EXPLOITING THE VARIABILITY IN PASTURE PRODUCTION ON NEW ZEALAND HILL COUNTRY.

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ABSTRACT

New Zealand has about four million hectares in medium to steep hill country pasture to which granular solid fertiliser is applied by airplane. On most New Zealand hill country properties where cultivation is not possible the only means of influencing pasture production yield is through the addition of fertilizers and paddock subdivision to control grazing and pasture growth rates. Pasture response to fertilizer varies in production zones within the farm which can be modelled using decision mining trees.

New Zealand pastoral farmers target production of a blend of perennial rye grass (*Lolium perenne*$_{cv}$) and white clover (*Trifolium repens* $_{cv}$). Concentrations of these desired species reduce as pasture fertility reduces and topography becomes steeper, being replaced by wild grasses and weed species. As a result there are often significant differences in pasture quality, expressed as Crude Protein, (CP) Metabolisable Energy, (ME) and in-vitro Organic Matter Digestibility, (OMD). Traditionally these have not been measured as the process is extremely time consuming, expensive and there is often a long delay between sampling and the farmer receiving the results, which is inconvenient for decision making. This results in a lack of information around pasture productivity and differences in pasture quality not being fully recognised.

These differences in quality have been measured in the field using a hyperspectral sensor (ASD FieldSpec Pro), which allowed the full range of pasture quality within one large station to be observed and measured in-situ. In one farm case study completed, the sites examined had a range of pasture quality results, ME (7.2 to 11 MJ kg^{-1}), CP (7.8 to 22%) and OMD (45 to 75%) which would significantly impact animal production. Results were compared to wet chemistry in order to calibrate and validate the methods. The results indicate that this method can give useful results with a high level of explanation of the data, providing a reliable means to determine pasture quality parameters from non-destructive field measurement.

Pasture production is considerably effected by variations in slope, aspect, seasonal rainfall and soil type, factors which in some cases do not change and other variables which do change but are outside the control of the farmer. In this variable environment the traditional method of soil testing a monitor paddock, assuming it represents the whole farm and planning a blanket application of fertiliser makes little sense as there is significant variation in production on different hill country zones reflected in the decision mining tree. Many of the factors affecting productivity can be represented in a GIS, which allows production zones and fertiliser response to be mapped once the farm plan is overlaid over an accurate digital terrain map.

In order to gain this benefit from such a decision mining tree the fertiliser application system must be accurate in terms of achieving the desired application rate from an aircraft. A computer controlled delivery system fitted to the topdressing aircraft has been developed which has significantly improved the coefficient of variation c.v. of spread. Trials have a reduction in the in-field coefficient of variation (CV) in spread from around 70% to about 40%, which is the level achieved on flat dairy pasture by spreading trucks using differential global positioning system (DGPS). This has enabled more complex fertiliser application plans to be carried out.

Keywords: Precision Agriculture, pasture production, hyperspectral sensing, aerial topdressing.

INTRODUCTION.

Feed Requirements.

Pasture quality varies greatly on hill country properties. Improving and managing pasture quality is an area of opportunity for hill country farmers to lift stock performance and increase their profit margin. A knowledge of current quality and quantity of pasture on farm would give farmers the ability to match animal nutritional needs, especially at crucial times, to ensure that target or optimal animal performance is being met. Good pasture utilisation and management are essential for achieving a highly productive pastoral system. At the present time this farming sector is lacking such methods to quickly evaluate pasture quality in near real time. Current practice would be to take physical samples and send these to a registered laboratory, an expensive and time consuming process which results in little uptake.

New Zealand relies on a pasture based system for beef and sheep production on hill country properties. Pasture quantity and quality are equally important for the production of sheep and beef. Farmers too often focus on quantity; however pasture quality is critical for optimising an animals' 'efficiency of conversion' of feed into maintenance and production. Pasture quality has a major effect on the performance of cattle and sheep, including live weight gains, milk production, fibre production, health and reproductive performance. Feed requirements vary for different classes of stock and their state: maintenance, growth, pregnancy, lactation etc. Some of these requirements of different pasture quality parameters are stated in table 1.

Table 1. Indicative Feed Requirements for Ruminant Animals (Adapted from: Hills Laboratories)

Animal	Crude Protein (%CP)	Acid Det. Fibre (%ADF)	Neutral Det. Fibre (%NDF)	Digestibility (%DOMD)	Metabolisable Energy (M/kg)
Beef					
Cattle	>12	19	25	61	9.5 - 10.5
Calf	>16	>16	23	69	11
Sheep	9 -12	20 - 25	25 - 35	55 - 65	8 - 10
Lamb	11 - 14	16 -20	20 - 25	65 - 75	9 - 11

Pasture quality is determined by a number of factors. Factors include those out of the farmers control such as climate, slope, aspect, and soil type. However other factors can be controlled or altered by the farmer such as soil fertility and grazing management. Botanical composition naturally has a major influence on pasture quality, however altering this on hill country is expensive.

Murray *et al,* (2007) used a decision mining approach to model the production on a hill country property in New Zealand using a decision tree developed by (Zhang *et al*, 2004). The potential gains in fertiliser response if variable rate application was applied to the farm were calculated, based on the decision tree (Murray *et al*, 2007). A similar approach was used to measure the cost of inaccurate spread, using the same decision tree based on calculated application rates from recorded hopper openings (Grafton *et al*, 2011). The results from this work concluded that the benefits of variable rate application and improving the accuracy of spread were greater than the cost of application by aircraft.

In-Field Pasture Quality Measurements.

A range of pasture measurement tools such as rising plate meter (RPM), electronic probes, C-Dax Pasturemeter™, pendulum sensor and remote sensing devices have been tried in order to measure pasture quantity in this environment. A number of these tools are pedestrian based and the size and scale of these large farms makes their use limited, the C-Dax Pasturemeter is pulled using an ATV but this is limited by slope and therefore safety considerations. These tools use a range of calibration methods to transform the instrument readings to herbage mass. However, farmers only use them occasionally due to time constraints and lack confidence in their accuracy. Calibration errors, operational bias are the commonly associated problems with electronic probes and RPM (Hodgson *et al*., 2000). In addition most of the devices can produce unreliable results under extreme herbage conditions. Frame (1993) highlighted that the calibration model for RPM is susceptible to variations pasture management, pastures, seasons and climate, and these calibration models performed poorly when they were adapted to different pasture systems. Moreover, an understanding of the measurement procedures is required to achieve accurate data capture. For example, RPM underestimates the pasture biomass if the RPM forcing angle is incorrect (Thomson *et al* 2001).

Remote sensing tools have the potential to describe pasture characters including quantity, quality and phenotype composition. Researchers such as (Pullanagari *et al*, 2012), and (Kawamura *et al*, 2008) have successfully predicted pasture quality parameters using remote sensing tools. In order to predict pasture quality such as CP, OMD and ME hyperspectral instruments have been required, best results have been achieved when illumination of the target has been controlled as described by Sanches (2010). However ground based sensing systems still have considerable limitations in covering a sufficient area of the farm, sampling is still slow and equipment mounted on a back-pack carried around the farm. Simple VisNIR systems have been used to estimate pasture biomass and N content, these can be useful but also suffer from problems associated with moisture as well as continuing calibration to cope with grazing and growth stage as well as pasture maturity. Measuring pasture is a far more complex process than mono-crop situations.

Achieving accurate fertiliser application rates is important as research indicates that nutrient use efficiency is closely linked to application rate. Fertiliser response trials undertaken by (Morton *et al*, 1998) and (Gillingham *et al*, 2007) show that fertiliser response exhibits diminishing returns when fertiliser is applied off-rate. Some areas receiving less than the targeted rate produce a sub-optimal response, whereas areas receiving more than the target rate do not produce a significantly greater response than the target application. Grafton *et al*, (2011) took the data from these trials and showed on a cost benefit analysis that the response reaches an asymptote, where luxury applications add cost but little benefit. As a set quantity of fertiliser is purchased, each area receiving less than the target application is matched by areas receiving more than the targeted response.

Previous research by Murray(2007) illustrated that even under test conditions pilots find it difficult to prevent off-target application and achieve low in-field CV's. Measurement tests conducted by Murray and Grafton and Yule (2011) indicate that an in-field CV of 70% is what can be expected from a topdressing aircraft. Therefore in order to increase the nutrient use efficiency spreading accuracy needs to be improved.

Aircraft Requirements

The traditional method of applying granular fertilisers to hill country farms has been by application from fixed wing aircraft and in some cases helicopters. This is because the New Zealand climate is mild enough to allow pasture production and therefore, dry sheep and beef farming on terrain that is too steep to allow fertiliser application by vehicle.

The most common fertilisers applied are single superphosphate (SSP) (0.0%, N, 9.1%, P, 10.8%, S, 0.0%, K, 20%, Ca) and urea (46%, N) applied separately. SSP is applied mainly to supply phosphate for clover which is a good source of crude protein in pasture and fixes atmospheric Nitrogen through rhizobial fixation and Sulphur as hill country soils have a tendency not to retain Sulphur well (Cornforth and Sinclair, 1984). Urea is applied sparingly from time to time to boost production in late winter on some properties.

Fertiliser application from aircraft has involved blanket applications, manually controlled by the pilot manipulating a lever which controls the hopper opening via pushrods. Over the last 20 years some rate control has been attempted by the pilot matching his application runs by recording the hectares covered using an aircraft agricultural differential global positioning system (DGPS), then altering the opening to provide the required rate. This is not accurately achieved especially when contour flying, which is necessary in steeper country as the aircraft speed alters considerably over short distances as it climbs and descends (Murray *et al*, 2007). Flying in this environment is a difficult and dangerous operation and it is extremely difficult for the pilot to consistently achieve accurate flying and control of the hopper. Mistakes can be made and boundaries missed as well as an inability to control the flow rate from the hopper as aircraft speed changes. An automated system has been in development and testing; this system allows electronic farm boundaries to be recognised and flow control to be applied in order to achieve a more consistent application rate on the ground.

METHOD

Fieldwork was carried out at Limestone Downs, a 2,500ha coastal sheep and beef property south of Port Waikato on the North Island west coast of New Zealand. This work aimed to explore the possibilities of using proximal hyperspectral remote sensing to predict in situ pasture quality. As an initial 105 samples were taken from 7 different sites (see figure 1), 15 samples were collected at each site. The sites covered a range of slope, aspects, soil types and pasture species compositions. Each sample was measured in situ using an ASD Field Spec® Pro (ASD Inc., USA) with a spectral range from 350-2500nm this was used in conjunction with a Canopy Pasture Probe (CAPP) developed by Sanches (2010) to ensure consistent illumination of the live plant material. Pasture samples were cut to ground covering the $0.1m^2$ quadrat. The pasture samples were oven dried, weighed, ground and sent to a laboratory for wet chemistry analysis. The following pasture quality parameters were analysed: crude protein content, metabolisable energy and in-vitro organic matter digestibility. A sub sample of the oven dried and ground plant tissue sample was taken and measured with the ASD Field Spec Pro® using the contact pasture probe.

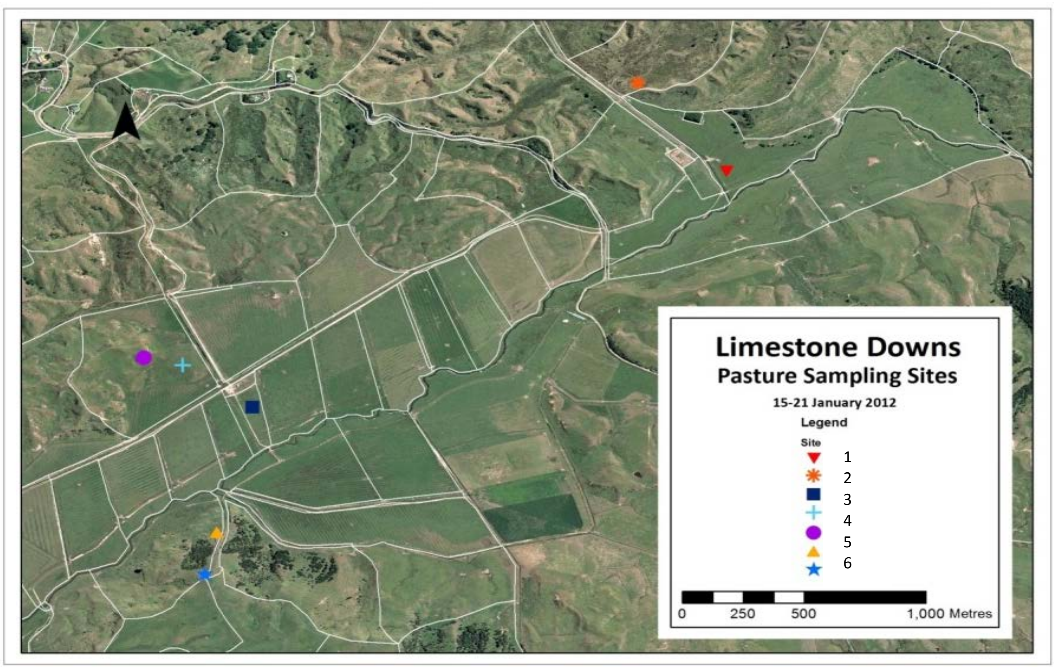

Figure 1. Pasture sampling sites, Limestone Downs.

Computer controlled rate application was trialled using a Pacific Aerospace Ltd. Cresco 600 aircraft equipped with a Satloc M3 DGPS which was used to input a Satloc Dry Gate Controller (Hemisphere GPS) that supplied outputs to variable rate hydraulic head which controlled the hopper opening at calculated flow rates. Three prescription application maps were input into the aircraft's

DGPS system, one for SSP at 125 $Kgha^{-1}$, and two others at 250 $Kgha^{-1}$ and 750 $kgha^{-1}$ respectively. The dry gate controller was programmed to respond to aircraft speed and application rate changes. Three separate zones were mapped for manual application, the use of pilot controlled hydraulics were also inputted for a direct comparison of spreading accuracy. The aircraft swath or bout width was measured for each rate using the New Zealand Spreadmark pattern test. Swath widths were measured at 15 m for 125 $kgha^{-1}$, SSP application, 14 m for 250 $Kgha^{-1}$ and 13 m for 750 $Kgha^{-1}$ application rates.

Application rates and spreading accuracy were established by collecting samples from the application in 180 cones with a surface area of 0.5 m^2 each. These were set up in 3 areas where different rates were being applied in 3 rows of twenty cones , spaced 20 m apart by row and 2 m apart within rows. Accuracy was established by measuring the coefficient of variation (CV) which is the standard deviation of the application rate, divided by the mean application rate measured by mass.

RESULTS

Pasture Quality Assessment

Three pasture quality parameters, CP, ME and OMD, were estimated from the field and lab spectral data. The results indicate that a very good agreement was achieved between the processed samples when measured by chemical analysis methods and the ASD with the CAPP on the ground and using the contact pasture probe on the dried samples. Very high levels of agreement were achieved, as illustrated by summary statistics in in table 2. Figure 2 illustrates the range of results comparing wet chemistry analysis with ASD analysis conducted on processed samples. Figure 3 shows the data from the same sites, but comparing in-situ pasture measurements with wet chemistry analysis.

As expected the predicted values from laboratory spectral data has a closer association with measured data compared to field spectra. In Figure 3, the explanation of the data is reduced and would appear to have more noise. This is consistent with other trials, where because of the way each sample is presented to the sensor more variation is expected. However the overall pattern remains consistent with the laboratory based measurement and the ranking or order of quality parameters remains the same between paddocks.

There are many causes of pasture quality variation both internal and external to individual paddocks such as animal interference, soil type, elevation, moisture, pasture types and management practices and it looks as if these methodologies will pick up on this.

Table 2. Results of Hyperspectral analysis of pasture samples from Limestone Downs.

Sample	Metabolisable Energy M.E.		Crude Protein C.P.		Organic Matter Digestability OMD	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
Dry Sample Spectra	0.95	0.20	0.96	0.75	0.95	1.44
Green Vegetation spectra. In-field ASD Field Spec Pro.	0.83	0.34	0.80	1.66	0.85	2.63
Green vegetation spectra. In-field ASD Handheld 2	0.74	0.46	0.69	2.09	0.76	3.27

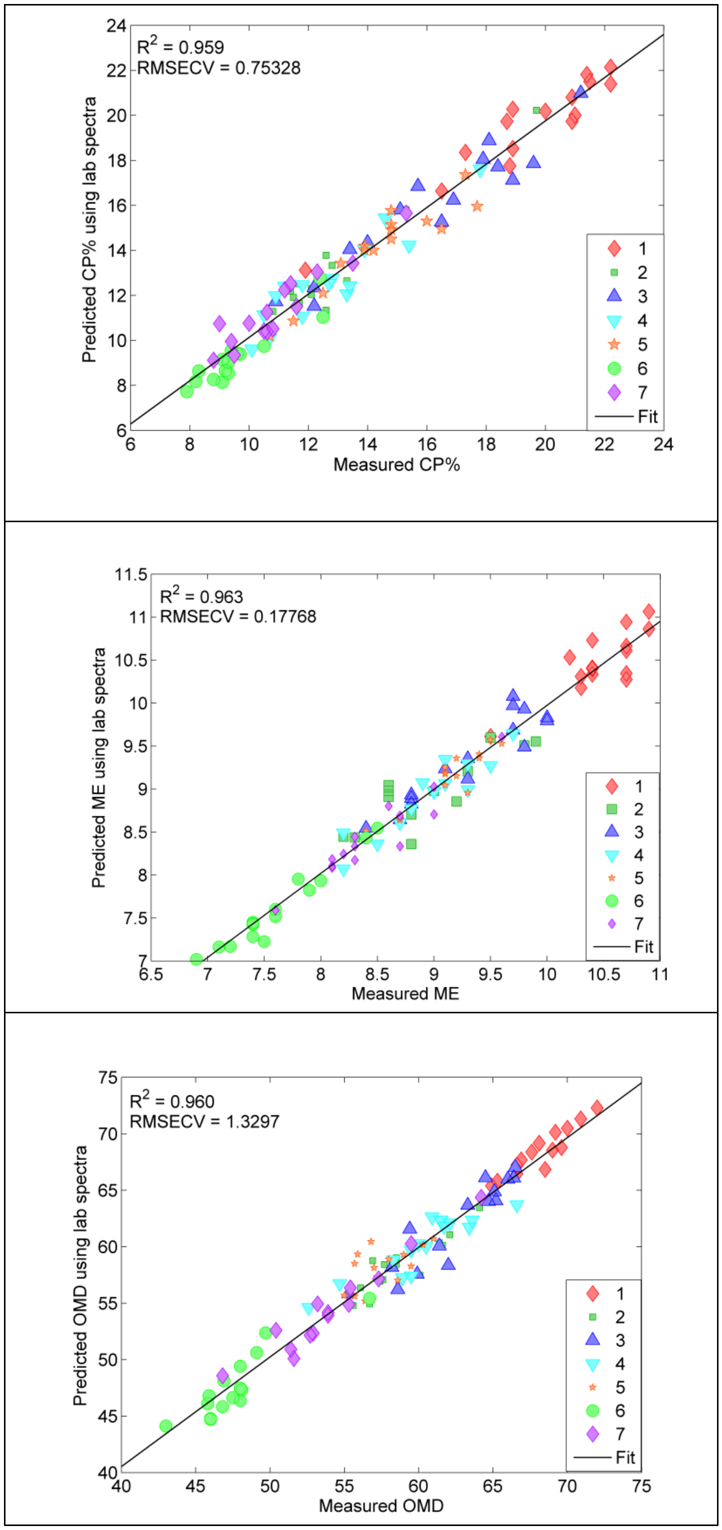

Figure 2. 2a) Measured Crude Protein versus predicted, 2b) measured ME versus predicted, 2c) measured OMD versus predicted.

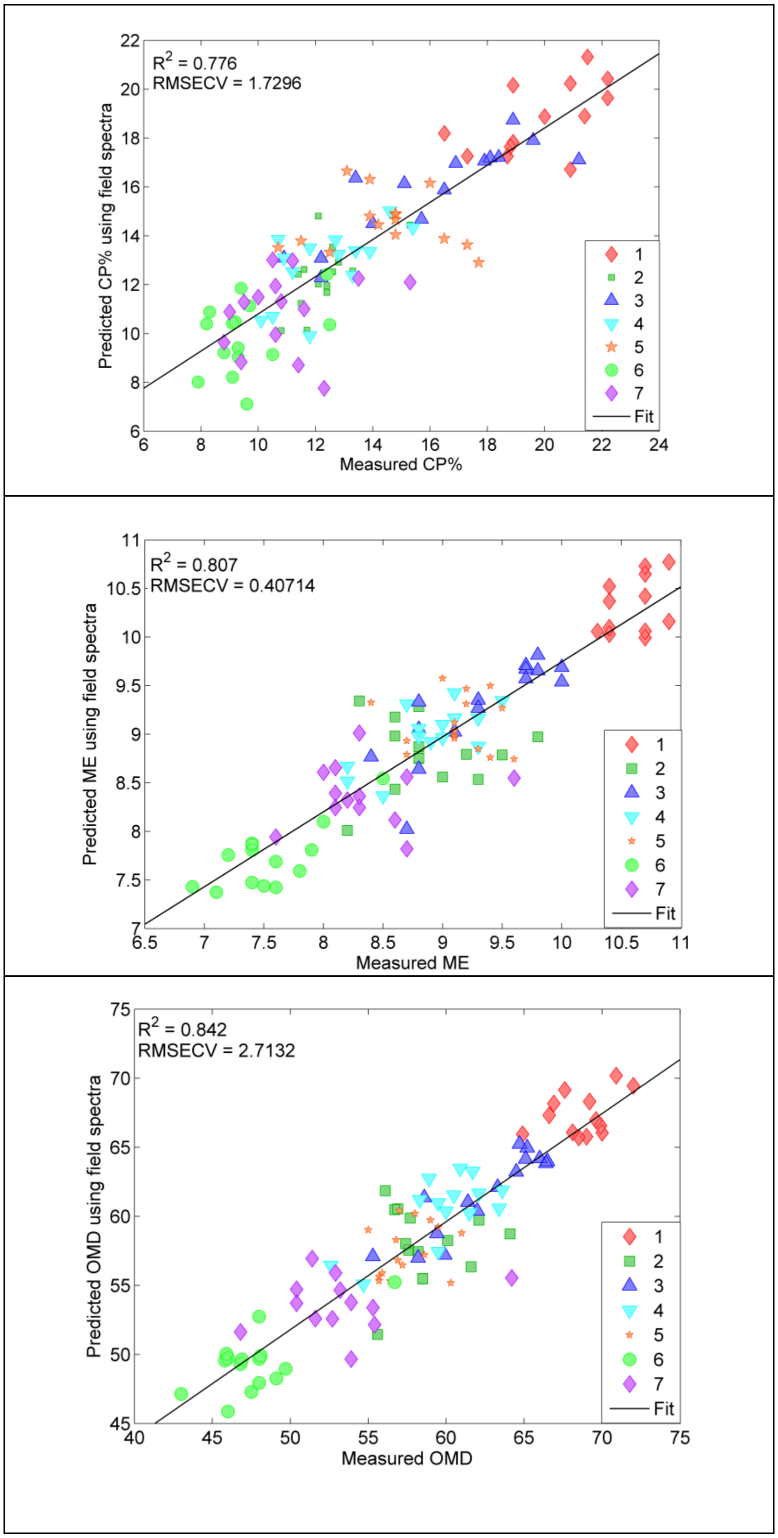

Figure 3. Field measure in-situ pasture measurement versus laboratory based chemical analysis. 3a) Crude Protein, 3b) ME, 3c) OMD.

Aircraft Spreading Performance.

The spreading performance of the aircraft was measured using in-field collectors and the in-field CV calculated. The average CV for fertiliser spread manually was 67%, with the highest CV percentages 92% and 96% and the most even spread achieved a CV of 27%. The average CV for fertiliser spread using the Satloc® Dry Gate Controller was 44% with CV's ranging from 15% to 62%. The results achieved by the pilot (while operating the gate controller) were consistent with earlier studies in terms of the CV achieved. The performance while operating the automatic gate saw a considerable improvement. Only one site at Limestone Downs achieved a CV less than 25%, this was site 3 spread using the automated system at 250kg/ha.

Unfortunately when the trail was carried out not all of the fertiliser ordered was delivered on time, resulting in the prescription area of automated application of 125kg/ha not being covered at this time. Time constraints and logistics also resulted in the prescribed area of manual application at 750kg/ha was also not measured. The results are shown in Table 3.

Table 3. Results of in-field spreading accuracy of fertiliser application within trial**.**

Limestone Downs - Aerial Top Dressing Trial									
	Rate of Fertiliser Applied (kg/ha)								
	125			250			750		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
	Coefficient of Variation (CV%)								
Manual	71.0	26.8	92.2	51.3	96.3	62.2	N/A	N/A	N/A
Automated	N/A	N/A	N/A	52.8	61.5	15.1	44.1	45.5	42.6

CONCLUSIONS

One of the first steps to achieving precision application or variable rate application of fertiliser in hill country is to improve the evenness of spread from the aircraft and achieve rate control. The aircraft system would appear to be starting to achieve this.

Automated application systems remove the need for blanket application of fertilisers. In future different rates can be applied to different zones, or certain classes within the farm may receive applications of different fertilisers. For example on steeper slopes where clover growth is often restricted by lack of moisture, urea may be applied to boost production when moisture is present and SSP may not be applied at all as clover is not present to absorb the nutrient.

Hyperspectral in-situ measurement of pasture quality parameters appears to be possible and give results which are useful at the farm scale. This form of measurement can give the farmer useful information to improve productivity, by better utilising pasture on the farm, growing more pasture through better tailored fertiliser programmes and improving live weight gains from animals through improved grazing management practices. Additional work is now going on to more thoroughly test this technology on a number of large New Zealand beef and sheep farms and develop a robust system to deliver these benefits to New Zealand hill country farmers.

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