Variable rate lime for cropping systems in the HRZ: an economic analysis

Kirsten Barlow[1], Kerry Stott[2], Sebastian Ie[1]

[1] Precision Agriculture, 113 Main Street, Rutherglen, Vic, 3685, www.precisionagriculture.com.au, k.barlow@precisionagriculture.com.au
[2] Agriculture Victoria Research, AgriBio, 5 Ring Road, La Trobe University, Bundoora Vic, 3083

Abstract
Soil acidity affects 50% of Australia's agricultural land and significantly affects crop production. Results from grid soil sampling (0-10 cm) for pH_{Ca} across hundreds of cropping paddocks in the high rainfall zone (HRZ) in Victoria highlight the variability in soil pH across a paddock, where the coefficient of variation averaged 4.7% and ranged from 0.7 up to 16%. The range in soil pH and the coefficient of variation from the field data were used to develop eight hypothetical paddocks. A discounted cash flow model was used investigate the economics of grid soil mapping and variable rate lime application to ameliorate surface soil acidity. Both variable rate and fixed rate lime addition had a positive net present value (NPV) across the hypothetical scenarios, with the inclusion of a pH-sensitive pulse crop increasing the NPV. With a pulse crop in the rotation, variable rate lime had a greater NPV in six of the eight hypothetical paddocks, while in the remaining two paddocks variable rate and fixed rate applications produced similar NPV results.

Key Words
grid soil sampling, variable rate lime application, profitability, HRZ cropping, surface soils.

Introduction
Soil acidity affects 50% of Australia's agricultural land and our agricultural systems will continue to acidify without intervention. Acidic soils can cause significant losses in production, reduced crop choice and, if not treated further, reductions in the health of our soil resources. Liming is the most common method for ameliorating soil acidity, with the amount of lime required dependent on the soil pH profile, lime quality, soil type, farming system and rainfall.

This paper will present results from grid soil sampling (0-10 cm) for pH_{Ca} across 340 cropping paddocks in the HRZ (>600 mm rainfall) in Victoria. It will use these data to develop eight hypothetical paddocks which reflect the range of pH levels and variability detected across the HRZ. A discounted cash flow (DCF) model (Stott *et al.* 2019), which determines the profitability of applying lime using the net present value criterion, was used to investigate the economic and financial benefits associated with grid soil mapping and variable rate lime application to ameliorate surface soil acidity.

Methods
Grid soil mapping and variable rate lime application
Grid soil mapping is the process of collecting soil samples on a standard grid to quantify the spatial variability of soil pH across a paddock. The process of grid soil mapping used in this study was (1) digitise the paddock boundary and develop a sampling grid of 1-2 hectares in size; (2) collect GPS referenced surface soil (0-10 cm) samples with eight sub samples collected on a diagonal transect in each grid cell; (3) samples were submitted to an accredited laboratory and analysed for pH_{Ca}; and (4) results were processed and used to generate a soil pH map for the paddock as well as a variable rate lime application map to a target pH of 5.5 with the maps based on texture, target pH and the neutralising value of the lime source. Results from commercial grid soil sampling by Precision Agriculture Pty Ltd on 340 HRZ paddocks in Victoria in 2018 were used in this paper.

The economics of lime addition
The DCF model used soil properties to determine the pH buffer capacity of the soil and therefore the response to lime addition and acidification rates (the 'counterfactual'). The full benefits of the applied lime were assumed to develop over a 2-year period. The changes in soil pH were then used to estimate the changes in crop yield based on response curves which define the relationship between soil pH and relative crop yield.

The analysis looked at the net present value (NPV) and pay-back period over a 5-year timeframe. The analysis was conducted using a Barley-Canola-Pulse-Wheat-Wheat (BCPWW) crop rotation (with selected comparisons to a Barley-Canola-Wheat-Canola-Wheat, BCWCW rotation) which is being used in the HRZ of SW Victoria (Cameron *et al.* pers. comm.) and other locations. The hypothetical paddocks are 100 ha in size with a sandy clay soil. Each paddock was divided into 7 zones with the pH in each zone calculated using a normal distribution based on an average pH and a coefficient of variation (CoV). Based on the 2018 grid of soil mapping data (Figure 1), eight hypothetical paddocks have been developed for four pH ranges (<4.5, 4.5-4.75, 4.75-5.0, >5.0) using the average pH for each range and either the average or 80th percentile CoV. Within each hypothetical paddock, lime was applied at either a constant rate of 2.5 t/ha or a variable rate aimed to achieve a uniform 5.5 pH across the paddock. The variable lime rate was constrained to a maximum application of 5 t/ha.

Table 1. Average pH_{Ca} and the average and 80th Percentile Coefficient of Variation (CoV) calculated from historic data used to calculate the pH in 7 zones of our hypothetical paddocks.

pH Range	pH_{Ca}	Mean CoV (%)	80th Percentile CoV (%)
<4.5	4.39	3.90	6.18
4.5-4.75	4.65	3.17	5.58
4.75-5.0	4.86	4.80	6.03
>5.0	5.11	4.92	6.62

Results

How variable is soil pH at the farm and paddock scale under pasture or mixed farming systems?
Grid based soil sampling on 340 HRZ paddocks in Victoria in 2018 highlighted the variability in soil pH within a paddock and between individual properties (Fig. 1). The average pH in the paddocks ranged from 4.18 to 6.25, with the variation in soil pH within a single paddock (minimum to maximum pH) ranging from 0.1 to 3.2 pH units. Across this data set the standard deviation averaged 0.23 (CoV 4.7%) and ranged from 0.05 to 0.86 (CoV of 0.7-16%).

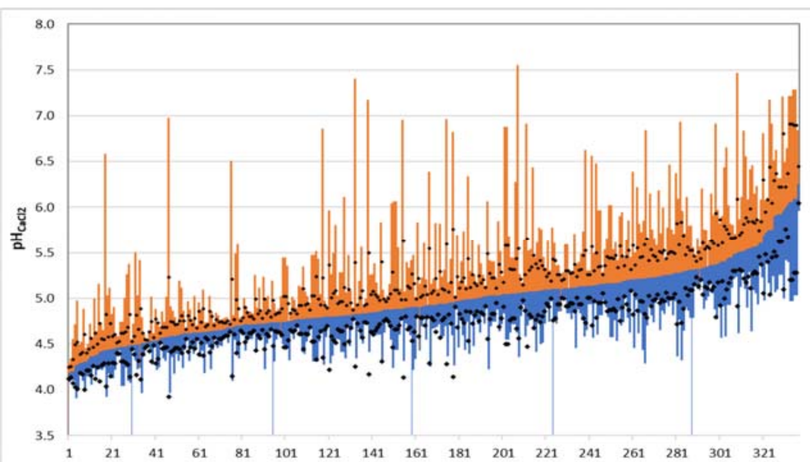

Figure 1. Grid mapped soil $pH_{C)}$ data from 340 paddocks in the HRZ of Victoria (>500mm annual rainfall), blue line represents minimum to average pH, orange line represents average to maximum pH and the black dots are plus and minus one standard deviation.

Why manage the pH variability across the property?
The within-paddock pH variability (Figure 1) shows the potential to target lime addition (through variable rate inputs) to either reduce the lime required to achieve a target pH across a property or to ameliorate the most acidic soils in a paddock or farm.

Using the eight hypothetical paddocks (Table 1) the economic model was used to describe the change in soil pH, the crop response and based on this the NPV of the different approaches to lime application. The results for the eight paddocks are summarised in Table 2. If we look at a single scenario (Scenario 1: average pH = 4.4, CoV = 6.2) we can see the change in pH over the 5 years in response to either a variable rate strategy (Figure 2A) or a fixed rate lime application (Figure 2C). The change in pH in response to lime occurs over a 2-year period, while the natural process of soil acidification occurs each year. The variable rate strategy (Figure 2A) showed a significant decrease in the variability across the paddock, with the limit on lime application of 5 t/ha in this scenario responsible for the most acidic zones remaining below the target pH. In contrast the fixed rate application of 2.5 t/ha lime increased the pH in each zone by a uniform amount (Figure 2C) but didn't reduce variability – an average pH in year 2 of 5.1 (range 4.4-6.1) included 4 zones below the target pH of 5.5 and two zones above this target.

The net cash flows for both VRA and Fixed rate scenarios were calculated for each 100 ha paddock and they reflect the costs of sampling, applying lime and the increased crop production due to changes in soil pH from the paddocks baseline (no lime) (Figures 2B and 2D). In Scenario 1 (average pH = 4.4, CoV = 6.2), the VRA strategy has higher costs in year 0 (VRA - $22,167 versus Fixed - $13,765), with most of the extra expense ($7,372) associated with greater rates of lime and consequent application costs. The additional net cash flow in years 1-5 was due to increased yield in response to increases in soil pH, in addition to a value in year 5 placed on the residual lime that increased soil pH above initial soil levels. The additional net cash flow was affected by the crop rotation, with the inclusion of a pulse as a high value, pH sensitive crop in year 3 providing a strong influence on the economics. At a pH of 5.5 wheat and canola are presumed to be at their full yield potential, barley is at 99% yield potential while the pulses are at 94% of yield potential.

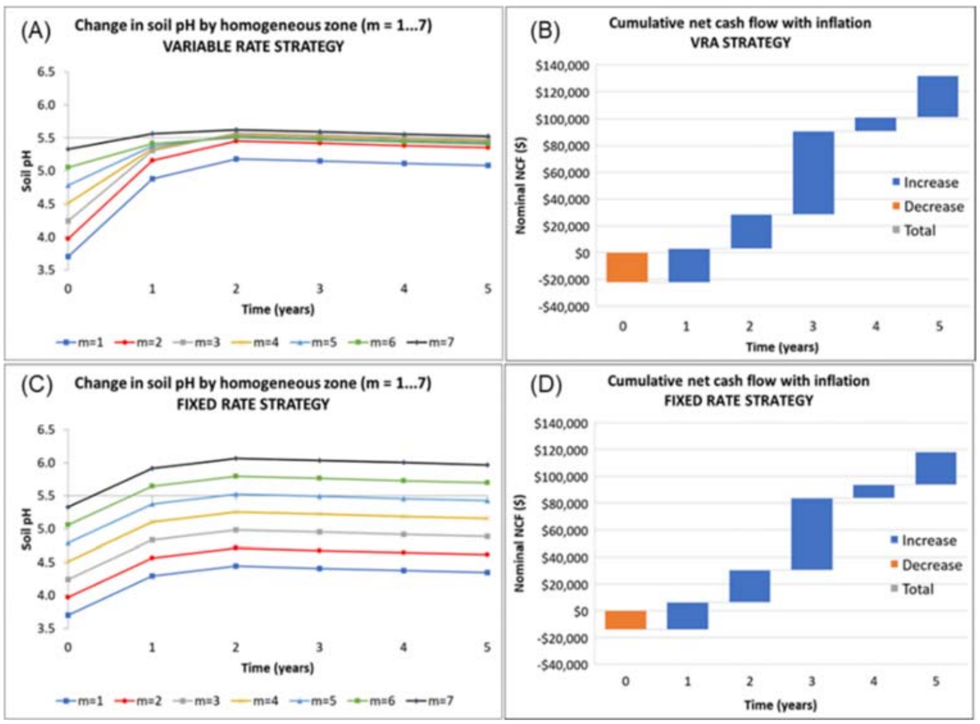

Figure 2. The predicted change in soil pH_{Ca} and cumulative net cash flow calculated for a hypothetical paddock which started with an average pH of 4.38 and a CoV of 6.2% and with a crop rotation of BCPWW. A and B are the results for a variable rate lime strategy and C and D are a fixed rate of 2.5 t/ha lime.

While the benefits of making investments based on detailed data (thereby reducing soil variability and minimising soil constraints across a paddock) make sense, developing and applying a variable rate strategy can be more expensive than a blanket rate application depending on the amount of lime applied. Costs of $16/ha to grid map soil pH and an estimated $4 per hectare additional cost to spread lime at a variable rate have been used within the DCF model. Based on the hypothetical paddocks we then investigated when grid soil mapping and variable rate lime applications were profitable. The results (Table 2) show that across all the scenarios both VRA and Fixed lime applications resulted in a positive NPV. For the BCPWW rotation the results showed that under more acidic and more variable scenarios (Scenarios 1-6) the NPV from VRA exceeded the Fixed because although the costs in year zero were greater, crop yield in subsequent years was less variable with most of the paddock performing at close to full yield potential (except for the more lime-sensitive pulse). In scenarios 7 and 8, where less lime is applied in the VRA than the Fixed strategy, the Fixed treatment has a greater NPV, suggesting that even at the higher pH there is sufficient crop response to warrant greater rates of lime addition.

Table 2. Average pH_{Ca} and the Coefficient of Variation (CoV) used to calculate the pH in 7 zones of our hypothetical paddocks. Predicted NPV over 5 years with a BCPWW. Results show the average rate of lime applied on the 100 ha for Variable Rate Application (VRA) and Fixed rate.

	Initial Paddock		VRA				Fixed			
Scenario	Avg pH_{Ca}	CoV (%)	NPV ($/ha)	Avg Lime (t/ha)	Final pH_{Ca} min	Final pH_{Ca} max	NPV ($/ha)	Avg Lime (t/ha)	Final pH_{Ca} min	Final pH_{Ca} max
1	4.4	6.2	$ 1,023	3.9	5.2	5.6	$ 866	2.5	4.4	6.1
2	4.4	3.9	$ 1,089	4.2	5.4	5.7	$ 946	2.5	4.7	5.7
3	4.6	5.6	$ 630	3.1	5.5	5.6	$ 587	2.5	4.7	6.3
4	4.6	3.2	$ 584	3.2	5.6	5.6	$ 548	2.5	5.0	5.9
5	4.9	6.0	$ 416	3.4	5.5	5.9	$ 382	2.5	4.9	6.6
6	4.9	4.8	$ 366	2.8	5.5	5.8	$ 358	2.5	5.0	6.4
7	5.1	6.6	$ 222	2.4	5.6	6.2	$ 226	2.5	5.0	7.0
8	5.1	4.9	$ 157	1.6	5.5	5.9	$ 193	2.5	5.2	6.7

Similar trends are observed in a BCWCW rotation, although the NPV across all treatments was reduced due to the pH sensitivity and value of the pulse crop in the previous rotation. In the BCWCW rotation the returns across all treatments were less; $730/ha and $650/ha for VRA and Fixed rates in Scenario 1. In addition, VRA was only greater than Fixed rate in Scenarios 1and 2 after which there was less than $15/ha difference between the two application rates and methods.

Conclusions

The analysis in this paper has shown:

- The potential for VRA to result in a reasonably uniform soil pH across the hypothetical paddocks returning a positive NPV across all the scenarios.
- The analysis reflects an increase in crop yield associated with an increase in soil pH above initial conditions. So, if we increase pH by 0.2 there is an increase in yield potential, but if the final pH is only 4.6 then we are still only getting 86% yield potential in barley and 72% yield potential in pulse crops. While this paper has targeted a fixed pH of 5.5 to remove yield constraints, this target may not always be the most profitable option. Stott et al (2019) applied the model to optimise profits by attaining pH levels that balanced the value of the extra grain produced to the additional liming costs.
- As the initial pH in the paddock increases and the variability across the paddock reduces the difference in the NPV for VRA and Fixed rate lime become similar and then marginally higher for fixed rate application.
- The final NPV in the less acidic soils was strongly influenced by the residual lime in the soils (calculated from initial soil conditions) as the crop response to increasing soil pH was small. As such the treatments with the greatest lime rates had the greatest NPV.

This economic analysis has focused solely on the effects of lime on the surface soils. In deciding on lime targets and strategies it is important to consider the potential implications on sub-surface acidity, with Miller (2018) suggesting that setting a surface soil pH of at least 5.5 will allow for some movement of lime below 10 cm soil depth and reduce the risks associated with sub-surface acidity. Even in the scenarios where there were similar NPV between fixed and variable rate strategies (in the less acidic and less variable paddocks), with fixed lime rates parts of the paddock still had pH values <5.2, presenting other soil health risks not considered within these analyses.

Acknowledgements

The authors would like to acknowledge the Department of Jobs, Precincts and Regions as well as the Grains Research and Development Corporation for their financial support of the DCF model used in this paper. We also thank Doug Crawford for his technical advice and input into the paper.

References

Miller L (2018) Lessons learned from soil acidity. http://www.sfs.org.au

Stott K, Crawford D and Norng S (2019), Quantifying the economic benefits of intensive point sampling and variable rate liming of 10 case-study paddocks in the High Rainfall Zone. Technical Report: Agriculture Victoria, Melbourne, Vic.