Economics of a variable rate fertiliser strategy on a Whanganui hill country station

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Abstract
Automated flow control coupled to differential GPS guidance systems in aerial topdressing aircraft will allow variable rate (VR) fertiliser strategies to be applied on hill country farms. The effectiveness of these strategies will be enhanced with the use of remotely sensed hyperspectral data to categorise and quantify the farm landscape in greater detail. The economic benefit of a variable rate fertiliser strategy in comparison to a single rate (blanket) strategy was evaluated for a case study Whanganui hill country station. The analysis illustrates the robustness of a VR strategy in the face of volatile returns in that it produced a higher 10 year cumulative net present value (NPV) and remained at a positive advantage at three different stock gross margins, in comparison to a blanket approach. The effectiveness of hyperspectral imagery for defining effective pasture areas to assist development of more precise variable rate fertiliser applications, compared to the current visual classification from farm photography is discussed.

Keywords: economic benefit, variable rate fertiliser, hyperspectral data

Introduction
There is a wealth of scientific evidence showing that the addition of the fertiliser nutrients phosphorus (P), potassium (K), sulphur (S) and lime increase pasture production and quality in New Zealand hill country (Roberts & White 2016; Morton & Roberts 2009). However, hill country farms also have a myriad of slopes, aspects, soil types, soil depths, moisture status, grazing management and pasture composition contributing to both actual and potential differences in pasture production, which then impact animal performance and farm profitability. Historically, available technology and practicalities have resulted in aerial fertiliser applications to hill country usually being a single rate of a single product (Roberts & White 2016; Morton *et al*. 2016) sometimes referred to as a blanket (B) application.

The benefit of a variable rate fertiliser application as opposed to blanket application has previously been advanced as an improved strategy for hill country farms (Yule & Gillingham 2002; Murray & Yule 2007; White *et al.* 2017).

Applying a variable rate (VR) strategy has been referred to in two commercial examples in Edmeades *et al.* (2016) and broadly includes:

- Classifying the farm into different land management units (LMU) based on an assessment of actual and potential productivity of these units
- Undertaking soil and herbage sampling to assess the soil fertility of these units
- Using an econometric modelling approach (Metherell *et al*. 1996) to allocate fertiliser and lime applications (including capital and maintenance) across the LMUs to achieve the optimum outcome either by increasing productivity by applying more nutrients or by achieving cost reductions where reduced nutrient application is justified.

The recent advent of automated flow control of aerial topdressing application systems has facilitated the spreading of the nominated fertiliser rate to the intended area of application. One of the critical components for using this new technology is that it requires a current digital image of the farm to effectively map the sensitive and/or non-productive areas. These systems have also been shown to reduce the field coefficient of variation (CV) of aerial fertiliser application from 78% to 42%, which is aligned with CV values found in ground spreading (Chok *et al.* 2016). Morton *et al*. (2016) concluded benefits from variable rate equipped aircraft can be both economic and environmental due to the avoidance of non-productive zones and/or environmentally sensitive areas. Anecdotally, pilots using non-automated systems for fertiliser applications can also avoid non-productive zones and change fertiliser rates manually while in the air. However, in practice this represents an enormous strain on the pilot and the effectiveness may vary. Automation will also improve pilot safety as they are able to focus on aircraft operation rather than fertiliser spreading.

Remotely sensed hyperspectral imagery can

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differentiate pasture species from other plant species in the landscape to an accuracy of 99% (Cushnahan *et al.* 2017). This should allow for more accurate assessment of productive pasture area. Hyperspectral imagery was also shown to have potential to accurately classify landscape components such as pine trees, manuka, gum trees, rushes, farm tracks, open soil and water bodies (Cushnahan *et al.* 2017). This offers potential for such imagery to inform fertiliser prescription maps for variable rate application by automating the process of defining non-pasture areas and environmentally sensitive areas where fertiliser application is not required.

The objective of this paper was to compare a case study of the economics of a variable rate fertiliser strategy with a blanket strategy for a Whanganui hill country farm (Ohorea Station). Additionally, the effectiveness of hyperspectral imagery for defining pasture areas to develop variable rate fertiliser applications is discussed.

Methods and analysis

Economic analysis of variable rate strategy

The economics of a variable rate fertiliser strategy as compared to a blanket strategy was evaluated for Ohorea Station, a 5420 ha breeding and finishing hill country farm located in the Parapara range (Manawatu-Whanganui). Overseer® (version 6.2.3) was used to model Ohorea Station's current farm management. The farm production and physical characteristics are described in Table 1. The soil classification and fertility characteristics are shown in Table 2. The mean soil fertility levels for each LMU were determined from permanent representative soil transects already established in each LMU as part of the annual farm planning cycle. The current analysis considered P, K and S requirements only. The AgResearch PKS lime econometric model (Metherell *et al.* 1996) was used to determine optimal soil fertility levels, associated nutrient inputs and comparison of practical fertiliser strategies. The key model inputs are shown in Table 3. A blanket strategy, based on recent farm practise, was modelled as 200 kg/ha of single superphosphate (SSP) applied annually (except for an unfertilised area of steep hill country). A variable rate scenario, using available fertiliser products, was created to approximate the nutrient rates and ratios recommended by the optimum analysis. A sensitivity analysis to test the robustness of the strategy to changes of ±20% in livestock gross margin was also completed.

Using hyperspectral imagery to measure effective area in pasture

Ohorea Station is being used as a research/focus farm, involved in a Primary Growth Partnership programme to assist calibration of a hyperspectral sensor, with the objective of remotely sensing soil fertility across hill country farms. This is still work in progress and is not discussed in this paper. A co-benefit of the hyperspectral data is that it has enabled the percentage of pasture cover to be calculated. Approximately 927 ha of Ohorea Station has been surveyed with the hyperspectral sensor as part of the calibration exercise and also manually classified for aerial fertiliser application using standard aerial imagery. Using the hyperspectral data, Cushnahan (2017) has classified the vegetation on part of Ohorea Station into pasture and a variety of non-pasture classes at a resolution of 1 m^2 pixels. To create an effective area map suitable for aerial fertiliser application, this vegetation layer was processed by calculating the proportion of 1 m^2 pasture pixels in 100 m^2 grid cells. Where there was greater than 50% pasture the grid cell was classified as pasture. This was then simplified by eliminating small areas of either pasture or non-pasture less than 0.5 ha and narrow areas less than about 70 m in width. This calculated area could then be compared to the pasture area determined by visual classification and the total pasture area from the original 1 m^2 resolution hyperspectral classification. The visual classification involved manually editing the farm map using GIS software.

Table 1 Ohorea Station production and physical characteristics for econometric analysis.

LMUs	Block area (ha)	Slope (degrees)	Soil Order	Sheep (RSU/ha)	Beef (RSU/ha)
Class 1	65	Flat (0°-7°)	Allophanic	659	311
Class 2 - GFC*	299	Rolling (8°-15°)	Allophanic	3035	1434
Class 2 - no crops	905	Rolling (8°-15°)	Allophanic	7336	3484
Class 3 - Fertilised	2582	Steep (>26°)	Brown	15720	7437
Class 3 - Unfertilised	288	Steep (>26°)	Brown	833	397

* greenfeed crop.

Table 2 Soil fertility characteristics of Ohorea Station before implementation of a VR fertiliser strategy.

LMUs	pH	Olsen P (μg/ml)	Quick test K	Organic S (μg/g)
Class 1	6.0	22	12	20
Class 2 - GFC	5.8	32	17	22
Class 2 - no crops	5.4	18	12	9
Class 3 - Fertilised	5.3	13	12	7
Class 3 - Unfertilised	5.3	8	10	5

Table 3 Key inputs used in the FANZ econometric model analysis.

Net Present Value (NPV) discount rate (%)	4
Gross Margins ($/RSU)	
Sheep	59.3
Beef	60.1
Stock value ($/RSU)	
Sheep	120
Beef	170
Cost of transport and spreading ($/tonne)	
Class 1	21.38
Class 2 and Class 3	103.6
Cost of nutrients ($/kg, ex-store)	
P	2.92
K	1.18
S	0.57

Results

Economic analysis of variable rate strategy

The VR strategy applied a different rate of SSP each year for Class 1, Class 2 - no crops, Class 3 - fertilised LMU's of 180, 170 and 200 kg SSP/ha, respectively (Table 4). For the Class 2 - GFC LMU, P was withheld for 7 years and when resumed in year eight, was applied at a rate of 200 kg SSP/ha (Table 4). For the Class 3 - Unfertilised LMU Maxi SSP at 100 kg/ha was applied in Year 1 and from Year 2 onwards was changed to sulphur fortified SSP (SS20) (Table 4).

A maintenance P strategy maintains soil Olsen P levels while a capital P strategy aims to increase these levels. At the current soil K levels no potassium nutrient applications were required within the optimum strategy. The VR strategy maintained soil Olsen P levels in Class 1, Class 2 - no crops, Class 3 - fertilised, Class 3 - Unfertilised LMUs, and decreased them on the Class 2 - GFC LMU (Table 4). In comparison, the B strategy largely maintained soil Olsen P levels on all LMUs that received fertiliser. On the Class 3 unfertilised LMU, withholding fertiliser resulted in a reduction from Olsen P 8 to 4 by Year 10 (Table 4).

The 10 year cumulative net present value (NPV) relative to no fertiliser application of both the VR and the B strategies for Ohorea Station (Table 5) assumes that only the effective areas, determined from visual classification of photographic imagery for the whole farm, were fertilised. The 10 year cumulative NPV's compared to no fertiliser application were greater, ranging from $42 to $410/ha (average $57/ha) across all the LMU's under the variable rate strategy with the exception of the Class 3 - Fertilised (Table 5). For this class, the fertiliser policy was the same under either strategy. The AgResearch PKS lime econometric model optimises long-term NPV while the accumulated NPV is shown at 10 years. The negative NPV values from Class 1 and Class 2-GFC (Table 5) are a reflection of the costs of the fertiliser strategies, while the returns from increased pasture production, quality and better animal productivity from these strategies manifest over a longer timeframe.

Table 5 Ten year cumulative NPV ($/ha) relative to no fertiliser application of the VR and the B strategies for Ohorea Station.

LMUs	VR	B
Class 1	-277	-319
Class 2 - GFC	-143	-553
Class 2 - no crops	204	149
Class 3 - Fertilised	176	176
Class 3 - Unfertilised	217	0
Total	155	98

Table 4 Olsen P soil test levels at Year 0 and Year 10 following implementation of a VR or B fertiliser strategy on Ohorea Station. The VR strategy employed is also described.

LMUs	Year 0	VR strategy employed	Year 10 (VR)	Year 10 (B)
Class 1	22	180 kg SSP/ha	21	23
Class 2 - GFC	32	Withhold P (for 7 years)* 200 kg SSP/ha (Year 8 onwards)	17	26
Class 2 - no crops	18	170 kg SSP/ha	17	19
Class 3 - Fertilised	13	200 kg SSP/ha	12	12
Class 3 - Unfertilised	8	100 kg Maxi SSP/ha (year 1), 140 kg SS20 /ha (year 2 on)	8	4

*It is assumed any greenfeed crops will be fertilised as appropriate within each year.

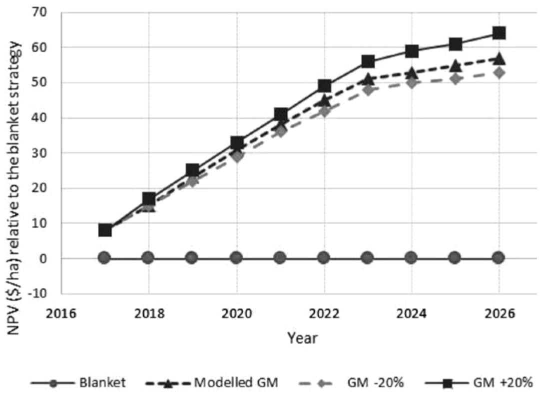

Figure 1 Ten year cumulative NPV's ($/ha) of the VR strategy relative to the blanket strategy at three different GM's.

The sensitivity of the two strategies to changes in stock gross margin (GM) was tested by adjusting the GM by ±20%. Ten year cumulative NPV's across the farm for the VR strategy relative to the B strategy were $53 to $64/ha greater across the range of GM's tested (Figure 1). The VR strategy showed a positive NPV compared to the B strategy immediately from when the strategies were implemented at Year 1 (Figure 1).

Using hyperspectral imagery to estimate effective area in pasture

Vegetation classification from visual classification of pasture areas on the 927 ha block on Ohorea using photographic imagery, estimated 94% of the pasture area should be fertilised compared to 88% using the hyperspectral imagery (Table 6). The visual estimate excluded 61% of the non-pasture area from fertiliser application compared to 81% using the hyperspectral imagery (Table 6). These differences were due to shape effects regarding what was deemed suitable or practical for aerial application. Additionally, the automated classification excluded a higher proportion of poplar plantings in the non-pasture area.

The differences in classification of pasture and non-pasture areas has noticeable effects on the area of a hill country property that should receive fertiliser and hence the cost of fertiliser applied.

Discussion

Economic analysis of variable rate strategy

The analysis presented in this paper shows the potential benefit of the VR strategy for Ohorea Station in that it produced a higher 10 year cumulative NPV. Similarly, White *et al.* (2017) showed a VR strategy provided a higher NPV across modelled North and South Island hill country farms across two different Olsen P fertility levels. These results also align with the findings of a modelled study of Limestone Downs by Murray & Yule (2007) where they concluded that a VR strategy with fertiliser applied so that it was a non-limiting factor to pasture production, excluding non-responsive areas, increased the cash surplus generated by 26% compared to a blanket application.

The gross margin sensitivity analysis on Ohorea supports previous findings (White *et al*. 2017) that the VR strategy, in comparison to a blanket approach, was more sustainable in terms of farm profitability in the face of volatile returns.

An important caveat to the NPV analysis shown here in respect to the value of increased fertiliser inputs, is that the FANZ econometric model assumes that the farm is in a position to utilise the extra feed grown. It is assumed that extra stock are required to utilise the extra feed grown. If sub-division and additional farm labour is required to capture the extra growth from increased fertiliser inputs then that cost is not considered in this analysis. However, the econometric model does not include any management gains from changes in seasonality, or improved pasture quality and composition from increased fertiliser inputs. In general, the application of SSP fertiliser has been reported to result in a change in the botanical composition to clover and ryegrass pastures (Roberts & White 2016), so the model analysis may alternatively be considered to be conservative if farm infrastructure is appropriate or if the additional grass grown is reflected in increased slaughter weights or lambing/calving percentages from existing stock rather than purchasing additional stock.

Table 6 Fertilised area classification from visual classification compared to vegetation classification from hyperspectral imagery for 927 ha of Ohorea Station.

Vegetation classification	Excluded (ha)	Fertilised (ha)	Total (ha)	Excluded %	Fertilised %
Visual classification					
Pasture	41.9	615.8	657.7	6	94
Non Pasture	165.2	104.3	269.5	61	39
Automated classification (derived from hyperspectral imagery)					
Pasture	76.0	581.7	657.7	12	88
Non Pasture	218.5	51	269.5	81	19

Using hyperspectral imagery to estimate effective area in pasture

Operationally, technological advancements with the use of differential correction to GPS guidance systems combined with automated flow control in topdressing aircraft allows VR fertiliser strategies to be applied with confidence to hill country farms (Roberts & White 2016; Morton *et al*. 2016). To date, Ravensdown has completed over 40 fertiliser applications on a commercial basis using this technology and from these applications, sensitive or non-productive zones have on average comprised 9% of the total land area (assessed by visual classification) of the farms indicating potential savings from more accurately quantifying the non-productive or environmentally sensitive areas. This benefit will be enhanced if hyperspectral imagery is used to assess effective farm areas. The main difference between the methods presented here was due to shape effects regarding what was deemed suitable or practical for aerial application, and these differences would be minimised by aligning the assessment criteria. The advantage of using hyperspectral imagery is that it can overlay current digital imagery of a farm, automates what is a laborious and time consuming process and eliminates the risk of human error for assessment of effective farm area for fertiliser applications.

Early indications from the completed commercial applications using variable rate applications and exclusion zones involving SSP, are that the additional flying hours and hours to process digital maps to complete these applications suggests (according to the senior author) less than a 5% increase in applications costs. Murray & Yule (2007) concluded that even with a 20% increase in application costs the farm's annual cash position when using a VR strategy only varied by 0.4%.

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