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THE USE OF VARIABLE RATE FERTILISER APPLICATIONS IN NZ HILL COUNTRY

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Abstract

The basis of a variable rate fertiliser strategy is identifying the productivity potential of differing land management units, undertaking sufficient soil and herbage sampling to assess the soil characteristics and fertility across these land management units and then applying the appropriate fertiliser to attain the economic optimum soil fertility that matches the assessed potential production.

Four scenarios were analysed using the AgResearch PKS lime econometric model comparing a variable rate to a blanket fertiliser strategy. The scenarios represented typical North Island and South Island hill country with the farms classified into land management units (LMUs) representing different slope classes. Soil fertility levels for each slope class were extrapolated from Ravensdown's Primary Growth Partnership (PGP) research farms where a significant number of soil tests have been sampled across slope classes and seasons. The current analysis considered P and S requirements only.

The analysis showed that, in comparison to a blanket application, the variable rate strategy produced a higher 10 year cumulative net present value (NPV) for all four scenario's modelled. A sensitivity analysis also showed that the variable rate strategy was more sustainable for farm profitability in the face of volatile returns with positive cumulative NPV's observed within 9 years in all the scenarios tested compared to the blanket application.

Operationally, technological advancements with the use of differential correction to GPS guidance systems combined with automated flow control in topdressing aircraft are also discussed in terms of the implications for variable rate strategies that can increasingly be put into practice more effectively.

Introduction

There is a wealth of scientific evidence showing that the addition of the fertiliser nutrients phosphorus (P), potassium (K) , sulphur (S) and lime, when applied at optimum soil fertility levels where required, increase pasture production and quality in New Zealand hill country (Roberts and White, 2016; Morton and Roberts, 2009). However, hill country farms also have a myriad of slopes, aspects, soil types, soil depths, moisture status, grazing management and pasture composition which all contribute to both actual and potential differences in pasture production which then impact animal performance and farm profitability. Available technology and practicalities have resulted in hill country fertiliser aerial applications usually being a single rate of a single product (Roberts and 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 and Gillingham 2002, Murray and Yule, 2007). The process of developing a variable rate (VR) strategy broadly includes:

- classifying the farm into different LMUs 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.

Operationally, technological advancements with the use of differential correction to GPS guidance systems combined with automated flow control in topdressing aircraft has meant that variable rate strategies can effectively be used in practice. The variable rate application system has been shown to reduce the coefficient of variation (CV) from 78% without the system to 42%, which is aligned with CV values found in ground spreading (Chok *et al.,* 2016). Morton *et al*. 2016 concluded the benefits of a strategy using variable rate equipped aircraft on hill country can be both economic and environmental due to the avoidance of non-productive zones and/or environmentally sensitive areas. A further benefit of variable rate equipped aircraft is the improvement in pilot safety as they are able to focus on aircraft operation rather than fertiliser spreading. While conventional fertiliser applications can also avoid areas in practice this represents an enormous potential strain on pilots and the effectiveness may vary.

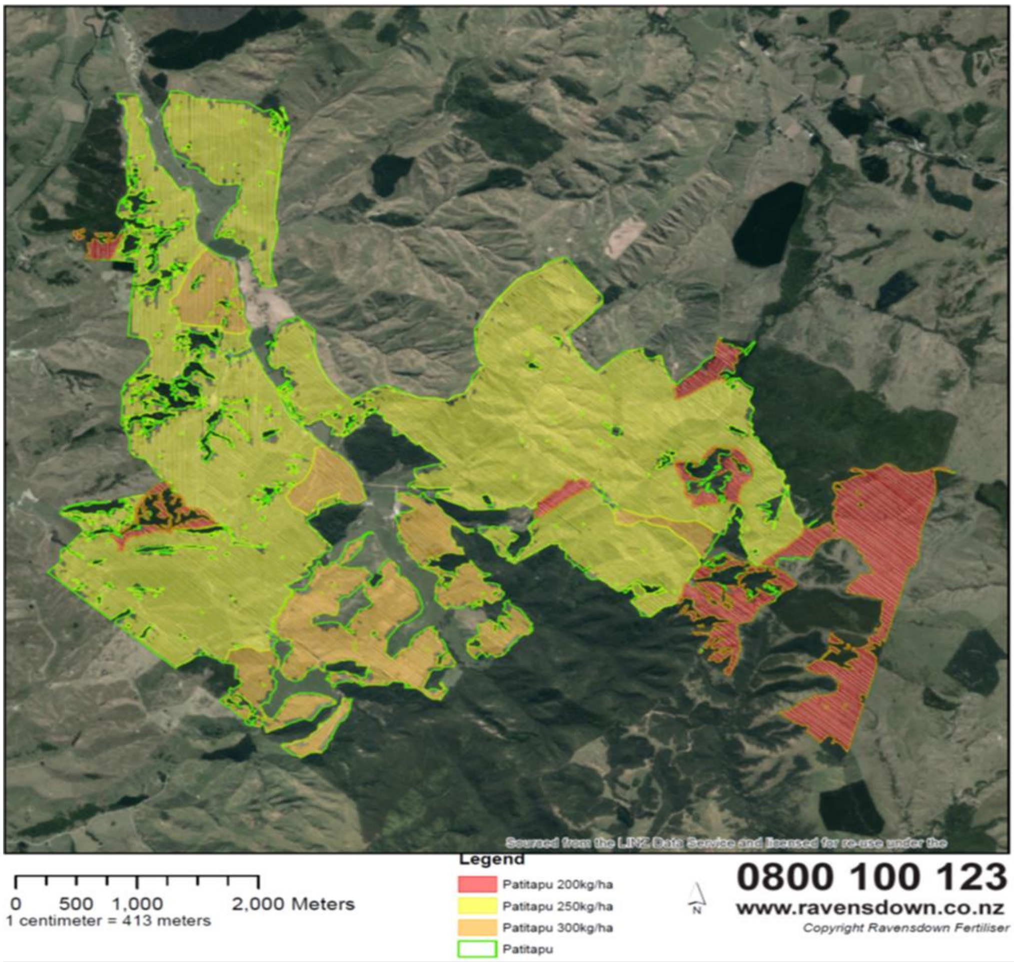
This paper describes recent experience with the effectiveness of variable rate equipped aircraft in avoiding sensitive or non-productive zones and also explores the economics of a variable rate strategy compared to blanket strategy in 4 different scenarios using two modelled hill country farms.

Sensitive/Non-productive zones

After considerable development, which began in the early 2000s, Ravensdown has been commercially operating a variable rate equipped topdressing aircraft since 2014. Currently it has two aircraft operating commercially in the North Island. In conjunction with the Primary Growth Partnership programme “Pioneering to Precision” which is aimed at evaluating the effectiveness of remote sensing techniques for estimating soil fertility across hill country farms, Ravensdown has experienced an increasing demand for this technology from early adopting farmers.

The effectiveness of the technology in changing fertiliser rates and avoiding sensitive or non-productive zones for a superphosphate (SSP) application applied to a Wairapara farm in late 2015 is shown in Figure 1. In this case 16% of the farm area was designated non-productive and fertiliser was not targeted to these areas representing a $26,000 savings in fertiliser not applied. The non-productive area represented 291 hectares. One of the critical components for using this technology is that it requires a digital map of the farm which enables the avoidance of sensitive or non-productive zones to be programmed. The effectiveness of this depends on the availability of up to date digital imagery which accurately reflects the farm.

Figure 1: Superphosphate application using variable rate application technology applied to a Wairapara farm in late 2015.



Ravensdown has completed over 40 fertiliser applications on a commercial basis using this technology. From these applications the sensitive or non-productive zones have on average comprised 9% of the total land area of the farms. Early indicative numbers from applications involving SSP based products are that additional flying hours and hours to process digital maps to complete these applications represented less than a 5% increase in application costs.

Scenarios for econometric modelling

Nutrient budgets, using Overseer® Version 6.2.3, were developed to represent a typical North Island (NI) and South Island (SI) hill country farm. The nutrient budgets were developed from an analysis using statistically based Farmax models to ensure they accurately represented New Zealand hill country production systems. Farm size and proportion of slope classes for each scenario farm, were extrapolated from Beef and Lamb 2016 farm survey results using SI hill country, NI hard hill country and NI hill country classifications in conjunction with consultant estimation for slope class proportions. The farm production and physical characteristics are described in Table 1. In practice, blocks would be described by their predominant slope. For the SI model, a distinction between developed and undeveloped steep land was made, defining the undeveloped land as Steep/Tussock.

Soil fertility levels for each slope class were extrapolated from Ravensdown's Primary Growth Partnership (PGP) research farms where a significant number of soil tests (7,165 individual samples) have been sampled across slope classes and seasons and include up to three years of soil data per farm. These levels were termed the base model. A further scenario for each farm was modelled where the soil Olsen P levels were reduced to illustrate comparison of a VR strategy vs a B strategy at lower fertility levels (low fertility model). The soil classification and fertility characteristics of the four scenarios modelled are described in Table 2. The analysis considered P and S requirements only as the soil K levels from the PGP research farms were not below target levels and therefore did not limit production while soil pH was not considered.

Stocking rate was not reduced in the low fertility model so as not to replicate the base model analysis and also to reflect differences in natural production characteristics found between farms.

Table 1: Scenario hill country farms production and physical characteristics

	North Island scenario	**South Island scenario**
Sheep RSU/ha	5.1	3.2
Beef RSU/ha	4.2	2.2
Total RSU/ha	9.3	5.4
Effective farm area (ha) by slope classes		
Flat (0^o-7^o)	36	135
Rolling (8^o-15^o)	133	254
Easy (16^o-25^o)	158	359
Steep (>26^o)	184	148
Steep/Tussock (>26^o)		600
Total area (ha)	511	1496

Table 2: Soil fertility characteristics of the scenarios before implementing VR or B fertiliser strategies.

	North Island scenario farm			**South Island scenario farm**		
	Soil classification: Volcanic			Soil classification: Sedimentary		
		Base model Olsen P (µg/ml)	Low fertility model Olsen P (µg/ml)		Base model Olsen P (µg/ml)	Low fertility model Olsen P (µg/ml)
Flat (0°-7°)	pH: 5.8 QT K: 13 Org S: 14	24	26	pH: 5.8 QT K: 10 Org S: 11	18	25
Rolling (8°-15°)	pH: 5.7 QT K: 11 Org S: 11	19	15	pH: 5.7 QT K: 7 Org S: 10	15	13
Easy (16°-25°)	pH: 5.7 QT K: 10 Org S: 10	14	10	pH: 5.5 QT K: 7 Org S: 9	13	10
Steep (>26°)	pH: 5.6 QT K: 7 Org S: 9	13	10	pH: 5.6 QT K: 6 Org S: 7	12	10
Steep /Tussock (>26°)				pH: 5.6 QT K: 6 Org S: 7	12	7

Using the farm information from the Overseer® nutrient budgets, the four scenarios were analysed using the AgResearch PKS lime econometric model. The B strategy for the NI farm was modelled as 250 kg/ha of SSP which was deemed to be close to common practice while the B strategy for the SI farm was modelled as 200 kg/ha of SSP to reflect the lower stocking rate. The econometric model optimises the outcome in terms of kilograms of nutrients so a user defined scenario was created to approximate as closely the nutrient ratios recommended by the optimum analysis into available fertiliser products. This also meant that the VR and B strategy for the undeveloped Steep/Tussock block on the SI farm mirrored each other with triennial applications of Maxi Sulphur SSP which again reflects common practice.

The key model defaults are shown in Table 3. The sensitivity analysis to changes in gross margin was completed by calculating the gross margin weighted by stock class.

Table 3: Key model defaults for the scenarios. These were not changed between the base and low fertility model for the North and South Island farms.

	North Island scenario	**South Island scenario**
Net Present Value (NPV) discount rate (%)	4	4
Gross Margins ($/SU)		
Sheep	77	77
Beef	60	60
Weighted average	70	69
Stock value ($/SU)		
Sheep	120	120
Beef	170	170
Cost of application ($/T)		
Flats	65	65
All other slope classes	93	93
Cost of nutrients ($/kg)		
P	2.92	2.92
S	0.57	0.57

Results

Tables 4 and 5 show the Olsen P levels at year 0 before either a VR or B strategy was implemented and also the predicted Olsen P levels at year 10 for either strategy after implementation. In addition the VR strategy to obtain the Olsen P resulting at year 10 is described in terms of capital, maintenance or withholding fertiliser applications.

Where the econometric model recommended withholding P, S inputs were maintained via sulphur fortified SSP applications (which also apply a small amount of P). A maintenance P strategy maintains soil Olsen P levels while a capital P strategy looks to increase soil Olsen P levels.

In the NI scenario over a ten year period within the Base model, the VR strategy reduced soil Olsen P levels in the Flat, Rolling and Steep LMUs and only increased them on the Easy LMU. This compared to the B strategy which increased soil Olsen P levels on all LMUs with the exception of the Flat where Olsen P was maintained. In the NI Low fertility model, the VR strategy reduced soil Olsen P levels on the Flat but increased them on the Rolling, Easy and Steep LMU's. In comparison the B strategy maintained the Olsen P on the Flat to near the initial Olsen P levels while increasing them on the other LMU's but did not mirror the VR strategy in the P levels achieved.

In the SI scenario over a ten year period within the Base model, the VR strategy reduced soil Olsen P levels in the Steep and Steep/Tussock LMUs, maintained them on the Flat and Easy LMUs and only increased them slightly on the Rolling LMU. This compared to the B strategy which increased soil Olsen P levels on all LMUs with the exception of the Steep/Tussock LMU where the levels reduced. In the SI Low fertility model, the VR strategy reduced soil Olsen P levels on the Flat but increased them on the Rolling and Easy LMUs. Olsen P levels were maintained on the Steep LMU while the Steep/Tussock LMU was reduced. In comparison the B strategy increased Olsen P on the Flat, Rolling, Easy and Steep LMUs. The B strategy also reduced soil Olsen P levels on the Steep/Tussock LMU as the fertiliser policy matched that of the VR strategy.

Table 4: Olsen P levels at year 0 and year 10 from a VR or B strategy implemented on a model North Island farm. VR strategy employed described how the variable rate strategy achieved the resulting Olsen P at year 10.

	North Island Hill country scenario							
	Base model				Low fertility model			
	Yr 0	**VR Strategy employed**	**Yr 10 (VR)**	**Yr 10 (B)**	**Yr 0**	**VR Strategy employed**	**Yr 10 (VR)**	**Yr 10 (B)**
Flat	24	Withhold P	20	24	26	Withhold P	20	25
Rolling	19	Withhold P (1st year) Maintenance P 2nd year on	17	20	15	Capital P (1st year) Maintenance P 2nd year on	18	18
Easy	14	Capital P (1st year) Maintenance P 2nd year on	16	17	10	Capital P (1st year) Maintenance P 2nd year on	16	15
Steep	13	Withhold P (1st year) Maintenance P 2nd year on	12	16	10	Capital P (1st year) Maintenance P 2nd year on	13	14

Table 5: Olsen P levels at year 0 and year 10 from a VR or B strategy implemented on a model South Island farm. VR strategy employed described how the VR strategy achieved the resulting Olsen P at year 10.

	South Island Hill country scenario							
	Base model				Low fertility model			
	Yr 0	**VR Strategy employed**	**Yr 10 (VR)**	**Yr 10 (B)**	**Yr 0**	**VR Strategy employed**	**Yr 10 (VR)**	**Yr 10 (B)**
Flat	18	Maintenance P	18	21	25	Withhold P (1st & 3rd year Maxi superphosphate applied) Maintenance P 4th year on	18	26
Rolling	15	Capital P (1st year) Maintenance P2nd year on	16	18	13	Capital P (1st year) Maintenance P 2nd year on	16	17
Easy	13	Maintenance P	13	17	10	Capital P (1st year) Maintenance P	13	14
Steep	12	Withhold P by reducing Maintenance P	10	15	10	Maintenance P	10	14
Steep/ Tussock	12	Withhold P by reducing Maintenance P	7	7	7	Withhold P by reducing Maintenance P	5	5

The 10 year cumulative NPV relative to no fertiliser application of the VR and the B strategies for the two model farms at the two soil fertility levels are shown in Table 6. The calculation of NPV for the VR and B strategies assumes that only the effective areas are fertilised.

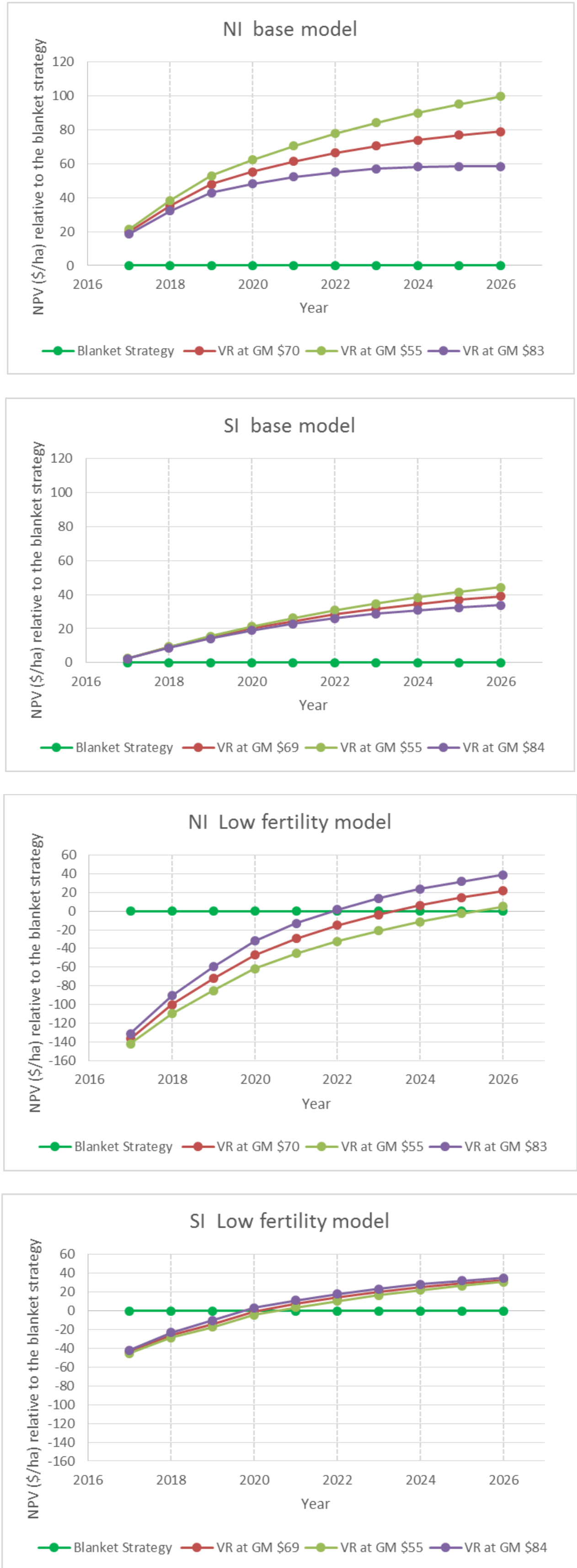
The NPV's were higher for the NI compared to SI farm for the same fertiliser strategy reflecting the higher stocking rate of the NI farm. For all scenarios the NPV at year 10 was higher for the VR strategy compared to the B strategy. In the NI scenario's the B strategy produced negative NPV's for the Flat LMU and the VR strategy achieved higher NPV's in all LMU's with the exception of the Rolling LMU. This was due to both strategies achieving the same Olsen P level in the Rolling LMU at year 10 but the VR strategy included a capital P application in the 1st year. In the SI scenario's the VR strategy achieved higher NPV's in all LMU's with the exception of the Steep/Tussock where the NPV's were the same as the fertiliser strategies employed matched each other.

Table 6: 10 year cumulative NPV ($/ha) relative to no fertiliser application of the VR and the B strategies for the two model farms.

	North Island scenario farm NPV				**South Island scenario farm NPV**			
	Base model		Low fertility model		Base model		Low fertility model	
LMU	VR	Blanket	VR	Blanket	VR	Blanket	VR	Blanket
Flat (0°-7°)	101	-26	57	-114	245	183	225	46
Rolling (8°-15°)	295	220	395	405	252	224	301	280
Easy (16°-25°)	281	257	542	541	210	140	252	231
Steep (>26°)	172	52	236	203	183	63	231	146
Steep/Tussock (>26°)					24.3	24.3	28.1	28.1
Total	**233**	**154**	**359**	**338**	**143**	**104**	**166**	**133**

Once a fertiliser strategy had been selected the sensitivity of that strategy to changes in stock gross margin (GM) was tested by adjusting the stock gross margins by 20% up or down. The 10 year cumulative NPV ($/ha) of the VR strategy is shown relative to the B strategy at each GM (Figure 2). In both the NI and SI base models the VR was positive compared to the B strategy at any GM tested from when the strategies were implemented (year 1). The SI farm was less sensitive to changes in GM due to lower stocking rate and lower total P fertiliser requirements. However where reduced fertiliser application was achieved through withholding and/or maintenance strategies as was the case for the base models the largest difference between VR and B strategies was at the lower GM where fertiliser savings had a larger effect between the two strategies. In the NI low fertility model the VR NPV was positive compared to the B strategy from year 6 onwards at the highest GM and year 9 onwards at the lowest GM's tested. The longer payback period reflects the capital applications to achieve the economic optimum soil Olsen P levels from P fertiliser applied in this scenario. In the SI low fertility model the VR was positive compared to the B strategy from year 4 onwards at the GM's tested. The shorter payback period in the SI low fertility model reflects the smaller capital applications compared to the NI low fertility model to achieve the economic optimum soil Olsen P levels from P fertiliser applied in this scenario.

Figure 2: 10 year cumulative NPV's ($/ha) of the VR strategies relative to the blanket strategy for the four scenarios at three different stock GM's.



Discussion

Identifying the productivity potential of differing LMUs, undertaking sufficient soil and herbage sampling to assess the soil characteristics and fertility across these LMUs and then fertilising them to the economic optimum that matches the assessed potential is the basis of a VR strategy. This approach has been advocated as a way to achieve more efficient use of fertiliser by many authors (Gillingham *et al.*, 1973; Lambert *et al.*, 1981; Yule and Gillingham 2002; Murray and Yule, 2007; Morton *et al.*, 2016). The analysis presented in this paper shows the robustness of the VR strategy in that it produced a higher 10 year cumulative NPV for a typical North Island and South Island hill country farm modelled at two fertility scenarios respectively in comparison to a blanket application. These results align with the findings of a modelled study of Limestone Downs by Murray and Yule (2007) where they concluded that a VR strategy where fertiliser was applied so that it was a non-limiting factor to pasture production and excluded non-responsive areas increased the cash surplus generated by 26% compared to a blanket application.

The sensitivity analysis suggests in comparison to a blanket approach the VR strategy is also more sustainable for farm profitability in the face of volatile returns with positive cumulative NPV's observed within 9 years in all the scenarios tested compared to the blanket application

An important caveat to the NPV analysis shown here in respect to the value of increased fertiliser inputs is that the AgResearch PKS lime econometric model assumes that the farm is in a position to utilise the extra feed grown. In this analysis 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 also 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 and 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.

Operationally, technological advancements with the use of differential correction to GPS guidance systems combined with automated flow control in topdressing aircraft mean that VR strategies can increasingly be used more effectively in practice (Roberts and 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 of the farms indicating potential savings from more accurately quantifying the non-productive or environmentally sensitive areas on farms. The benefit will be enhanced if it is ensured that the digital imagery accurately reflects the current effective farm areas. Early indications from some of the commercial applications Ravensdown has completed using this technology involving SSP, are that the additional flying hours and hours to process digital maps to complete these applications are in the range of less than a 5% increase in applications costs. Murray and 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%.

In practice a variable rate strategy uses both these advantages by allowing avoidance of non-productive areas and better targeting of areas which require capital fertiliser applications because fertility levels are currently low and reduced fertiliser application rates where fertility is high, all of which have a positive economic benefit, either immediately for reduced or nil application or over a longer time frame for capital application.

Conclusions.

The VR strategy produced a higher cumulative NPV for a typical North Island and South Island hill country farm modelled at two fertility scenarios respectively in comparison to a blanket application. A higher NPV corresponds to increased farm profitability.

Sensitivity analysis suggests in comparison to a blanket approach the VR strategy is also significantly more sustainable for farm profitability in the face of volatile returns with positive NPV's compared to the blanket application observed within 9 years in all the scenarios tested.

Operationally, technological advancements with the use of differential correction to GPS guidance systems combined with automated flow control in topdressing aircraft mean that avoidance of non-productive/sensitive areas and VR strategies can increasingly be put into practice more effectively.

In practice a variable rate strategy will use both these advantages by allowing avoidance of non-productive areas and better targeting of areas which require capital fertiliser applications because fertility levels are currently low and reduced fertiliser application rates where fertility is high, all of which have a positive economic benefit, either immediately for reduced or nil application or over a longer time frame for capital application.

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