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Variable and differential application of nutrients to a hill country farm

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Abstract
Traditionally fertiliser has been aerially applied at a uniform rate to hill country, but the technology now exists to apply nutrients at a variable rate (VR) and each nutrient differentially, depending on the production potential and pasture composition of each part of the hill. A hypothetical case study of a sheep farm was modelled to show the economic benefits of VR application of phosphorus (P) and sulphur (S) and differential application of nitrogen (N), compared with application of a uniform rate of P and S. The financial analysis demonstrates that the VR strategy of less P and S to steeper slopes where there is low legume and more on easier slopes where there is more legume, costs less than the application of P and S at a uniform rate over all slopes. The cost saving could be used to apply N to steep land on both sunny and shady aspects and easy land on sunny aspects. This differential N application in late winter/early spring ensures better pasture cover for lactating ewes to improve ewe condition at weaning. When this gain in condition was maintained through to mating, lambing percentage increased in the following spring. The benefit from this increased lamb production was an increase in financial returns of $63/ha/year. A qualitative sensitivity analysis indicated that this value remains stable in response to changes in the proportion of each slope class, soil Olsen P level, the relative cost of fertiliser P and N and sheep to cattle ratio.

Keywords: differential application, hill country, lamb production, nitrogen, phosphorus, aerial topdressing, variable rate

Terminology
Variable rate (VR) fertiliser application occurs when the same nutrients, normally P and S, are flown onto an area at different rates according to the production potential and stocking rate of each slope class. The slope ranges of the area were identified using a Digital Elevation Map, and quadrats (normally representing not less than 0.5 ha) are allocated one slope class in a prescription map, if they have the largest proportion of the area within that class (Morton *et al*. 2016).

Differential nutrient application occurs when one fertiliser nutrient, usually N, is applied to certain parts of the farm, usually steep slopes or sunny aspects where the pasture production response is greatest (Gillingham *et al*. 1998).

Introduction
Fertiliser is a discretionary cost in a sheep and beef farm budget and is frequently reduced in years where income is limited by poor returns or adverse climatic events. With the prospect of no consistent inflation-adjusted increase in meat and wool prices, the only way of ensuring that adequate fertiliser is applied is to improve the efficiency of nutrient use. While fertiliser has been traditionally spread at a uniform rate, the aircraft technology now exists to apply nutrients both at a variable rate and differentially to different parts of a hill country farm, depending on production potential and pasture composition (Murray & Yule 2007; Morton *et al*. 2016; White *et al*. 2017).

Nearly all hill country requires P and S to sustain legume and pasture growth. A uniform application rate of P and S results in a mis-match between the variable requirement of the pasture, depending on production potential that determines stocking rate, and the uniform rates traditionally applied in fertiliser (Gillingham *et al*. 1998). Variable rate application allows fertiliser P and S rates to be adjusted, usually on the basis of slope, which is the main determinant of pasture production (Lambert *et al*. 1983); flatter areas with better legume growth receiving more than steeper areas with poorer legume growth.

Several trials have shown a high efficiency of response in pasture production to fertiliser N in hill country, especially on steeper slopes with less soil N (Morton *et al*. 2016).

This paper investigates the economic benefits of VR and differential nutrient application, by applying them optimally to a case study hill sheep farm in a modelling exercise.

Methodology
The case study farm had a total area of 600 ha - 200 ha of flat within the hill landscape, 200 ha of easy hill (12-25 degree slope) comprising 100 ha each of sunny (north and west aspects) and shady (south and east aspects), and 200 ha of steep hill (>26 degrees slope) comprising 100 ha each of sunny and shady aspect, all on sedimentary soils with adequate soil potassium.

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Average rainfall was 1000 mm/year with a lack of soil moisture during summer, typical of a North Island dry hill country farm. For simplicity, the farm carried all sheep, but the inclusion of cattle was considered in the qualitative sensitivity analysis. It was also assumed for simplicity, that most of the non-productive areas on the farm were being avoided by the uniform application fertiliser programme, so there is no cost saving from the ability of VR application to more accurately achieve this objective.

The approximate 3:2:1 ratio in relative stocking rate between land classes in Table 1, was assumed from different studies of pasture productivity on contrasting slopes (Morton *et al*. 2016). Soil Olsen P levels for each land class were within (flat and easy) or above (steep) the economic optimal ranges as modelled by the AgResearch PKS Lime model. The average annual pasture composition was based on a long-term hill country grazing trial at Ballantrae (Lambert *et al.* 1986).

A qualitative sensitivity analysis for other farm scenarios (Table 4) was mainly based on knowledge gained from earlier research on the responses in pasture production from P and N in relation to slope, aspect and soil Olsen P level (e.g. Gillingham *et al*. 1998, 2003, 2017).

Fertiliser programme

Uniform application

Uniform application was the annual routine programme of maintenance application in spring to supply 18 kg P and 22 kg S/ha over the whole farm.

VR and differential nutrient application

With this programme, the maintenance P and S applications have been chosen on the basis of the pasture growth required to support the different stocking rates (Table 1) on each slope and aspect type. This meant the 200 ha of land that was predominantly flat within the hill country landscape received 18 kg P and 22 kg S/ha; the 100 ha of predominantly shady easy land received 15 kg P and 18 kg S/ha/year; the 100 ha of predominantly sunny easy land received 30 kg N, 12 kg P and 20 kg S/ha; the 100 ha of predominantly shady steep land received 30 kg N/ha applied one year and 30 kg N, 12 kg P and 20 kg S/ha in the second year, providing an annual rate of 6 kg P and 7 kg S/ha; the 100 ha of predominantly sunny steep land received 30 kg N/ha, 2 years out of three, and in the third year had 30 kg N, 12 kg P and 15 kg S/ha applied. As for the shady steep land, this sustains the low legume content (Table 1).

If ground conditions do not allow application of N at the optimal time of late winter/early spring and there was a serious feed deficit in early spring, then a more expensive helicopter operation could be carried out for N, and the P and S applied later.

Comparative experimental data

The Waipawa Research Area provided data (Table 2) as it represents a similar scenario to the case study farm.

Morton *et al*. (2016) deduced from a review of the literature on N responses in hill country, that the efficiency of N use for slopes of 15-35º was 26 kg DM/kg N. Under higher annual mean rainfall of 1426 mm at Whatawhata Research Station, Gillingham (2017) also measured a higher efficiency of P use on easy (595 kg DM/kg P) compared with steep (337 kg DM/kg P) slopes receiving 20 kg P/ha/year. At Ballantrae Research Station, with a slightly lower annual rainfall (1276 mm) Lambert *et al*. (1983) measured efficiencies of P use of 408, 296 and 217 kg DM/kg P for flat, easy and steep land, respectively, receiving an average of 29 kg P/ha/year.

Financial analysis

Fertiliser costs

In Table 3, the cost of ground applied fertilisers averaged over land classes is presented. It was assumed that transport of fertiliser to the farm was $30/tonne, uniform aerial application costs $70/tonne and variable rate application $85/tonne.

Table 1 Stocking rate (SU/ha), soil Olsen P (μg/ml) and percentage of total pasture composition for each land class.

Land class (slope/aspect)	Stocking rate	Soil Olsen P	Percentage of total pasture composition		
			High fertility demanding grasses e.g. ryegrass, cocksfoot	Low fertility demanding grasses e.g. browntop, sweet vernal, crested dogstail	Legumes e.g. white and subterranean clover
Flat	16	20 - 25	45	45	10
Shady easy	12	15 - 20	23	70	7
Sunny easy	10	15 - 20	17	76	7
Shady steep	6	10 - 15	10	85	5
Sunny steep	5	10 - 15	5	90	5

The total applied fertiliser costs are similar for uniform versus variable rate and differential application (Table 3). The VR programme applied less P and S which makes finance available to include N which is approximately half the cost per kg of P.

Financial returns

Because the VR programme closely matches specific pasture species requirements for P and S (legumes>ryegrass>browntop) and stocking rate of each land class, it should achieve similar pasture production to that arising from the application of a uniform fertiliser rate considered appropriate for the average stocking rate. The production advantage from the VR and differential application was the extra feed generated from the N fertiliser. The calculations used are as follows:

Extra feed generated from N = 300 ha x 30 kg N/ha x 29 kg DM/kg N (proportionate response from Table 3) = 261 000 kg DM; at 70% pasture utilisation this represents 183 000 kg available DM/year; which for the 6000 SU on this farm translates into another 31 kg DM/SU consumed.

If 1 kg of liveweight gain requires 5 kg DM consumed, each ewe would be expected to be about 6 kg heavier at weaning and mating, resulting in an increase in lambing percentage of 8% (or 7% at sale allowing for losses of 15%) (Geenty 1997); for 6000 SU this represents an

Table 2 Referenced responses in nutrient use efficiency from grazing trials at Waipawa Research Area and lamb liveweights and gross margins per hectare from a simulation study.

Parameter	Comparison		Result		Reference
Efficiency of P use	Easy slope	Steep slope	Easy - 128 kg DM/kg P	Steep - 66 kg DM/kg P	Gillingham *et al.* 1998
Efficiency of N use	Easy sunny slope	Steep sunny and shady slope	Easy - 17 kg DM/kg N	Steep - 35 kg DM/kg N	Gillingham *et al.* 2003
Lamb liveweight	No N	30 kg N/ha with same ewe stocking rate	No N - 139 kg/ha	N - 207 kg/ha	Gillingham *et al.* 2003
Gross margin	No N	30 kg N/ha with same stocking rate	No N -$557/ha	N - $642/ha	Gillingham *et al.* 2003

Table 3 Applied fertiliser costs for each land class.

Land class	Fertiliser	Fertiliser cost ($)	Transport cost ($)	Application cost ($)	Total cost ($)
Uniform application					
Whole farm (600 ha)	Superphosphate (0-9-0-11) - 120 t	40200	3600	8400	52200
VR and differential application					
Flat (200 ha)	Superphosphate (0-9-0-11) - 40 t	13400	1200	3400	18000
Shady easy (100 ha)	Superphosphate (0-9-0-11) - 20 t	6700	600	1700	9000
Sunny easy (100 ha)	Cropmaster 20* (19-10-0-13) - 15 t	10500	450	1275	12225
Shady steep (100 ha)	Urea (46-0-0-0) for one year - 6.5 t	3250	195	553	4000
	Cropmaster 20 (19-10-0-13) for other year - 15 t	10500	450	1275	1222
	Average per year				8110
Sunny steep (100 ha)	Urea (46-0-0-0) for two years – 13 t	6500	390	1105	7995
	Cropmaster 20 (19-10-0-13) for the third year – 15 t	10500	450	1275	12225
	Average per year	6300	280	793	6740
Total cost for VR and differential application					54075

* The approximate equivalent fertiliser supplied by Ballance is Pasture Zeal G2 Impact (12-6-0-7), priced at $430/tonne.

extra 420 lambs, at say $90/lamb, equivalent to $38 000 or $63/ha/year.

Although the value is not a true gross margin as the costs associated with rearing and finishing the extra lambs have not been included, it is still lower than the increase in gross margin from N use included in Table 2 (Gillingham *et al*. 2003). However, these authors assumed a much larger increase in lambing percentage (from 120 to 165%), resulting in an increase of 68 kg/ha of lamb liveweight (Table 2), than occurred in this analysis.

Other uses of extra finance

If there was no desire or need to apply N, then the savings in P and S application from VR compared with uniform application (about $10 000/year) could be used to apply P to areas of the farm with soil Olsen P levels below the economic optimum or for lime application.

Qualitative sensitivity analysis

The main variables that potentially affect the financial benefit from this VR and differential nutrient strategy compared with uniform application are the proportion of farm in each slope class, soil Olsen P levels, the comparative cost of P and N and the sheep to cattle ratio (Table 4).

The analysis shows that changes in the major variables affecting financial performance have a neutral to positive effect. Murray & Yule (2007) also reported that the cash surplus/ha was inelastic to increasing application costs from VR.

The case study farm example outlined in this paper is only one of a multitude of farm scenarios that could be tested. Murray & Yule (2007) calculated that the cash surplus increased from $386 to $487/ha when changing from a blanket application of superphosphate to VR for a hill country farm case study. Morton *et al* (2016) estimated a greater net margin from VR than uniform application at lower rather than higher soil Olsen P levels from a single year of analysis. White & Roberts (2107) used the AgResearch PKS Lime model for 10 years and found a significant increase in Net Present Value to VR compared with uniform application, on farms with optimal soil Olsen P levels.

Conclusions

The current policy of uniform fertiliser application to hill country sheep and beef farms is inefficient as it applies more P and S than is required to sunny and steep areas, where lack of moisture limits legume and pasture growth. Variable rate application technology allows P and S to be applied at closer to the required rates for hill areas depending on legume content and stocking rate. Less P and S to steeper land that lack legumes allows cheaper differential N to be substituted, resulting in large economic pasture production responses to N. This extra feed can be used to increase ewe weaning liveweights that can be maintained through to mating with improved ovulation rates increasing the number of lambs sold in the following year. Alternatively, the savings from VR, compared with uniform application of P and S, can be used for targeted P or lime applications. For this case study farm, the costs of the uniform compared with the VR and differential nutrient applications were similar, so the extra $63/ha/year gained from the differential N application represents profit.

Table 4 Qualitative sensitivity analysis for changes in variables affecting financial benefit from VR and differential nutrient application.

Change in variable	Effect on financial benefit	Explanation
Increasing proportion of flat land and decreasing proportion of steeper land or vice versa	A small effect	Although cost of VR will increase because more expensive P is required, stocking rate and production will also increase, offsetting the cost. Where there is steeper land, fertiliser costs will be lower but also will production
Lower than economic optimum Olsen P levels	Lower benefit in the short-term because of capital P required, but higher in longer term as benefits accrue	Initial cost of capital P will be regained and profitability increased over time from more pasture production
Higher than economic optimum Olsen P levels	Greater benefit overall	P rates can be reduced over all the farm resulting in saving in fertiliser costs
Change in cost of fertiliser P relative to N	Unlikely to be a factor	Pricing history shows that cost of N and P changes in a largely similar pattern
Inclusion of cattle	Small effect	Cattle performance will also benefit from greater pasture growth during spring

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