Effect of variable rate lime application on autumn sown barley performance

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Abstract

The expense of farm inputs, as well as environmental concerns, has been driving the interest in using variable rate application technology for the spatial optimisation of crop inputs. For arable cropping, lime is an important input for adjusting soil pH to improve crop growth. Trials were conducted at two South Canterbury sites to investigate the effects of variable-rate lime (VRL) applications prior to autumn sown barley on yield and gross margin (GM). No significant differences or strong correlations were found between the different lime application treatments and yield or gross margin. However, the trial identified that lime-spreading applications were not accurate enough to allow the effect of VRL to be adequately measured and ultimately this work has highlighted that while it is straightforward to generate VRL recommendations, the current fleet of ground spreading trucks may not be able to deliver these rates accurately.

Additional keywords: geospatial, proof-of-placement, variable-rate-lime, Veris

Introduction

Traditionally, lime applications to cropping paddocks have been prescribed on the basis of the average pH of the paddock, with this value being obtained by collecting soil samples from a transect across the field. However, pH values along with nutrients vary widely within paddocks according to differences in parent material, cropping history and previous lime applications. Variations of over two pH units have been recorded in some cropping paddocks in the United States (Lund, 2012) and similar results have been reported in New Zealand (Hurst *et al*., 2015). As a result of using average pH value of a paddock, lime is regularly applied to some areas of paddocks with high pH, even though none was required. As well as being an inefficient use of resources, supplying excessive amounts of lime can hinder crop growth (Bongiovanni and Lowenberg-Deboer, 2000). In-paddock soil pH variation becomes increasingly apparent as paddock sizes become greater, most likely because of the amalgamation of smaller paddocks to accommodate irrigation booms and larger machinery (Wilson, 2015). Some crops (e.g. barley, soybeans and potatoes) are considered very sensitive to soil pH, with the effect of lime applications to cereal crops well-known (Šekularac, 2012). There is potential to use variable rate application technology to optimise the amount of lime applied to the soil in an attempt to minimise variation in the soil pH for the benefit of crop nutrient uptake and growth. Modern food production practices require optimisation of input use efficiency, and the variable rate application of lime should help meet this requirement.

The objective of this trial was to measure the effect of variable-rate lime (VRL) applications on autumn-sown barley gross margins, compared to average rate, and nil lime applications.

Materials and Methods

Site descriptions

Two paddocks to be sown in barley in April 2016 were chosen for this trial. They were located near Makikihi (44°37'3.77"S, 171° 8'46.01"E) and Orton (44°12'21.34"S, 171°28'2.97"E), in the Canterbury Region. The total area of the Makikihi site is 9.2 ha, and of the Orton site 19.58 ha. For the Makikihi site, the soil type is a shallow Eyre silty loam; and for the Orton site, the soil is a moderately deep Templeton silty loam.

Soil pH sampling

Smart Ag Solutions® used a Veris® MSP3 undertook geospatial soil sampling in each paddock (Lund, 2012). The Veris® MSP3 takes physical soil samples approximately every 40 metres, and these are analysed using two on-board probes. The pH readings from the Veris® MSP3 are then calibrated against pH measurements made on physical soil samples collected from specific points in the paddock, as determined by the Veris software.

Lime recommendations

The aim was to add sufficient lime to the paddock to raise the soil pH into the optimal range for barley growth with the aim of 5.8. Where the soil pH was already 5.8 or above, nil lime was prescribed. The quantity of lime applied was based on adding 1 t/ha lime for each 0.1 pH unit increase (Nicol *et al.*, 2012) (Equation 1).

Equation 1:
Quadrat lime recommendation (t/ha)
= (5.8 − quadrat pH) x 10

Trial design

Lime recommendations were made on a 12 m x 12 m quadrat, with lime rates ranging from 0-5 t/ha. The average lime rates for the Makikihi site was 3.1 t/ha, and the Orton site 0.7 t/ha.

The trial included four replicates of 12-metre wide strips of three treatments, were replicated four times. (Figure 1). Each plot was 12-metre and the following treatments were assigned:

1. No lime applied
2. Variable rate lime applied
3. Fixed rate of lime applied (3 t/ha at Makikihi; 1 t/ha at Orton)

The data for these plots was generated using AgLeader SMS™ Advanced, and exported as a shape file to the fertiliser company to import into their fertiliser spreader.

Lime application

Dry fine lime containing 36% Ca, ground to a nominal 70-micron particle size was applied using standard truck bulk spreaders (Figure 2) which travelled the paddocks at a 12-metre swath width, and approximately 8-12 km/h as recommended by the fertiliser company. Variable-rate lime (VRL) applications are implemented by starting, stopping and changing the speed of the hydraulically driven chain drive in the bottom of the lime bin on the lime spreader truck. The lime was supplied from the local fertiliser company.

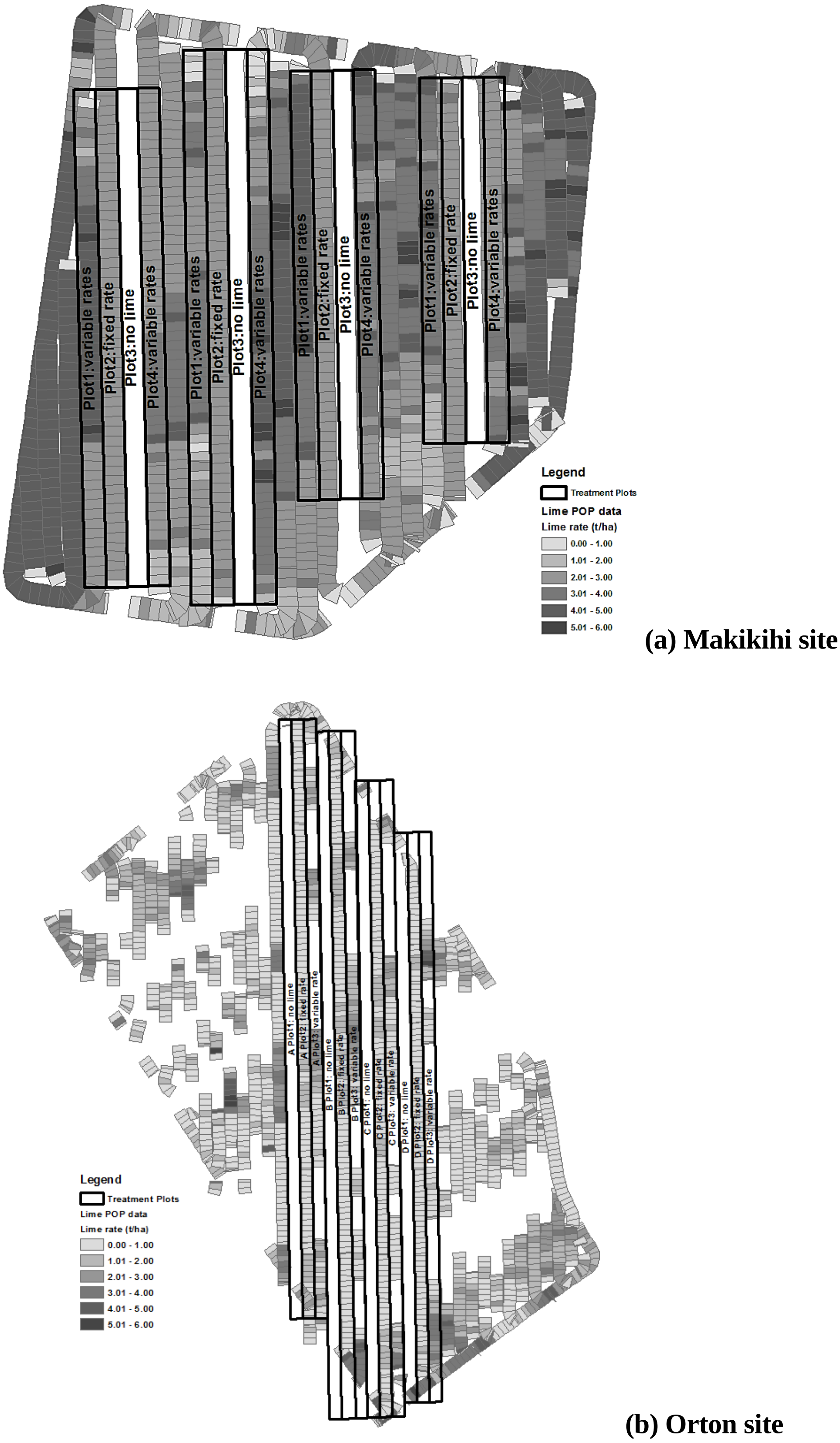


Figure 1: Variable Lime Rate trial layout.

Figure 2: Lime spreader applying variable rate lime at Orton site.

Proof-of-placement

The fertiliser company supplies proof-of-placement (POP) maps of lime application as PDF files to growers. The POP information confirms that the application is made as requested. It is also becoming more important for growers to be able to accurately record crop input applications to validate environmental stewardship. This POP data was imported into our GIS mapping software and analysed against the barley yield performance.

Imagery

An unmanned aerial vehicle (UAV with a near-infrared (NIR) sensor) made a single pass over each crop paddock on 30 August 2016, when the barley crop was nearly at canopy cover stage, to see if there were any visual or Normalized Difference Vegetation Index (NDVI) differences between the lime treatments showing in the barley crop. The UAV used NIR sensor recorded data in the following bands: Green (550 nm); Red (660nm); Red Edge (735 nm) and Near-Infrared (790 nm). Based on the reflectance of these bands, the NDVI was calculated (Equation 2).

Equation 2:

$$NDVI = (NIR - Green) / (NIR + Green)$$

NDVI measures the amount of green vegetation in an area, based on the principle that actively growing green plants strongly absorb radiation in the visible light region of the spectrum, while strongly reflecting radiation in the NIR region.

Harvest

The trial aimed to assess the geospatial variability of barley yield; however, undertaking hand harvests of quadrats in the trial would not have been practical, as this would have required a very large number of harvest samples to gain an acceptable data set for yield. Hence, it was decided to use the yield monitors in the respective combine harvesters to gather the trial harvest data. The combines were to harvest the central nine-metres (the width of the harvester header) of each 12-metre wide lime-spreading swath, with the POP data from the lime spreading operation used to identify the centre of the swath. At the Makikihi site, the combine harvester undertook this harvest as planned, however at the Orton site, the other combine harvester was unable to load the navigation data and so it was unable to travel the same lines as the lime spreader, and therefore harvested the entire paddock in conventional fashion (Orton site). The barley fields were harvested on 12 January 2017 using CLAAS combine harvesters, equipped with the CLAAS Quantimeter volumetric yield sensors (yield monitor) and auto-steer. The yield data was recorded every 2 seconds in the combine harvesters. The travel velocity during harvesting was reasonably consistent (8-10 km/h).

Data processing

Data stored in the process monitor of the combine harvester was transferred to an office computer for data analysis. Prior to mapping, data in the headland areas was removed with a pre-determined internal boundary. The errors (e.g. combine fill mode and lag time, points near the headlands, carriers and erroneous set width) were removed using a spatial filtering algorithm proposed by Spekken et *al.* (2013). Ordinary Kriging (a method of predicting unknown values at the un-sampled locations with known values at the sampled locations based on distance-variance relationship between two locations) was used to interpolate the yield data points into 10 m grids with the block size of 9 m. The estimated yields of the treatments were extracted using the statistical program R©.

Gross margin

The gross margin (GM) for each point in the trial was calculated by subtracting the costs of lime application and the crop establishment from the income, derived from the barley yield at that location, based on the following assumptions:

i. Lime cost $ 40 per tonne
ii. Spreading $ 34 per hectare
iii. Fixed costs barley crop $ 1,400 per hectare
iv. Barley value $ 300 per tonne

Other costs such as harvest and post-harvest freight and drying were not included.

Results

Lime spreading

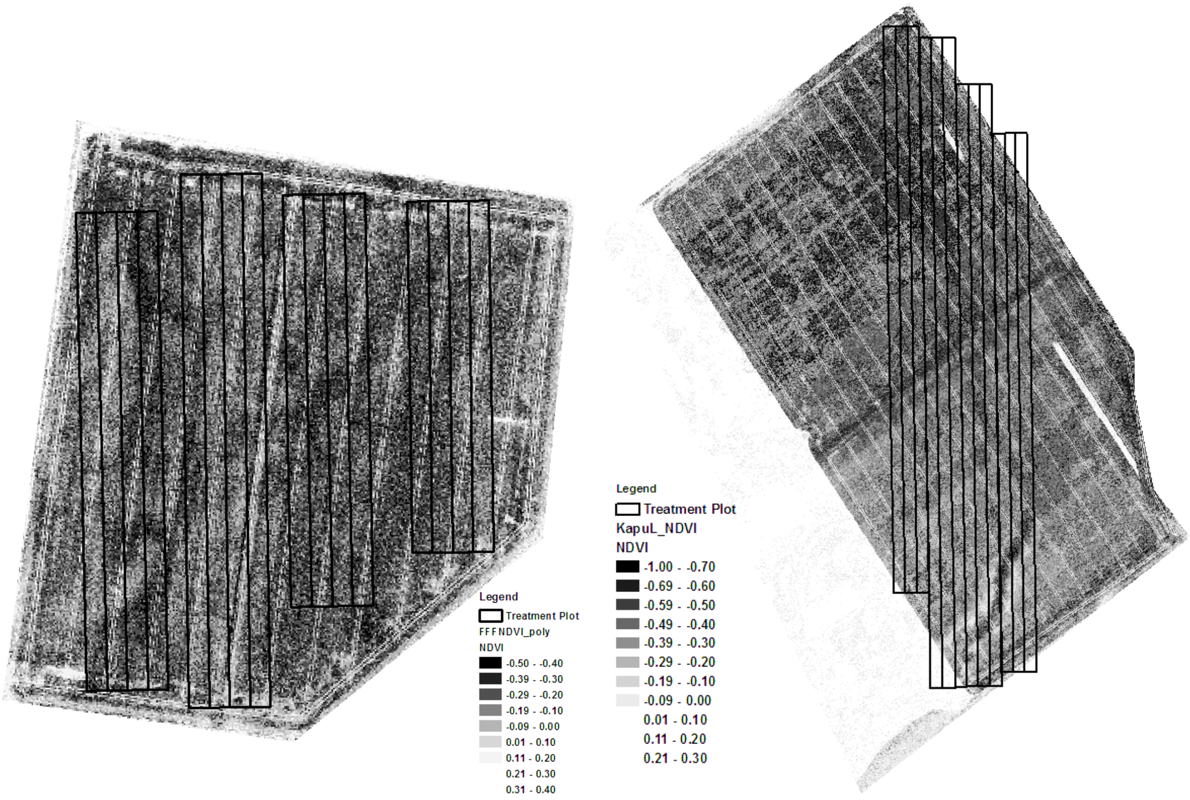
We investigated the accuracy of the 'as applied' POP application rates as measured by the lime spreaders. We correlated the prescribed application rate with the 'as applied' rates (Table 1) and found R^2 values of 0.57 and 0.75 for the Makikihi and Orton sites, respectively. Table 1 shows that 25-30% of each plot had lime applied at a rate within 0.5 t/ha of the prescribed rate, and over 70% of the plot area had lime applied at greater than 0.5 t/ha variation from prescribed rate.

Normalized Difference Vegetation Index (NDVI)

There were no strong correlations between NDVI and yield (Fig. 3 Table 3 and Table 4). This may be due to a number of reasons: it had appeared that the sensor or the algorithm was not functioning properly because NDVI values should be positive (Heuvelink and van Egmond, 2010); The NDVI images should have been taken at different stages (e.g. tillering, stem elongation, booting, anthesis, grain filling and physiological maturity). Particularly at the maturity stage, yield should correlate to NDVI the most (Sultana et *al.* 2014); The NDVI values should also be significantly different between prior- top-dressing and post- top-dressing of nitrogen. Barley was sown in April, and the measurement in August may be too early as the crops canopy had not properly developed. The NDVI images, with one-metre spatial resolution, appeared to be "noisy" due to other environmental variables such as temperature and bare soils in previous vehicle wheel tracks (tramlines). Therefore, post-processing of the NDVI data would be required, such as re-adjusting the image resolution and removing the data “noises” from the soil using different image processing techniques.

Table 1: Variation between prescribed lime application rate and rate applied.

		Trial site	
		Makikihi	Orton
Average pH before lime application		5.2	5.8
Average lime application rate		3.1	0.7
Variation from prescribed rate (t/ha)	< 0.1	3%	4%
	0.1-0.5	22%	26%
	0.5-1	53%	41%
	1-1.5	20%	15%
	1.5 +	2%	14%
Correlation	R^2	0.566	0.748



(a) Makikihi site **(b) Orton site**

Figure 3: NDVI values at the Makikihi and Orton sites

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Barley yield

We were aware that it may have taken some time for the lime to have an effect on the soil pH, and found there were no significant differences (*significance at the level of* 0.05) in the yields between the different lime treatments at either site (Tables 3 and 4). There were significant differences in the yields between the four blocks of replicated treatments at both the Makikihi site and the Orton site (Table 2), which suggests strong underlying yield trends across both paddocks.

Gross margin

The ANOVA analysis found that there were significant differences in the GM between the different lime treatments at both sites (Table 2). However, no strong correlations (correlation coefficient r = -0.19) were found between the lime rates applied and crop gross margin in either the Orton site (Table 4) and the Makikihi site (r = -0.04) across all treatment plots (Table 3).

Table 2: ANOVA test results for statistical significances in the yields and gross margin between the replicates and between different treatments.

Sites	Variables	Reps	Treatments
Makikihi	Yield	2e-16***	0.135ns
	GM	2e-16***	0.000131***
Orton	Yield	0.0192*	0.0921ns
	GM	0.0142*	0.0114*

Significance level		
	< 0.001	***
	0.001 to 0.01	**
	0.01 to 0.05	*
	≥ 0.05	ns

Table 3: Correlations between the average lime rates and the average barley yields, the average lime rates and the average NDVI, the average yields and the average NDVI across the treatment plots (Makikihi site).

Treatment	Mean Yield (t/ha)	Mean NDVI	Mean Lime (t/ha)	Correlation Coefficients (r)			
				Lime: Yield	Lime: NDVI	NDVI: Yield	Lime: GM
Average variable rates	7.33	-0.21	3.51	0.13	-0.04	-0.16	-0.6
Average fixed rate	7.21	-0.19	2.66	0.12	0.11	0.01	-0.09
Average no lime	7.20	-0.19	0.03	0.04	0.06	-0.01	0.00
Average all treatments	7.26	-0.20	2.45	0.12	-0.03	-0.05	-0.04

Table 4: Correlations between the average lime rates and the average barley yields, the average lime rates and the average NDVI, the average yields and the average NDVI across the treatment plots (Orton site).

Treatment	Mean Yield (t/ha)	Mean NDVI	Mean Lime (t/ha)	Correlation Coefficients (r)			
				Lime: Yield	Lime: NDVI	NDVI: Yield	Lime: GM
Average variable rates	9.39	-0.40	0.03	0.05	0.01	0.10	0.02
Average fixed rate	9.16	-0.40	0.52	-0.20	0.02	0.13	-0.24
Average no lime	9.16	-0.40	0.83	-0.08	-0.01	0.22	-0.20
Average all treatments	9.24	-0.40	0.46	-0.11	-0.01	0.15	-0.19

Discussion and Conclusions

The initial objective of this study was to investigate autumn sown barley performance and associated gross margins, in response to variable rate application, fixed rate application and no application of lime. Responses to VRL have been found in other pH sensitive crops such as soybeans (Weisz *et al.*, 2003); and it was hoped to assess similar effects on barley. However, during the trial it became apparent that the accuracy of the lime spreading applications to the two trial paddocks was not accurate enough (R^2=0.57 and 0.75) to allow this objective to be met, and ultimately this work has highlighted a number of issues regarding variable rate lime spreading:

1. Developing VRL application recommendations from geospatial soil pH is viable using farm mapping software and online freeware
2. Applying these recommendations is challenging, as current spreading equipment does not provide the accuracy needed to undertake VRL trials
3. The period of the effectiveness of lime applications. This trial involved the spreading of lime in April 2016, followed shortly by barley planting, with harvest occurring in January 2017. It may take longer than this timeframe for the effects of lime applications to come into effect. Therefore it is also possible that previous applications of lime could affect the site after the soil pH was measured, resulting in conflicting effects to those imposed by the trial. (Nye and Ameloko, 1987)

During the course of this study, it was discovered that due to the variation in lime particle size, the spreading pattern and material drift from lime spreader varies widely (Grafton *et al.*, 2015). Small and light particles can be strongly influenced by high air temperatures and strong winds, and hence the lime particles may not be spread as uniformly as we were expecting.

We plan to undertake further work to quantify the variation in lime application and the effective swath width of lime, as well as continue to investigate the potential for the use of VRL application to barley crops. We will also measure the geo-spatial soil pH in the two trial paddocks to assess the effect of the lime applications.

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