From there to where? Past, present and future soil fertility management on hill country farms

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Abstract
This review paper discusses aspects of hill country science-based soil fertility management advice given to farmers in the past on the use of fertiliser, principally superphosphate, on hill country farms. This shows that both pasture quantity and quality are improved with the application of the nutrients phosphorus (P) and sulphur (S) in superphosphate and that an unseen benefit of this is the increased food supply to soil biological organisms which also flourish under this management. The large potential for nitrogen (N) fertiliser application is explored and demonstrated. New thinking and technologies are allowing farmers to differentially apply variable rates and types of fertiliser nutrients by air to better match the growth potentials of contrasting hill country zones and so ensure that the investment in fertiliser will give the best financial returns possible.

Keywords: soil fertility, hill country, differential application, variable rate

Key messages
- There is a wealth of scientific evidence showing that fertiliser nutrients and lime, where required, increase pasture production and quality in hill country.
- The production of greater quantities of quality pasture through good fertiliser practice, when grazed *in situ* by livestock, enhances the number and activity of beneficial soil organisms.
- New technologies being developed will allow targeting of the right amounts of nutrients and lime to optimise the potential productivity of different land management units within the farm, to maximise the benefit of the investment in soil fertility management on hill country farms.

Soils of the hill country
Hill country is an all-encompassing term which describes large areas of New Zealand where sheep, cattle and deer farming are a major land use. Much of the hill country is dominated by sedimentary soils, with brown soils (Hewitt 1998) on hill country in both North and South Islands and terraces in Southland, which are generally well drained under moderate rainfall. In contrast, pallic soils (Hewitt 1998) are either poorly drained on terraces or rolling lands under moderate rainfall (Manawatu, South Otago), or are free draining soils on terraces or rolling lands under low rainfall (Hawkes Bay, Wairarapa, Marlborough, Canterbury). Northland, Waikato and Taranaki hill country soils are volcanic in origin overlying sedimentary rock and are predominantly allophanic (Hewitt 1998). Pumice soils (Hewitt 1998), derived from rhyolitic volcanic material, are common on the Central Plateau. Each of these areas have a combination of climate, topography and soils which present different challenges and opportunities. The special challenges of hill country are slope and aspect dominated pasture productivity levels, with production declining as slope increases (mainly due to moisture limitations) while nutrient transfer and runoff losses (of both nutrient and sediment) increase.

Soil fertility principles
Legumes are an extremely important component in New Zealand pastoral systems. Legumes supply N via bacteria in nodules on their roots that can 'fix' nitrogen from the atmosphere into a form used by the legume. Nitrogen is the nutrient required in greatest quantities in pastoral systems, and the size of the soil N pool drives pasture composition and production and provides high quality forage for animal production. Grazing animals eat the pasture and return a high proportion of fixed N to the soil in dung and urine. Nitrogen also returns to the soil through death and decay of plant material. The N returned to the soil in this way adds to the plant-available N pool, and becomes available to the grasses in the pasture through the action of micro-organisms in the soil (Morton & Roberts 2009).

Farmers using grass/legume pastures as a principal feed source for livestock must ensure that they have created soil conditions to achieve the level of pasture productivity and quality appropriate to their physical land resources and farm business. Phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg), some trace elements and lime are essential for good pasture growth and N fixation. In the virgin state, many New Zealand soils, are inherently deficient in P, S and to a lesser extent K and some trace elements, for growing grass/legume based pastures. Large inputs of fertiliser (and often lime) and the recycling of nutrients through the grazing animal over many years, are required to build up soil nutrient reserves

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and soil organic matter content. Grasses require the same nutrients as legumes but are more competitive in nutrient uptake and therefore grow better than legumes in soils with lower nutrient levels.

As soil nutrient status increases, pasture production rapidly increases, and this is often referred to as the development phase. In the development phase, capital (large) applications of fertiliser will be required for one or more years. However, as soil fertility improves in hill country, pastures develop and composition improves, and soil moisture availability often becomes the limiting factor to pasture production, composition and quality. This is most evident on steeper north facing hill slopes where legume content is low because of regular dry summers.

Eventually, further increases in soil nutrient levels will result in only very small increases in pasture production. At this stage, the optimum soil nutrient status has been achieved and the soil has reached the maintenance phase, when fertiliser is required simply to replace the yearly losses of nutrients from the productive areas of the farm. These losses are in animal products leaving the farm and in animal transfer losses (i.e., dung and urine deposited in yards and sheds, laneways, gateways, tracks and camp sites). Soils on moderate and steep slopes also incur higher nutrient transfer losses than on flat areas and these should be compensated for in additional fertiliser application. In addition, there are runoff losses (Gillingham & Thorrold 2000) and the inevitable losses that occur in soils through leaching from the root zone and immobilisation (Morton & Roberts 2009).

Fertiliser improves sheep and beef pasture production

There have been a large number of historical fertiliser trials on pasture all over New Zealand showing the benefit to pasture production and quality of the addition of P, K, S and lime, which have been used to establish optimum soil fertility levels and rates of nutrient addition required to achieve these levels (Edmeades *et al*. 1985; Morton & Roberts 2009). However, many of these trials were not on hill country and/or were conducted over short periods of 3-6 years. The most compelling information on the beneficial effects of the long-term addition of P and S fertiliser to increase and sustain pasture production and quality, come from two sheep and beef grazed pastoral farmlet trials based at the summer moist Ballantrae Hill Country Research Station near Woodville and Winchmore Research Station in mid Canterbury. While the Winchmore site is not hill country and is irrigated, the long term (60+ years) effects of P and S application on pasture productivity and composition demonstrate the principles of sustainable fertiliser use. In terms of 'soil health' and biological ecosystem services this information is critical to farmer understanding that fertiliser is not 'bad'. The information is also relevant for South Island rain-fed sheep and beef farms on sedimentary soils, and many of these farms have productive flats as well as rolling to steep hill and high country.

Ballantrae results do not report the pasture production where no fertiliser was applied but clearly show the advantage of lifting soil P and S fertility by applying single superphosphate (SSP) (Table 1). The farmlet with the higher rate of application (375 kg SSP/ha/yr) grew 38% more pasture ($P<0.001$) than the lower application rate of 125 kg SSP/ha/yr (Lambert *et al.* 2014) over the first 13 years of the trial. Similarly, the fertilised and irrigated farmlets at Winchmore grew significantly more pasture ($P<0.001$) than the nil fertiliser farmlet (Table 1). The lower rate of superphosphate grew 117% more pasture than the unfertilised farmlet and 137% more at the higher rate of superphosphate (Smith *et al.* 2012). In general, the application of SSP fertiliser resulted in a change in botanical composition to clover and ryegrass pastures (Smith *et al.* 2012; A. D. Mackay pers. comm.). A 4 year trial at Whatawhata Hill Country Research Station, in Waikato, demonstrated similar effects of SSP fertiliser on production and quality (Gillingham *et al.* 1989; Gillingham 2016).

Lest we forget

Three trials conducted on pastures growing on sedimentary soils typical of much of the hill country in the North Island highlight what happens when SSP is withheld from hill country pastures. Olsen P levels were typically in the 10-15 range with an annual fertiliser history of between 200 and 300 kg superphosphate/ha/yr.

At the Te Kuiti Research Area, despite moderate soil Olsen P levels, pasture and animal production decreases were evident by the second year of withholding SSP (i.e., both P and S). By years 3 and 4, ewe and lamb liveweight and fleece weight had fallen by 20-30%, Olsen P fell from 14 to 9, white clover content decreased with more moss and weeds evident after 6 years of withholding SSP (O'Connor *et al.* 1989).

Table 1 Annual pasture production (kg DM/ha) from long-term grazed farmlets with different annual SSP application rates (kg/ha).

Ballantrae (1975 – 1988)[1]			Winchmore (1952-2011)[2]		
Rate	Production	LSD 5%	Rate	Production	SED
125	8850		0	5017	
375	12190	1105	88	10918	
			376	11888	774

[1]Extracted from Lambert et al. (2014);
[2]Extracted from Smith et al. (2012)

At Whatawhata Hill Country Research Centre, where superphosphate was withheld from grazed farmlets previously treated with 200-300 kg/ha/yr, pasture production fell between 4 and 11% in the first 2 years, pasture quality declined (more moss and dead matter) and animal grazing days declined by around 11 and 14% in years 1 and 2 of withholding (Gillingham *et al.* 1989).

At Ballantrae Hill Country Research Station, where 375 kg/ha SSP annually had been previously applied for some years, soil Olsen P fell from 11 to 5 (after 7 years of withholding) and pasture production declined by nearly 5% every year. Ewe and lamb wool and liveweights also decreased over the withholding period (Lambert *et al.* 1989).

Combining the data from these three trials to examine the predicted economic impact of withholding superphosphate, showed that where 200-375 kg/ha/yr had been previously applied, continued application gave a positive financial benefit after 4 to 6 years (compared to stopping fertiliser and saving money in the current year) (Clark *et al.* 1989). The authors concluded that "fertiliser cessation was a sound strategy to survive periods of low product price:fertiliser cost ratios" but did add the rider that "it will decrease sustainable productivity and affect farm resale value" (Clark *et al.* 1989).

The basis for current soil fertility recommendations

About 1800 field trials have been conducted in New Zealand measuring the effect of fertiliser P, K and S application on pasture production, and analysis of these led to industry recommendations for fertiliser use on sheep and beef farms (Morton & Roberts 2009). Subsets of results from these trials have been used more recently to refine relationships between relative pasture production and soil Olsen P levels (Edmeades *et al.* 2006) and Quicktest K (Edmeades *et al*. 2010).

Around 60% of sedimentary hill country soils in the Wairarapa and Whanganui were identified as being below pH 5.4-5.6 in 1979-1980 (Gillingham *et al.* 1984) and in the eastern Taranaki hill country 30% of farms surveyed in 1983/1984 were below pH 5.6 (Roberts 1985). Given the high cost of carting and aerially spreading tonnes of lime onto hill country, the situation has changed little to the present. Pasture responses to lime application are related to the initial soil pH (Edmeades *et al*. 1984), with yield responses decreasing the closer the soil pH is to the biological optimum (Table 2). Lime responses have been shown to be seasonal (Shannon *et al.* 1984) with the largest relative pasture yield increases occurring in summer and/or autumn. Pasture responses to lime application, through the resultant increase in soil pH, are mainly due to one or more of the following three mechanisms:

1) Reduction in aluminium (Al) toxicity affecting grass and clover performance. Extractable Al levels over the threshold level of 3-5 ppm usually only occur below pH 5.5 (Jackson & Edmeades 1984) and liming soil to increase soil pH is an effective way of reducing the effects of Al toxicity.
2) Increase in plant available molybdenum (Mo) leading to better legume growth and N fixation. Field trials investigating the relationship between liming and availability of soil Mo (During 1972) demonstrated that many soils were Mo deficient and that small applications of Mo could greatly reduce the need for lime on many soils. These two mechanisms occur because raising soil pH on most New Zealand variable charge soils increases the net negative charge on soil colloids (McLaren & Cameron 1996) and so positively charged ions such as Al are bound more tightly to the colloids, while negatively charged ions like Mo are less well bound, and hence become more plant available provided total soil Mo levels are not too low (McLaren & Cameron 1996). Excessive levels of Mo in pasture can affect stock health. High Mo intakes by stock, coupled with adequate sulphur levels complex dietary copper (Cu) reducing its absorption by the animal and hence inducing secondary Cu deficiency (McLaren & Cameron 1996). Too frequent applications of Mo or lime can cause this dietary Mo-Cu imbalance.
3) An increase in soil N through organic matter mineralisation by increased soil biota and microbiological activity (e.g., bacteria and earthworms), and improvement in soil structure (e.g., earthworms) (Jackson & Edmeades 1984).

Table 2 Target soil test ranges for volcanic ash, pumice and sedimentary soils (Morton & Roberts 2009).

	pH	Olsen P	QTK[1]	Sulphate-S	QTMg
Ash	5.8-6.0	20-30	7-10	10-12	8-10
Pumice	5.8-6.0	35-45	7-10	10-12	8-10
Sedimentary	5.8-6.0	20-30	5-8	10-12	8-10

[1]QT is an abbreviation for Quicktest

Getting the best return from your fertiliser and/or lime investment

The soil test targets (Table 2) for near maximum pasture production (usually taken as 97% maximum production) are based on biological responses. The economic optimum soil test levels will differ considerably from these depending on the relativity between cost of applied fertiliser and/or lime and returns from animal products sold. To determine the economically optimal pH, P, K and S soil test targets and the lime and nutrient requirements to achieve these, a decision support model variously called Outlook, AgResearch PKSLime model and the Econometric model (Metherell *et al.* 1996; Metherell 1997; Metherell *et al.* 1997) has been developed based on the understanding of nutrient cycling on pastoral farms, and including pasture responses to lime application (Edmeades *et al.* 1985). The Econometric decision support model takes into account physical factors of the farm, animal classes, stocking rates and cost of applied nutrients and once set up for the property may be used to look at a range of scenarios from no fertiliser, through to maintenance or optimum strategies for the nutrients P, K and S as well as capital lime strategies. The net present value (NPV) of the resulting scenarios may be compared to assist farmers make investment decisions around their fertiliser programme.

Does nitrogen fertiliser have a place on hill country pastures?

Even if soil P and S fertility and pH were maximised on hill country properties and there were large pools of soil nutrients cycling around the farm, pastures would still respond to a greater or lesser extent to N fertiliser application. Often the steeper northerly aspects on hill country farms are characterised by shallower soils with low moisture holding capacity and as such do not support legume survival over dry summers. As a result the pastures are severely N deficient and respond well to low rates of N fertiliser after they wet-up in winter (Gillingham *et al.* 2007; 2008a). Summer moist hill country pastures, usually with higher legume content, still respond to the use of N fertiliser as was ably demonstrated in a trial at Ballantrae (Lambert *et al.* 2003). Applying 400 kg N/ha in total (8 applications of 50 kg N/ha) increased annual pasture production from 9.2 tonnes DM/ha to 17.1 tonnes DM/ha averaged across low, medium and high fertility blocks over 2 years of measurement. Significant responses to N fertiliser occurred in all 4 seasons of each year, with highest responses recorded in spring and summer (Lambert *et al.* 2003). The response was similar across the fertility blocks ranging from 7.4 and 7.3 tonnes/ha for the medium and high fertility blocks and 8.9 tonnes DM/ha for the low fertility block with response efficiencies ranging from 18.2 to 22.3 kg DM/kg N applied (Lambert *et al.* 2003). Various other authors have previously reported a large range of N responses on sheep-grazed and/or hill country pastures e.g., 14 to 31 kg DM/kg N (Ball *et al.* 1976), 24 to 43 kg DM/kg N (Gillingham *et al.* 1998), 7 to 55 kg DM/kg N (Lambert *et al*. 2012), 13 and 21kg DM/kg N (Ledgard *et al.* 1983), and 10 to 25 kg DM/kg N (Luscombe 1979).

An experiment to test how strategic N fertiliser applications could assist pasture and animal performance on a hill country sheep and beef farm was conducted at Limestone Downs, Port Waikato. Inadequate pasture growth from September to November has been a major constraint on animal production at Limestone Downs. In an attempt to reduce underfeeding, ewe wastage, the need to sell more lambs as prime rather than store, and purchasing weaner bull calves in autumn instead of both autumn and spring, an area of 500ha (out of 2500ha effective) was identified for N fertiliser application. Urea was applied by air in two applications per year (late autumn and late winter) at total annual rates of 250 kg N/ha for the first year and 200 kg N/ha for each of the other 2 years (2004-2006). Over the 3 years of the experiment the average pasture response to N fertiliser was 3340 kg DM/ha, with a 15.2 kg DM/kg N response efficiency (Table 3). The average cost of the extra pasture was 9c/kg DM.

The low average N response is partly attributable to a low response on north-facing areas with moderate or steep slopes. While the south-facing and flatter north-facing areas showed N responses of 18.3 and 27.7 kg DM/kg N, averaged over 3 years, the moderately sloping and steep north-facing plots had responses of only 2.9 and 11.3 kg DM/kg N, respectively (Puha *et al.* 2008). Presumably, this was because of low soil moisture availability (O'Connor & Cumberland 1973) and resultant poor species composition (Sheath & MacFarlane 1990). In contrast, responses over 3 years obtained by Gillingham *et al.*(1998) in a summer dry, Hawkes Bay environment showed N provided greater responses on north-facing slopes and P gave better responses on south-facing slopes.

There was a planned strategy and considerable change in the farm system to utilise the expected extra pasture grown with multiple lamb bearing ewes mated to terminal sires set stocked on the treated area and a 'put and take' cattle grazing policy to control surplus pasture.

Over the 3 years of the N strategy, the use of cool season N enabled an increased stocking rate and much better pasture cover control, especially of the summer/autumn surplus, with undoubted improvements in pasture quality because of this. In the first year of the

Table 3 Pasture production response (kg DM/ha) to N fertiliser application and N response efficiencies (kg DM/kg N) at Limestone Downs Station (from Puha *et al.* 2008).

Treatment	Years			
	2004/2005	2005/2006	2006/2007	Average
No N	6660	7630	7880	7390
N	11380	10280	10540	10730
Response	4720	2650	2660	3340
Response Efficiency	18.9	13.3	13.3	15.2

trial, the immediate net financial returns were estimated to be around $120 000 i.e., $240/ha. In the second and third years fertiliser N prices rose and lamb returns fell such that by year 3 the net return was around $60 000 i.e., $120/ha (Kevin Lowe pers. comm.).

The national Wise Use of N project investigating N use on 16 commercial hill country farms showed an estimated net economic benefit ranging from -$322 to +$221/ha with an average of +$35/ha, with N applications of less than 100kg N/ha being most profitable (Lambert *et al.* 2012). Factors influencing profitability included the cost of extra feed generated, the timing that feed was produced, the percentage of extra feed harvested and the efficiency of the feed converted into saleable product (Lambert *et al.* 2012). The variability in the economic benefit underlines the importance of ensuring that any N fertiliser strategy is carefully designed to meet specific feed demand for productive animal classes.

In summer dry hill country, a series of trials was established and conducted over 2 years on seven farms down the east coast of the North and South Islands, to evaluate pasture responses to N fertiliser at a range of soil P fertility levels. Responses on easy slopes ranged from 3.7- 14.4 kg DM/kg N (Gillingham *et al.* 2007; 2008) and on steep slopes 8.2-17.9 kg DM/kg N (Gillingham *et al.* 2008a) to applications of 90 kg N/ha, with greater response efficiency obtained from lower N rates on easy slopes. The authors concluded that the higher the proportion of grass in the pasture the better the N response. Furthermore, they suggested that on steep hill country, particularly north facing slopes, which have little legume due to regular seasonal dryness, greater pasture responses will be obtained using N rather than P fertiliser, although a moderate soil P and S would be required to support grass responses (Gillingham *et al.* 2008a). These findings lead into the opportunity for application of differing nutrients to different land management units on hill country farms.

Chemical fertilisers – death to soil life?

There are many commentators in the agricultural arena who claim that 'chemical' fertilisers are anathema to soil biology and these claims have spawned a plethora of products which either contain living microorganisms or substances which are claimed to elicit a positive response in the numbers and activities of beneficial microorganisms. It is well known that soil organisms drive nutrient transformations in soils and make a major contribution to soil fertility (Fraser *et al.* 1994). Soil systems which have the highest organic matter input also have the greatest microbial biomass and activity (Sparling 1985).

Soil biological responses have been measured at both Ballantrae (Schon *et al.* 2008) and Winchmore (Haynes *et al.* 1995). At Ballantrae, earthworm numbers have increased more than 7-fold where the lower rate of SSP was applied and more than 11-fold at the higher rate, between 1979 and 2006 (Table 4). At Winchmore, after 38 years of annual application of different rates of fertiliser, earthworm numbers increased 42% at the low rate and 62% at the higher fertiliser rate compared to the Control (no fertiliser) farmlet (Table 4). The increase in earthworm numbers between the Control and fertiliser treatments was significant ($P<0.05$) but not between the two fertiliser rates (Haynes *et al.* 1995).

Additionally, at Winchmore, microbial biomass carbon (C) was also measured after 38 years of annual fertiliser applications. In the surface soil (0-5 cm) microbial biomass C increased ($P<0.05$) from 673 mg/kg soil on the Control farmlet to 775 mg/kg soil on the fertilised farmlets, with no measurable difference between the two rates of fertiliser (Haynes *et al.* 1995).

So how does fertiliser application benefit soil biology? As demonstrated, fertiliser increases pasture production. This pasture is grazed by farm animals who, by depositing a considerable amount of plant derived excreta back onto the soil, coupled with root turnover and death and decay of uneaten herbage all adds organic matter to the soil in a greater quantity than where no fertiliser is used. Increased organic matter inputs to the soil system means more substrate (food) for earthworms and soil microorganisms (Lee 1985; Sparling 1985), hence their numbers and activity increases.

Getting smarter – using the fertiliser investment more wisely?

Until recently, hill country fertiliser additions, driven by research and practice have mostly been single rate aerial applications of a single product. Flatter areas in hill country properties which are generally more productive and often cropped may well have better soil fertility through higher applications of fertiliser where they are accessible by ground-spread equipment.

Given that hill country farms have a variable range of slope, aspect, soil types, soil depths, moisture status, grazing management and pasture composition, this

Table 4 Earthworm numbers (No./m^2) from long-term grazed farmlets with different superphosphate application rates (kg/ha).

Ballantrae			Winchmore (after 38 years)	
Rate	1979	2006	Rate	
125	75	557	0	520
375	93	1068	188	740
			376	840

variability will lead to variable pasture production and quality which then impacts animal performance and hence capital and maintenance nutrient requirements. In the past the whole farm has been treated equally with respect to fertiliser and lime application. The potential for a variable rate, precision agriculture approach to hill country fertiliser application was earlier proposed by Yule & Gillingham (2002).

Some hill country farms have been broken up into different land management units (LMUs) based on a qualitative assessment by farm staff of potential pasture production. Based on this assessment the Econometric model, discussed earlier, may then be used to set target soil pH and soil test levels for each LMU based on stocking rate differences (Table 5).

Once identified, more intensive soil and herbage sampling is undertaken to assess soil fertility and requirement for nutrients for the each class of land (LMU) so that the appropriate rates (capital and/or maintenance) of lime and superphosphate can be recommended. This analysis and the subsequent recommendations often result in a reallocation of fertiliser and lime expenditure across the farm where in some cases cost savings are possible or greater productivity is achieved by applying nutrients and lime where they will have the best effect.

The application of variable rates of fertiliser and/or lime across a hill country farm may seem to be a difficult operation to achieve with any accuracy, however, technology development has allowed this to become practically possible. A variable rate control system for use in aerial topdressing planes was first developed by the New Zealand Centre for Precision Agriculture, Massey University and Whanganui Aeroworks (now Ravensdown Aeroworks) (Murray & Yule 2007) and commercially available systems have improved in terms of computer processing power and speeds. The uptake of variable rate application technology (VRAT) will depend on the economic benefit to hill country farmers in terms of either increased returns from the fertiliser investment, savings through increased fertiliser use efficiency or both, relative to the costs associated with aerial operators.

A modelling study (Murray & Yule 2007; 2007a; Murray *et al.* 2007) has been undertaken to demonstrate the potential benefits of VRAT. Limestone Downs, a 2 500 ha hill country sheep and beef farm on the West Coast south of Port Waikato, was used for the study. Three scenarios were chosen for comparison: a) Blanket application to the whole farm based on the fertiliser policy current at the time of the study; b) Simple VRAT which used the same rate as the blanket application except that areas which were deemed unresponsive (i.e., steep slopes, rocky outcrops, wide creeks, scrub and camp sites) were excluded saving fertiliser, and c) Full VRAT where fertiliser was applied so that it was a non-limiting factor in pasture production. Fertiliser was not applied to unresponsive areas and applied to areas with 46-76% high fertility responsive grasses (Murray & Yule 2007a).

The blanket application rate for Limestone Downs was 24 kg P/ha (equivalent to ~267 kg SSP/ha) and this rate was also applied in the Simple VRAT scenario although some 484 ha of the farm were deemed to be non-responsive areas and no fertiliser was applied. The Full VRAT scenario applied no fertiliser to pastures less than 17% of high fertility grasses and the highest rate applied at ~35 kg P/ha (~390 kg superphosphate/ha), with a mean rate to responsive areas of ~33 kg P/ha (~367 kg superphosphate/ha).

Changing the Blanket application to Simple VRAT resulted in a decrease of 129 tonne of superphosphate required hence making an immediate saving of NZ$20 000 (at $158/tonne superphosphate) and increasing the efficiency of fertiliser P use from 30-37 kg DM/kg P and the cash surplus by 2% (Table 6). Whereas maximising the productivity of the responsive areas resulted in applying 67 tonne more SSP than the Blanket scenario (Table 6). Despite the increased requirement for fertiliser, the Full VRAT scenario resulted in more total pasture grown and an increase in stock carried (Table 6) which increased the cash surplus generated

Table 5 Target stocking rates (stock unit/ha) and soil fertility targets for a Whanganui hill country farm.

LMU	Target Range				
	Stocking rate	pH	Olsen P	Sulphate S	QT K
Class 1	10-12	5.8-6.0	20-30	10-12	7-10
Class 2-GFC[1]	10-12	5.8-6.0	20-30	10-12	7-10
Class 2-No crop	9-10	5.6-5.8	18-25	10-12	7-10
Class 3-Fert	8-10	5.5-5.7	13-18	10-12	7-10
Class 3-No Fert	2-4		No targets		

[1]Green feed crop

by 26 % compared to the Blanket application and 23% compared to the Simple VRAT.

In all the scenarios examined VRAT increased cash farm surplus on the Limestone Downs property and a sensitivity analysis revealed even with a 20% increase in application costs the farm's annual cash position when using VRAT only varied by 0.4% (Murray & Yule 2007a).

Variable rate applications have now been completed at Limestone Downs in early 2015 and on six other farms on a commercial basis.

Rocket science?

Identification of the potential productivity of differing LMUs and the more detailed assessment of soil fertility status by physically sampling soils (and herbage) more intensively means that rolling out this opportunity to hill country farmers nationwide becomes capability restrained. Currently, the Ravensdown Primary Growth Partnership "Pioneering to Precision" is looking to develop seamless integration between decision support systems to predict potential productivity, N fertiliser responsiveness, and econometric analysis (all to help block the farm into differing LMUs) with remote sensing, using hyperspectral cameras mounted in aeroplanes. A remote sensing project, with the Centre for Precision Agriculture (Massey University) and the Farms Systems Group (AgResearch) providing the science, experiments with using near and mid infra-red spectra to assess plant and soil nutrient status to allow the most cost-effective differential nutrient application strategies to be developed for the farm business. As more aerial topdressing aeroplanes are fitted with computer-guided gate-control mechanisms on the fertiliser hoppers, there will be greater availability of the technology for hill country farmers to make the most of their fertiliser investment in terms of pasture production and quality.

Final thoughts

It makes economic sense, given the cost/price relationship between fertiliser requirements and financial returns from hill country farming, that a rethink is necessary of the advice provided to farmers with regard to extracting the best value for their fertiliser investment. Along with many other areas of investment into hill country farms, soil fertility has often not been optimised and this is a major drag on hill country productivity potential. Evolving thinking and technology are pointing to an exciting future for hill country farms in terms of optimising soil fertility which is an important driver, given adequate soil moisture, of pasture production and quality. Making the most of fertiliser expenditure should improve resilience of these farms to the volatility of both climatic and market forces.

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Table 6 Estimated productivity, fertiliser efficiency and cash surplus generated under three different modelled fertiliser application scenarios (Murray & Yule 2007a).

	Blanket	Simple VRAT	Full VRAT
Mean pasture production (kg DM/ha)	7918	7918	9846
Superphosphate used (t)	671	542	738
Fertiliser response (kg DM/kg P)[1]	30	37	34
Carrying capacity (stock units)	36246	36246	45070
Cash surplus[2] (NZ$/ha)	386	395	487

[1]Rounded to nearest whole number
[2]Superphosphate cost ($158/ha); Gross farm revenue $70/stock unit

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