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Case studies to review methods for defining within-paddock management zones - Kwinana West zone
FUT0001

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Executive Summary

This study investigates the use of spatial information to define within-paddock management zones in the Kwinana West zone. Results show zone management is not a 'one size' fits all approach. Analysis of paddock variability on three case study farms at Wickepin, Corrigin and Popanyinning showed that the cause of crop yield within a production zone can vary significantly. For example, two low performing areas can be low for different reasons such as an ironstone gravel or a potassium deficient sand and require different management, making ground-truthing essential. This makes zoning for fertiliser in these landscapes that have high variability, challenging. It is not a case of production vs soil zones. It is a combination of the information that will determine the best management option to maximise profitability. Farmer knowledge of the paddock also plays a significant role determining management zones.

Electromagnetics (EM) and gamma radiometrics (Gamma Potassium, Thorium, Uranium & Total Count) can help interpret causes of yield variation. EM strongly correlated with yield in landscapes with highly contrasting soils (i.e. sands to clays at Corrigin and Wickepin). Gamma helps delineate different soil types in combination with EM, however no layers were particularly useful in isolation. Interpretation of the different gamma layers varied on a paddock by paddock basis.

The development of management zones was considered for variable rate lime, potassium, gypsum and ripping. The defined zones were different for each management issue as were the layers of information that were helpful. For example, EM and Gamma Thorium (Th) can be used to identify ironstone areas for variable ripping and yield in one paddock correlated to soil potassium but not in other paddocks. Topsoil pH did not correlate well with yield, biomass, or EM which is likely due to the fact that surface pH is rarely the primary driver of yield variation, and more commonly it is the water holding capacity of the soil. Grid soil pH mapping of the topsoil is globally accepted as a more reliable method for developing accurate variable rate lime applications.

Using precision agriculture technologies can be frustrating. There were problems with yield data collection at one farm due to a faulty yield monitor. More farmers should be collecting, storing and most importantly utilising yield data. It is an effective method for defining within paddock variability and a great entry point for zonal crop/soil management. Over 60% of farmers in Australia have a yield monitor (CSIRO, pers comm. 2012) yet few properly calibrate, store or examine the data after each season. Another important learning from this project is that using technology for paddock scouting, such as IPADs or IPHONES, was very challenging due to intermittent mobile data signal.

Keep it simple! Collecting multiple spatial information layers can lead to data over load and difficulty making use of the data as there is so much information to digest. Start with a yield map and/or aerial photo, assess variation using local grower knowledge and strategic soil sampling. This process of utilising grower knowledge underpins the success of any precision agriculture plan as it focuses variable rate management strategies around the key limiting yield constraints for each paddock.

Introduction

The commercial availability of Precision Agriculture (PA) technologies such as yield mapping, EM, Gamma, biomass (NDVI) imagery and grid soil sampling, together with rising input costs and declining terms of trade are motivating growers to adopt a zonal management approach to improve input use efficiency.

The division of paddocks or farms into areas of similar production potential 'Zonal Management' is not a new concept. The original concept was farming to soil type for which many farms in WA were fenced according to soil type. As the scale of farming has increased, paddocks are now larger and incorporate many different soil types. GPS and computer technology enable 'virtual fencing' in modern zone farming.

There are many types of spatial information available to measure production variation within a paddock or across a farm, from low cost simple farmer mud maps; yield maps, satellite imagery or proximal sensor (NDVI), to costlier EM and gamma surveys. Each layer brings different information to the table to help growers and their agronomists make decisions about how to target inputs and improve profitability.

Production based information (i.e. yield maps, satellite imagery and farmer knowledge) measure plant performance as a result of interaction with soil type, season and agronomy. EM and gamma surveys can be used to map soil type zones and associated soil constraints such as salinity and non-wetting sands. They do not always reflect yield as these constraints or soil properties may not be the key driver of production variation due to other factors such as frost, machinery impacts, disease, farmer management, or waterlogging.

The cost of spatial information layers can vary greatly from $14-25/ha for EM and gamma mapping, to less than a $1/ha for biomass imagery and yield maps. This wide range of costs causes much uncertainty from growers and consultants about where to invest in spatial information for zonal management.

The use of soil versus production factors to define management zones is a long-standing debate between PA practitioners. Both approaches have been successfully demonstrated in WA, however there is still a need for grower historical knowledge of the paddock to help set the final zone boundaries. There are also examples where soil survey data has been collected and disregarded because it did not reflect yield, or satellite imagery discarded because it did not reflect soil pH that the grower was hoping to manage by zone. Similarly, a large proportion of WA growers collect yield data but do nothing with it because it can be hard to interpret or they are not confident with computer technology. Understanding which spatial layer to collect to help manage a specific yield constraint is important, in order to develop a confident management strategy and ultimately achieve a positive return on investment.

There has been much research and investment into zonal management and PA technologies over the past 15 to 20 years in Western Australia. Reported benefits of variable rate management range from $15-50 /ha in WA (Robertson et al 2008). Studies have also shown that not all paddocks may offer a benefit from zonal management depending on starting soil nutrient levels if there was a greater than one tonne per hectare variation in yield between zones (Lawes et al 2011). Hence the importance of having a clear understanding of what needs to be managed spatially for each paddock.

Spatial information collected using sensors remotely (i.e. satellites) or proximally (i.e. EM, gamma, and yield monitors), measures variation across a paddock that can be combined with farmer knowledge to manage the application of soil ameliorants and crop inputs. This may be dividing the paddock up into 2-5 zones of similar performance and managing them accordingly. There are two strategies can be followed with zone management:

- *Manage according to zone potential. If* zone performance is consistent or amelioration is too expensive you can manage according to the current zone potential (i.e. put less fertiliser on the low yield potential zone and more on the high performing zone). This can be done without knowing the factors limiting production. It may also be the most economic option for soil constraints that are difficult to ameliorate such as salinity, boron toxicity, deep wodjil sand acidity, impenetrable clay layers or differences in plant available water capacity.
- *Identify cause of variation and ameliorate per zone*. This is suited to managing soil acidity, compaction, poor structure, waterlogging or nutrient deficiencies.

Past GRDC projects with the Corrigin Farm Improvement Group (CFIG), The Department of Agriculture and Food WA, and CSIRO have shown a key characteristic of the Kwinana west zone that has challenged the application of variable rate fertiliser, is production variation driven by rainfall season to season. These are referred to as 'flip/flop' zones; in one year the areas of the paddock produce well, and the next they produce poorly. This lack of consistency makes it difficult to apply nitrogen according to zone potential as sometimes poor performing areas may perform well (i.e. well drained soils with low water holding capacity are likely to be poor in dry years and good in wet years). This is where farmer knowledge of the paddock has a significant role determining zones. Data such as elevation that can be mapped using data collected by GPS RTK systems may also be helpful to identify areas with high risk of frost or waterlogging.

Research and practical application of the technology over the past 10 years have shown zonal management is more than just varying seed, fertiliser and inputs such as soil ameliorants. Altering paddock layout to improve drainage, targeted weed or pest treatment, can also help to improve profitability. In some cases, these may be more cost effective uses of zonal management. The information to derive management zones will vary depending on the landscape and target management issue.

Objectives

This project aimed to evaluate if there are any differences in deriving management zones from soil or production spatial information, and in what situations each of these layers may be useful to help maximise grower investment in PA technologies.

Trial locations

Hemley, Wickepin
Glenview (GV) 9 -32.813641, 117.529789
Valleyview (VV) 11 -32.718021, 117.524691
Larke, Corrigin
C1 -32.211263, 117.773761
C22 -32.205635, 117.787957
Lyneham, Popanyinning
Paddock 3 -32.686248, 117.077818
Paddock 7 -32.685880, 117.102765

Methodology

There were two stages to this project. The first was interrogating the different layers of spatial information for case study paddocks, to determine if there were any relationships between layers and soil test data. The next step was to determine the key management issues the case study farmers were looking to manage and what layers can be useful to help develop appropriate management zones to improve efficiency of treatments.

Three case study farms were selected at Wickepin, Popanyinning and Corrigin. Each grower selected two focus paddocks that had soil types typical of their farm and the area (Figure 1).

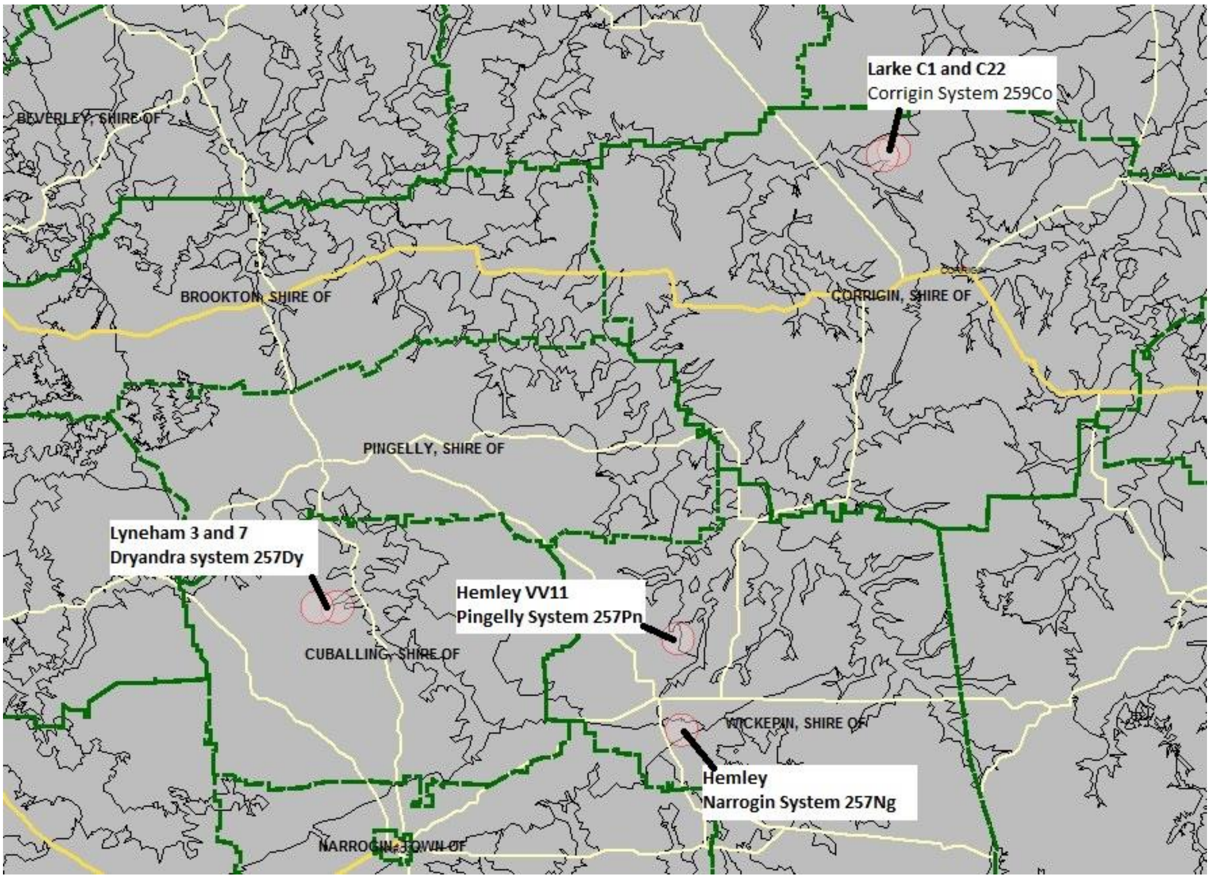


Figure 1. Locations and soil landscape systems of the three case study farms (Source: www.agric.wa.gov.au NRM INFO website)

Site details

Case study 1: Clinton Hemley
Average Rainfall: 500mm
Main soil types: yellow brown ironstone gravel, red loam, grey brown sandy loam over clay, brown sandy loam over clay.
Original target management issues: variable rate lime and potassium (K), micronutrients, ripping ironstone gravels

Table 1 Hemley paddock history Glenview 9(GV9) and Valleyview 11&12 (VV11)

	2015	2014	2013	2010	2009	2007	2004	2003
GV9	wheat	barley	canola	wheat	peas	canola	canola	wheat
VV 11	Canola	wheat	wheat	wheat	pasture	canola	wheat	pasture
VV12	canola	wheat	wheat	wheat	canola	pasture	pasture	wheat
Rainfall mm*	292	398	397	236	327	403	320	

*Data from Wickepin weather station, paddock VV11 and VV12 are now the same paddock

Case study 2: Stephen Lyneham
Location: Popanyinning
Average Rainfall: 445mm
Main soil types: pale deep sand, loamy sand over gravel, grey loamy sand over clay, sandy ironstone gravel.

Original target management issues: variable rate Lime and potassium (K) after reviewing data, target issues variable rate K and P

Table 2. Lyneham paddock 3 and paddock 7 rainfall and rotations for the years spatial information was collected

	2015	2014	2013	2012	2010	2009	2007	2004	2003
Paddock 3	wheat	wheat	barley	barley	pasture		wheat		pasture
Paddock 7	canola	wheat	wheat		wheat	pasture	canola	wheat	pasture
Rainfall* mm	402.6	313.8	415.8	423.6	287.7	336.2	437.5	404.8	333.6

*Data from Pingelly weather station 13 km away.

Case study 3: Craig Larke
Location: Corrigin
Average Rainfall: 370mm
Main soil types: loamy ironstone gravel, grey clay, pale sand, grey sandy loam over clay
Original target management issues: is PA worth investing in, ripping zones, and variable rate gypsum

<u>Spatial information analysis</u>
The initial criteria for selecting the growers, was they had to have several years of yield maps. It proved challenging to find a farmer at Corrigin not previously involved in a precision agriculture project so the farmer selected showed a keen interest in adopting new technology. Satellite imagery (NDVI) was used as a surrogate for yield.

The following data layers were collected:

- yield,
- satellite derived biomass imagery (historical analysis of 10 years data),
- electromagnetics at depths of 0.75m and 1.5m,
- gamma radiometrics (total counts, potassium (K), thorium (Th), uranium (U)),
- elevation (from the farm RTK GPS systems), and
- an aerial image.

EM and gamma surveys were conducted across the paddock on a swath width of 30 metres at the beginning of May 2015.

During the season, the satellite image was ground-truthed to examine what was actually occurring in the paddock at the time. Before looking through any of the layers of information with the growers, they were asked to draw a mud map of their paddock performance.

Soil sampling was collected post-harvest in 2016 at 10cm increments down to 50cm. The top 0-10cm were analysed for nitrogen (N), phosphorus (P), potassium (K), sulphur (S), gravel content, texture, phosphorus buffering index (PBI), pH and electrical conductivity (EC). The other depths were analysed for pH, EC, K, P, gravel content and texture. Soil test sites were selected to ground truth spatial data not based on zones.

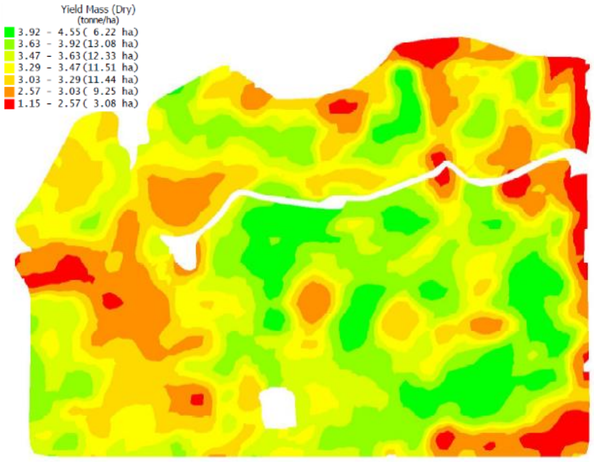
Zonal analysis statistics were used to compare each layer to yield by reclassifying the spatial layers (yield, biomass, gamma Potassium (K), Thorium (Th), Uranium (U), and EM) into nine zones. Yield data from each paddock was cleaned and calibrated. The digital soil test results were imported. A buffer zone of 10m (radial) was applied at the soil sample sites and zonal stats were used to determine the predominant zonal readings at the soil test points. A regression analysis was completed comparing each layer against the yield or biomass.

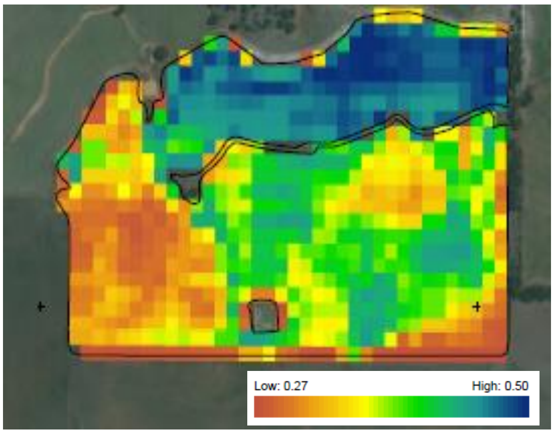
Potential applications for zonal management were selected by the growers. These included ripping zones, variable rate potassium, lime, and gypsum. The different layers of spatial information were interrogated to determine which were the most useful for the identified management issues.

Results

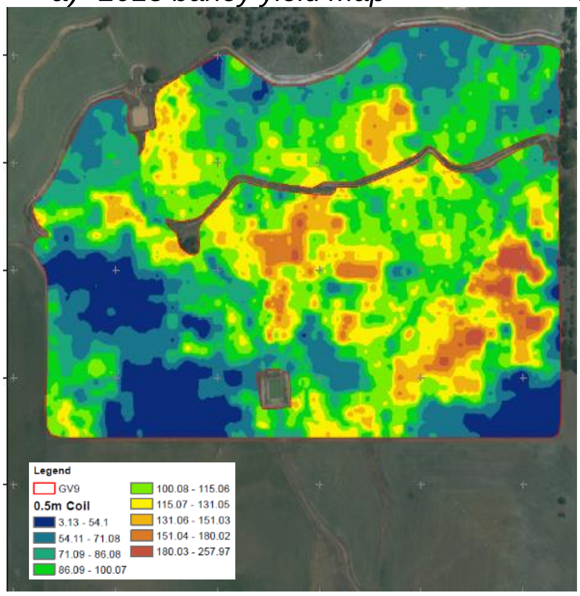
<u>Case study 1 Hemley</u>

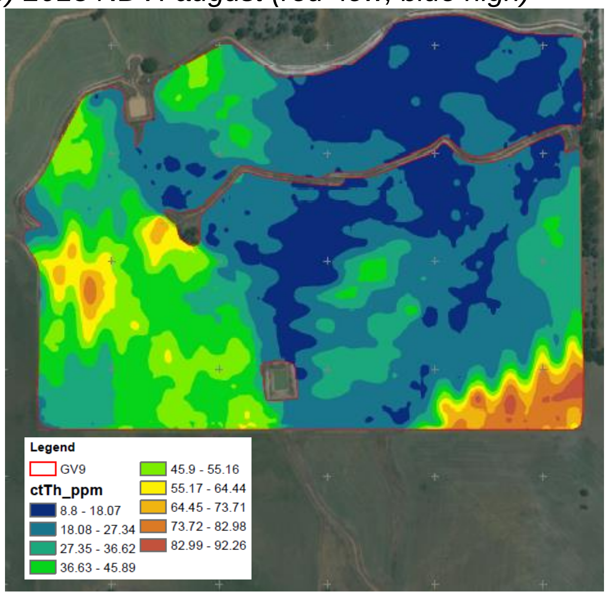
Examples of spatial information collected for Hemley paddocks Glenview 9 (GV9) and Valleyview 11 (VV11) are shown in Figure 2 and 3.





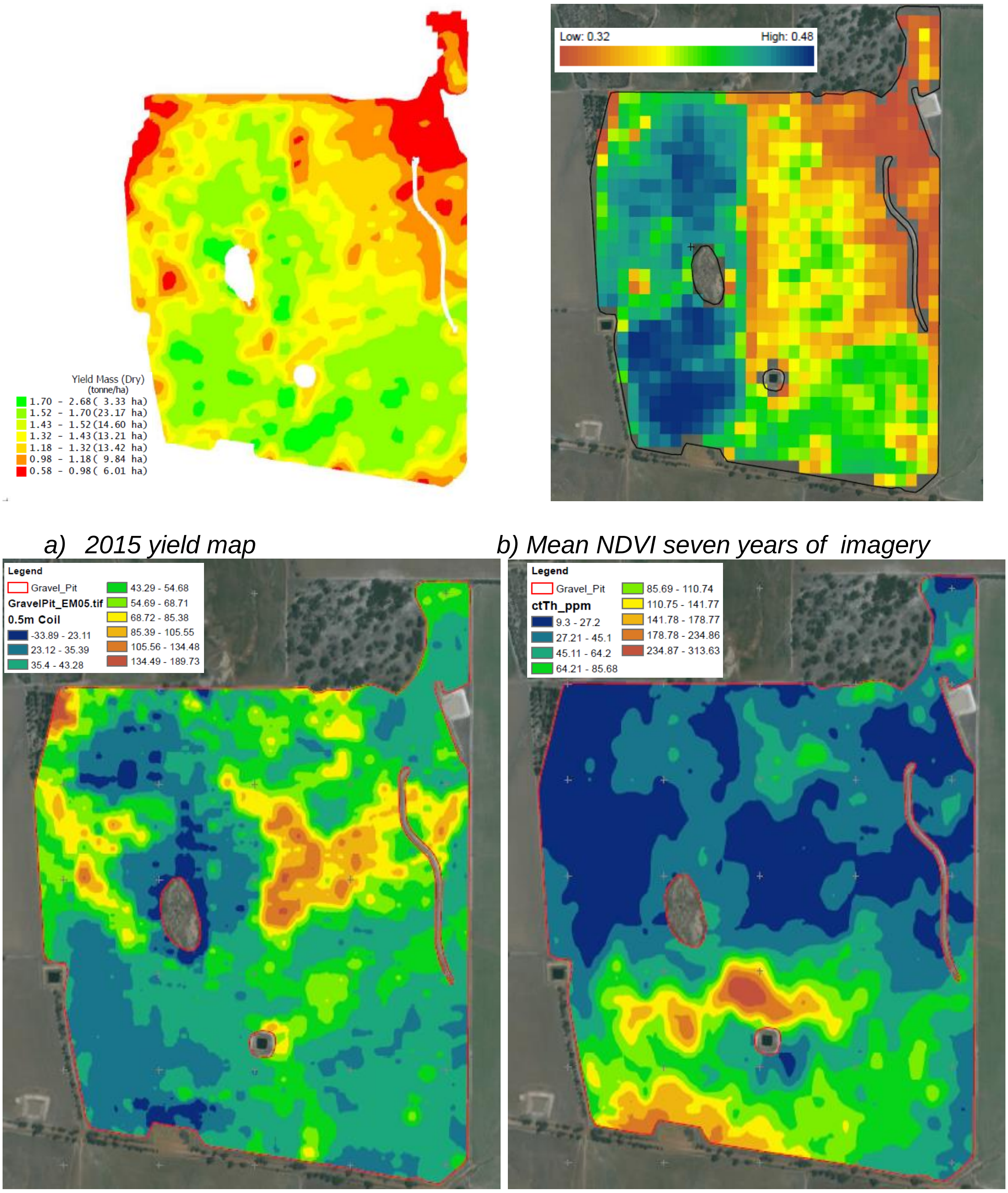
a) 2015 barley yield map *b) 2015 NDVI august (red=low, blue high)*





c)EM0.5 *d) gamma thorium*

Figure 2. Hemley paddock GV9 examples of spatial information collected.



a) 2015 yield map *b) Mean NDVI seven years of imagery*

c) EM 0.5m *d) gamma thorium*

Figure 3. Hemley paddock VV11 examples of spatial information collected

The key findings for Hemley were:

- Both EM and gamma radiometrics correlate well to yield in particular canola.
- Ironstone gravels can be identified from gamma Th, EM and yield. These can be targeted for ripping.
- A farmer's mud map integrated with other spatial information can accurately define management zones. This historical knowledge of paddock performance and variability is a very important data layer.
- Yield maps can be used to zone paddocks however canola and wheat need to be considered separately as they perform the opposite in some parts of the paddock

depending on soil type. Despite the canola and yield performing differently the yield stability analysis indicated the yield variation is consistent, however the biomass is inconsistent. Yield can also show variation due to management as in 2015 where two crop varieties were sown in the same paddock.

- Biomass maps taken at different times of the season, can show differences in soil types for example July image clay soils had low biomass and in August they had caught up and were high biomass.
- Topsoil pH did not correlate well with any data layer. However, there was a correlation with EM to subsoil pH. Grid sampling topsoil pH is recommended as acidity is not always the driver or yield variation so it is difficult to zone with yield. Defining soil type with multiple layers may allow targeted sampling and the generation of accurate pH maps, however in this landscape with complex soil types more soil test points maybe required.
- Yield data - it is good practice to format the data card every year to minimise paddock name changes.
- The usefulness of different spatial datasets will vary across landscapes. Therefore, growers with multiple properties must be mindful that different strategies may need to be employed to develop paddock management zones. This also highlights the fundamental requirement for ground-truthing such maps with local knowledge and soil testing.

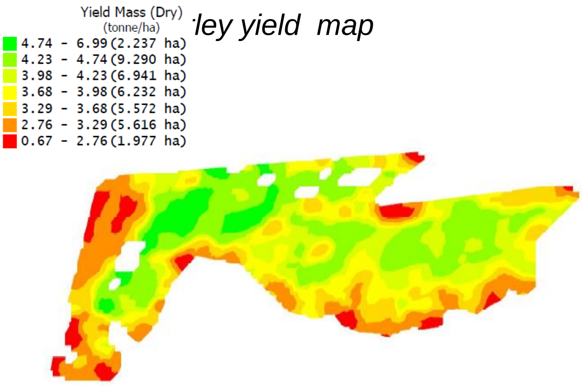
Clinton Hemley, Wickepin and Bindi Isbister, Precision Agriculture ground-truthing paddock GV9

Case study 2 Lyneham

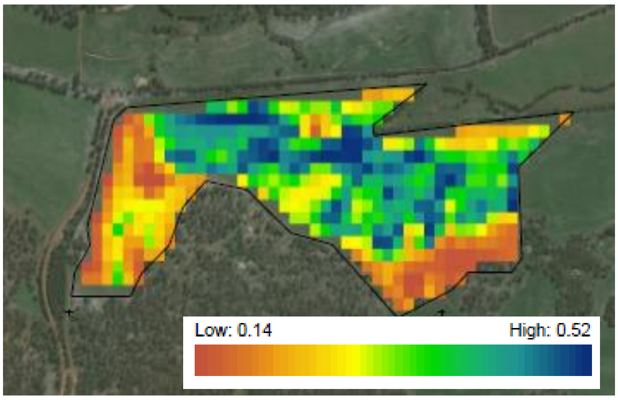
Steve Lyneham paddock 3

Figure 4 and 5 show examples of spatial information collected to Lyneham paddock 3 and paddock 7.

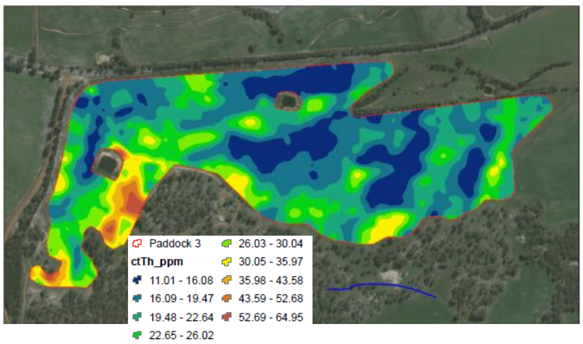
ley yield map



b) Mean NDVI seven years



c) Gamma thorium



d) EM0.5

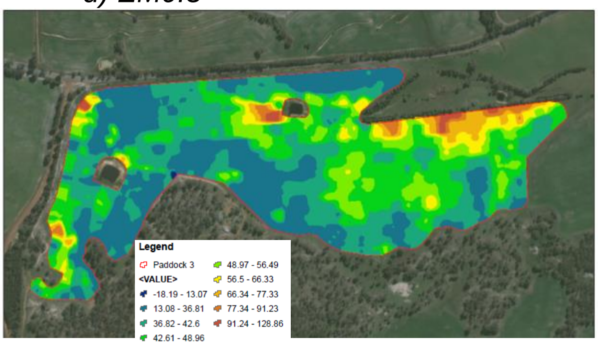
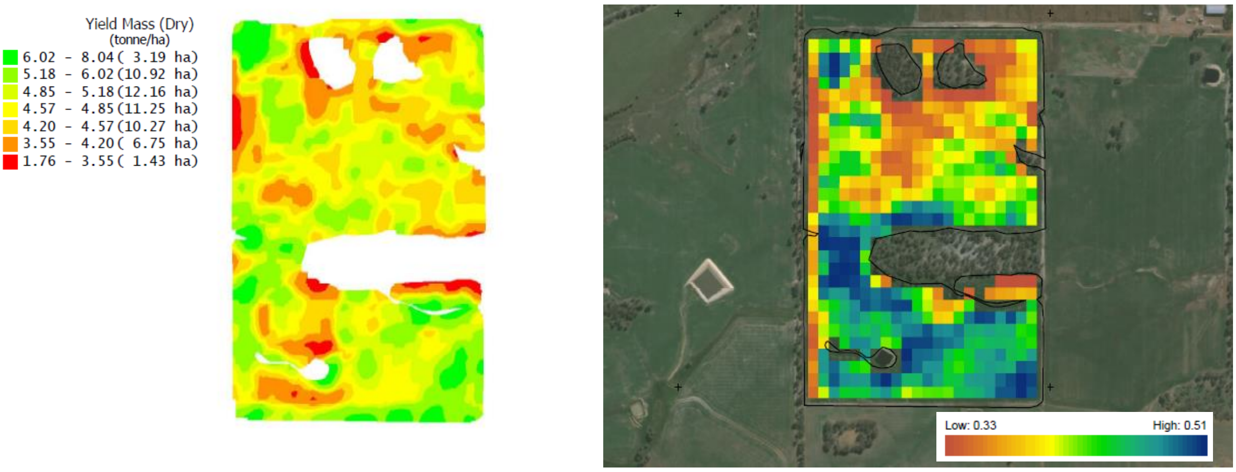
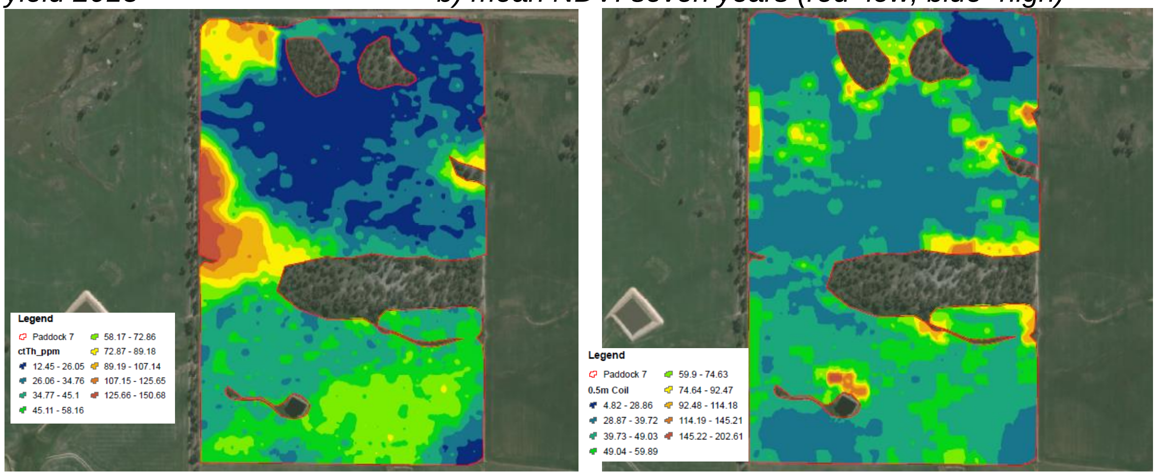


Figure 4. Examples of spatial information collected for Lynehams paddock 3



a) *yield 2013* *b) mean NDVI seven years (red=low, blue=high)*



c)gamma potassium (red=high, blue=low) d) EM0.5 (red=high, blue=low)
Figure 5. Examples of spatial information collected for Lynehams paddock 7

The key findings for Lyneham paddock 3 and 7 were:

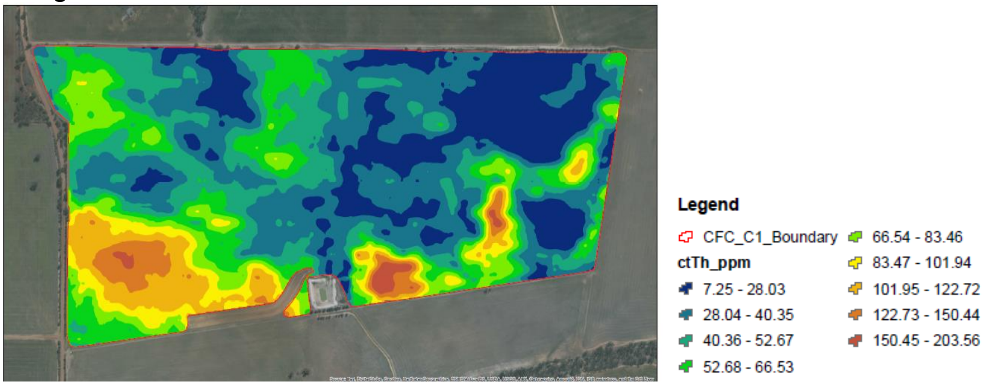
- In this landscape there is less variation in soil texture than at Wickepin or Corrigin, with soil types ranging from pale deep sands, sandy loam, sand over clay and sandy ironstone gravels. Individually, EM and gamma did not correlate with yield or biomass. They could however help define the causes of variation in paddock 7 such as the presence of gravel or slightly higher clay content.
- Biomass reflects yield in this landscape and was stable over seven seasons, thus it is a good option for defining production zones. It identified the weaker sandy areas (low biomass) such as in paddock 7 the pale deep sand that is commonly low water holding capacity and non-wetting. However, it did not accurately map out all the areas deficient in potassium. Therefore, selecting the right layer to target a specific issue is important.
- EM was predominantly low across both paddocks suggesting the soil types are sandy. The EM did identify saline areas in both paddocks.
- The relationship of gamma to yield varied between the two paddocks. Gamma Th correlated to yield in paddock 3 and gamma K correlated well to yield in paddock 7.
- Soil testing indicated all sites were acidic and in need for lime across both paddocks.
- Soil testing indicated variation in soil potassium in paddock 7 therefore applying VR potash using variable rate has potential to minimise input costs Low soil K did not

correlate to yield or biomass, therefore EM was used to identify sandy soils and zones requiring potash.

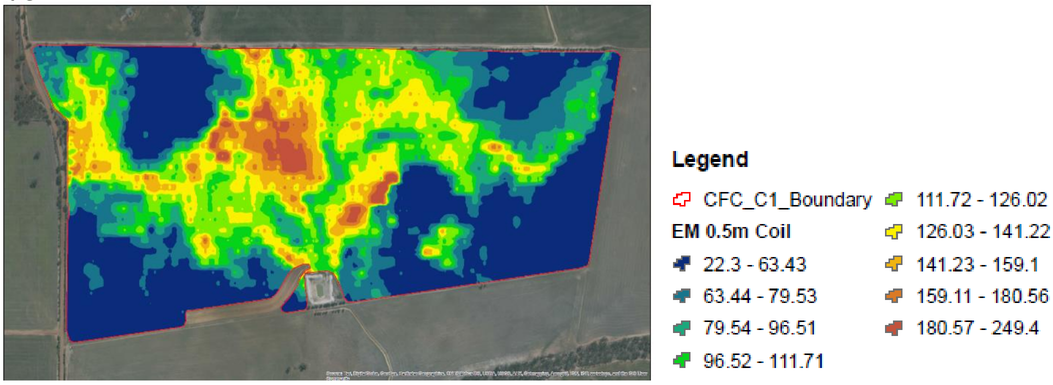
- PA technologies can certainly experience technical difficulties such as yield monitors not logging correctly. It is important to check data is logging correctly during harvest. A problem with a sensor was identified and fixed in 2014, yet the problem reoccurred for harvest 2015. Another technical issue was limited mobile reception. This meant ground-truthing or crop scouting using mobile devices i.e. IPHONE or IPAD had limited value as the signal was too intermittent.

Case study 3 Larke

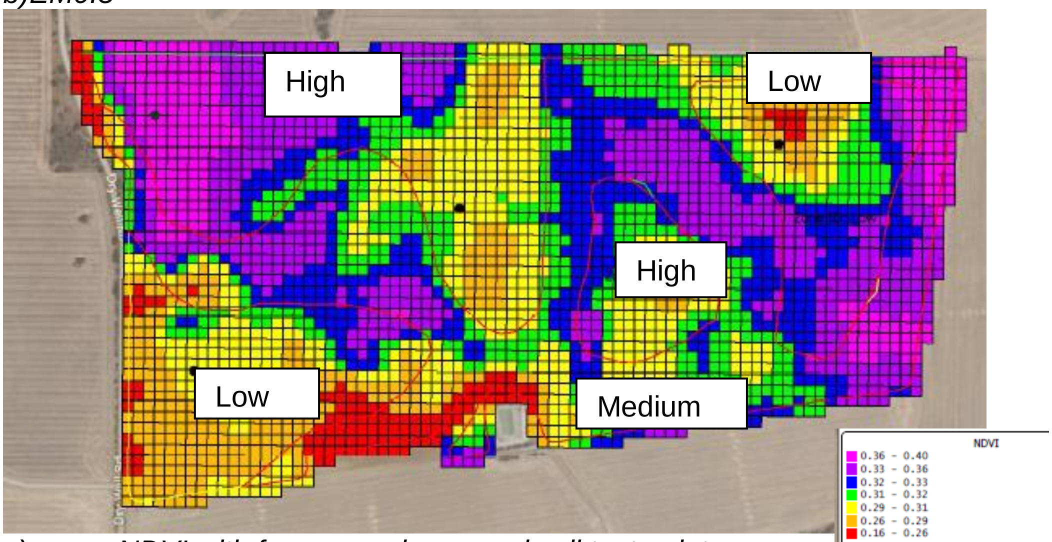
Examples of spatial information collected for Larke's paddocks C1 and C22 each are shown in Figure 6 and 7.



a)gamma thorium

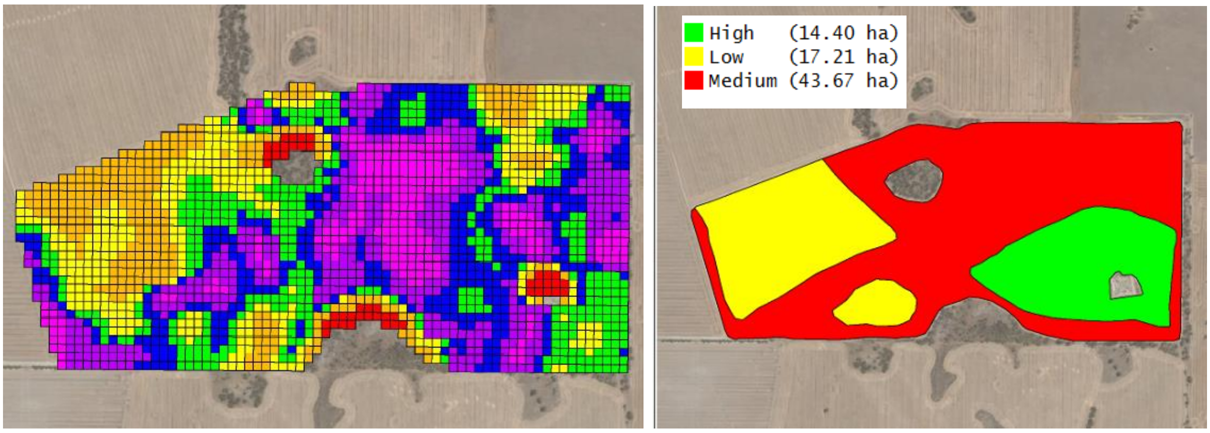


b)EM0.5

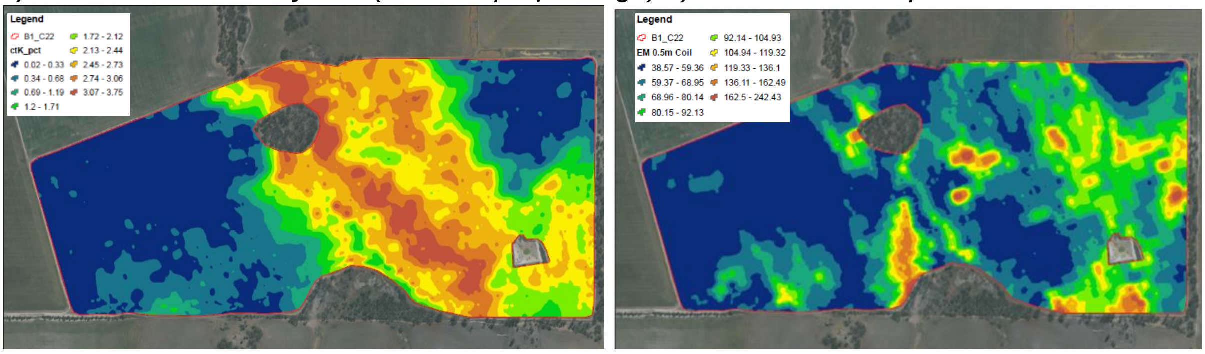


c) mean NDVI with farmer mud map and soil test points

Figure 6. Examples of spatial information collected for Larke paddock C1



a) *Mean NDVI cereal years (red=low purple=high) b) Farmer mud map*



c)Gamma potassium *d) EM0.5*

Figure 7. Examples of spatial information collected for Larke paddock C22

The key findings for Larke's paddock C1 and C22 were:

- Biomass in this landscape is not a consistent indicator of paddock variability however, it can help identify flip flop zones, such as in paddock C1 where an area of low biomass was zoned high production by the grower. Flip-flopping is related to rainfall, low lying clay areas perform well in wet years and poorly in dry years as do the ironstone gravels. It also highlighted different soil types depending on the seasonal conditions.
- Elevation can be useful to help define flip-flop areas. If collected using a Topcon RTK GPS system, the Topcon software program is required to extract it. Generic programs such as SMS cannot be used.
- Canola and cereals perform differently particularly in the ironstone gravels. The ironstone gravels can be identified using EM, gamma th and biomass. Comparing canola yield vs wheat maps may help map these soil types as the Hemley canola correlated well with gamma th, however this relationship was unable to be tested at Larkes due to no yield data being available.
- Gamma K correlated well to NDVI. Biomass was higher where gamma K was high. This soil type was a grey brown loam over loamy clay.
- It is possible to identify ripping zones using EM and gamma Thorium, unfortunately a ripper was unable to be sourced for this season to do some test strips.
- Topsoil pH is variable therefore grid sampling is a good option as no spatial information layer correlated with topsoil pH. Grid sampling would accurate map boundaries between different soil acidity levels across the paddock. Subsoil pH did correlate to EM therefore it could be used for strategic subsoil sampling in this paddock.

- Yield maps would be very helpful to measure the actual variation; Craig is buying a new header this year with yield mapping capability.

Production vs soil based spatial information analysis

The different spatial layers were compared to yield or biomass to determine if they correlate. Each paddock had a different relationship to the different spatial datasets. This is not unexpected given the different landscapes and geological processes of the focus paddocks. It highlights that each paddock has different factors affecting it, so within farms it important to interpret information on a paddock by paddock basis.

Below is the summary of correlations (Table 4) for all spatial information datasets: the higher the number (r^2), the greater the correlation. Yellow colours represent moderate correlations, whereas green represents strong correlations.

Table 4. Summary of correlations (r^2) for all spatial information datasets for each case study paddock

	Compared to yield data				Compared to satellite imagery	
	Hemley 9	**Hemley 11**	**Lyneham 3**	**Lyneham 7**	**Larke c1**	**Larke c22**
Gamma Total	0.06	0.79	0.08	0.24	0.00	0.01
Gamma K	0.31	0.11	0.18	0.82	0.60	0.75
Gamma Th	0.10	0.81	0.61	0.02	0.00	0.00
Gamma U	0.27	0.80	0.19	0.29	0.01	0.22
EM 0.5m	0.92	0.86	0.51	0.00	0.79	0.95
EM 1m	0.91	0.83	0.55	0.03	0.75	0.97
Elevation	0.88	0.87	0.13	0.76	-	-
Imagery(NDVI)	0.29	0.60	0.80	0.92	-	-

Applications of zone management

Soil acidity (lime application)

The three growers identified soil acidity as a key management issue they would like to address using a zonal management approach. Soil testing indicated soil pH did vary across the paddock at Larke and Hemleys therefore a zonal management approach has potential. Lynehams required lime across the entire paddock, therefore a blanket application is the best strategy to start with. The different spatial information layers were interrogated to determine which layer maybe useful to define lime application zones. Table 5 is a summary of correlations of yield/biomass against soil pH, and Table 6 is the EM against soil pH at different depths. As found in other studies in WA, surface pH isn't always related to subsoil pH, and these sites were no different.

Table 5. Summary of yield/biomass vs soil pH (yield Hemley and Lyneham biomass Larkes)

	pH Topsoil (0-10cm)	**pH midsoil (10-20cm)**	**pH Subsoil (20-30cm)**
Hemley 9	0.01	0.13	0.62
Hemley 11	0.08	0.13	0.00
Lyneham 3	0.18	0.01	0.01
Lyneham 7	0.76	0.69	0.37
Larke 1	0.00	0.78	0.86
Larke 22	0.05	0.94	0.94

Table 6. Summary of EM (75cm) vs pH

	Topsoil (0-10cm)	Mid (10-20cm)	Subsoil (20-30cm)
Hemley 9	0.49	0.66	0.78
Hemley 11	0.78	0.86	0.89
Larke 1	0.42	0.59	0.77
Larke 22	0.72	0.62	0.72

There was a strong correlation between the amount of lime recommended to be applied based on soil pH results to depth compared to the general soil type classification across the three case studies (Figure 7).

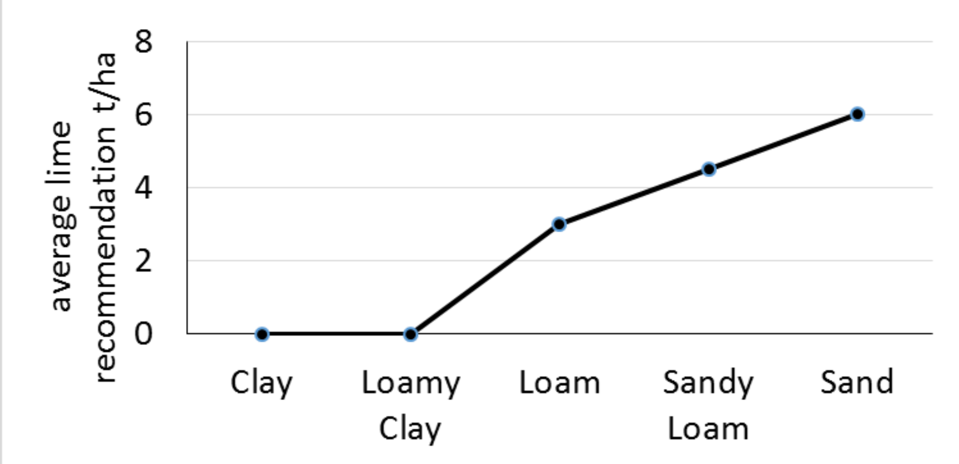


Figure 7. Average amount of lime recommended to be applied based on soil test results vs general soil type for the three case studies

Lyneham soil test results showed lime was required across the whole paddock and therefore variable rate lime is not required (see figure 8 and 9 below). There was no correlation of yield to pH in paddock 3. Note the pH range is small, meaning there isn't a great deal of variation.

Figure 9. Lyneham Paddock 7 soil pH, potassium (k) and phosphorus (P) results

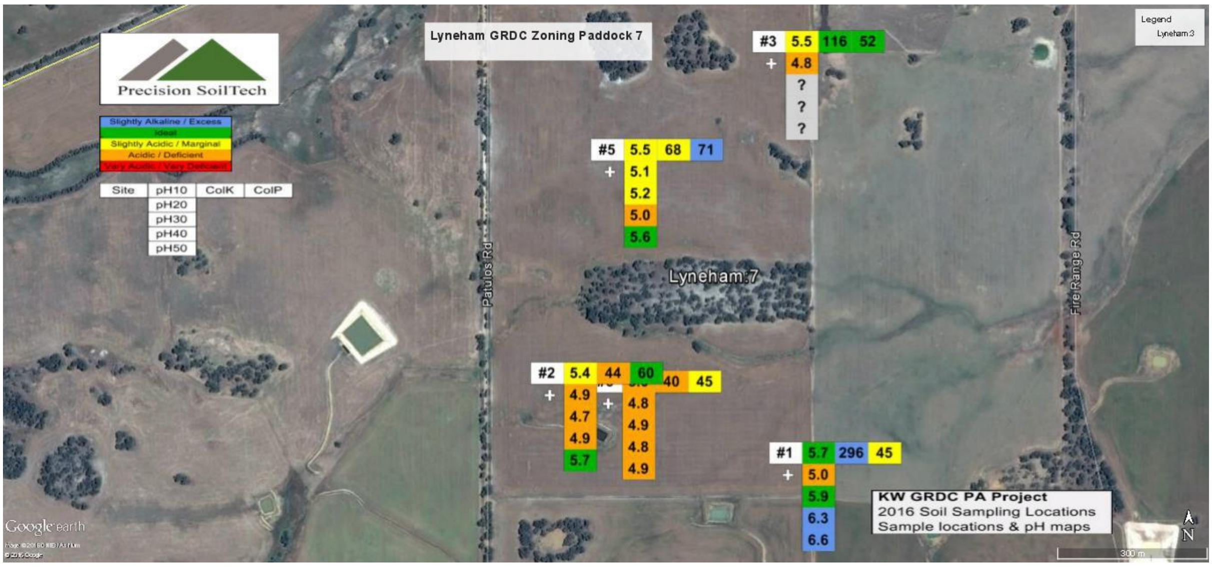


Figure 8. Lyneham Paddock 3 soil pH, potassium (k) and phosphorus (P) results

Variable rate lime would be useful for Larke as the subsoil pH readings in some areas are slightly acidic requiring 3 t lime (C22 site 4), acidic subsoil requiring 6t lime over 10 years (C22 site 1), whilst other areas are alkaline (C22 Site 3) – see Figure 10 below.

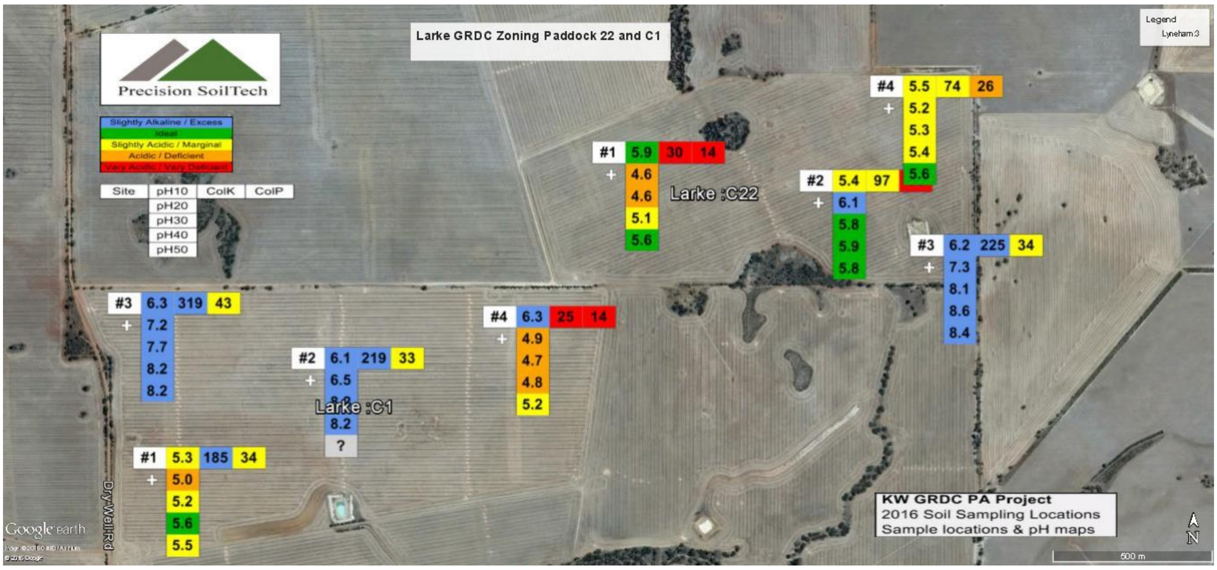


Figure 10. Larke C1 and C22 soil pH, potassium (k) and phosphorus (P) results

Topsoil pH rarely correlates with EM, mainly because EM is most sensitive to soil properties below 30cm. This was the case for paddock C1, yet not C22 (Figure 11). Topsoil pH did not correlate to biomass however pH did correlate with biomass with biomass and EM in both paddocks. This is due to the soil type difference where the heavier soils have higher pH. Biomass and yield reflect the interaction of the plant with their environment and agronomy and therefore pH may not always be the main cause of poor yield. Similarly, high performing areas (high yield and biomass) can have low pH as they may be better sands.

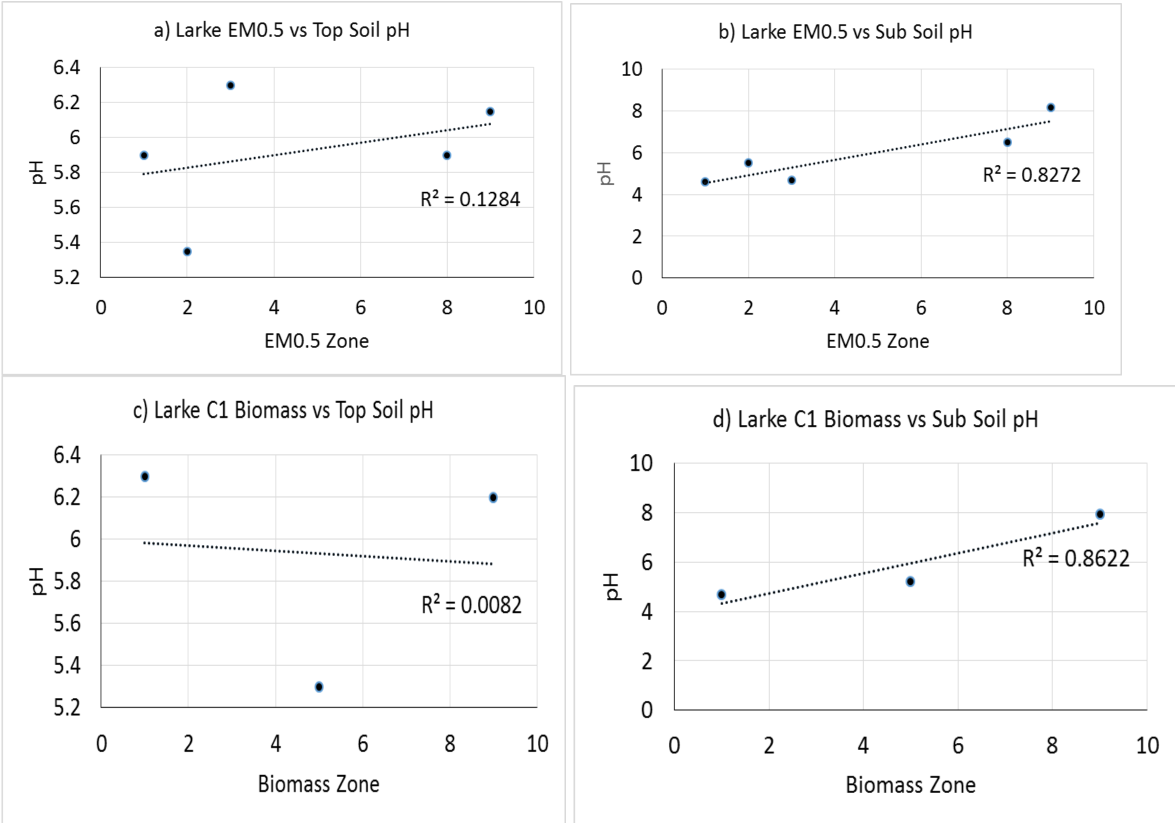


Figure 11. Larke paddock C1 average of soil pH topsoil 0-10cm, subsoil20-30cm for biomass zones and EM0.5 zones sampled (EM zones 1 = lowest EM value to 9 = highest EM value)

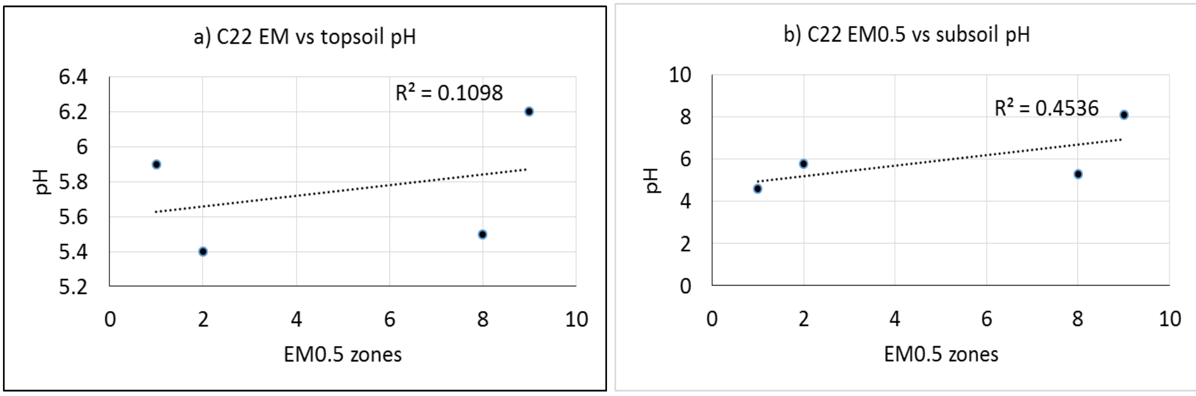


Figure 12. Larke paddock C22 average of topsoil 0-10cm pHand subsoil 20-30cm EM0.5 zones sampled. (EM zones 1 = lowest EM value to 9 = highest EM value)

There was a correlation with total amount of lime recommended to be applied based on soil test results and biomass (Figure 13) suggesting the lower biomass areas are more acidic and require more lime (these areas are sandy). This is a good example of where grid pH in the topsoil with strategic subsoil sampling would be suitable to accurately map variation across the paddock.

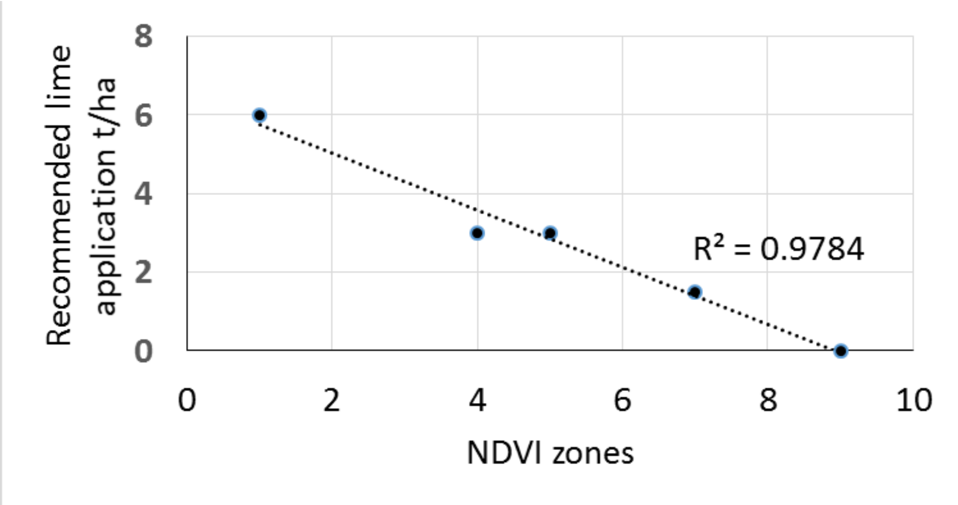


Figure 13. Total amount lime recommended vs NDVI 2015 zone Larke (NDVI zones 1 = lowest EM value to 9 = highest EM value)

Hemley soil test results indicated both paddocks were potential candidates for variable rate lime, potash and phosphorus (figure 14 and 15 below). pH readings varied widely, with some areas neutral to alkaline, and other areas quite acidic therefore the amount of lime required will vary across the paddock.

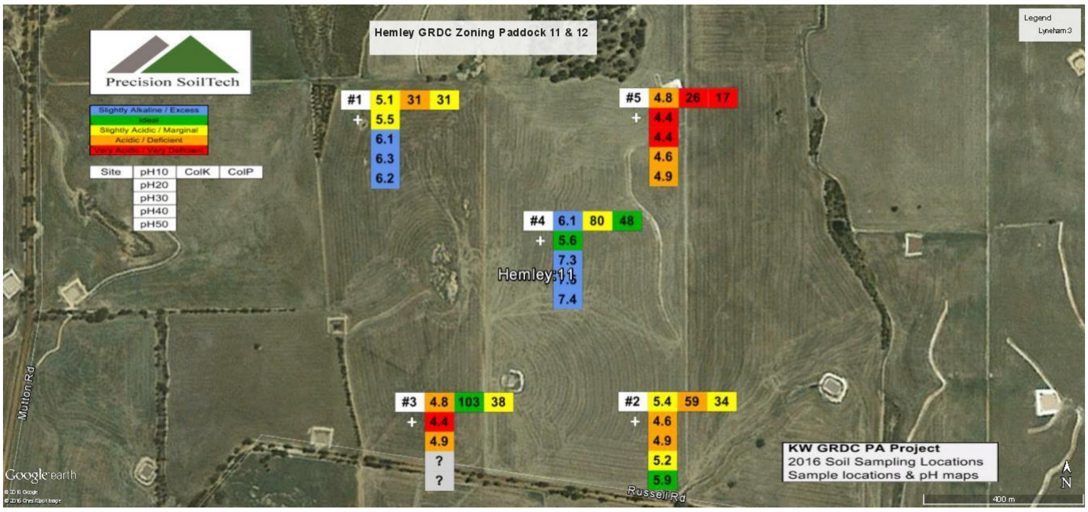


Figure 14. Hemley Paddock VV 11 soil pH, potassium (k) and phosphorus (P) results

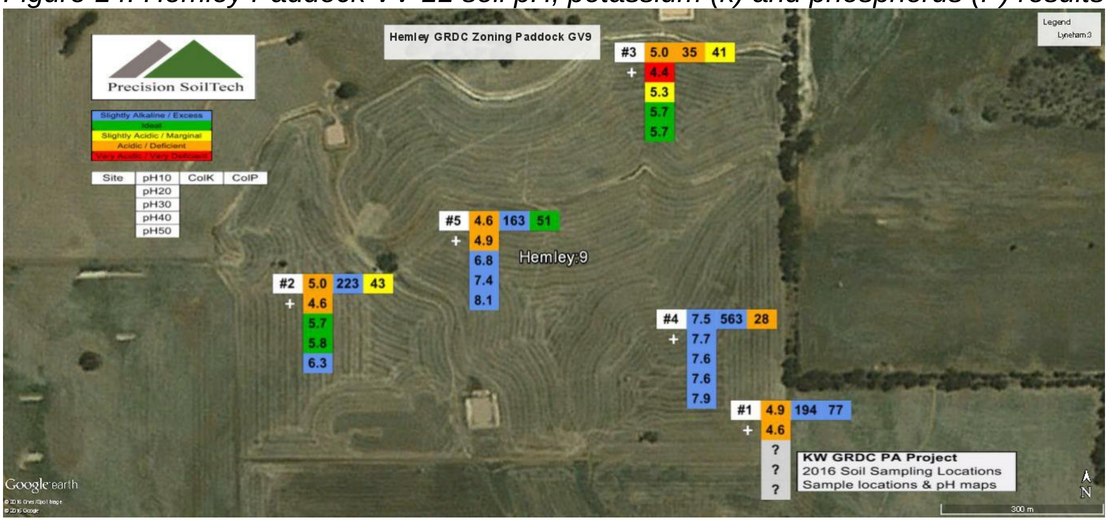


Figure 15. Hemley Paddock GV9 soil pH, potassium (k) and phosphorus (P) results

Yield is commonly used to identify areas to apply lime. GV9 showed a poor correlation between 2015 yield and topsoil pH, but a good correlation with subsoil pH (Figure 16). However, paddock VV11 did not show correlation at any depth.

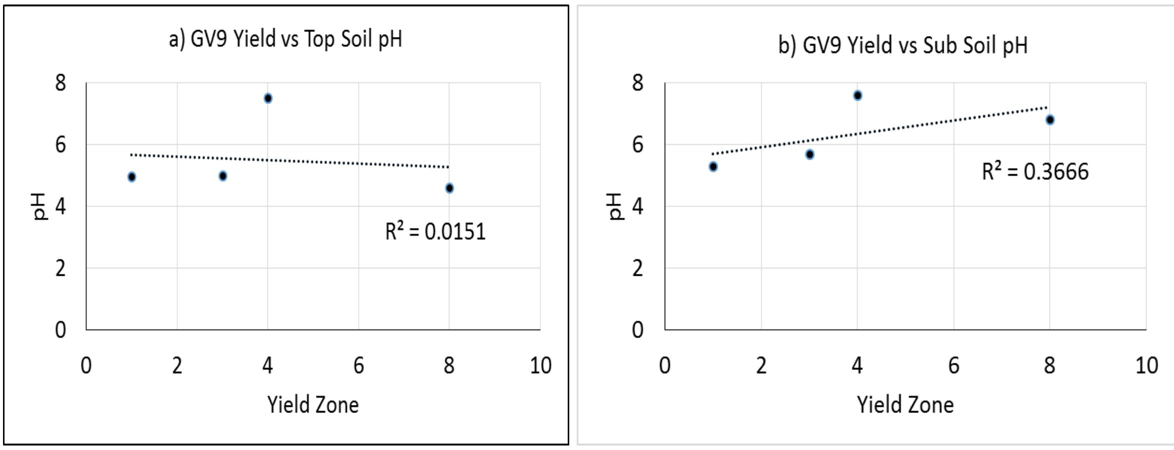


Figure 16. Hemley GV9 yield zone and corresponding soil pH values of the topsoil (0-10cm)and subsoil (20-30cm)

pH correlated well with EM0.5 in paddock 11 topsoil, mid and subsoil and therefore it cobe used for variable rate lime in paddock 11 (Figure 18). However in paddock 9 soil pH mid and subsoil correlated to EM0.5 but there was no correlation to topsoil pH. EM measures the electrical conductivity of the top 75cm therefore it cannot define duplex soils such site 5 paddock 9 that is a sandy loam over clay and the highest EM zone (Figure 19).

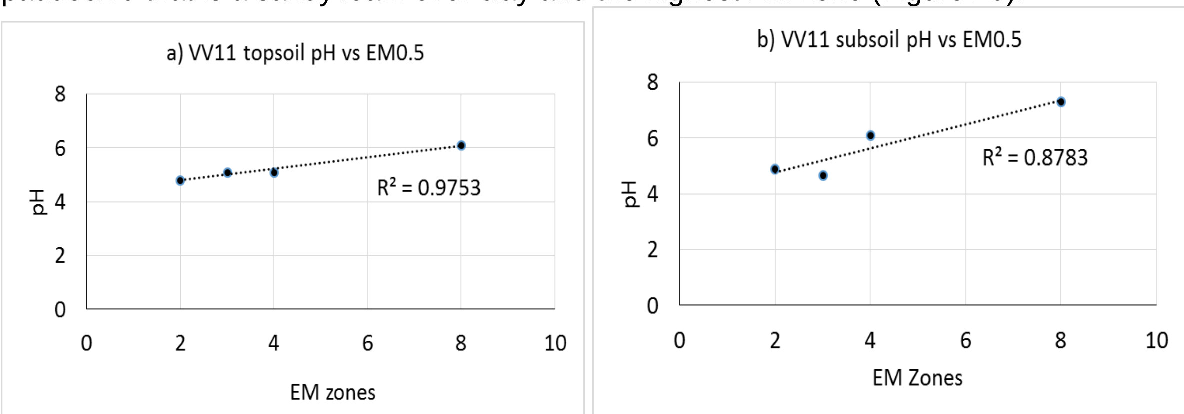


Figure 18. Hemley 11 EM0.5 zone and corresponding soil pH values of the topsoil (0-10cm), midsoil(10-20cm) and subsoil (20-30cm)

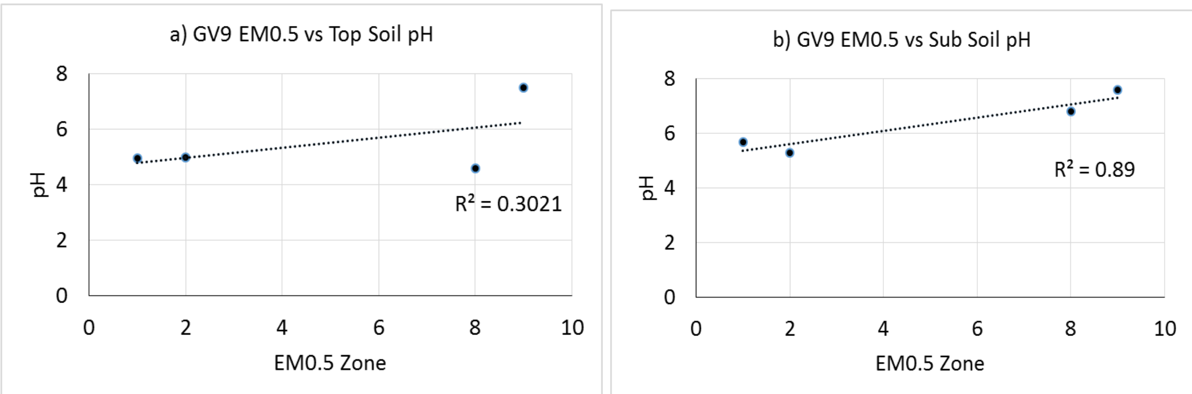


Figure 19. Hemley 9 EM0.5 zone and corresponding soil pH values of the topsoil (0-10cm)and subsoil (20-30cm)

This soil type map was drawn using a combination of features from EM, gamma Th, soil K, soil type, yield, and farmer knowledge. Ironstone gravels with sandy topsoil (0-30cm) are commonly acidic, and the heavier clay soils are generally slightly alkaline. It could be assumed that these would correlate well to pH, so each soil type could be targeted for sampling and then lime applied as required. However there was a lot of variation in crop performance in the brown red sandy loam zone so this favours a grid soil sampling program to accurately define lime requirements.

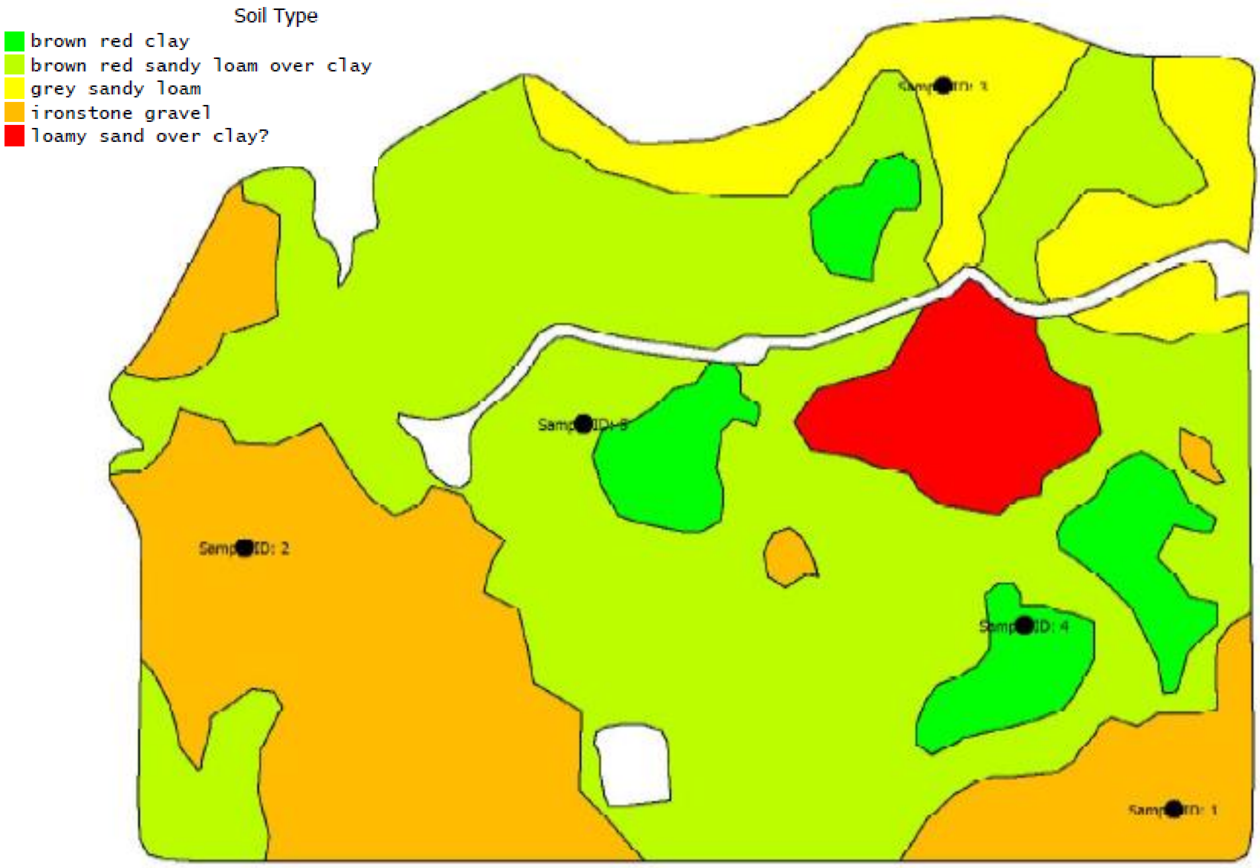


Figure 20.Soil type and soil pH results for Hemley GV9

Deep ripping zones

Hemley and Larke case studies demonstrated it is possible to map ironstone gravels with high gamma Th, low yield/biomass and low EM (Figure 21). These areas can be targeted for ironstone ripping with the new “rocksgone reefinator” ripper as Clinton Hemley has done in paddock 9 or a standard ripper could be lifted over these areas to avoid damaging the tines. This is the approach Craig Larke plans to use in paddock C1. The cost of ripping ironstone gravels is about $500/ha therefore being able to accurately target areas, is beneficial.

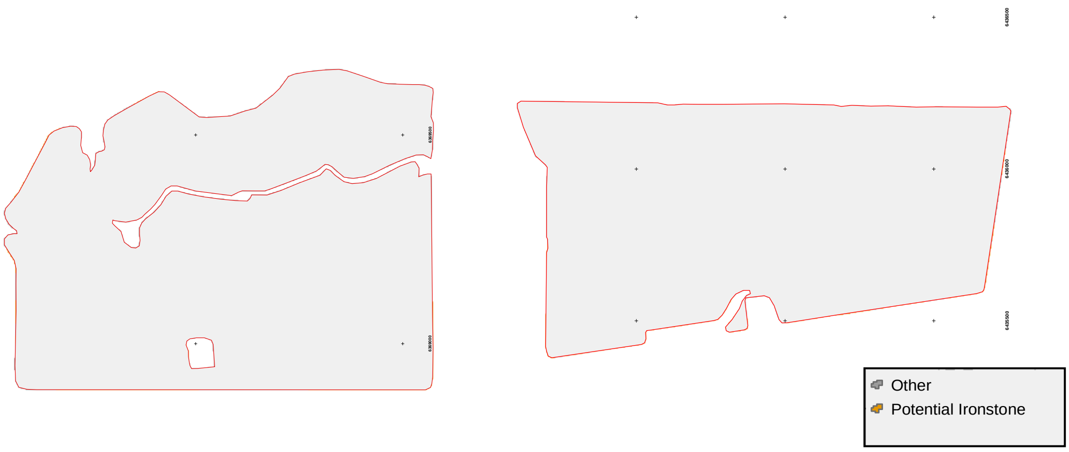


Figure 21. Ironstone areas identified using EM, gamma radiometrics thorium and yield for Hemley paddock 9 (left) and Larke paddock C1 (right)

Variable rate K

Soil test results indicated both Hemley paddocks were candidates for variable rate potassium (K). There was no correlation with soil K and EM and yield in GV9. This is likely due to the different cause of variation in the low performing areas i.e. ironstone gravel vs grey sand over clay. Therefore a straight yield map or EM map is not sufficient to zone for K application. In this paddock, variable rate potassium maps should be defined using a combination of spatial layers or grid potassium mapping. Figure 22 shows the areas identified for K application by the farmer using the yield map & soil tests as guide compared to b that identifies the area using low EM, low gamma Th and low yield. The patterns are clearly similar.

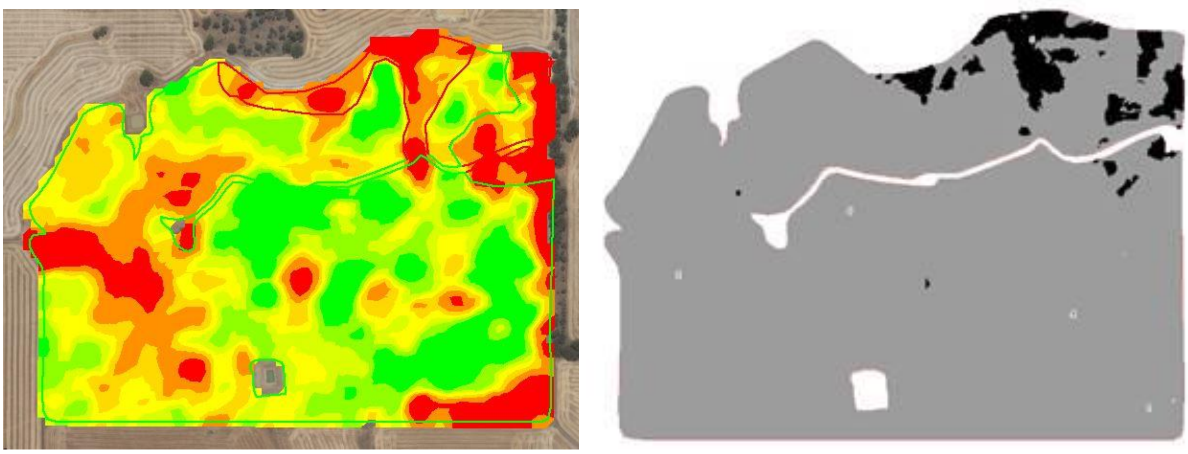


Figure 22. Left: Barley yield red = low green = high Red contour shows area to apply potassium generated using a yield & farmer knowledge Right: Low potassium areas (black) identified by low EM, Low gamma th and low yield

Soil potassium does correlate to yield in VV11, therefore yield could be used for applying K (Figure 23).

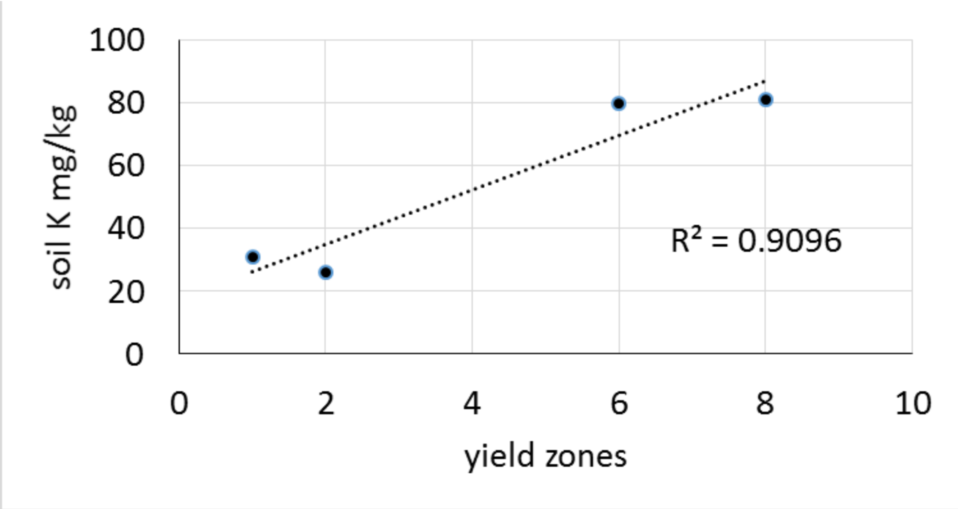


Figure 23. Hemley VV11 correlation of soil K 0-10cm to yield zones 2014 (1=low yield and 9= highest

The stacked yield map presented as three zones does reflect the soil type map and the farmer mud map of applied K (Figure 24). Although there is an area in the southwest corner of the paddock zoned high performing, soil test results indicate could benefit from some potash application (Figure 25). This soil test point was picked up by the farmer's mud map. It is likely soil potassium is not a key yield driver in this area of the paddock, but further investigation is required.

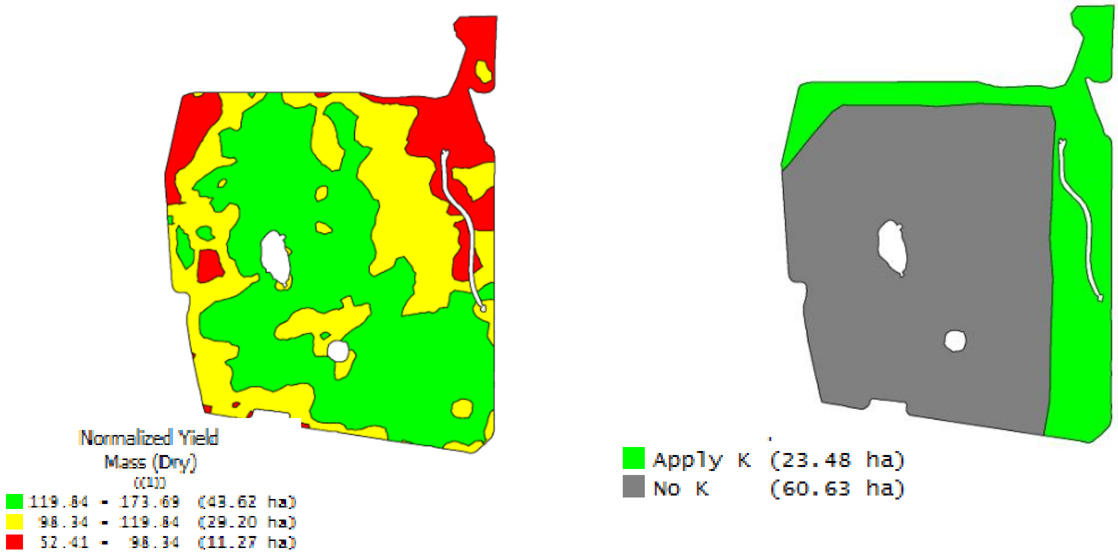


Figure 24. Hemley 11 left: yield in three zones right: farmer mud map potash application

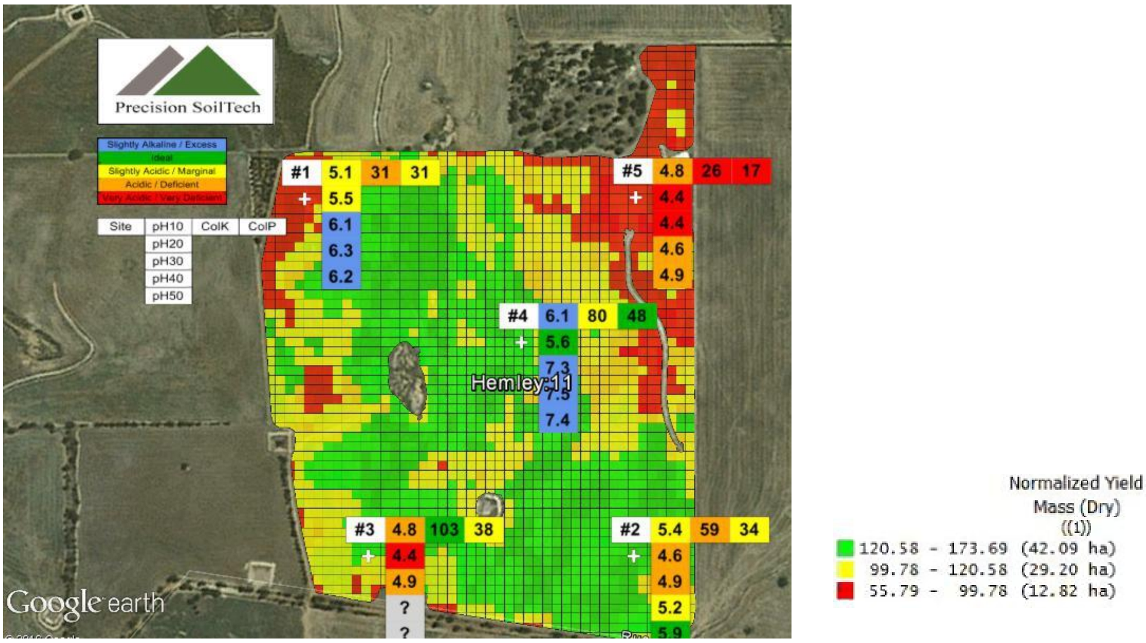


Figure 25. Hemley 11 split into three yield zones and soil test results pH, lime and phosphorus

Variable rate gypsum

Variable rate gypsum was a management issue identified at Larkes as Craig has noted only some areas of the paddock C22 require gypsum. When reviewing the spatial information Craig revised where he thought may need gypsum as the EM map indicated clay soils were more wide spread across the paddock (Figure 26a). A potential gypsum application map was generated using EM. (Figure 26). This was a similar area to where Craig identified although there were some more patches across the paddock. Further ground truthing is required to determine if these areas are gypsum responsive.

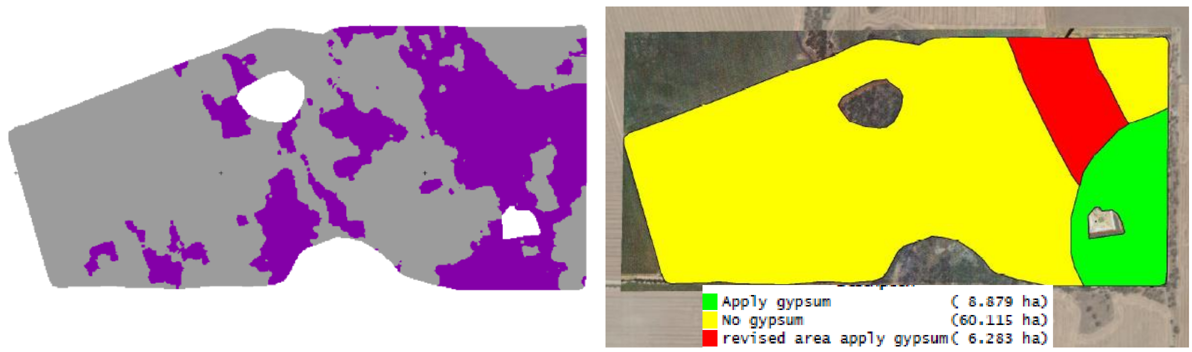


Figure 26. Variable rate gypsum potential areas on left (purple = application areas) identified using electromagnetics; with grower determine gypsum application map on the right.

Discussion of Results

Each spatial data layer was compared to yield data (Hemley and Lyneham) and biomass (Larke) to determine if they reflected yield. Different relationships were found for each paddock. This is not unexpected given the variation in soil type and landscape between the case study paddocks. In general paddocks with contrasting soil types ranging from sand to clay had a good correlation of EM to yield. At Lyneham's, where the soils range from sand to sand over gravelly clay, a combination of EM and gamma radiometrics was required to identify different zones.

The results concur with earlier studies completed by Smolinski et al. 2008 that there is not one layer that can be used for zoning in its own right as the soil types in the Kwinana West zone are quite complex. Added to this complexity is the production variation due to rainfall. A combination of data layers is required to delineate soil types accurately.

Yield can be used to initially help understand production variation and for targeting soil testing sites. In landscapes that are highly variable, soil types and elevation can flip/flop, where the canola and wheat perform differently due to soil type (ironstone gravels), and yield varies because of season i.e. low rainfall, or water logging wet years. A yield map can also show variation due to management such as changing barley variety within a paddock, therefore where possible it is important for farmers to integrate their local paddock knowledge when processing yield data into management zones.

Satellite Imagery (NDVI) can be used initially to help develop an understanding of crop variation and for targeting soil testing sites. Comparison of NDVI to yield showed good correlation at Lynehams but poor correlation at Hemleys. We predict the poor correlation at Hemleys to be due to the variable soil types (sand to clay) and variable crop type performance (cereal vs canola), particularly in the ironstone gravels where canola performs well and cereals poorly and also interaction with elevation and rainfall.

Historical analysis of satellite imagery indicated biomass production in Larke paddocks was highly variable (unstable biomass zones) compared to Lyneham and Hemelys. Annual rainfall does vary a lot more at Corrigin (max-min variance 283mm) than Wickepin (max-min 160mm) and Lynehman (max-min 167mm) over the 9 years of biomass. The stability of biomass at Lynehams is suprising as this landscape is historically subjected to waterlogging, however rainfall records show the rainfall has been below average since 2003. It will be interesting to see if biomass production varies in an above average season.

These landscapes, in many cases, would not be suitable for **Variable rate (VR) fertiliser** as seasonal conditions may often change significantly, which would impact on the crop response to the application, as well as the profitability of the variable rate. If VR Nitrogen was identified as a possibility, the recommended approach would be to determine production zones, start with an average fertiliser rate then top up higher production potential areas as the season unfolds if conditions are favourable. This approach has been identified by RCSN Geraldton Agrarian project and West Midlands Group National Landcare "Engaging our community to improve soil health in the West Midlands" variable Rate Case study (Isbister et. al 2016).

Yield and Satellite Imagery can be used to identify production zones, however the cause of the variation within a production zone may be different and therefore require different inputs or remediation. For example, soil testing indicated K was variable across the paddock at Hemley's. Soils requiring potash are generally sandy and low performing however at Hemley paddock 9 the low yielding areas were ironstone gravels or sand over clay. The sand was deficient in K yet the ironstone gravel was not, therefore we cannot apply a simple rule that potash is required across all low performing areas. Local paddock knowledge must be integrated with yield and/or satellite imagery and soil testing in order to confidently map yield constraints and ultimately develop management strategies.

Electromagnetic (EM) maps should be developed when a paddock has consistent soil moisture levels (typically end of summer) and for paddocks without high salts. These maps can be used to define clay content zones (and therefore PAWC – plant available water capacity). EM correlated well with yield at Hemleys and differently at Larkes. The low EM areas were sands and the high EM areas were clays. EM didn't differentiate between the various sandy soil types at Hemleys, where the low yielding/ low EM zones consisted of both sandy ironstone gravel and sandy loam (gritty quartz clay). Once again this highlights the need for ground-truthing each dataset with targeted soil testing and local knowledge in order to develop the appropriate management strategy. EM did identify saline areas at Lynehams however there was no correlation with EM and yield.

Gamma Radiometric (Gamma) reflects the mineralogy; the case studies have shown gamma is helpful to determine soil types in sands where the EM values are low as it is able to identify gravels (gamma Th), or distinguish between pale sand and loamy sands often yellow in colour (gamma K). PA practitioners have developed their own guidelines to which gamma layer is most useful from experience however they have found relationships are not easily translated across different landscapes. Ground-truthing is critical.

Given the differences in correlation of gamma radiometrics to yield and biomass across the three farms it is difficult to come up with specific recommendations for the Kwinana West zone for this layer. The three farms are located in different soil landscapes that have different geological parent material and processes occurring therefore it is not unexpected there will be difference relationships. The Larke sites are located in the Corrigin system, an ancient drainage zone, other sites are situated in rejuvenated landscapes. Hemley 9 and 11 are located on different farms about 20km apart they showed a different relationship of gamma layers to yield that may be explained due to the different soil type systems. Hemley 9 is in the Narrogin system that is located on the divide of three catchments Blackwood Avon and Hotham. This landscape is highly variable (Verboom and Galloway 2004). Hemely 11 is located in the Pingelly system 257, a zone of rejuvenated drainage in which most soil types formed by colluvial or weathered granite rock. Lyneham is in the Dryandra system (also rejuvenated drainage) mostly formed from granitic material, gently undulating with lateritic mesas and mafic dykes throughout the landscape (Sawkins 2010). Further work is required to determine key indicators or soil characteristics that could help interpret gamma across landscapes.

Elevation correlated to yield at Lynehams paddock 7 and biomass at Larkes; and therefore forms an important layer which is often closely related to soil type based on the formation/erosion of material over time. Most RTK (2cm accurate) GPS systems used for tractor steering collect elevation data whilst they are operating, so it would be a relatively easy dataset for most farmers to obtain.

Variable ripping maps can be generated from EM, gamma Th and yield data to map ironstone gravel areas that may either damage a standard ripper or could target with the new "Rocks Gone" ripper. This confirms a previous finding of the RCSN project "Understanding map layers for VRT", by the Kondinin Group that said Thorium can identify areas suitable for ripping and spading (White 2016).

Soil pH is a serious management issue identified by all three case study farmers, and variable rate lime is a simple and effective solution. There was poor correlation to topsoil pH with yield/biomass at all sites. There was a strong correlation with topsoil pH and EM at Hemley GV11 and Larke C22 however not the other paddocks. Further investigation is required to determine why. EM measures to about 75cm deep therefore is an average over this depth so in shallow duplex soils (sand over clay at 20cm) such as those found in Hemley GV9 EM will indicate a higher clay content but define it is a lighter soil texture at the surface. Lynehams required lime across both paddocks, these soil types ranged from sand to sandy duplexes that are more prone to acidity.

There was a strong correlation between subsoil pH at Larkes to EM 75cm and Hemleys due to the higher clay content of the soil. A better correlation is expected with EM (1.5m) as it would be related to a higher clay content at depth (generally the more clay the more alkaline the soil).

Subsoil acidity is generally an issue in sandy soils or sandy ironstone gravels either induced by management i.e. plant roots cannot keep up with leaching nitrogen, high production, no lime applied historically, or naturally acidic sands e.g. wodjil soils common in the eastern wheatbelt. The lower (more acidic) the subsoil pH, the higher the recommended amount of lime is required. There was a strong correlation between the recommended amount of lime to be applied based on soil test results and broad soil type classifications of the topsoil for all three case studies. Sandy soils on average required more lime. At Hemley and Lynehams there was also a correlation with amount of lime recommended and elevation, generally the sandier soils (more acidic) were higher in the landscape. At Larkes interestingly there was a correlation with the total amount of lime recommended and biomass. This suggests the lower biomass areas require more lime and have a lower subsoil pH, therefore this may be a factor limiting production or one of several constraints.

If soil pH does not correlate with yield/biomass zones or EM/gamma then a grid based soil sampling approach is required to accurately ascertain zones and rates of lime per zone. This supports the findings of a Precision Soil Tech Southcoast NRM project, that found a 2ha grid is needed to accurately map soil pH (develop variable rate lime maps) on the south coast (Lefroy 2015).

Variable rate Potassium is often touted as a potential output of gamma K readings; however, in these case studies there was no relationship between gamma K and soil K for any of the six paddocks. The Kondinin Group RCSN project "Understanding map layers for VRT" found a correlation with EM and soil K in the Kwinana West zone site, however this project didn't. There was a relationship between yield and soil K for Hemley paddock 11 and for biomass Larke paddock C1. The Kwinana West zone landscape is highly variable therefore rule of thumbs relating to the interpretation of gamma is still unclear.

Yield maps, farmer knowledge and soil sampling should be integrated in order to develop potash application maps. The intensity of soil sampling will depend upon how variable the soil, the availability of multiple seasons yield maps and level of local paddock knowledge. Grid sampling (2ha grid) will be the most accurate method for many paddocks.

Implications

The implications for this research are that low cost approaches to zoning work are effective and the decision of which spatial information layer to use will depend on what you are trying to manage. This is a good outcome as many growers are put off by the possible high cost starting point for PA that is often reported in the industry.

More farmers should be collecting, storing and most importantly utilising yield data as it can provide very good insights in to return on investment within a paddock and across the farm Yield data is an effective method for defining within paddock variability and a great entry point to zonal crop/soil management. Over 60% of farmers in Australia have a yield monitor (CSIRO, pers comm. 2012) yet few properly calibrate, store or examine the data after each season.

As a starting point for zone management yield and biomass can help map production variation and be used to target soil testing. These are the cheapest data layers to collect. In the highly variable landscapes at Wickepin and Corrigin, more than the usual three to five samples per paddock may be required. While it is useful to initially consider paddock variation in terms of low, medium and high performance the underlying cause (generally different soil type) maybe different within each zone so consideration must be given to sampling various locations within the identified production zones as the best management practice for the different soil types within a zone may vary.

Soil based data such as EM and gamma can help identify different causes of variation (largely soil type) and with ground truthing can map zones for specific applications particularly those soil related. In areas with contrasting soil types sand vs clay such as Wickepin and Corrigin, EM can reflect yield. EM is most useful in combination with gamma to distinguish between the characteristics of sandy soils that have low EM such as sand vs sandy gravels. The soil based information did help identify some management issues that were more widespread in a paddock than the farmers originally thought foe example larger area required gypsum or ironstone gravel areas not observed.

Treatment zones may be different depending on the management issue you are trying to address. Common practice for zone management is to separate the paddock into three production zones (low, medium and high). This is a good place to start assessing yield variation and may be appropriate in some landscapes with less variation or for fertiliser management. However, in complex soil landscapes found in the Kwinana west port zone more zones may be required and the zones may be different depending on what management issue is being addressed for example variable ripping zones are different to gypsum application or potassium application zones.

Variable rate lime is currently being promoted using yield maps to identify where lime is to be applied. These case studies show topsoil acidity is not always correlated to yield, biomass and/or EM. This is because topsoil acidity may not always be the dominant yield constraint, the primary cause of the variation is often plant available water capacity. Ameliorating subsoil acidity however may increase the yield of these zones. Acidity is often found in conjunction with other constraints such as compaction or a dense subsoil such as ironstone gravel or clay duplexes, so this needs to be factored in to decisions as well.

A possible strategy to apply variable rate lime is to first look at yield or biomass maps and strategically sample pH to at least 30cm in 10cm increments for five or more sites in a paddock. If VR lime is warranted, yet there is no relationship between soil pH and yield maps, use a grid sampling approach to accurately define a lime application map. If soil types are contrasting textures such as at Larkes then EM maps may be a suitable guide for strategic soil pH sampling. Alternatively, if specific soil types can be defined using a combination of layers then these may relate to the expression of acidity as is shown in the Hemley example. Each soil type could then be tested for pH and the soil zones could be used to variable rate lime if soil acidity is present. It may be than more than the usual three to five soil test sites are required depending on what the variability of the landscape, paddocks such as GV9 have more than five soil types. This requires more investigation.

Each paddock is different and therefore the outputs won't be a “one size fits all” approach. Table 7 below is a guide for farmers to use when deciding on which spatial data layers to gather and use.

Table 7. Zone management applications and useful spatial information layers

Application	*Spatial information*
Deep ripping	EM & Gamma Thorium to identify ironstone gravels that may break a standard ripper.
Ripping ironstone	EM & Gamma Thorium to identify ironstone gravels. Canola yield can be used to identify ironstone gravels (which requires further investigation).
Variable rate gypsum	EM is often the best if high EM identifies clay soils and they exhibit sodic properties. Grid based soil sampling is possible.
Variable rate potassium	Yield maps and targeted soil sampling (stable landscapes). Combination of EM, gamma (all signals) and yield to define soil types (highly variable landscapes). Grid based soil sampling is possible (highly variable landscapes.)
Variable rate lime	Grid pH sampling is the most effective (particularly topsoil). Yield, EM and gamma to delineate soil types and targeted sampling for each soil type. Satellite imagery/yield maps and targeted soil sampling (consider different soil types within production zones, may need more than five sites per paddock).
Crop scouting	Satellite imagery is good for targeting specific areas of the paddock not usually assessed. High resolution would help identify management changes and can pick up non-wetting areas early in the season.
On-farm trials	Yield data to measure production benefit and calculate a return on investment. Satellite imagery can be used to gather crop responses if no yield data exists.

Recommendations

The following recommendations for growers and the Grains Research and Development Corporation have come out of this project:

1. The highly variable nature of the Kwinana West landscape means that not one spatial information layer is useful on its own. Production based information requires interpretation with soil based information even in its simplest form of soil testing and grower knowledge. Similarly soil based information requires interpretation with production information to determine the best management option. Seasonal influence is also important to consider with production data.
2. Growers should start with yield, satellite imagery (or even Google Earth) and farmer knowledge to understand paddock variation, then strategically soil sample (at least 3-5 sites possible more in highly complex landscapes like Wickepin) and assess what is causing variation. This will then determine what to manage first and if other layers of information or technologies are required to refine zones. This initial assessment could

avoid unnecessary expense on PA technologies if they are not applicable for example variable rate lime.

3. Zones may vary depending on management issues for example ripping zones are different to variable rate potassium zones or variable rate gypsum zones as they target different soil properties therefore soil types within a paddock.
4. Soil based information (EM and gamma radiometircs) can help define soil types and causes of variation in the Kwinana West zone, however the complex geology of the region means relationships cannot be easily translated across farms or paddocks, ground truthing is essential.
5. Further evaluation of VR application maps generated in the project with ground truthing test strips applied by farmers would be beneficial to assist assessing economics (this would require a further project).
6. Further testing is required to confirm the relationships of gamma and EM to identify ironstone gravels in other paddocks.
7. Evaluate the pH grid mapping process to confirm this is the most cost effective management approach to lime application in highly variable landscapes. Hemley's GV9 would be a very good candidate to test grid mapping as the soil types are highly variable.
8. The huge volume of data data generated for these three case studies meant that not all aspects of how the data can be used have were able to be explored in the scope of this project. Further projects could utilise this data to dig further and conduct additional analyses in particular further investigation of EM and gamma radiometrics to see if guidelines or critical values can be identified to map soil type as Department of Agriculture and Food Western Australia's GRDC funded project DAW000242 Subsoil constraints is investigating.
9. No presentations were given during the project due to this topic not being listed as a group priority for updates or field days in 2015. Society for Precision Agriculture Australia have flagged presenting the findings of this project particularly VR ripping at a forthcoming event in Three Springs and the Corrigin Farm Improvement Group and Facey group are keen to extend the key learnings to their members.
10. It would be beneficial to review these project findings with the other RCSN Geraldton Port zone project currently underway with Precision Soil Tech that is investigating the application of spatial information and soil sampling resolution (Bindi Isbister and Wes Lefroy have talked about the findings of this project) and DAW00242 to determine if findings are consistent across landscapes or are highly variable.

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The Precision Agriculture Pty Ltd staff Brett Coppard, Peta Neale, and Grant Canning.

Appendices

Appendix 1 Isbister B (2015) Within Paddock Management Zones, Facey Group Newsletter June 2015

Appendix 2 Isbister B (2015) Is your yield mapping ready for harvest, Facey Group Newsletter October 2015

Appendix 3 Precision Agriculture Pty Ltd podcast Episode 10 Are WA Farmers leading the way in precision ag technology 24/9/2015
http://www.precisionagriculture.com.au/apps-podcasts.php

Plain English Summary

Project Title:	Case studies to review methods for defining within-paddock management zones - Kwinana West zone
GRDC Project No.:	FUT0001
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Objectives	This project aims to evaluate if there is any difference in deriving management zones from soil or production spatial information and in what situations each of these layers may be useful to help maximise grower investment in PA technologies.
Background	Rising costs and declining terms of trade are driving growers to invest in Precision Agriculture technology for zonal management such as variable rate fertiliser or lime. There is a wide range of spatial information that can be collected from production based information (i.e. yield maps, satellite and farmer knowledge) that measure plant performance as a result of interaction with soil type, season and agronomy; to electromagnetics and gamma radiometric surveys that can be used to map soil type zones and associated soil constraints such as subsoil acidity or salinity. The cost of spatial information layers can vary greatly from $14-25/ha for electromagnetic (EM) and gamma radiometric mapping, to less than a $1/ha for biomass imagery and yield maps. This wide range of costs causes much uncertainty from growers and consultants about where to being investing in spatial information for zone management.
Research	Three case study farms were selected at Wickepin, Popanyinning and Corrigin. Each grower selected two focus paddocks that had soil types typical of their farm and the area. Data layers collected included yield, biomass imagery (historical analysis), electromagnetics 0.5m and 1m, gamma radiometrics (Total counts, potassium, thorium, uranium), elevation (from the farm GPS systems), and aerial imagery. The layers were ground-truthed by soil sampling and farmer and agronomist knowledge. Zonal statistics were completed to determine correlations between datasets. Based on data interpretation zone manage applications investigated included variable ripping, lime application, potash and gypsum.
Outcomes	The relationship of the different layers varied across the case studies. The cause of yield variation commonly varied within production zones. EM and gamma can help interpret causes of yield variation. EM strongly correlated with yield in landscapes with highly contrasting soils i.e. sands to clays at Corrigin and Wickepin. Gamma helps delineate different soil types in combination with EM. These layers were used to determine variable ripping zones and gypsum. No layers were very useful on their own. Topsoil pH did not correlate with any data layer therefore grid sampling is recommended to accurately map pH.
Implications	Yield, biomass or an aerial photograph is a good starting point to assess variation and identify soil sampling points (more than 5 may be needed). However, the cause of yield variation can vary within production zones so zones may differ depending on management input targeted. Other layers of spatial information such as EM and gamma can help to further refine zones. Ground truthing is essential including grower knowledge.
Publications	Isbister B, Neale T (2016) Appling zone management in the Kwinana West Zone (to be published).