# Economic and Scientific assessment of direct soil survey for the creation of high resolution maps of soil acidity and nutrition in the Stirling's to Coast region

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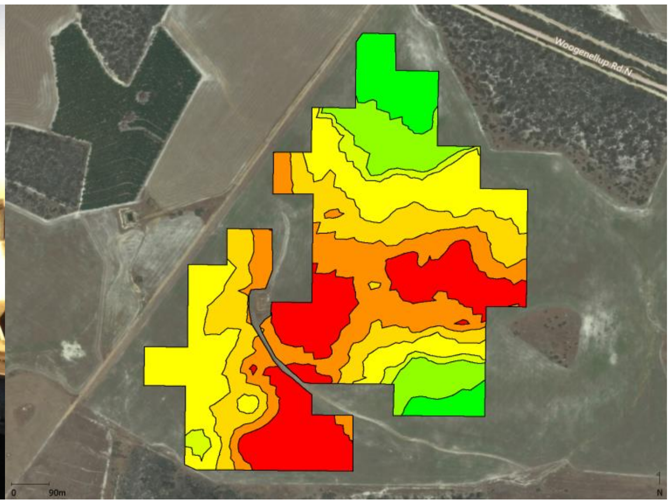
Technical Report

**August 2015**



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Australian Government

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# Contents

# Introduction

Soil acidity is a major constraint on productivity in the Stirlings to Coast Area. The report card on sustainable and natural resource use in agriculture (DAFWA, 2013) concluded acidity in the surface layer was extreme, with between 80 and 91% of samples collected being below the recommended 5.5 pHCa. Treatment of the soil acidification in this area may difficult, as many lime sources in the area have a lower neutralising value and are of a coarser fraction than the lime sources north of Perth. This project not only seeks to slow acidity with remedial actions (more efficient liming strategies) but also with preventative actions (more efficient fertiliser usage).

This project will examine the optimal level of direct survey (soil sampling) required to create topsoil and subsoil pH maps for variable rate liming, and nutrition maps for variable rate fertiliser application. The project will determine change in confidence as sampling numbers are decreased across a number of soil types in the Stirlings to Coast region. An economic analysis will assess the change in profitability as confidence decreases. The end result will be two outputs – confidence of soil variation vs number of sites sampled and confidence of soil variation vs cost of information. The conclusion will identify the most profitable density of soil sampling required to accurately represent pH and nutrition conditions in the soil profile.

In total, 14 paddocks across the Stirlings to Coast Farmers region were sampled. The locations of each of these paddocks are located below (Figure 1). At each of the paddocks, 50 sites were sampled on a 1 site per ha grid. At each site, samples were taken from a depth of 0-10cm (topsoil), 10-20cm (midsoil) and 20-30cm (subsoil). Topsoil samples were analysed for Colwell Phosphorus and Potassium, Phosphorus Buffering Index and pH (1:5 $CaCl_2$). Midsoil and subsoil samples were analysed for pH (1:5 CaCl2).


**Figure 1: Locations and Index Numbers of the 14 sites sampled as a part of this project in the South Stirlings region of Western Australia.**

**Method of Analysis –**

This analysis consists of two main components, the scientific and economic analysis. The scientific analysis assessed the correlation between high resolution maps created with data points at 1 per ha resolution and maps created with a lower resolution than 1 per ha. For each paddock, 12 different resolutions were examined for their ability to create high resolution maps. Data was selected on spatial structure as per industry practice for choosing sampling sites. For the EM & Gamma analysis a similar process was followed, however sites were selected on variation of the EM & Gamma maps.

The resulting correlations provided an insight into the ideal number of sampling sites for creating high resolution maps in the South Stirling's region.

The economic component of this research analysed the costs of the extra lime in the areas where product was over applied in comparison to the cost of identification.

# Scientific Overall Results

**Soil Sampling Analysis –**

The soil sampling component of this project analysed the ability of the 12 different densities of soil sampling to create maps equal to what was created with the full data set (50 soil sampling sites). Each map was tested with an $r^2$ correlation for the full data set.

Table 1 illustrates the median $r^2$ correlations between the high resolution maps created with limited soil sampling data and high resolution maps created with the full data set. This table gives an indication of the variability of each of the chemical soil properties examined and the strength of the correlation between the lower resolution soil maps and the full data set for each soil property.

**Table 1 – median $r^2$ correlations for high resolution maps created with limited data sites compared to the full data set for 50 sites. Numbers in bold indicate the number of sites it took for the $r^2$ correlation to exceed 0.7.**

| No. of Soil Sampling Sites | 2 | 4 | 6 | 8 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0.02 | 0.18 | 0.26 | 0.34 | 0.35 | 0.41 | 0.54 | **0.79** | 0.74 | 0.85 | 0.91 | 1.00 |
| P | 0.07 | 0.32 | 0.19 | 0.28 | 0.35 | 0.31 | 0.44 | 0.66 | 0.68 | **0.78** | 0.83 | 1.00 |
| PBI | 0.10 | 0.19 | 0.20 | 0.30 | 0.45 | 0.51 | 0.59 | **0.75** | 0.77 | 0.86 | 0.93 | 1.00 |
| Top pH | 0.13 | 0.12 | 0.13 | 0.22 | 0.36 | 0.41 | 0.55 | 0.66 | **0.70** | 0.73 | 0.85 | 1.00 |
| Mid pH | 0.12 | 0.15 | 0.18 | 0.32 | 0.35 | 0.42 | 0.50 | 0.61 | 0.68 | **0.70** | 0.84 | 1.00 |
| Sub pH | 0.09 | 0.15 | 0.22 | 0.20 | 0.25 | 0.33 | 0.41 | 0.55 | 0.63 | 0.67 | **0.72** | 1.00 |

Both Potassium (K) and Phosphorus Buffering Index (PBI) were considered to be the most spatially predictable nutrients by the model. When only 25 soil sampling sites were included in the map creation process, both K and PBI had an $r^2$ >0.70. Subsoil pH required the highest resolution of sampling for accurate high resolution. The predictability of the subsoil pH was ultimately affected by the varying depth of gravel and clay across the region.

It can be concluded that the required sampling resolution for soil sampling for high resolution maps in the South Stirlings ($r^2$=0.75) was 30 sites per 50ha (1 per 1.66ha) for P, K and PBI, and 35 sites per 50 ha (1 per 1.4ha) for pH. At these densities, from table 1, creators of the high resolution prescription maps can expect an $r^2$ correlation with the actual soil data of around 0.7.

## Biomass Imagery Analysis

The NDVI data used in the project was supplied from Landgate at a 30m resolution. The dates and times of the images varied from site to site dependent on the availability of the image. The images were taken late within the last two seasons, however cloud cover caused some major issues in terms of the timing and availability of the data. For the farms where there is no data listed in table 1, there was no data available due to cloud cover obstructing the satellites.

**Table 2: $r^2$ correlations between NDVI data at each of the sites, and the chemical soil properties measured during the project.**

| Site No. | Phos (mg/kg) | Pot (mg/kg) | PBI | pH TopSoil | pH Midsoil | pH Subsoil |
|---|---|---|---|---|---|---|
| 1 | 0.04 | 0.02 | 0.05 | 0.12 | 0.11 | 0.09 |
| 6 | 0.04 | 0.01 | 0.07 | 0.04 | 0.05 | 0.00 |
| 7 | 0.18 | 0.05 | 0.14 | 0.04 | 0.03 | 0.06 |
| 8 | 0.04 | 0.06 | 0.02 | 0.02 | 0.07 | 0.07 |
| 9 | 0.07 | 0.02 | 0.03 | 0.07 | 0.06 | 0.04 |
| 10 | 0.04 | 0.06 | 0.02 | 0.02 | 0.07 | 0.07 |
| 11 | 0.02 | 0.03 | 0.04 | 0.09 | 0.04 | 0.01 |
| 12 | 0.03 | 0.00 | 0.01 | 0.07 | 0.02 | 0.17 |
| 13 | 0.13 | 0.00 | 0.24 | 0.32 | 0.12 | 0.03 |
| 14 | 0.03 | 0.10 | 0.05 | 0.00 | 0.08 | 0.11 |

Table 2 summarises the relationships found between the available satellite data and the soil properties measured during the project. Very little evidence was found about any possible existing relationships between the 30m imagery and soil properties across all sites found. It was concluded that the 30m was resolution was too large and not specific enough for identifying soil properties. Low resolution images could be useful for roughly identifying areas of poor growth; however the maps were of too lower quality to create high resolution soil maps.

## Yield Data Analysis

Yield data for the project was voluntarily submitted by those farmers who had the data available. The raw data was submitted by the farmers and then sampled against each of the soil sampling locations. For the sites where multiple years of data was supplied, a normalized yield map was created, which effectively merged the layers creating a long term yield map.

Table 3 summarises the $r^2$ correlations between the yield data and the measured soil chemical nutrients. Some very weak relationships were evident across the data set, however these two too weak to draw conclusions about trends in the data.

**Table 3 $r^2$ correlations between the available yield data and the soil data collected from each of the sites.**

| Site No. | Grain (Year) | NDVI | Phos(mg/kg) | Pot (mg/kg) | PBI | pH Topsoil | pH Midsoil | pH Subsoil |
|---|---|---|---|---|---|---|---|---|
| 1 | Canola 14 | 0.25 | 0.15 | 0.09 | 0.20 | 0.20 | 0.25 | 0.17 |
| | Canola 12 | 0.47 | 0.03 | 0.05 | 0.04 | 0.33 | 0.26 | 0.16 |
| | Barley 13 | 0.24 | 0.01 | 0.00 | 0.04 | 0.04 | 0.17 | 0.19 |
| | Normalized | 0.22 | 0.06 | 0.02 | 0.10 | 0.16 | 0.18 | 0.18 |
| 6 | Canola (?) | 0.00 | 0.04 | 0.02 | 0.06 | 0.02 | 0.00 | 0.00 |
| 7 | Canola (?) | 0.36 | 0.02 | 0.13 | 0.15 | 0.01 | 0.05 | 0.02 |
| 14 | Barley 14 | 0.02 | 0.04 | 0.09 | 0.08 | 0.03 | 0.00 | 0.05 |
| | Canola 13 | 0.06 | 0.06 | 0.28 | 0.15 | 0.00 | 0.01 | 0.09 |
| | Normalized | 0.04 | 0.02 | 0.11 | 0.08 | 0.02 | 0.00 | 0.05 |

Although correlations were low, yield mapping remains an important tool in the precision agriculture system. Yield mapping allows farmers to monitor production on a micro scale, and is an essential first step for identifying how production varies across a paddock. Due to the weakness of relationships in Table 2, the use of yield maps needs to be more general rather than being used to create specific prescription maps. Yield maps provide an important additional tool for identifying areas where production is under potential and identifying locations for soil and plant analysis.

## Proximal Sensing (EM & Gamma) Analysis

Proximal sensing is becoming an increasingly more popular method to map soil variability, create management zones and prescription maps. Both Electromagnetic Induction (EM) and Gamma- Ray Spectrometry (Gamma) give provide an insight to the variation of the physical characteristics such as clay, moisture, salt, gravel and general soil type. The values from these physical characteristics are then analysed for their relationships with soil chemical properties such as phosphorus, potassium and pH. Where strong relationships are evident, the proximal maps are used to create prescription maps for fertiliser and soil ameliorant inputs such as lime sand. Table 4 summarises the proximal sensing data $r^2$ analysis from the data was available in the Stirlings to Coast area.

The strength of the relationships evident between soil properties and proximal sensed layers in the Stirlings to Coast Area were very low, with only two correlation values $>r^2=0.5$. The first of these correlations was at site 7, and was between the gamma thorium layer and phosphorus buffering index. Gravel is accepted to be the main source of thorium emissions, meaning that often the thorium layer can reflect gravel distribution in the profile. Thus the main cause of the correlation between Thorium and PBI, was the relationship between Thorium, Gravel and PBI. This relationship, although slightly weaker was also evident at site 9, which like site 7 is a gravel dominated profile.

Table 4 illustrates how relationships can vary between sites for all layers. For instance, at site 7 a weak relationship ($r^2=0.55$) was evident between Colwell K and Gamma K emissions. This was mainly due to potassium rich quartz sand in the centre of the site. However at site 9, a site also classified as grey sandy gravel, no relationship existed between Colwell K and Gamma K emissions. Figure 2 illustrates the distribution of each relationship.

**Table 4 $r^2$ Correlations with Proximal Sensing Data available.**

| Site Number | Sensor Type | P | K | PBI | pH (Top) | pH (Mid) | pH(Sub) |
|---|---|---|---|---|---|---|---|
| 6 | EM (Deep) | 0.28 | 0.02 | 0.14 | 0.00 | 0.02 | 0.05 |
| 7 | | 0.08 | 0.02 | 0.03 | 0.00 | 0.03 | 0.05 |
| 9 | | 0.32 | 0.17 | 0.15 | 0.01 | 0.00 | 0.05 |
| 6 | | 0.35 | 0.04 | 0.19 | 0.00 | 0.02 | 0.07 |
| 7 | EM (Shallow) | 0.14 | 0.00 | 0.00 | 0.00 | 0.01 | 0.08 |
| 9 | | 0.34 | 0.19 | 0.20 | 0.04 | 0.01 | 0.08 |
| 6 | K | 0.20 | 0.10 | 0.19 | 0.10 | 0.02 | 0.11 |
| 7 | | 0.14 | 0.55 | 0.40 | 0.12 | 0.19 | 0.00 |
| 9 | | 0.02 | 0.01 | 0.02 | 0.00 | 0.00 | 0.07 |
| 7 | Total Count | 0.17 | 0.29 | 0.70 | 0.34 | 0.32 | 0.08 |
| 9 | | 0.31 | 0.39 | 0.47 | 0.15 | 0.15 | 0.23 |
| 6 | Th | 0.01 | 0.25 | 0.07 | 0.17 | 0.02 | 0.04 |
| 7 | | 0.16 | 0.29 | 0.59 | 0.35 | 0.30 | 0.05 |
| 9 | | 0.32 | 0.38 | 0.47 | 0.18 | 0.15 | 0.21 |
| 6 | U | 0.11 | 0.16 | 0.00 | 0.15 | 0.08 | 0.00 |
| 9 | | 0.14 | 0.23 | 0.19 | 0.04 | 0.08 | 0.11 |
| 6 | NDVI | 0.04 | 0.00 | 0.06 | 0.04 | 0.05 | 0.00 |
| 7 | | 0.23 | 0.05 | 0.17 | 0.05 | 0.04 | 0.06 |
| 9 | | 0.09 | 0.00 | 0.03 | 0.05 | 0.04 | 0.02 |

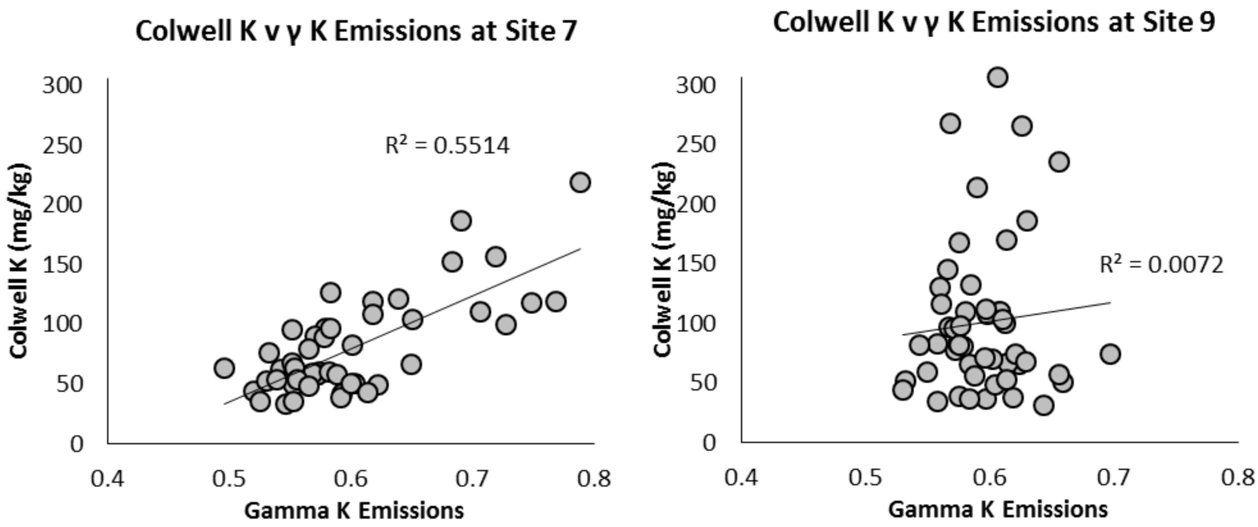


**Figure 2 Comparison of the correlation between Colwell K and γ K emissions between site 7 and site 9.**

EM and Gamma can be an effective tool for management zone creation, especially for identifying physical variations in soil type and management zone boundaries. However as Figure 2 and table 4 illustrate, relationships can significantly vary from site to site. Therefore it is imperative that a number of calibration soil samples are taken to identify; firstly if a relationship exists, and secondly if it is strong enough to make a prescription map.

# Economic Overall Results

## Variable Rate Lime Analysis

For each of the 12 maps created for each site, a lime prescription analysis was also conducted and associated costs measured. Each map was analysed for the amount of tonnes that were over prescribed, and the amount of tonnes under prescribed. In the economic analysis, a monetary figure was only put on the amount of tonnes over prescribed as the opportunity cost of under applying limesand and other inputs was too difficult to simply accurately.

Each of the sites had varying levels of misallocated lime, dependent on a number of factors. The main determining factor was pH variability across the paddocks. Sites with less variability had a lower amount of misallocated lime because the variation was more predictable.

The selection of sampling sites used in the analysis was also a critical factor for the creation of accurate prescription maps. Figure 3 illustrates how poor initial selection of sampling sites can affect costs on inputs and profitability.

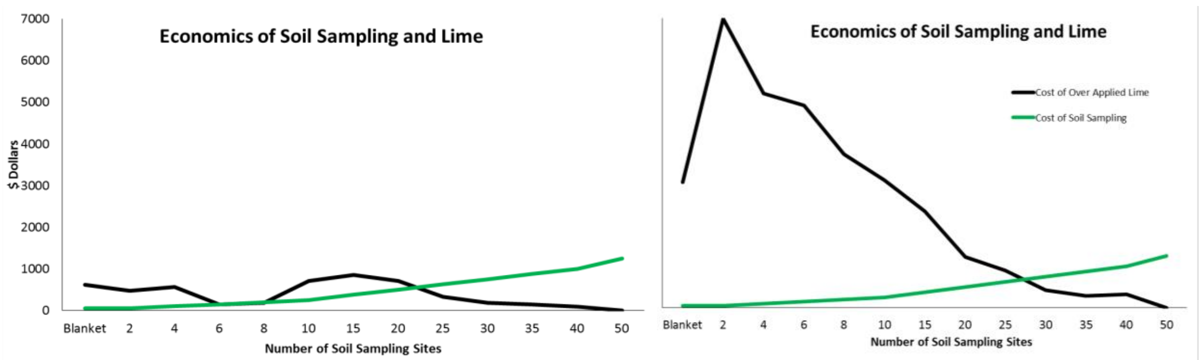


**Figure 3 Economic Analysis from Over Application of Lime for site 5 (left) and site 3 (right). Costs were initially a lot higher for site 3 due to poor selection of sampling sites.**

The graph on the left of figure 3 illustrates the costs associated with over applied lime on a relatively uniform site with a low lime requirement. At this site, it would be considered that a variable rate program was not justified as the cost of implementing the variable rate program would generally outweigh the cost of not using variable rate.

The graph on the right, illustrates how poor site selection can significantly increase unnecessary costs in inputs. One of the soil sampling sites used in the low resolution calculations was not representative of the paddock, and skewed lime recommendations far higher than required. As more soil sampling sites were added the total cost of over applied lime decreased as the effect of the misrepresentative site diminished from the calculations.

Using more information for map creation did not necessarily mean that there was a saving in the total amount of product required. The graph on the left of figure 4 illustrates how the total amount of product at site did not vary greatly depending on the quantity of information used in the mapping process. However, the graph on the right of figure 4 illustrates how the lime sand was used more efficiently across the site with the increased level of information, thus the increase is efficiency is gained by a more efficient allocation of product, rather than applying less. Across all sites, the cost of information outweighed the cost of over applied lime for between 20-30 sites. This illustrates, that comparatively the cost of information is cheap compared to the associated cost of product.

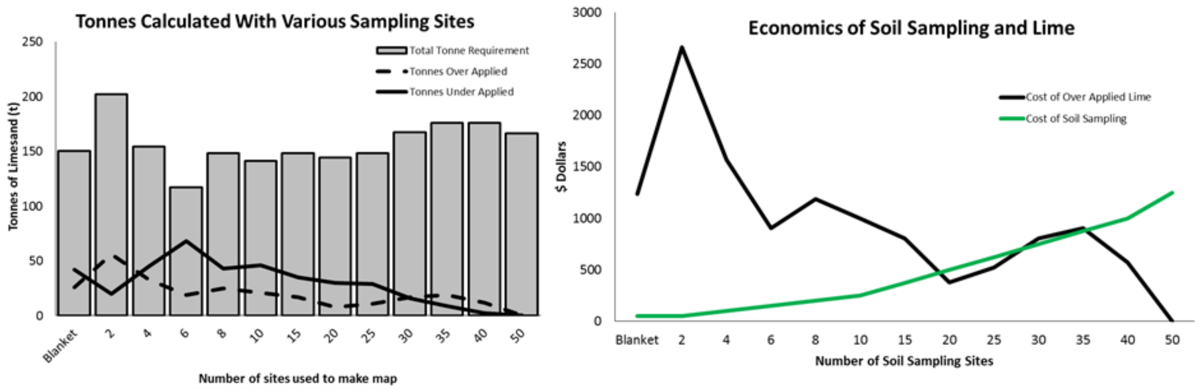


**Figure 4: The left illustrates the total lime requirement across the site with various levels of information. The graph on the right shows how the cost of over applied lime**

For each site, a number of samples is identified where the cost of the over applied lime is equal to the number of soil samples. For the majority of sites this was roughly around 25 – 30 sites. Up to this point it is more cost effective to spend more on soil sampling to save a larger amount on unrequired lime. A higher resolution of soil sampling will also decrease the yield penalty from acidity on management zones where lime was initially under prescribed.

## Variable Rate Nutrient Analysis

Variable rate technology is the most efficient where there is a variation in the rates of inputs to be applied. In the variable rate lime analysis there was a large variability in the areas across each of the sites, which resulted in variable rate liming being a very feasible option.

However, for the two nutrients tested as a part of this study, Phosphorus and Potassium, many of the sites had a very low requirement for nutrients, due to high residual levels in the soil. This meant that when the analysis was conducted for misallocated inputs that many of the analyses, many of the maps came back as accurate. This simply is because there was a low requirement for Phosphorus and Potassium due to the high residual levels in the soil; meaning that when it came to assessing misallocated inputs, there was only very low levels to assess. Figure 5 is an example from site five where K levels across the whole site were classified as well in excess, so therefore there was no requirement for any variation of inputs because the demands were low across the 50ha block.

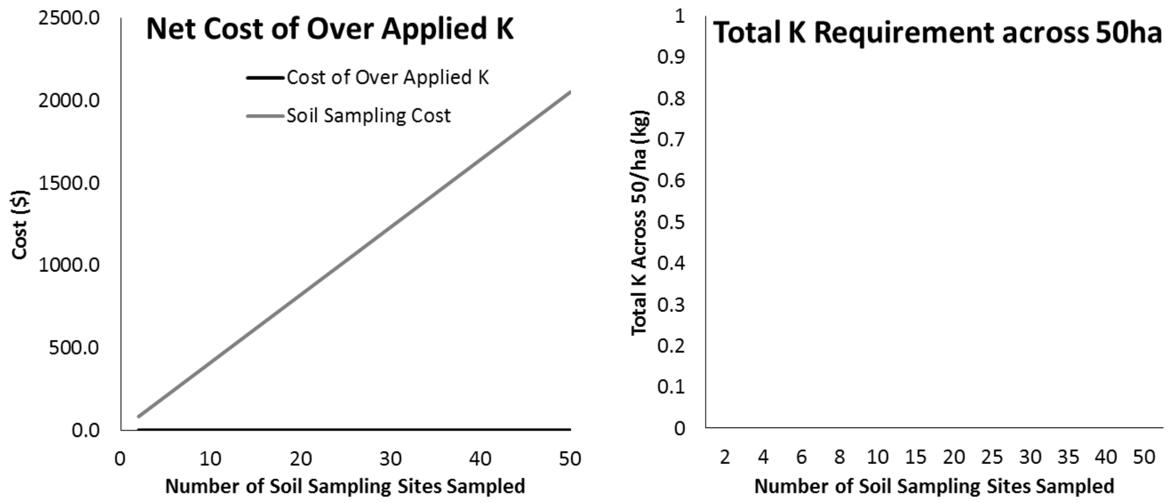


**Figure 5: K requirements and associated mis-allocated inputs for the site 5, where K was in excess.**

Not all sites had a low requirement for potassium and phosphorus. Figure 6 shows an example from site 3 where the overall P requirement has relatively high. This follows the trend across all sites, that nutrient requirements weren't as variable as the requirements for lime. In figure 6 the cost of acquiring information about P status was equal to misallocated over allocated P, when using a map created with 15 samples sites for the 50ha. This was among the highest across all sites; representing the general lack of variability for P & K requirements across the South Stirling's region.

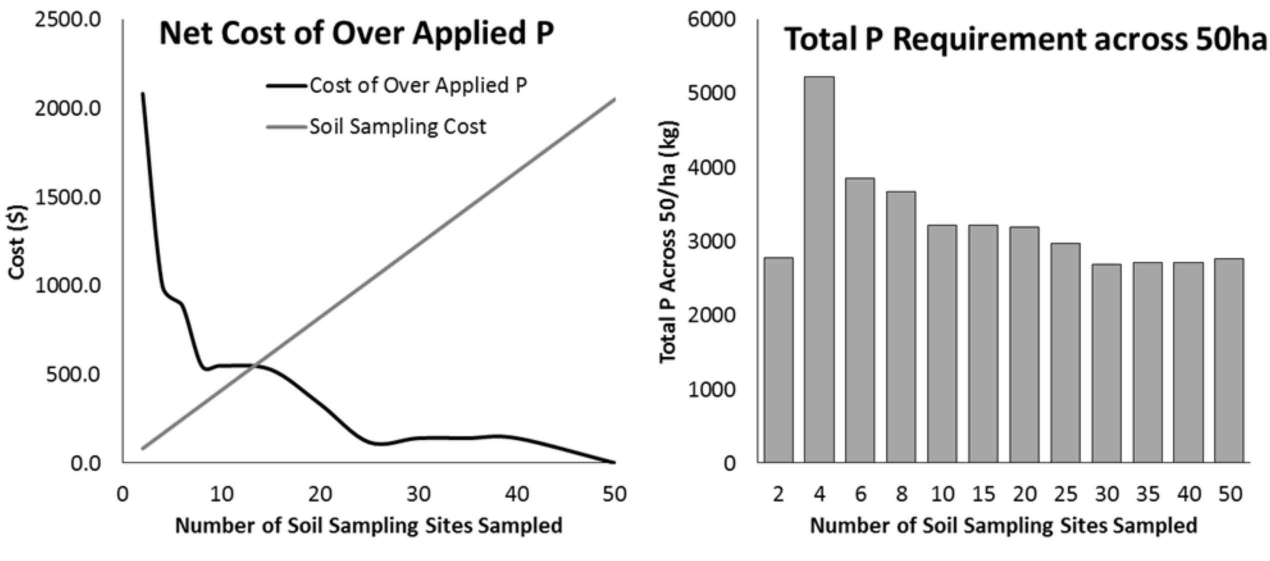


**Figure 6: P requirement (right) and net cost of over applied P (left).**

# Conclusion

This project has gathered an extremely large data set across the South Stirlings region, providing a unique insight into trends about soil variability right across the South Stirling's region. The first goal of this project was to analyse how many sampling sites are required to create accurate high resolution prescription maps. For an $r^2$=0.7 with actual soil data, it was recommended that between 30-35 soil sampling sites per 50ha (1 per 1.5) is required. When this was related back to creating lime and fertiliser recommendations, a much higher resolution of soil sampling was required for accurate lime recommendations than fertiliser recommendations. The economic equilibrium for creating lime recommendations 25 samples her 50ha, while it was much lower for Phosphorus and Potassium, with the equilibrium around 5 sites, due to the low variability in P & K demands.

Supplementary mapping techniques were also analysed for their ability to predict soil properties and variation to supplement the soil mapping process. Poor direct relationships were evident all the supplementary layers, including yield, EM Gamma and Biomass. However further investigation is required about the ability of these supplementary layers, using a more precise spatial approach (management zone level calibration) rather than the holistic correlation across the paddock.

# Key Messages

- Under soil sampling can have significant effects on application accuracy.
- Paying for actual information is relatively cheap.
    - Over application and opportunity cost of lost yield from under application.
- Understand the performance of additional information before paying to obtain the data is critical.