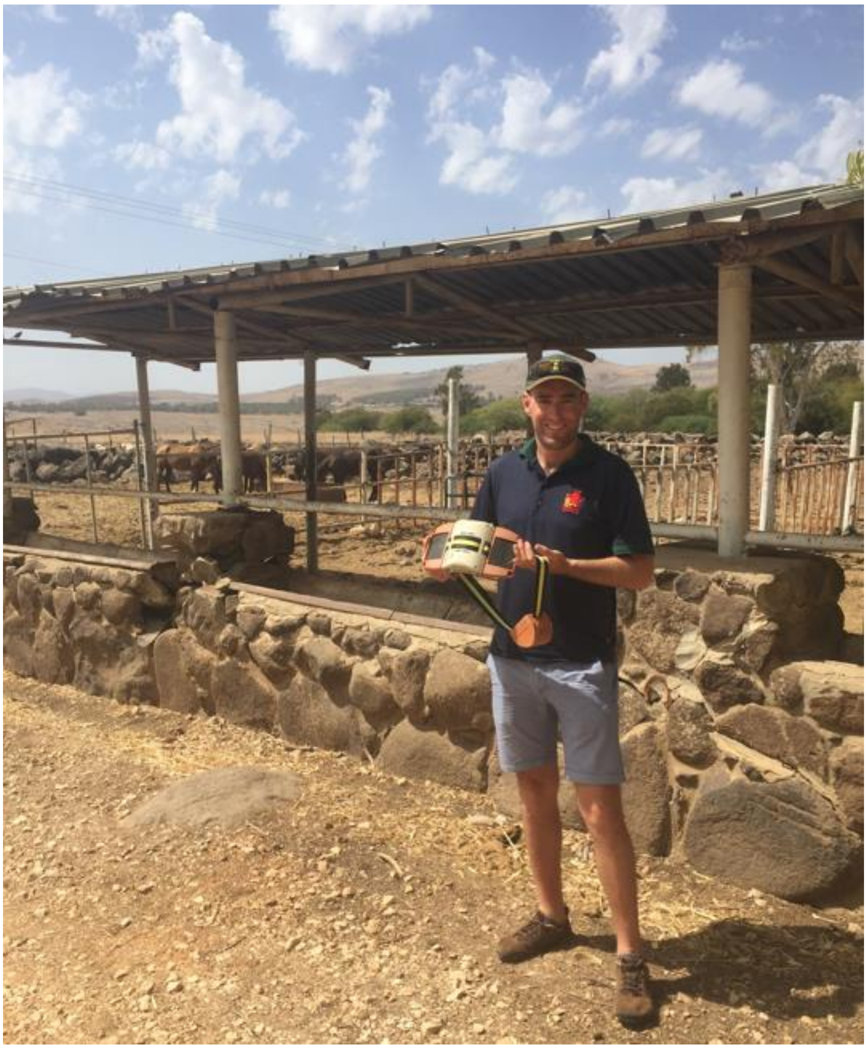


Figure 1: Author Jack England holding GPS animal tracking device in Golan Heights, Israel. (Source. McNab, 2016)

Abbreviations

DSE	Dry sheep equivalent
EM	Electro-magnetic
GPS	Global positioning system
GRS	Gamma-ray spectrometry
Ha	Hectare
ME	Metabolisable energy
NDVI	Normalised difference vegetation index
P	Phosphorus
PA	Precision agriculture
PFS	Pastures from space
VRT	Variable rate technology

Acknowledgments

I simply could not have taken the time out of the family business to complete this adventure without the support and commitment of my parents Rob and Min, my wife Franky and workman Axel Robinson. In one of the most challenging, unseasonably wet years, they absorbed the workload and made sound decisions that have been invaluable for my experience and management development. Thank you!

Thank you to the China GFP group – Michael, John, Pete, John S, Rob, Em, Mitch and Beeby, along with all the other 2016 Scholars for sharing contacts, ideas and great conversation. I sincerely hope to catch up with you and all and our country hosts again.

Australian Wool Innovation invested in me and I look forward to re-paying the generosity and assistance given by sharing my findings with industry peers. To the Nuffield Australia team, thank you. An enormous amount of work goes on behind the scenes and while not wanting to single anyone out, I feel I must thank Jim Geltch, Jodie Dean for getting me home in one piece and Tim Hutchings for his editorial and critical review of this report.

To the researchers and farmers around the world who have opened my eyes – thank you for having me in your homes, businesses and sharing your knowledge. I will always be keen to return the favour!

Finally thank you to Graham Clothier – without your persistent yearly phone calls and encouragement it is unlikely I would have ever applied.

Objectives

It is the author’s view that livestock farmers must, like the cropping fraternity, make better use of our finite resources by applying variable rate technology (VRT) to suit the various agronomic growing conditions found within a field. Society is quite rightly demanding stronger agricultural nutrient run-off restrictions, and this fits with the social expectations that we create more efficient, yet profitable livestock farming systems, by making better use of the finite reserves of most macro fertiliser nutrients, water and arable land.

This study explored:

1. Animal grazing behaviour and emerging novel technologies.
2. The VRT methods that the cropping fraternity use, and which can be applied in livestock systems.
3. Developing the full potential of existing farm management software and capabilities.

Introduction

Precision agriculture and VRT have been applied in cropping and horticultural industries to maximise plant biomass and quality parameters for many years, but are not yet widespread across pasture and livestock systems. There is little doubt that benefits exist for nutrient use and pasture growth efficiencies by deploying PA and VR tools in grazing systems (Trotter, 2010). Where header yield monitors provide a simple cost/benefit measure of applied PA and VR techniques in the cropping sector, analytic tools and advances in spatial monitoring are now enabling the livestock sector to follow suit.

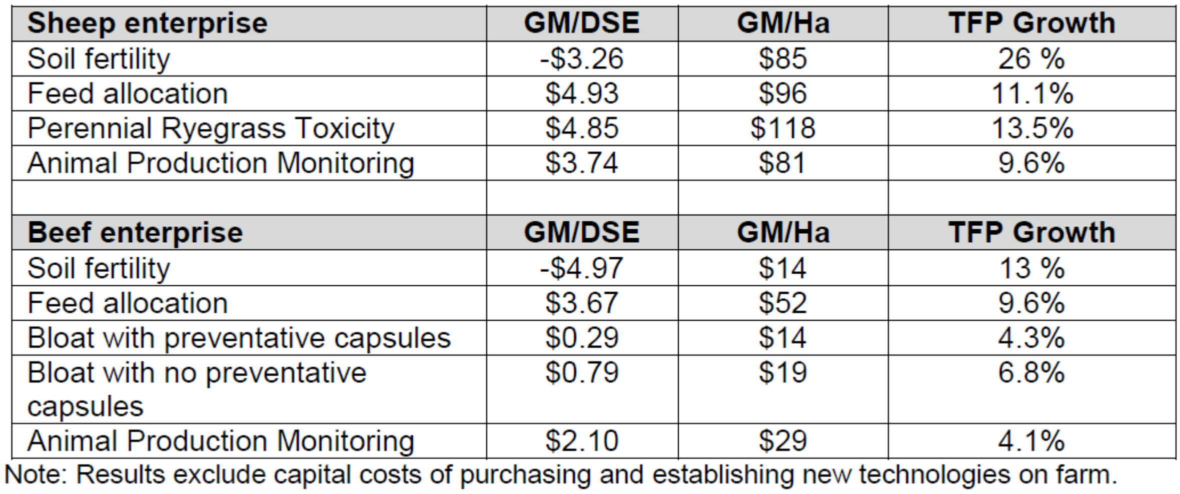
Traditional fertiliser applications in livestock enterprises are most commonly based on the nutrient content of representative soil sample transects (Kulczycki and Grocholski, 2013). Assumptions are made that the entire field is consistent, allowing calculated fertiliser dose estimations to be broadcast onto other fields assessed to be similar in topography, soil texture, livestock carrying capacity and pasture species sown. While treating for the average, this has total disregard for the enormous spatial variability of soil types, fertility measures and plant yield potentials found within every paddock (McLaughlin *et al,* 1999).

Crop and pastures also have major spatial and temporal biomass variation within a field, when many different pasture species grow only in specific zones that are agronomically suitable. Spatial variability refers to changes in pasture yield that occur across a field at a given time, mainly caused by management practices and environmental and landscape variability. Temporal variability is the change measured over seasons driven by climate or management practices (Trotter et al). Pasture quantity, quality and growth rates are still measured using pasture cuts, rising plate meters, or by using visual aids (with the accuracy of the latter very subjective and user dependant). More recently, active reflectance sensors have been used to measure pasture quality and quantity quickly with far less labour, and that will aid farm management decisions (Trotter et al).

Farmers are facing increasing cost pressures when it comes to nutrient use efficiency and minimising environmental pollution, which may necessitate mitigation strategies (Betteridge et al). While phosphorus (P), nitrogen (N) and faecal microbes are pollutants of major concern, inorganic P, organic N and microbes move in water, predominantly in overland flow, and N can be leached as nitrate or emitted as nitrous oxide or ammonia (McDowell et al. 2005; McDowell and Srinivasan 2009; McDowell 2012). Enriched nutrient areas can be caused by livestock camping where copious amounts of N from urine and N, P and microbes from faeces are deposited. Such sites, located using cattle fitted with GPS and motion sensors, could be targeted to reduce nutrient applications in these areas, to minimise additional nutrient loading and subsequent losses (Betteridge et al).

Australian farmers continue to receive the lowest levels of government subsidies worldwide as a proportion of national gross domestic product, government expenditure on agriculture is the lowest in the developed world (Keogh, 2011). Coupled with relatively stable commodity prices, the highest minimum wage in the world and enormous freight costs, this has created a highly competitive industry, forced to develop efficiencies to lower costs of production (OECD, 2015; Batt, 2015). Because the terms of trade are unlikely to improve, further efficiencies within livestock industries must be made to remain competitive.

A Meat and Livestock Australia economic analyses (Henry et al., 2012) found that decision support tools for zonal management of soil fertility increased gross margins per hectare by $85 for sheep and $14 for beef enterprises respectively (Figure 2). This Feed Base Investment Plan, commissioned in 2011, assessed research and development opportunities for precision technology priorities in all southern Australia agricultural zones with a focus on increased profitability and sustainability. Of the ten key areas highlighted where more precise data would benefit decision making, three were directly related to this study. These gross margin increases per hectare were not the highest in the analyses, but Total Factor Productivity (TFP) returns of 26% for sheep and 13% for beef enterprises were 12.5% and 3.4% higher for improvements in soil fertility than rival technologies respectively (Figure 2). TFP accounts for all land, labour, capital and material resources employed in farm enterprises enabling comparisons across variable landscapes and asset classes under management. More importantly it allows measurement of agricultural technical change and efficiency gains of inputs and how effectively and intensely they are deployed (Fischer et al., 2014). In this respect, the value of technical and efficiency gains discussed in this report, regard soil fertility management, measured as the gap between the farm operation and the technical potential, to be vitally important (Figure 2). A decrease in gross margin per DSE represents the deviation from normal production figures. Profit per DSE is still positive but it was less than without the technology application, hence the negative change in value per DSE. Specifically, the soil fertility technology required increasing the application of lime, P and potassium per DSE which resulted in an overall increase in carrying capacity per ha. This increase more than compensated for the higher cost per DSE such that the profit per Ha attributable to soil fertility technology use increased (Beattie pers. comm., 2017).



Sheep enterprise	**GM/DSE**	**GM/Ha**	**TFP Growth**
Soil fertility	-$3.26	$85	26 %
Feed allocation	$4.93	$96	11.1%
Perennial Ryegrass Toxicity	$4.85	$118	13.5%
Animal Production Monitoring	$3.74	$81	9.6%
Beef enterprise	**GM/DSE**	**GM/Ha**	**TFP Growth**
Soil fertility	-$4.97	$14	13 %
Feed allocation	$3.67	$52	9.6%
Bloat with preventative capsules	$0.29	$14	4.3%
Bloat with no preventative capsules	$0.79	$19	6.8%
Animal Production Monitoring	$2.10	$29	4.1%

Note: Results exclude capital costs of purchasing and establishing new technologies on farm.

Figure 2: Net benefit of technology (gross margin per DSE, per hectare, and total factor productivity growth) for sheep and beef enterprise case studies for four key farmer decision areas.

To quote Craige MacKenzie (International Precision Ag farmer of the year 2016), "*where variability is measurable and opportunities present, we should apply VRT to any system with the tools at our disposal*". For instance, a cropping farm that increased gross margins by 50% in three years by deploying PA and VR tools, without increasing but redirecting fertiliser inputs, is an environmental and profitable win that livestock producers should seek to emulate (Mackenzie pers. comm., 2017).

Chapter 1: Soil

This chapter does not attempt to differentiate between the varying forms of commercially available fertilisers but rather investigate the mechanisms using P as an example to explore potential replacement methods. None of the other 16 elements required for plant growth should be disregarded, as the author ascribes to Liebig’s law, where plant growth potential is limited by the nutrient in shortest supply (Smith and Loneragan, 1997). That is, extra P application in sulphur deficient soils will not have any effect unless sulphur deficiency is addressed.

Phosphorus is a finite resource and in a capitalist system, driven by supply and demand, it will continue to increase in price. Mined as phosphate rock, it is crushed, reacted with sulphuric acid (or phosphoric acid for higher quality fertilisers), which makes the product water soluble and available to plants (Lalor pers. comm., 2016). When applied to soil it undergoes several transformations; some is absorbed by plants and returned to the soil via animal excrement and plant residues, and some is consumed by organisms. A soils’ phosphorus-buffering ability will determine how much P reacts with soil minerals (such as aluminium, magnesium, calcium and iron) to form solid inorganic states. Inorganic and organic P forms are not directly plant-available and represent approximately 99% of the total P. Hence the amount of P in a soluble, plant-available form throughout a growing season is very small (McLaren, 2015).

If soils are maintained above the agronomic optimum level of soil P fertility, additional fertiliser P will accumulate as stable forms of phosphorus that are less ‘plant-available’ than that contained in the fertiliser at application (McLaren, 2015). These inorganic forms can take decades or centuries to become plant-available through the mineralisation or reversal process, but it is nature’s way of storing a vital nutrient in an insoluble form until it is required. Fertiliser advice prescribed by the common Australian “build-up and maintenance” technique can also lead to increased nutrient contamination of surface and groundwater resources (McLaughlin *et al,* 1999). Both factors result in poor nutrient use efficiency and further highlight opportunities for site specific management of the many variables found within a paddock (See Figure 3)

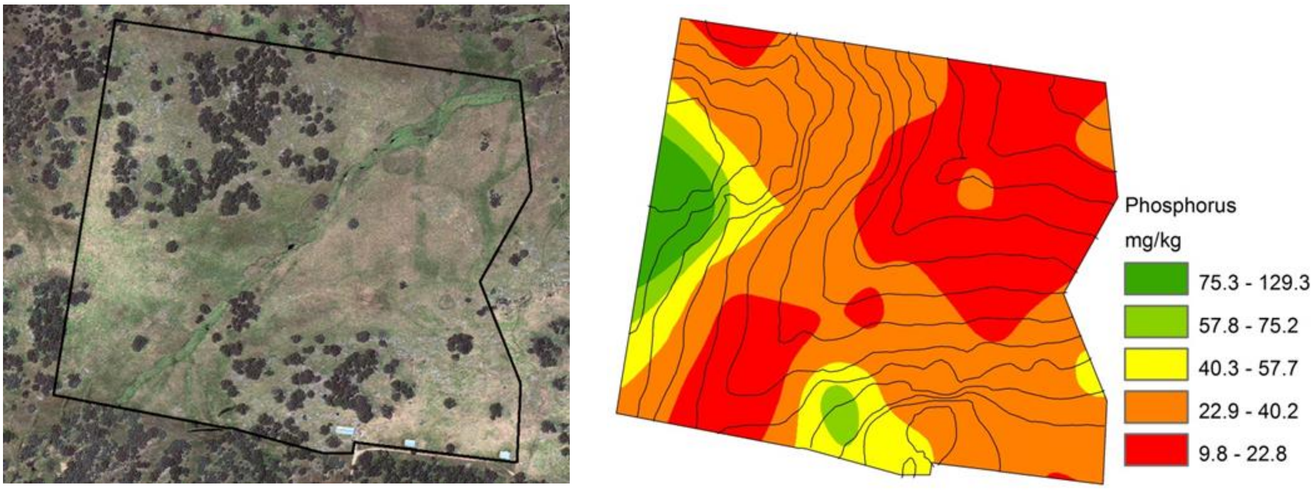


Figure 3: Phosphorus in-field variation in Australian livestock grazing system as measured using Colwell P. Five zones of Colwell P (mg/kg) are shown, depicting the effect of slope and vegetation, and showing the high concentration of P in stock camps (Source: Trotter et al, 2014)

1.1 Soil Sampling techniques

1.1.1 Conventional

One of the difficulties of current soil sampling techniques is that a GPS-located and representative soil sample from a transect is taken on a subjectively assessed average soil type from within a field. For pasture systems, 50 cores are collected from a 20-hectare paddock to a consistent 75-millimetre depth before thoroughly mixing to create one sample for analyses. A second transect may be established and tested if there is a notable change in soil type. Samplers are warned to stay away from trees, obvious stock camps, fence lines, changes in soil type, breaks in slope and waterlogged patches. The Tasmanian Government soil sampling procedure, (2014), further advises samplers to avoid dung and urine patches, and areas of unusually good or poor plant growth. Such sub-paddock variability suggests that site-specific use of ameliorants and fertilisers could provide substantial productivity improvements while possibly reducing fertiliser use (Trotter et al, 2014). The inaccuracies of this conventional sampling method are further emphasised when many fertiliser applications in multiple paddocks are based on a single “representative sample”.

1.1.2 Grid sampling

Development of VRT fertilizer application zones based on grid soil sampling (e.g. soil test on a one-hectare grid in a 40ha paddock, (See Figure 4) aims to give an accurate map of variations in nutrient levels across a paddock (Curkpatrick pers. comm., 2016). GPS allows the capacity to monitor site-specific nutrient trends and effectiveness of VRT over time. Typically, each GPS point is located with 20 soil cores collected in a circle around the central point to minimise soil variability (Mackenzie, pers. comm., 2017). Additional topography layers and electromagnetic mapping can be useful in determining areas that might need to be managed differently, other than purely in accordance with soil nutrient levels (Agrioptics, 2013). Allocating phosphorus and other elements to where they are needed to optimize yields is just as important for grazing as it is for cropping systems. However nutrient recommendations are still predominantly based on rates most likely to give an average response in most years, not the rate that, for your paddock, will give the best return under favourable growing conditions.

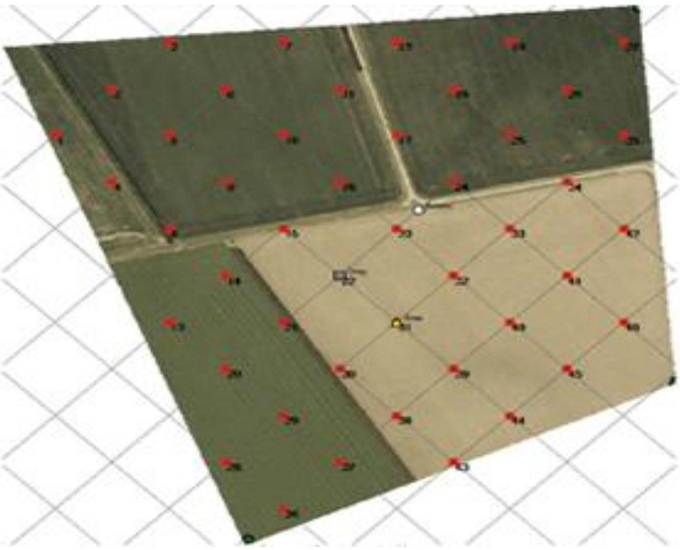
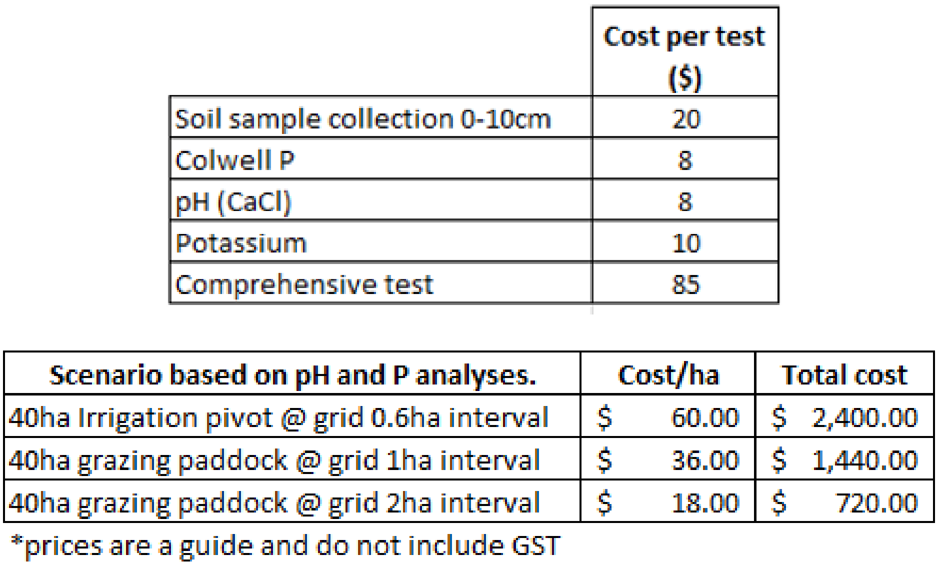


Figure 4: Grid soil sampling used to determine paddock variability and subsequent treatment zones. (Source: Agrioptics, 2013)

A cost guide for undertaking a grid or targeted zone soil sampling survey are shown in Figure 5, where three scenarios measuring soil pH and P levels demonstrate the cost per ha of varying grid sizes. Choice of grid size is user-defined but generally more intensive, irrigated pastures or paddocks with significant elevation and soil heterogeneity changes will require smaller sampling quadrants. Figure 6 demonstrates distinctive variability found using a grid based survey where three P concentration zones have been identified. Fertiliser recommendations to adjust P up or down are based on research linking soil phosphorus buffering indexes with historical reference Colwell P concentrations found to give adequate plant response rates as seen in the Figure 6 example. Other techniques include best guesses from either farmers or agronomists based on historical fertiliser rates and soil nutrient concentration changes over time, but there is no fixed formula to validate an optimum level.

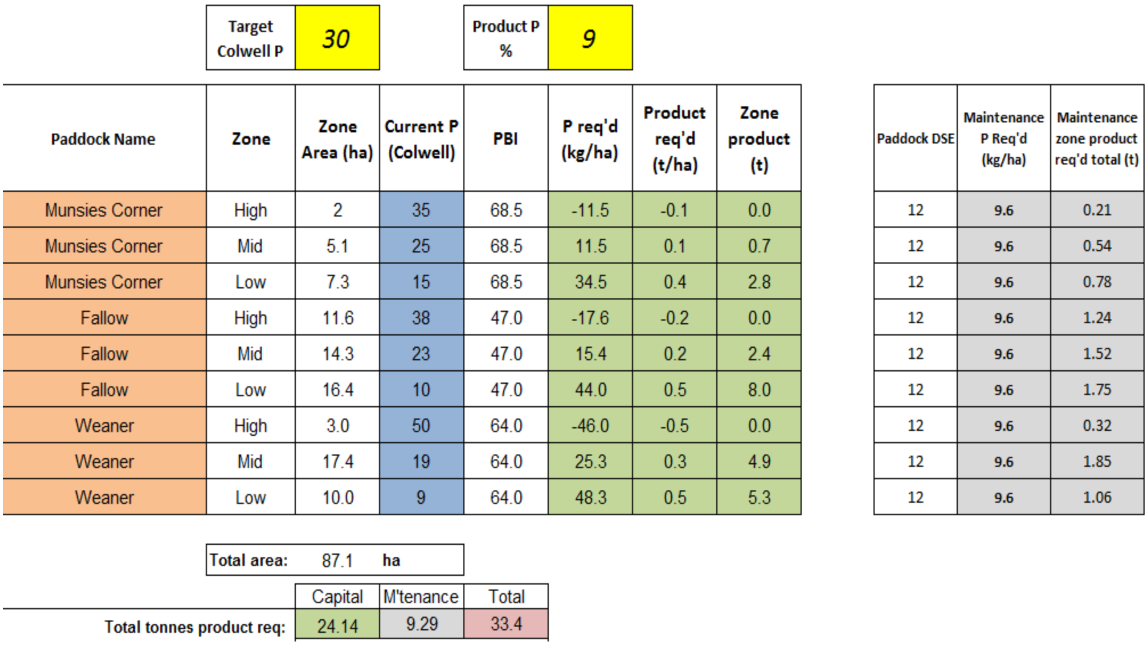


	Cost per test ($)
Soil sample collection 0-10cm	20
Colwell P	8
pH (CaCl)	8
Potassium	10
Comprehensive test	85

Scenario based on pH and P analyses.	Cost/ha	Total cost
40ha Irrigation pivot @ grid 0.6ha interval	$ 60.00	$ 2,400.00
40ha grazing paddock @ grid 1ha interval	$ 36.00	$ 1,440.00
40ha grazing paddock @ grid 2ha interval	$ 18.00	$ 720.00

*prices are a guide and do not include GST

Figure 5: **Indicative contractual cost of grid based soil testing. (Curkpatrick, 2016).**



Target Colwell P	30	Product P %	9

Paddock Name	Zone	Zone Area (ha)	Current P (Colwell)	PBI	P req'd (kg/ha)	Product req'd (t/ha)	Zone product (t)
Munsies Corner	High	2	35	68.5	-11.5	-0.1	0.0
Munsies Corner	Mid	5.1	25	68.5	11.5	0.1	0.7
Munsies Corner	Low	7.3	15	68.5	34.5	0.4	2.8
Fallow	High	11.6	38	47.0	-17.6	-0.2	0.0
Fallow	Mid	14.3	23	47.0	15.4	0.2	2.4
Fallow	Low	16.4	10	47.0	44.0	0.5	8.0
Weaner	High	3.0	50	64.0	-46.0	-0.5	0.0
Weaner	Mid	17.4	19	64.0	25.3	0.3	4.9
Weaner	Low	10.0	9	64.0	48.3	0.5	5.3

Paddock DSE	Maintenance P Req'd (kg/ha)	Maintenance zone product req'd total (t)
12	9.6	0.21
12	9.6	0.54
12	9.6	0.78
12	9.6	1.24
12	9.6	1.52
12	9.6	1.75
12	9.6	0.32
12	9.6	1.85
12	9.6	1.06

Total area:	87.1	ha

	Capital	M'tenance	Total
Total tonnes product req:	24.14	9.29	33.4

Figure 6: "Precision Pastures" high, medium and low paddock P application recommendations based on 2ha grid based soil testing. (Finlayson, 2016).

While the techniques in this chapter underpin efficient placement of fertiliser and ameliorants to optimise yields, livestock systems have the added complexity of high rainfall pugging constraints. The lack of a pasture yield monitor to offset such waterlogging (or oxygen deprivation) to plants makes it difficult to adjust future nutrient applications, based on product removal.

1.1.3 Zonal sampling

Zonal soil sampling involves separating a paddock into areas of uniformity from known spatial factors or historical management variations. Areas of known difference are able to be validated either by yield maps, EM (Electro-Magnetic) soil maps, ground elevation and ground penetrating radar. These measurements can then be used to provide information on field variability and indicate where soil sampling can help interpret this variability (Agrioptics, 2017). Zonal sampling is a cost-effective way to target testing of known production variances defined by spatially variable maps.

1.2 Sensors

The use of non-invasive sensors for soil analyses provides opportunities to identify trends and constraints and to create spatial layers enabling targeted management zones. While many farmers can draw soil type maps to a reasonable degree of accuracy, use of EM, gamma-ray spectrometry and the more intrusive Veris machines can define such boundaries with high accuracy. The type of sensor used will vary, based on what the farmer is trying to achieve and the sampling environment, but they are generally a good start for livestock producers who do not have the extensive soil testing or yield mapping data now available to crop growers (Balkwill, pers. comm., 2017). Sensors included in this review do not specifically require exposed soils, as required by other optical reflectance sensors.

1.2.1 Electromagnetic and gamma-ray spectrometry surveys

Using GPS in combination with EM reflectance measures electrical conductivity in the soil profile. Towing an EM machine behind a light vehicle at 12-48m swath widths, (dependant on terrain or variability), is a quick and easy way to obtain soil characteristics and create a spatially variable map. Twenty-five meter swaths that includes data interpretation and capturing of two-centimetre accuracy elevation data costs approximately twelve dollars per ha for an EM38 which is targeted at surveying the entire plant root zone (Moffitt, pers. comm., 2017). Measurements obtained at 0-50cm and 0-150cm soil depths show soil type variation based on electrical conductivity which increases with clay content, moisture and salt (MacKenzie, pers. comm., 2017). This enables the user to:

- differentiate between sand, loam and clay (see Figure 7) and to cross-reference soil tests to cation exchange capacities,
- identify topsoil depth,
- manage water allocations by variable rate (if irrigating),
- create grid soil sampling plans to target established zones that allows fertiliser to be applied as per test results, and
- improve yields and pasture performance where soil physical characteristics are limiting factors (Agrioptics).

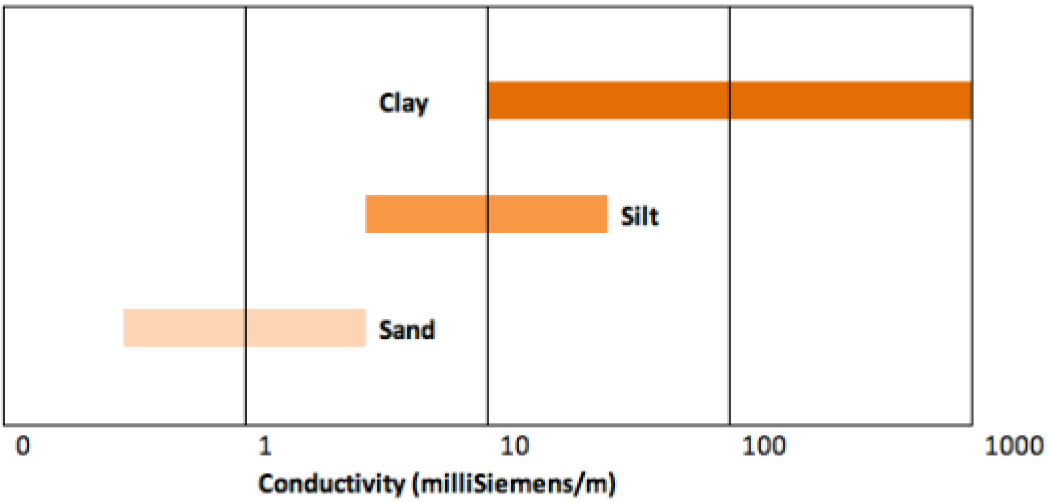


Figure 7: Electrical conductivity correlation with soil texture properties. (Source: Agrioptics, 2013)

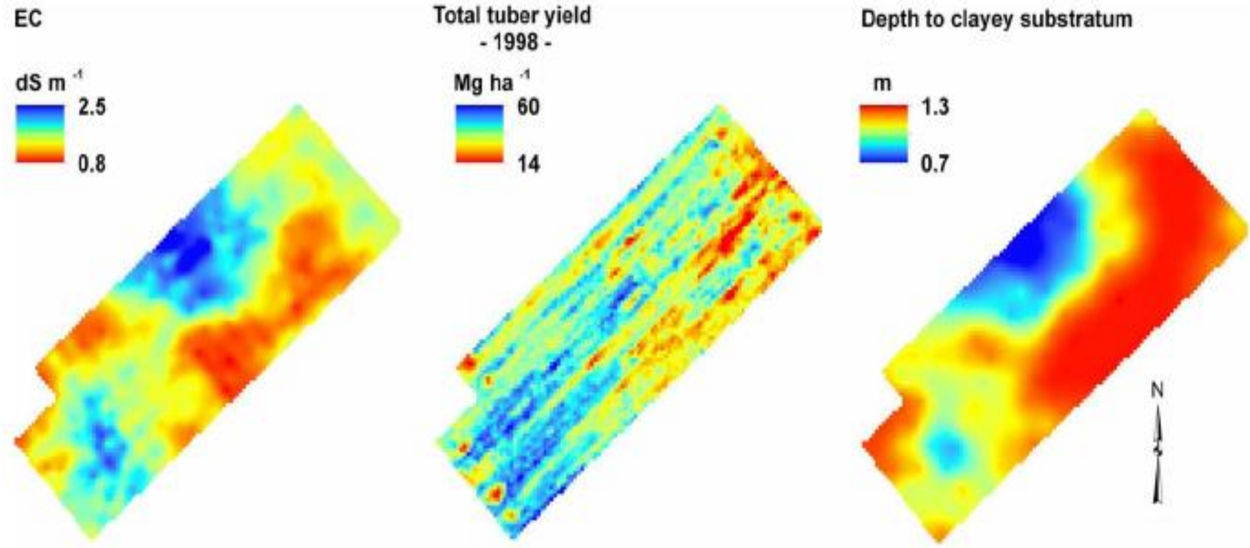


Figure 8: Map of soil electrical conductivity (EC), potato tuber yield, and soil depth to clay substratum survey. (Source: Cambouris et al, 2014)

Treloar, pers. comm., 2017 described the limitations of EM on low conductivity soils where differentiating between a sandy and gravel soil was extremely difficult. Precision Agronomics Australian researchers found a good fit for Gamma-Ray Spectrometry (GRS) to cover this shortcoming, where the natural radioactive isotopes potassium, uranium and thorium in the soil can be detected with radiometric instruments (Figure 8). When used to complement EM, more comprehensive definition is obtained between deep sand and gravel profiles of very low conductivities. In areas of high conductivities, saline soils and clay profiles can be distinguished, which would otherwise return similar EM conductivities (Sauer et al, 2013).

Figure 9: Ground penetrating radar and EM31/38 survey being conducted on the authors property. (Source: Author, 2006)

1.2.2 The Veris sensor

The Veris machine was primarily developed to measure pH and to create field maps linking the zones for VRT controlled applications of lime to acidic soils, or gypsum to alkaline soils, where required. The machine's pH electrode is a direct contact sensor which is pushed into the ground to obtain the measurement. Veris is usually used in tilled arable soils, and while the system has some ability to physically penetrate sward covers, care must be taken to avoid organic matter and to calibrate data (Trotter, pers. comm., 2016; Mackenzie, pers. comm., 2017). Sauer et al., (2013) advises that a minimum of three soil tests should be collected for laboratory analyses and calibration, as the soil/water based sensor is not considered accurate enough to prescribe lime applications. Based on advice received by commercial operators, use of Veris is likely to be a more expensive option (at fifteen dollars per ha) and is not reliable with inconsistencies arising between the pH sensor which uses water and the requirement for constant calibration, versus the alternative calcium chloride pH test used with a grid soil testing regime. Further complications caused by plant material on the soil surface present major difficulties for Veris used in livestock systems (Mackenzie, Treloar, Balkwill, pers. comm., 2017).

While the author’s intention was to target prescriptive use of fertiliser, it is important to understand that, as pH declines below five (calcium chloride) or 5.5 (water), the cation exchange capacity and subsequent adsorption sites for nutrients is dramatically reduced (Smith and Loneragan, 1997). Since this study is aimed at identifying factors which will have the greatest effect on profitability and sustainability, efficient cation exchange can be important in allowing this to be achieved. Liming applications are primarily recommended to amend surface acidity, but can also pre-empt subsoil acidity development, and the benefits of VRT application of this product therefore fits within the aims of this study.

Chapter 2: Understanding Animal Behaviour and Nutrient Removal

Pasture utilisation by sheep and cattle during a growing season is low relative to total pasture production. Meat and Livestock Australia estimates that only 40-48% of total pasture production is utilised in regions which have extended dry periods of greater than 150 days, a direct result of faecal contamination, senescence of leaves, trampling and pugging. Additionally, livestock will often remove more pasture (and therefore nutrients) from specific locations within a paddock and concentrate excrement in other locations (such as stock camps, or around watering points) making it difficult to target fertiliser replacement to maximise production.

There is a lot of supporting data depicting the benefits of short interval “techno” grazing, and much less on rotational grazing, and the more traditional set stocking systems. Each system has their strengths and weaknesses, but in general high stock density, with short grazing intervals, results in significantly increased pasture utilisation than a low stock density and long grazing duration (More Beef from Pastures, 2013). Additionally, rotating stock in short grazing periods enhances uniform excretal return while reducing nutrient loads near shade and watering sites. These results were supported in a Florida trial which investigated dung distribution of heifers in three grazing management replicates; set stocked; seven day rotational grazing; and one day rotational grazing (Vendramini, 2012).

In a trial on a paddock within the 800mm average rainfall district in New South Wales, Trotter (2010) concluded that set-stocked sheep grazing a native pasture were a key driver in the spatial P variability, particularly at elevation associated with camping activities. At a similar site where cattle were rotationally grazed on improved pastures, the combination of higher stocking rates, rotational grazing, and the lower tendency of cattle to concentrate their camp areas at higher elevations, resulted in less pronounced P zones (Trotter, 2010).
These factors raise the questions:

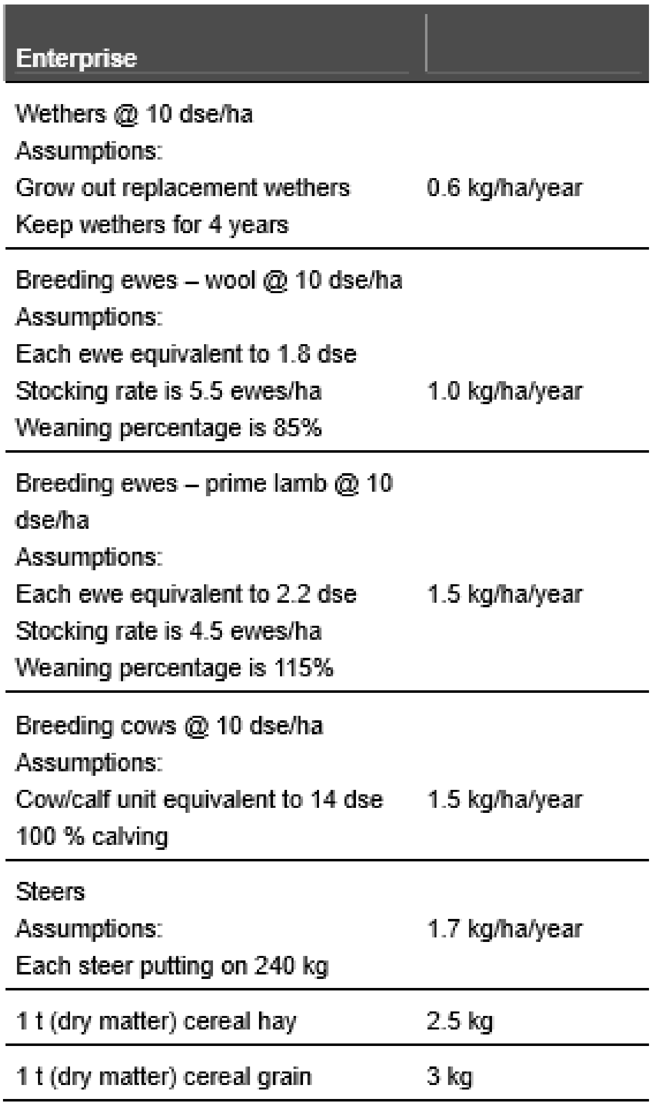
1. Should livestock farmers be replacing nutrients as a sum of biomass removed using paddock calculations, or

2. Can this nutrient replacement be made more prescriptive by mapping grazing intensity and nutrient excrement zones and replacing nutrients accordingly?

The following sections seek answers to each of these questions.

2.1 Animal class and nutrient removal

The livestock systems in Figure 10 show there are varied assumptions for P removal and replacement requirements for different classes of animals (Leech, 2009). Further review demonstrates the difference between mature and growing livestock. Lambs remove six grams of P for every kilogram of live weight gain, while mature dry sheep excrete almost the same amount of P in dung and urine as they have consumed in the pasture. For each tonne of cereal grain removed from a paddock, three kilograms of P needs to be replaced and one tonne of canola removes nearly seven kilograms of P. Pasture hay contains approximately 0.25% phosphorus and 2% potassium, so a 2.5 t/ha hay crop removes about 6 kg P/ha and 50 kg K/ha. If the fodder is not fed back onto the paddocks from which it was made, the nutrient status of the paddock will decline (Cayley and Quigley, 2004).



Enterprise	
Wethers @ 10 dse/ha Assumptions: Grow out replacement wethers Keep wethers for 4 years	0.6 kg/ha/year
Breeding ewes – wool @ 10 dse/ha Assumptions: Each ewe equivalent to 1.8 dse Stocking rate is 5.5 ewes/ha Weaning percentage is 85%	1.0 kg/ha/year
Breeding ewes – prime lamb @ 10 dse/ha Assumptions: Each ewe equivalent to 2.2 dse Stocking rate is 4.5 ewes/ha Weaning percentage is 115%	1.5 kg/ha/year
Breeding cows @ 10 dse/ha Assumptions: Cow/calf unit equivalent to 14 dse 100 % calving	1.5 kg/ha/year
Steers Assumptions: Each steer putting on 240 kg	1.7 kg/ha/year
1 t (dry matter) cereal hay	2.5 kg
1 t (dry matter) cereal grain	3 kg

Figure 10: Phosphorus removal rates for various livestock enterprises per year at a stocking rate of ten dry sheep equivalent (DSE) per hectare. (Source: Leech, 2009)

The Meat and Livestock Australia P replacement tool helps producers calculate how much nutrient is removed from paddocks according to stock class and stocking rate (DSE ratings) and therefore, how much P should be returned to achieve the economic optimum (see Figure 11 for DSE ratings) (https://www.mla.com.au/extension-training-and-tools/tools-calculators/phosphorus-tool/). One of the parameters in this tool estimates the proportion of nutrients removed and concentrated in stock camps, and clearly indicates the efficiencies to be gained by variable rate application of inputs (Karn, pers. comm., 2016).

Sheep	30 kg	40 kg	50 kg	60 kg
Dry ewes or wethers (maintaining weight)	-	0.9	1.0	1.2
Last month of pregnancy (singles or ***twins***)	-	1.2 / ***1.4***	1.4 / ***1.6***	1.6 / ***1.9***
Lactation (singles or ***twins***)	-	2.6 / ***3.7***	2.7 / ***3.9***	2.9 / ***4.4***
Weaners (growth rate 100 g/day)	1.1	1.3	-	-
Average (year) ewe	-	1.5	1.6	1.8

Beef cattle	400 kg	500 kg	600 kg
Dry cows or store steers (maintaining weight)	6	7	8
Dry cows or store steers (growth rate 0.5 kg/day)	8	11	12
Dry cows or store steers (growth rate 1.0 kg/day)	11	13	15
Last 3 months of pregnancy	8	9	11
Cows with 0-3 month calves	13	14	17
Cows with 3-9 month calves	19	21	24
Average (year) cow	15	16	19

Figure 11: Dry sheep equivalent (DSE) values for different classes of livestock, at different live weights. (Source: Cayley and Quigley, 2004)

2.1.1 Agriwebb – nutrient removal at the paddock level

Agriwebb is an evolving total farm management software application compatible with most new android and Apple smart phones and a range of tablets, (http://www.agriwebb.com/). The multiple user framework and offline capacity streamlines data capture for later performance analyses and benchmarking. Pertinent features and uses relative to this report include full mob traceability, quality control and the icon drag and drop technology which facilitates automatic paddock nutrient removal data collection (Figure 12). Users enter DSE ratings for each class of stock using live weight and growth measurement estimates. Joining entry and exit dates are recorded, which enables DSE rating changes to be automated, according to the stage of gestation/lactation with scanning and lamb marking percentages entered (see Figure 11). Supplementary feeding is recorded because it is a source of applied nutrients which reduces livestock paddock biomass ingestion, or adds to livestock bodyweight, which is subtracted from the seasonal carrying capacity.

The information portal accommodates individual paddock DSE carrying capacities and allows these to be viewed, allowing a choice of variable rate fertiliser applications based on nutrient removal per DSE calculations.

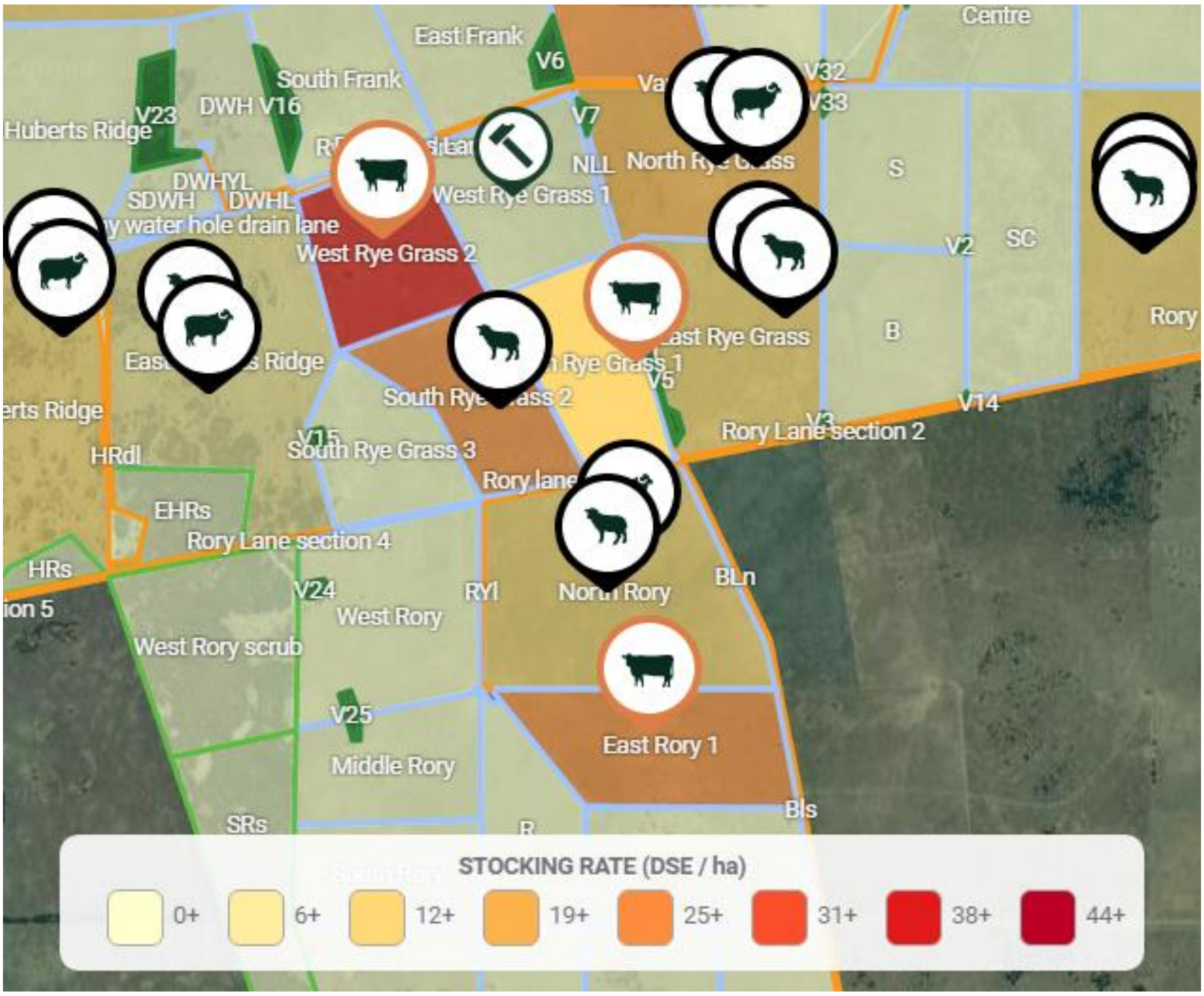


Figure 12: Farm map showing the author's livestock classification/location and grazing intensity in DSE per hectare. (Source: Agriwebb, 2017)

While manual data entry methods exist, using MS Excel spreadsheets to track paddock livestock number and entry/exit dates, these are more cumbersome, and calculating paddock fertilisation requirements based on DSE stocking capacities can still be inaccurate, due to the animal growth factor (Trotter, pers. com., 2016). Farmers who do not have accurate growth data, or have made poor estimates for young stock, can over or underestimate DSE values, thereby skewing a paddock carrying capacity significantly. This can be addressed with animal walk-over weighing systems which allow daily weight gains at the individual or herd level to be conducted in the field (Henry et al., 2012).

2.2 Nutrient redistribution – Using animals as yield monitors

Pasture biomass measurements record what is in the paddock, but not what has been eaten. There is a need for pasture yield maps at a sub-paddock scale that quantifies actual pasture productivity and considers animal intake (Trotter, pers. com., 2016).

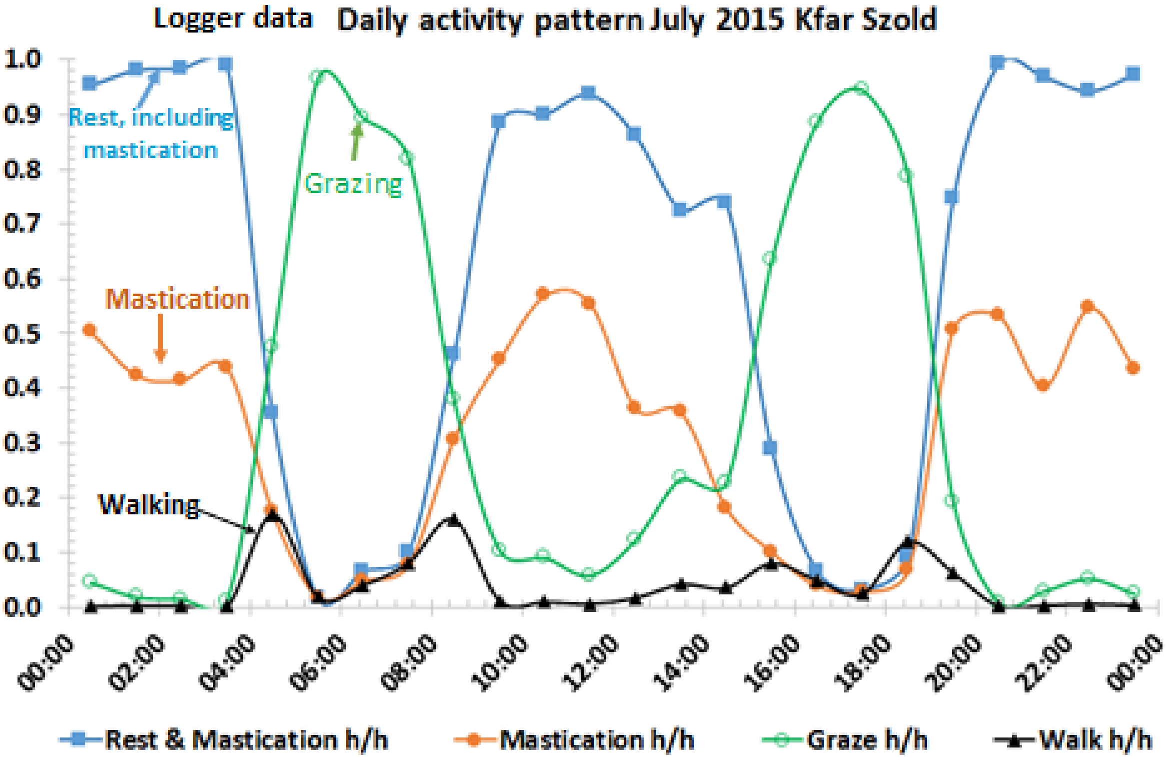
A high proportion of the P consumed by livestock returns to the soil in dung and urine, but since much of this is excreted in stock camps within the paddock, this leads to a net loss of phosphorus from the remainder of the paddock. Stock camps are more pronounced on hilly terrain and set stocked areas, and less pronounced on flat areas or where paddocks are rotationally grazed. Some phosphorus is exported from the grazing system when animals, meat, milk and (to a lesser degree) wool leave the farm (Vendramini, 2012). A link has been established between the timing, and the duration of time animals spend in an area and the frequency of urination and defecation which has enabled modelling of nutrient redistribution (Henry et al., 2012).

2.2.1 Moonitor

Developed in Israel, Moonitor consists of a solar-powered field collar fitted on a cow's neck which uses an inertial sensor and GPS combination that can break a cow's activity into resting, grazing or walking (Brosh, pers. com., 2016) (Figure 13). The daily activity summary is sent via satellite to a herd management system (Figure 14).

Figure 13: Simmental cross cow fitted with a Moonitor GPS tracking device in Israel. (Source: Brosh et al)

By tracking a mature sheep or cow to stock camps, it can be determined where they excrete large proportions of ingested nutrients - estimated to be 30 percent of dung in five percent of a paddock (Betteridge et al; Hilder, 1964).



*Note – cow locomotion modes expressed as fraction average per hour

Figure 14: Graph of animal movement separated into activity classifications by the proprietary herd management system. (Source: Brosh et al)

The key factor for this product, extensively tested in the Golan Heights, lies with the associated algorithm that was developed by assessing animal movement and the energy balance. Estimates of ME (Metabolisable Energy), from selectively grazed pasture can be made based on a cow's behaviour (Brosh, pers. com., 2016). Furthermore, estimates of herd average energy balances are calculated where feed recovered energy (RE), stored as body tissue is quantified by ME intake (MEI)' less heat production (HP) and milk production (Brosh, et. al., 2015). This was validated using NIR spectrometry of faecal samples under varying growing conditions in a Mediterranean climate. Subsequent analyses of GPS positioning with grazing quantity data will allow the yield maps to be developed (Brosh, et. al., 2015; Trotter pers com, 2016).

With commercial collars priced at $400, the author believes less than five percent of animals could be tracked allowing mob movement patterns to be captured. This capitalises on cow herding dynamics. A one-off cost for logging software ($1,000), local communication dongle ($500) and ongoing monthly satellite subscription of $10 per month per collar, will allow numerous behavioural patterns to be observed under various climatic and grazing conditions. This systematic approach to animal intake and locomotion tracking by combining data relationships with biomass quality and quantity is yet to be assessed under Australian conditions. Analyses of pasture quantity and quality influences on animal grazing habit and the reasons for preferential grazing (e.g. parasite burden, nutrient imbalance, waterlogging, shelter, prevailing wind etc) needs to be determined to enable targeted management solutions to be developed.

Chapter 3: Plant Monitoring

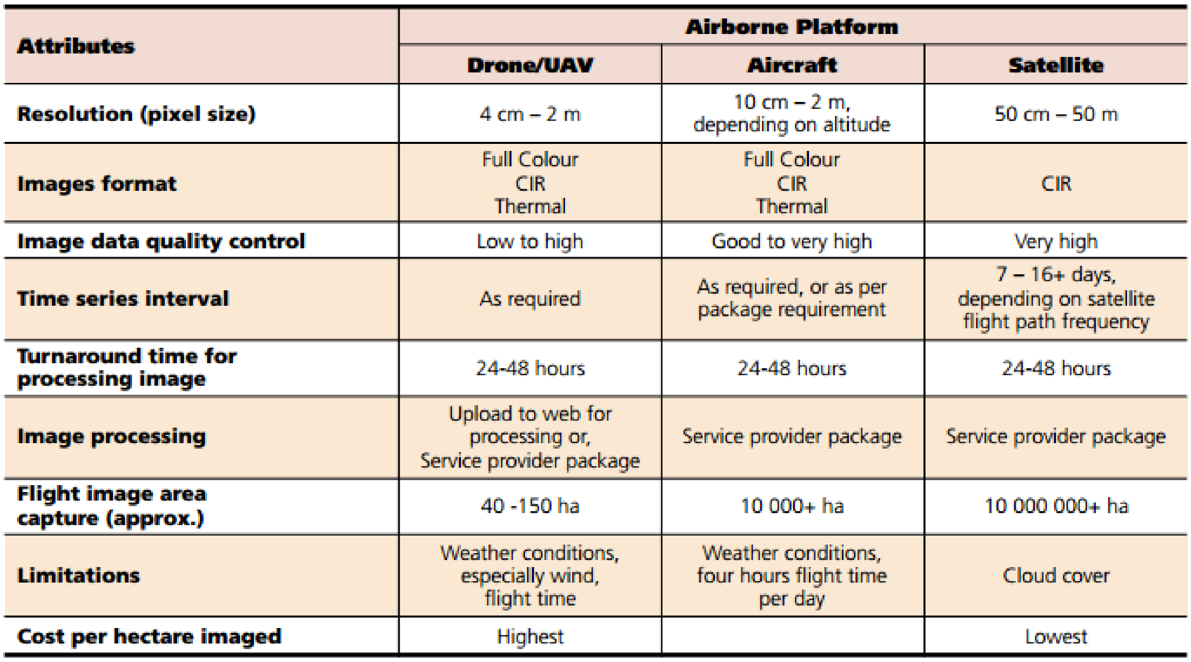
Optical sensing with multispectral and hyperspectral imagery has been applied in PA and VRT for many years. It uses visible, near-infrared (NIR) and thermal portions of the electromagnetic spectrum. Sunlight is either reflected, absorbed or transmitted by vegetation and soil. Knowledge of wavelengths and the intensity of reflectance can indicate the health or state of an object (Sauer et al., 2013). Normalised differential vegetation index (NDVI) is derived from red and NIR reflected solar radiation at specific spatial band wavelengths. Differential reflectance in these bands provides a tool to monitor plant density and the vigour of green vegetation.

A limitation of biomass measurements for livestock farmers is that low biomass areas are not necessarily the poor performing areas but are instead preferentially grazed (Henry et al., 2012). While Trotter, pers. com., (2016) found the use of hand-held sensors to be subjective and labour intensive at present, they are valuable tools in validating other more applicable methods of collection, such as satellite imagery and vehicle mounted or airborne sensors. These provide the greatest opportunity given the spatial and temporal properties of feed biomass indicators, and when validated are reported to be as accurate as ground-truthed methods (Henry et al., 2012).

Optical sensors are based on several sward characteristics including pasture height, density, and leaf area index, and require calibration across seasonal growth patterns and pasture types. Some sensors which measure pasture height can estimate the total above ground biomass but potentially include both green and senescent material (Trotter, 2010). Optical sensors utilising NDVI assess plant photosynthetically active material, where other sensors can use different indices to show pasture quality characteristics (Trotter pers. comm., 2016). It must be re-iterated that these sensors require a calibration equation to convert to pasture mass or quality estimates. Problems are encountered with the effect of shadows, varying pasture species and growth stage within a sward (i.e. chlorophyll content) and the ability to access the information from third parties in a timely matter. Hence, Henry et al, (2012) suggested the use of several technology sources where:

- satellites provide full spatial information at key times of the year with vehicle-mounted systems to provide more regular information in-between; or
- data is collected at key times, and pasture growth modelled in-between.

Integration of region-specific validation and calibration of the numerous sensors available, if incorporated into farm management software, could allow farmers to develop a protocol to suit their own requirements and obtain a level of objectivity previously unavailable (Henry, et al., 2012). Consideration of the varying attributes of airborne platforms (summarised in Figure 15) and the current commercially used technologies are briefly described below.



Attributes	**Airborne Platform**		
	Drone/UAV	**Aircraft**	**Satellite**
Resolution (pixel size)	4 cm – 2 m	10 cm – 2 m, depending on altitude	50 cm – 50 m
Images format	Full Colour CIR Thermal	Full Colour CIR Thermal	CIR
Image data quality control	Low to high	Good to very high	Very high
Time series interval	As required	As required, or as per package requirement	7 – 16+ days, depending on satellite flight path frequency
Turnaround time for processing image	24-48 hours	24-48 hours	24-48 hours
Image processing	Upload to web for processing or, Service provider package	Service provider package	Service provider package
Flight image area capture (approx.)	40 -150 ha	10 000+ ha	10 000 000+ ha
Limitations	Weather conditions, especially wind, flight time	Weather conditions, four hours flight time per day	Cloud cover
Cost per hectare imaged	Highest		Lowest

Figure 15: Comparison of features and limitations of airborne image platforms. (Source: SPAA precision ag fact sheet, Nov 2016)

3.1 Pastures from Space – Landsat

"Imagine if you could use state-of-the-art satellite technology to take the guesswork out of your farming, to give you effortless clarity on where your time is best spent. Developed with farmers, for farmers, the new Pastures from Space Plus makes it easy to calculate grazing, feed budgeting and fertiliser application, giving you a better view of your paddocks before you get out there, saving you time and money."

This statement, obtained from Pastures from the Space (PFS) website, requires some qualification. PFS is currently limited to specialised regions in Australia and estimates feed on offer (FOO) in kilograms per hectare. It is based on the relationship between NDVI and ground data to explain seasonal response patterns. Where other systems would require two biomass measurements with no grazing occurring between, PFS uses climate (rainfall, solar radiation) and soil data to estimate pasture growth rate (Pastures from Space, 2003). Satellite pixel sizes can measure down to 20-30 metres^2 spatial resolution, but two of the disadvantages still to be overcome are:

- the difficulties of satellite availability and timing arising from cloud cover, and
- pastures that contain multiple annual and perennial species (Yule, pers. comm., 2017).

Standard errors of 260-315 kg dry matter per hectare in annual pasture biomass accuracy have been reported by Edirisinghe, et al, (2011, 2012) but PFS is still considered the most accurate, cost-effective (see Figure 16) and simple predictive system to use after considering all currently available sensor technology available (Trotter, pers. com., 2016).

Property size (ha)	**Cost per annum**
0-500	$ 200
500-1500	$ 410
1500-5000	$ 610
5000-15000	$ 820

Figure 16: Pastures from Space annual subscription fee for MODIS satellite imagery. (Source: https://pfs.landgate.wa.gov.au/pricing)

3.2 Drones – what lies beneath

Drones are a convenient remote controlled or programmed access vectors allowing field observations, either by camera-fed information to the naked eye, or through interpretation of the data captured by the myriad of sensors that can be carried by these platforms. A major advantage to agricultural professionals is the widespread availability of low cost drones, allowing instant crop health information to be gathered without having to wait for a satellite or manned aircraft flight. There are currently limitations associated with optical sensors, but with the rapid developments in this area, it appears that these limitations will be overcome soon. Present accuracy levels associated with drone sensors are too variable, while aircraft and satellite produce spatial patterns that are more repeatable for zone predictions are of most benefit (Yule and Draganova, pers. comm., 2017).

A sensor used by Massey University researchers was The RedEdge^{TM} by Micasense valued at $5,000. It captures the five spectral bands (blue, green, red, red edge and NIR) seen in Figure 18. Draganova found that solar illumination had a strong effect on red edge measurements but not as much influence on NDVI pattern. By not using as much red edge in experiments, the sensor system allows the creation of tailored vegetation indices, where pasture at varying rotation stages (e.g. rye grass and white clover on long, medium, short pasture) could be matched with NDVI (Figure 17). Images obtained from drones have the advantage of being gathered while flying at low levels below cloud influence, and some sensors with downwelling light sensors enable more accurate data collection in varying light.

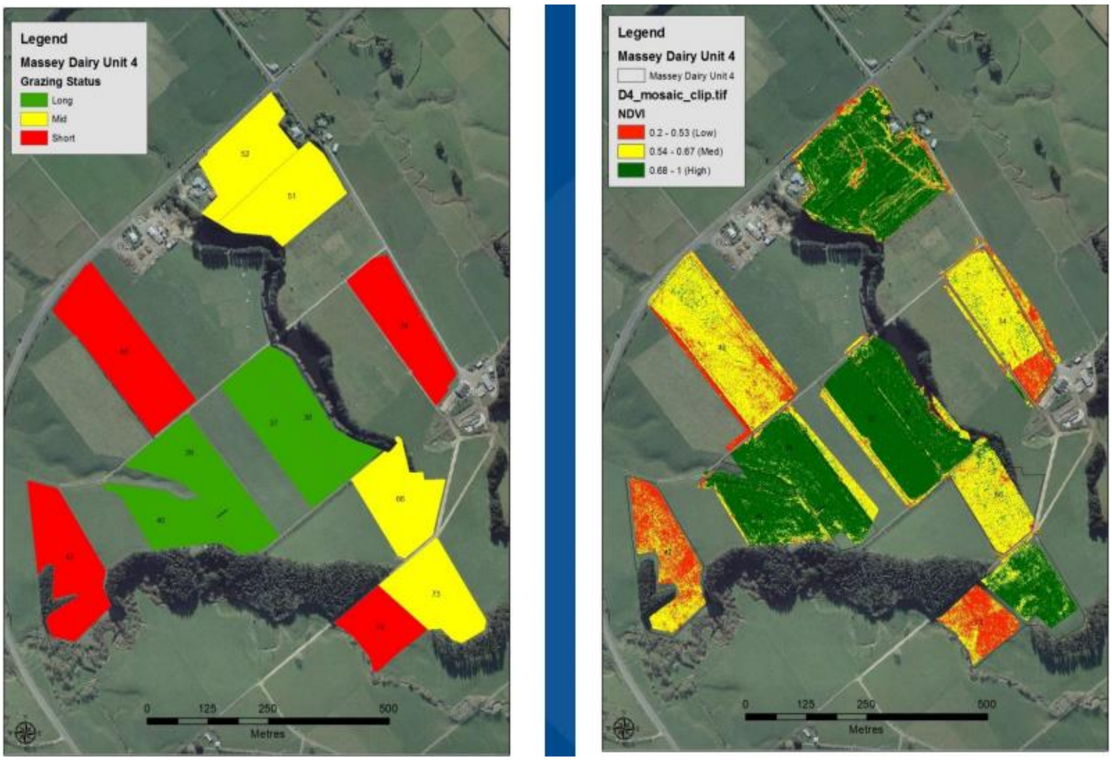


Figure 17: Correlation of RedEdge^{TM} optical sensor NDVI with three paddock pasture lengths – short, medium, long – on rotationally grazed dairy paddocks. (Source: Draganova, 2017)

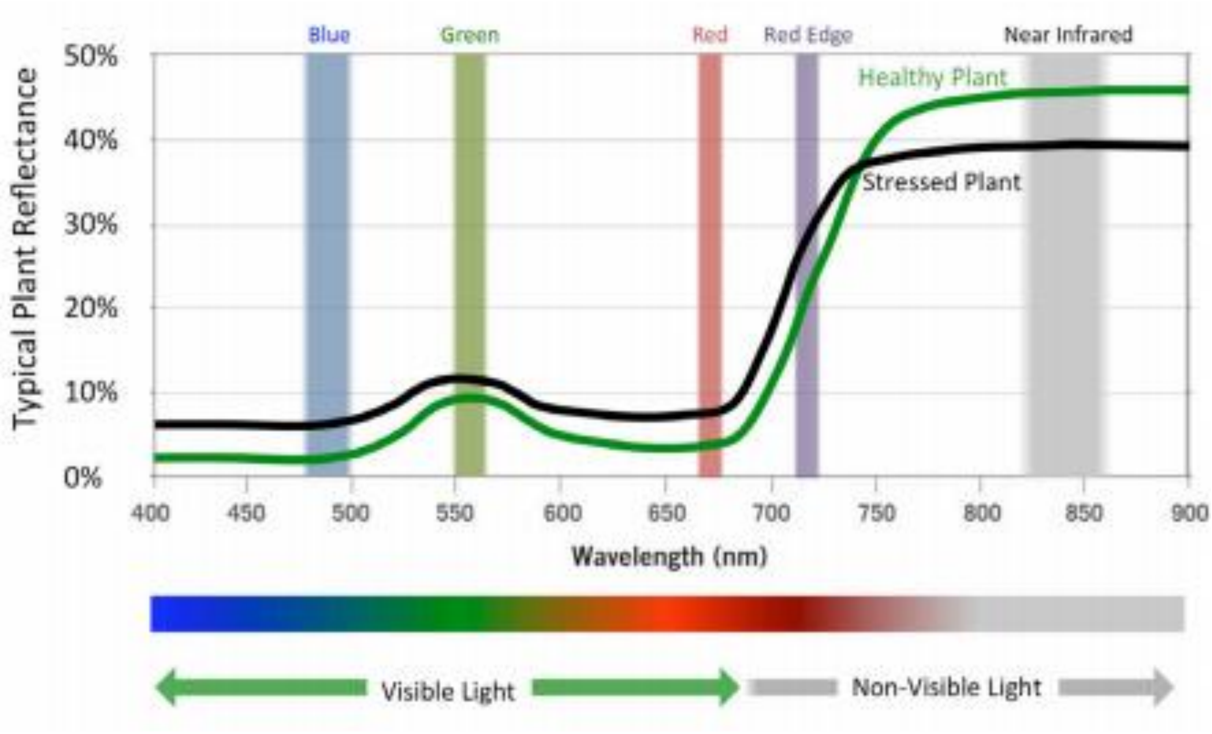


Figure 18: Spectral wavelengths deployed by RedEdge™, showing healthy and stressed plant reflectance indicators. (Source: Draganova, 2017)

3.3 Hyperceptions – Massey University

Most optical, multispectral sensors currently used in agriculture range from two to seven spectral channels. Two-channel NIR sensors are capable of estimating biomass with an additional one allowing rudimentary crude protein calculation (Yule and Pullanagari, 2012). Numerous studies have been conducted on correlating remotely sensed NDVI with pasture quality, but results were unreliable as an aid to estimate feed allocation and diet formulations (Yule, pers. comm., 2017). NIR spectroscopy, in a laboratory setting, has been proven to accurately predict plant quality parameters including crude protein, metabolizable energy, digestibility and measures of acid and neutral detergent fibre (Henry, et al., 2013).

Hyperceptions Limited is a “fee for service” spin-off company from Massey University in New Zealand due to commence in 2017. Hyperceptions uses the AisaFENIX hyperspectral sensor, attached to a fixed wing aircraft, and deploying up to 620 channels for a very acceptable analysis which enabled 98% accuracy in the prediction of metabolizable energy, crude protein and the digestibility measures acid and neutral detergent fibre (Yule, pers. com., 2017). Able to cover very large areas, a 600ha hill-country farm can be flown in approximately 40 minutes. This compares with the RedEdge™ five channel sensor, where metabolizable energy and nitrogen correlations of 58% and 70% were achieved respectively (Draganova, pers. com., 2017). This much smaller and lighter sensor can be fixed underneath most commercially available drones. Hyperceptions can accurately determine effective farming areas and paddock carrying capacities, along with more targeted pasture renewal and fertilizer application recommendations (Yule, pers. com., 2017).

These developments by Massey University have now realized an ability to achieve the rapid collection of data from any field, and to analyse that information. Key macro element deficiencies can now be determined with planned variable rate treatments applied. The conundrum of whether to fertilise the high or low performing fields and calculating the subsequent return on capital now has a major objective support tool. Although it is limited for use during the growing season, through the inability to detect and quantify senescent plant material, this sensor and others being developed will be an important tool for the livestock sector. The AisaFENIX sensor costs $500,000 with service prices yet to be advised versus the RedEdge™ priced at $5,300, accessible to most agronomists, service providers or even farmers.

Conclusion

Nutrient removal and calculated replacement quantities, based on crop yield maps, is still recognised as the preferred variable rate application system because of its simplicity. However, this system does not address the more complex problem of nutrient re-distribution via animals, or the needs of areas that have been preferentially grazed, and consequently falls short of being able to apply the nutrients required to specific areas. Providing the nutritious pasture that animals consume for maintenance and weight gain is essentially is what drives livestock producers' incomes. Creating a system where livestock producers can generate these productive pastures by placing their expensive fertiliser nutrient inputs in the areas where they produce the most abundant and sustainable growth, while avoiding losses through over or under fertilisation and avoiding polluting run-off, is the aim of PA. Further proof of concept, where a small proportion of animals fitted with GPS collars can clearly represent mob-based movement and grazing metrics within a paddock at the commercial level is still required. Once established, this would allow better interpretation of use, re-location, and replacement requirements of fertiliser inputs on a "within field" level of accuracy. Until this is validated, management programs (such as Agriwebb), or paddock biomass removal and fertiliser replacement calculations will reduce the inefficient fertilisation of paddocks. Paddocks that have sub-standard grazing performance, caused by historically low fertiliser applications which gives rise to suppression of the paddocks agronomic optimum, can also be identified using the systems identified above. Sub-optimum levels of fertility will still be open to remedy by a series of soil tests, which will identify constraints recommend remedial application of varying fertiliser/conditioner rates to optimise economic and agronomic responses.

Development of zone-based variable rate fertiliser applications, driven by an understanding of how all soil, animal and plant spatial datasets interrelate, could soon unleash substantial improvements in the livestock sector's productivity. These systems will also enhance grower's ability to analyse enterprise and management differences. The choice of combinations of available sensors that provide information for a diverse range of environments will no doubt be a challenging task and will require further independent scientific assessment and validation. For example, EM38 conductivity is extremely difficult to interpret when used to differentiate between sand and limestone, or shallow soils that are influenced by saline water tables. The addition of a topographic map and a GRS survey will enable more accurate interpretation, once soil testing of identified zones has been conducted. If soil texture classifications can be obtained, then fertiliser recommendations to suit zones and expected cost benefits could be calculated (Balkwill, pers. comm., 2017). Fertiliser application must be based on economic return, as well as agronomic potential. Soil testing is best used to monitor changes in nutrient status over time and, while expensive, due to the increased number of tests, sampling and laboratory testing error ranges must be considered. Different plant species (grass versus clover) also have different physical and nutritional requirements and a soil test may not be sufficient to determine nutrient requirements for either pasture. The identification of stress areas, using remote and optical plant sensing technology and subsequent analyses of trial strip plant response can be a very useful tool (Trotter, pers. com., 2016). However, until plant biomass sensors can differentiate between green and senescent material, objective assessment of management changes will be difficult. An additional limitation of recording what is in the paddock and not what has been consumed by animals, highlights the need to develop yield maps that indicate what is growing, plus what has been consumed prior to measurement. This would provide a better comparison between feed-on-offer and consumption rates to aid nutrient removal calculations (Trotter, pers. com., 2016).

Stock fitted with collars such as the *Moonitor GPS tracking device* will assist in giving a good indication of spatial pasture consumption at all points within a grazed paddock.

Trotter, (2010) developed the integration of plant monitoring technologies with soil surveys, which improved the understanding of spatial utilization of pastures by livestock. More traditional measures of soil fertility (sampled on a spatial scale using the above technologies to locate sample sites) will enable farmers to have a far better understanding of the flux of nutrients across a landscape and assist them to formulate a variable rate input strategy. The complexity of this task and the errors associated with the strengths and weaknesses of each technology are probably the underlying reasons why the livestock sector continues to be poor adopters of PA and VRT systems. It is difficult to quantify the benefits of management changes, and therefore to compare any benefits over the costs of adopting these systems. While presently a daunting task, development of spatial tools incorporated into easy-to-use commercial decision support applications will most certainly allow farmers to make better fertiliser investment decisions and grow more pasture more efficiently in the future.

The current conundrum of whether to target nutrients at high yielding areas or to lift poorly fertile, low yielding zones to the paddock average is constantly being debated. Where livestock are concerned, assumptions that the higher biomass zones should be fertilised more without further soil tests or soil textural analyses of these zones might simply reveal that:

- lesser yielding areas had never been fertilised to the soil's agronomic potential, due to an increased number of soil nutrient exchange sites;
- the loam was acidic and/or the clay was saline or sodic and dispersive, both inducing a raft of nutrient and physical restrictions on plant growth;
- livestock had preferentially over-grazed pasture species in a zone that was more palatable causing the reduced leaf area to diminish the plants ability to harvest sunlight and grow quickly;
- perhaps plant available water on the clay soil was restricted in an abnormally dry year.

Any number of these examples could induce a farmer to preferentially fertilise a zone, oblivious to the field's full potential. Fertiliser test strips, a combination of investigative soil tests and NDVI would identify those areas which require increased nutrient inputs to optimise pasture production, or those with which would suffer no production loss from omission or reduction (Trotter pers comm, 2016). Soil testing alone to bring all nutrients up to the agronomic optimum is all well and good but this must be validated with pasture growth measurements and increased livestock carrying capacities to justify the expenditure.

Recommendations

Independent research will be required to validate the concepts described in each Chapter (soil, animal, plant) for variable rate fertiliser applications in a commercial setting.

Incorporating data into easy-to-use decision support tools and clearly defined management guidelines will allow farmers to objectively quantify and benchmark management practice changes.

Suggested steps for service providers and farmers to adopt based on current technology and methodology are:

1. Adopt the use of farm management software such as Agriwebb. Objective measurement of key business performance indicators, quality control and grazing management (while identifying the best and worst performing paddocks) will allow further objective analysis and review. Then fertilise paddocks accordingly, based on stocking rate, calculated nutrient removal or measured responses to various treatments.
2. Identify paddocks that have distinct variations in pasture growth and define whether this is caused by management, stock grazing intensity (i.e. set-stock vs rotationally grazed), or pasture species. Set-stocked grazing systems and slow rotations cause the greatest redistribution of soil nutrients.
3. Spatial tools such as yield and topographical maps, EM, Veris or NDVI can all indicate where the variation within a paddock exists and why. Assess which tool/s are suitable and cost effective, and calculate the economic advantage (if any) and how you might use and apply information obtained before starting, e.g. EM38 might be useful to detect soil texture and depth to limestone, which is often correlated to water holding capacity and plant yields.
4. Using spatial maps or local/agronomic advice, identify 3-5 zones of soil type variability and or biomass production variations for further investigation.
5. The reasons for high and low biomass variation are a crucial assessment component and it would be worthwhile seeking professional assistance to identify causes of

agronomic variation. Do not underestimate the farmer’s knowledge and the power of a spade. Most producers know where these zones are. Soil tests at targeted zones in step 4 will often identify either physical or chemical constraints. Tissue tests of indicator species like clover (requires higher P than grass species) should be collected at the start and end of the growing season to ascertain macro-nutrient and trace element deficiencies. Different soil temperatures have a large effect on plant available nutrients. Soil tests are usually a sufficient indicator for requirements of macro elements P, potassium K and sulphur, while plant tissue tests are far more indicative of what is limiting growth for trace elements zinc, manganese, copper, molybdenum, magnesium, boron, selenium, cobalt, iron and nitrogen. Applying more P on a site that is limited by one or more nutrients will not provide a plant yield response.

6. Decisions can now be made where to allocate fertiliser or soil conditioning applications (such as lime or gypsum) at calculated zonal rates. Restricting both over and under-fertilisation of objectively measured zones is the primary focus.
7. Find a way to objectively measure treatment responses. Farmers are paid by kilograms of product produced per hectare. As such, quantity and quality of the pasture base would give an accurate assessment of pasture yield. Intra-paddock trial strip applications to assess biomass response after removal, and before livestock are returned to a paddock, is one way to compare and objectively assess.
8. Zonal or grid soil testing sites will need to be re-sampled for validation. It might be sufficient to re-test sites on a 5ha grid, instead of adhering to the original survey program at 1-2ha.

If the reader does not have the skills or knowledge to analyse the suitability of application of PA or VRT to their grazing system, the potential economic gains, or the effect adoption could have on the business in the long term, they should employ or talk to someone who does understand. For those who do wish to proceed, a nursery approach is recommended where one or two paddocks are selected to monitor and measure implemented changes. Target paddocks might include those with deeper soils which sustain plants with deep roots. Only one of the above steps might be relevant in your situation, and you will need to make your decision based on your assessment of any benefits applicable to your situation.

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Plain English Compendium Summary

Project Title:	**Variable rate fertiliser use in the livestock sector**
Nuffield Australia Project No.:	1610
Scholar:	Jack England
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Objectives	This study explored: 1. animal grazing behaviour and emerging novel technologies; 2. variable rate technologies the cropping fraternity uses that can be applied in livestock systems; and 3. existing farm management software and capabilities yet to be harnessed.
Background	Livestock farmers must, like the cropping sector, make better use of the world's finite resources and apply variable rate technology to optimise the numerous and highly variable agronomic growing conditions found within a field. Society is demanding and imposing agricultural nutrient run-off restrictions. It makes social and economic sense to create efficient yet profitable livestock farming systems utilising proven variable rate methodology.
Research	An extensive literature review provided much supporting evidence showed which countries, organisations, farms and research institutions would provide beneficial visits. Low agricultural subsidy countries, like Israel, New Zealand and Australia were particularly useful. Research in Wales, Scotland, Canada and Ireland all had their unique challenges, arising from societal pressures and varying production constraints, to be overcome.
Outcomes	Due to the difficult nature of measuring the cost-benefit of variable rate fertiliser techniques in the livestock sector, many of the technology and techniques outlined in this report remain unused – seemingly awaiting demonstration and generational change for adoption. Collaboration and trials with research institutions seeking to understand and validate opportunities will continue on the author's farm.
Implications	Most livestock farms rely on purchased nutrients to replace those removed by livestock sales and by-products. An assessment of methods available reveal that the livestock sector can significantly improve the industry's environmental impact in tandem with long term economic and profitability increases.