MODELLING FERTILISER BENEFITS USING AERIAL TOPDRESSING

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Abstract

This paper draws on data provided through an earlier case study to quantify the costs and benefits of fulfilling the fertiliser (Phosphate, Sulphur and any required Nitrogen) needs of a property using either DAP, or, urea and superphosphate. The performance of the application of nitrogen and phosphate on Limestone Downs is based on data of the aerial spread achieved in August 2005, whilst sowing di-ammonium phosphate (DAP). The spread operation was heavily monitored and the data set came from point data collected from the topdressing aircraft. The hopper openings were recorded using a potentiometer, alongside the location data recorded from differential global positioning system (DGPS). The hopper openings and flow rates were measured statically at Ravensdown, Aramoho store in order to calculate fertiliser application rates.

Geostatistics were applied to the point data to establish a CV for the spreading operation over every square meter of the property; and this approach was taken to model a hypothetical application based upon this CV, but varying the product applied and the response models. Nitrogen response is measured in kilograms of dry matter per kilogram of elemental nutrient supplied. Nitrogen was measured against a response curve; and also using a decision tree model. Phosphate response was quantified using a decision tree model.

The data set suggests that the difference between modelled actual application accuracy and targeted application is between \$34 and \$41 per hectare per application, although the most significant economic benefit was from applying fertiliser persae. The benefit of fertiliser application is between 2 to 2.5 times greater than the cost of application. This suggests there is an opportunity to improve fertiliser response by applying fertiliser more accurately. The best results in this instance were obtained by applying DAP a high analysis fertiliser which applied the targeted nitrogen and phosphate in one application in August. The returns are reduced by applying phosphate as superphosphate and nitrogen as urea in separate applications. The main reason for this is that the cost of separate applications is greater; and the cost of off target application is cumulative.

Applying fertiliser such as superphosphate (P, 9.1% and 10.8% S) by aircraft is more costly in total than applying the same amount of nutrient in a high analysis fertiliser, which although the latter is more costly to apply per tonne, is cheaper per kilogram of nutrient. However, this ignores the pasture response from the required sulphur and calcium content of superphosphate applied in the form of calcium sulphate. It has been found that in some pasture which has received little or no sulphur for some years; the immediate response to sulphur is often greater than the response to phosphate.

Keywords: di-ammonium phosphate; topdressing aircraft; superphosphate;; Geographic Information System (GIS)

Introduction

New Zealand's hill country sheep and beef farming systems are largely based on animal production from ryegrass *(Lolium perenne)* and white clover *(Trifolium repens)* swards. Easier topography exhibits higher populations of both while harder hill country swards are dominated by poorer species such as brown top *(Agrostis capillaries)* and crested dogstail *(Cynosurus cristatus)* with often little clover.

New Zealand's temperate climate allows year round outside grazing. In the most severe environments, such as that created by altitude, animals are typically grazed on lower and more highly productive soils during winter and early spring, especially through lambing and calving in the South Island, and to a lesser extent the North Island's central plateau.

Sheep and beef farming systems comprise 8.6M ha out of 15.6M ha farmed in New Zealand (MAF, 2009a). There are approximately 12,200 farms in this sector with an average farm size of 705ha (MAF, 2009b) which excludes non-commercial lifestyle properties. The sheep and beef sector contributes NZ$2.6 billion in beef production of which 83% is exported and some NZ$2.2 billion in sheep meat of which 90% is exported. A further NZ$440 million is earned through wool exports. This sector contributes 22.5% of New Zealand's agricultural output (MAF, 2009a). Farm gate income from this sector is some NZ$3.9 billion which includes some support for the more lucrative dairy industry, from over wintering dry cows and heifers to the purchase of surplus progeny – both bulls and heifers (MAF, 2009b).

In recent years the total tonnage of fertiliser applied on sheep and beef properties has fluctuated due to changes in the price of fertiliser raw materials and farm profitability; the latter has been largely affected by changes in the meat schedules due in part to exchange rate fluctuations between the New Zealand dollar, the Euro, US dollar and Great Britain pound (Davison and Williams, 2010 a and b).

The price of superphosphate fertiliser which is the main input to this sheep and beef sector by aerial application has moved from a little over $220 per tonne in 2007, to a peak of $510 per tonne in July 2008; and is $320 per tonne in 2010 (Ravensdown, 2010). During this period the fertiliser spend by the sheep and beef sector has been maintained between 14.3% and 15.3% of total farm expenditure (Davison and Williams, 2010 a). This demonstrates that demand for fertiliser is based upon a financial budget and not the nutrient requirements of the farm. As most of this farming sector has application undertaken by topdressing aircraft, demand for these services is equally elastic (Grafton *et al*, 2010) and (Lockhart, 2009).

This paper examines pasture response to fertiliser; and application accuracy to provide a cost benefit analysis of fertiliser use on New Zealand hill country sheep and beef farms.

Method

Fertiliser responses have been recorded in various scientific studies on a range of land classes. Some of those studies that relate to land classes which predominantly use aircraft for fertiliser application are the subject of this study.

Those studies which focused on fertiliser responses in areas which were nutrient deficient with poor fertiliser application history, were of special interest. Many farmers responded to increases in fertiliser prices by reducing fertiliser inputs, others maintained the same monetary value of inputs by reducing the quantity applied. Thus many hill country farms have received less than maintenance fertiliser inputs over several years (MAF, 2009a). For this reason a study on East coast easy hill country responses to nitrogen application in early spring was chosen (Gillingham *et al*, 2007). A phosphate and sulphur application study on freshly sown pasture with Olsen P of 5 and with no fertiliser use for at least four years undertaken in Southland was also examined (Morton *et al*, 1998).

Phosphate and sulphur fertilisers provide nutrients which are required for protein production; and encourage clover growth which provides the bulk of pasture nitrogen requirement through rhizobial fixation. When sub optimal fertiliser application is undertaken then a nutrient deficiency will become a limiting factor in pasture production. On New Zealand hill country pasture, this is likely to be sulphur in the first instance as many of these soils are low ability to retain sulphur (Cornforth and Sinclair, 1984) and (Jarvis *et al,* 2002). Once sulphur is a limiting factor clover production falls and nitrogen fixation reduces and nitrogen, even more so continues to be the limiting factor for pasture production. Phosphate is also lost from the system as a consequence of production but because of its relative immobility in soils at a slower rate. Production of quality meat and wool requires nitrogen, phosphate and sulphur to be present in the animal feed for synthesis of amino acids.

Pasture productivity is measured in kilograms of dry matter produced which in turn is valued in NZ $ based upon a kilogram of dry matter being converted to either milk solids or animal carcass. The carcass value used in this paper is based on the assumption of a 33 kg live weight lamb dressing out at 45% selling for $69 (Davison and Williams, 2010 b) and (Jarvis *et al*, 2002). The cost of fertiliser and the nutrient content is based upon the Ravensdown Fertiliser Co-op Ltd, price list (Ravensdown, 2010). Meadow hay can be purchased in bulk at $5.30 per bale (approximately 15 kg dry matter) which values a kg of dry matter at $0.35.

The conversion ratio of dry matter to milk solids or carcasss weight is dependent on the quality of the feed it is comprised of. The actual ratios vary significantly with pasture species, climate, fertility and season (Anon, 2010). Research on establishing a pasture composition decision mining tree (Wan *et al*, 2009) found that an Olsen P of 10.5 and a slope of 10.5° were critical points at which less desirable brown top out competes with ryegrass in pasture. Pastures with a small percentage of legumes and little ryegrass dominate in soils with low available phosphate and are less productive (Zhang *et al*, 2009). The decision modelling tree for dry matter production is used to calculate the conversion ratio of dry matter to carcass weight on the easy slope hill country farm studied (Zhang *et al*, 2009).

The comparison between a targeted application and an actual application was achieved by modelling a whole farm application based on data acquired on 5 August 2005 (Murray, 2007). The aircraft DGPS information was fed into a second industrial computer, ICP Electronics Inc. Model EB1820, which also recorded the hopper door opening via a potentiometer. The fertiliser spread was DAP, a free flowing fertiliser which has predictable flow characteristics in relation to hopper aperture size.

This spread data was then compared to fertiliser decision tree response models for phosphate (Zhang *et al*, 2009) and for nitrogen (Zhang and Tillman, 2007), in addition nitrogen response was compared to a nitrogen response curve which demonstrates diminishing returns (Ball and Field, 1982). The difference between actual modelled response and targeted response provides the cost of inaccurate fertiliser application.

A case study using a hill country farm called “Limestone Downs” was undertaken as the fertiliser history of the farm is known and the other branches of the decision tree models are known. Hence a response for the modelled application at all parts of the farm can be established. The topography of the property was established by overlaying the farm plan over a digital elevation model (DEM) and land classes which are required for the decision trees were produced using Spatial Analyst an extension of ArcGis 9.2 ESRI software.

Results Part 1

The cost benefit analysis is achieved by producing response curves from tabulated data (Gillingham *et al*, 2007); see Figure 1 and (Morton *et al*, 1998); see Figure 2, then calculating a conversion factor based on hill country production as modelled using a dry matter decision tree Zhang *et al*, (2009) on Limestone Downs described in Figure 3; a farm with known production; Figure 4 describes the farm productivity after the decision tree information has been related to the DEM and processed through a GIS, Murray (2007) .

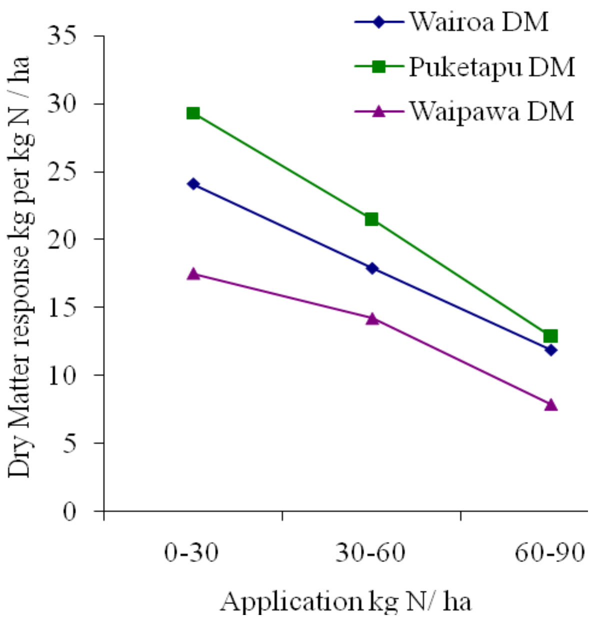

Figure 1: Dry matter response to Nitrogen applied (Gillingham *et al*, 2007).

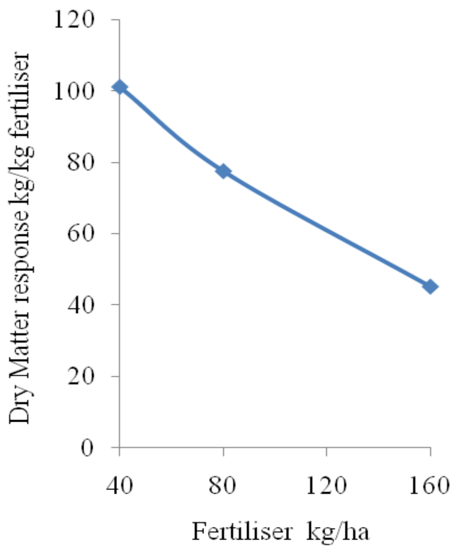

Figure 2: Response curve based on fertiliser response (Morton *et al*, 1998).

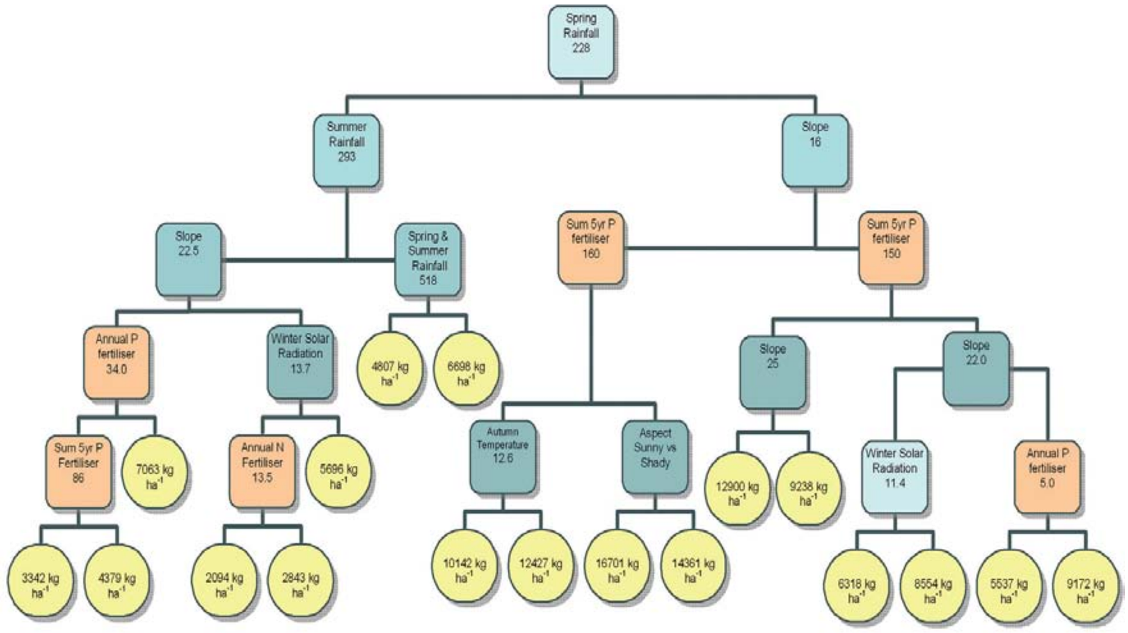

Figure 3: Dry Matter Decision tree mine, at each decision box take the left fork if the answer is equal to or less than value, if not take the right fork until the end leaf is reached (Zhang *et al*, 2004)

The total dry matter produced on a hill country farm was predicted using the decision tree on Limestone Downs a farm near Port Waikato, New Zealand see Figure 4.

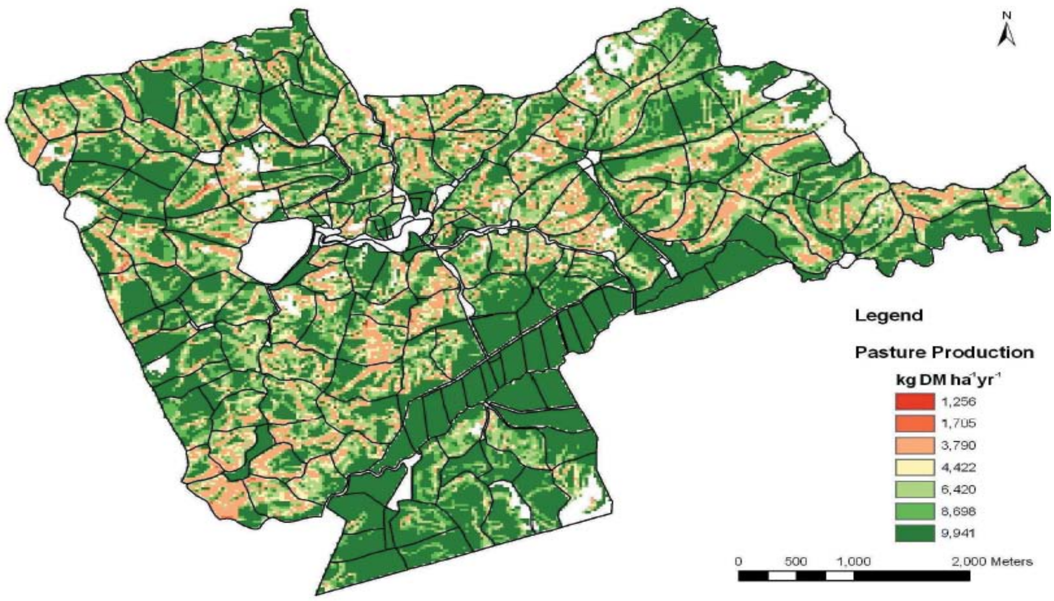

Figure 4: Dry matter response model based on decision mining tree (Murray *et al*, 2007)

The farm consists of 2,761 hectares of which 2,518 hectares is in pasture production (Murray *et al*, 2007) the bush block is omitted from Figure 4. Port Waikato receives between 1,250 mm and 1,500 mm of rainfall per year. Murray *et al*, (2007) modelled the total dry matter production using a maintenace fertiliser regime through a blanket application at 19,936 tonnes. The fertiliser history, Olsen P values, soil pH and stock units carried are known. A lamb carcass weight dry matter conversion rate can be established calculating the kilograms carcass weight removed over the six month period lambs remaining on the property. The other six months the ewes are pregnant, gestation period is 147 - 150 days. An all sheep farming regime is used to establish the conversion factor based on 11 stock units per hectare, see Table 1. A maintenance budget for an all sheep regime was established using Overseer ® Ag Research (2005), based on animal production nutrient removed see Table 2 and Table 3.

Table 1: Tonnes Product removed

Stock Type	Carcass weight kg & wool kg	Number Removed	Total tonnes carcass Removed
Lamb	15	24,297	364
Ewes & Hogget	26	9,111	237
Wool	4.5	136,670	137

Table 2: Nutrients removed g kg^{-1} live weight and g kg^{-1} greasy wool from (Jarvis *et al*, 2002)

	N	P	K	S	Ca	Live weight Conversion %
Sheep	13.0	6.0	2.0	0.8	13.4	48
Lamb	13.0	6.0	2.0	0.8	13.4	45
Wool	150.0	0.2	17.0	34.0	1.5	

Table 3: Nutrient budget for all sheep regime Limestone Downs

	N	P	K	S	Ca
Sheep kg Nutrient	6,416	2,961	987	395	6,613
Lamb kg Nutrient	10,529	4,859	1,620	648	10,853
Wool kg Nutrient	20,500	27	2,323	4,647	205
Leaching / run off	33,132	2,761	143,572	107,679	91,113
Atmospheric	46,937				
Immobilisation /Absorption	104,918	49,698			
Total Nutrient	222,432	60,306	148,502	113,369	108,784
Kg / ha	80.56	21.84	53.79	41.06	39.40

The lamb carcass weight conversion factor on this farm over 6 months is half the dry matter production which is 9,968 tonnes divided by the tonnes of carcass weight removed which is 601 tonnes; this gives a conversion factor of 16.6, which gives a value of $0.28 per kg of DM produced. This is less than 12 which is achievable on meadow rye grass and clover pasture found on farm flats. We can use this figure to value the hill country responses found by Gillingham *et al*, (2007) and Morton *et al*, (1998), as shown Figures 1 and 2, see Figure 5 and Figure 6.

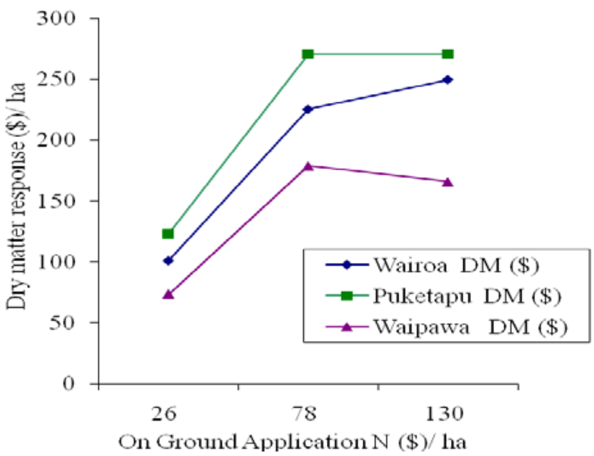

Figure 5: Dry matter response \$ ha^{-1} per cost \$ N ha^{-1}

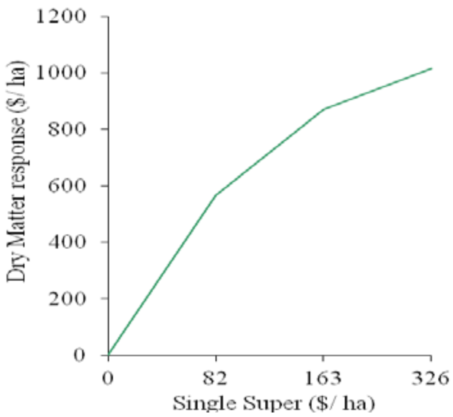

Figure 6: Dry matter response \$ ha^{-1} over \$ single superphosphate ha^{-1}

The nutrient budget can be achieved by applying 279 kg ha^{-1} Sulphur Super 15 (0.0%, N, 8.7%, P, 0.0%, K, 14.7%, S, 19.0%, Ca). In addition 40 kg ha^{-1} of Urea (46.0%, N) is required, some of which can be supplied from clover grown on the farm. Overseer ® predicts some 65 kg ha^{-1} of N is fixed by rhizobial legume fixation by clovers on the property which requires the addition of some external N, which is most cost effectively applied in the late winter or early spring.

The soils at Limestone Downs are high in clay and have adequate supplies of potassium. Applications of potassium salts are not required, to maintain fertility.

The value of farm gate produce can be compared to the value of applied fertiliser inputs, see Table 4. These show that a maintenance budget regime at Limestone Downs is about 13% of farm gate revenue, which is in line with the 14.3% - 15.3% of farm fertiliser expenditure reported by Davison and Williams (2010 a). This result supports the view that when fertiliser costs rise and farm income does not commensurately rise with fertiliser, then; sub – maintenance fertiliser inputs are being applied. The fertiliser cost was $138 per ha which produced an estimated net benefit of $932 per ha.

Table 4: Gross Revenue compared with value of nutrient applied

	Numbers Sold	Value ($)	($) per hectare
Sheep and hogget 26 kg @ $3.90	9,111	923,886	335
Lamb 15 kg @ $4.60	24,297	1,676,479	607
Wool (kg)@ $2.58	136,670	352,607	128
	Tonnes		
Cost Sulphur Super 15	770	242,958	88
Cost Urea	108	66,960	24
Application Cost Super	70	53,900	20
Application Cost Urea	160	17,280	6
Net Benefit		2,571,874	932

Results Part 2

The second part of the results measures the cost of poor application. A full farm application of 307 tonnes of DAP (18.0%, N, 20.0%, P, 1.0%, S) was modelled based on the application which was measured by the methods described. The aircraft hopper apperture was measured at 5 Hz, which is the speed of the aircraft DGPS (Satloc M3). The application rate was calcuated by recording the aircraft's swath or bout width, recording the aircraft speed and hopper door opening simultaneously, see Figure 7.

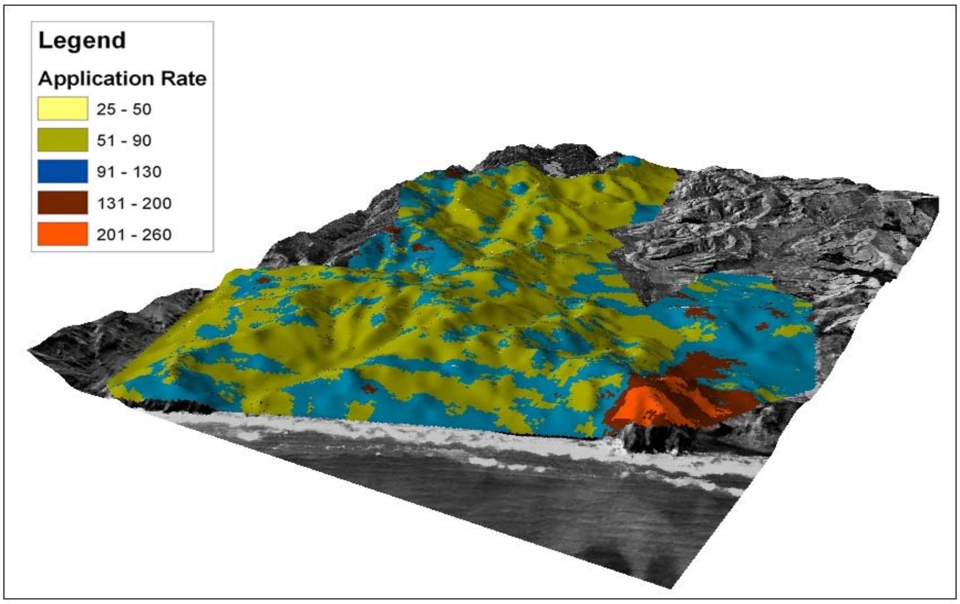

Figure 7: Application rate map kg ha^{-1} after Kriging. Source Yule and Grafton (2010)

The nitrogen and phosphorus response was measured by converting the point data recorded to a 3 dimensional raster using a digital elevation model of Limestone Downs and processing the point data through Kriging using Arc View 9.2 Spatial Analyst and 3D analyst extensions (ESRI). The Krig produces a layer which assigns an interpolated estimate of an application rate to a given area, this smooths the data somewhat reducing variability, see Figure 7.

The area of each application rate class field was matched to the criteria for the phosphorus decision tree, see Figure 8 and the calculated response mapped see Figure 10. The nitrogen response was calculated similarly, using both a nitrogen decision tree, see Figure 9 (Zhang *et al*, 2009). The nitrogen decision tree response was compared with a commonly used nitrogen response curve, Ball and Field (1982) in Figure 10 and mapped to Limestone Downs in Figure 12.

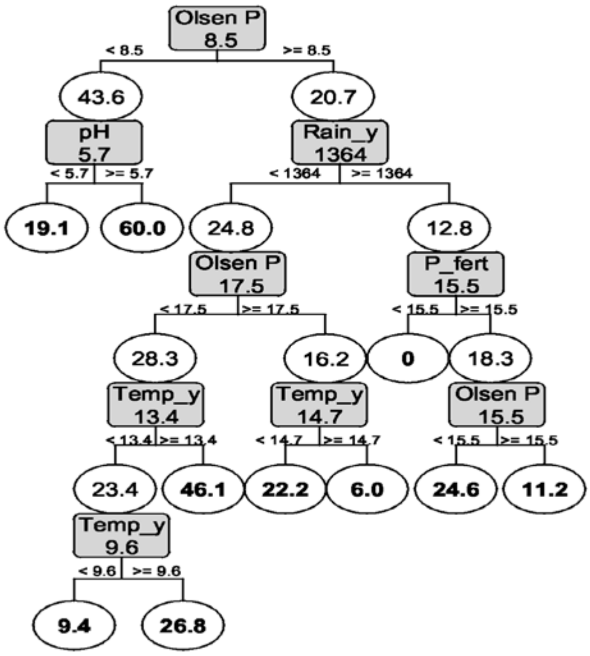

Figure 8: The decision tree for P response (Zhang *et al*, 2009)

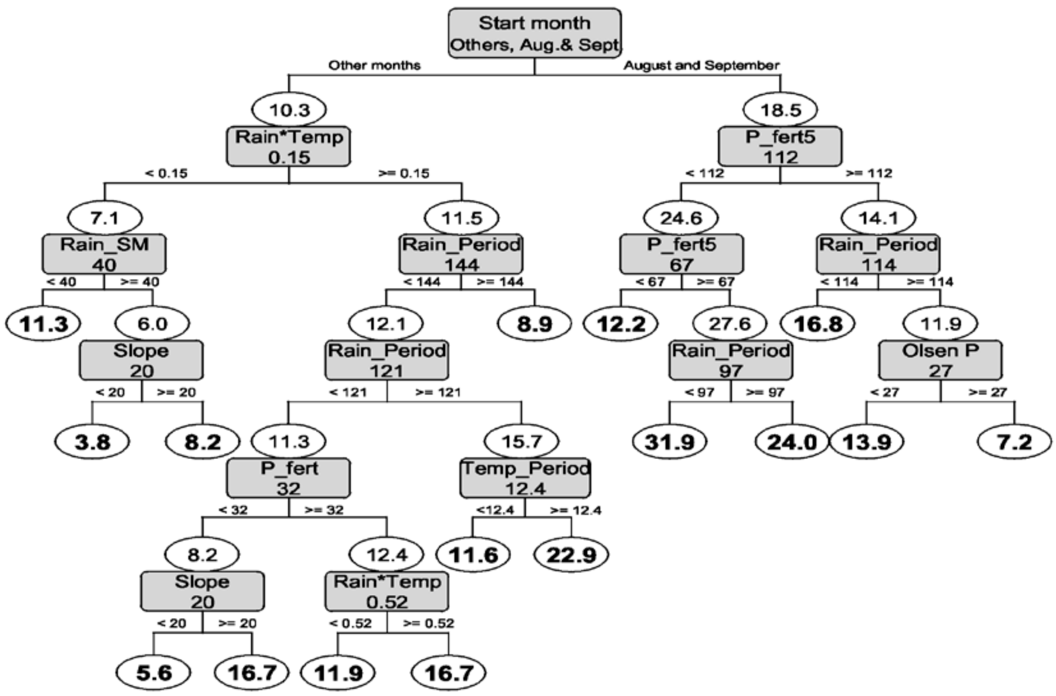

Figure 9: The decision tree for N response (Zhang *et al*, 2009)

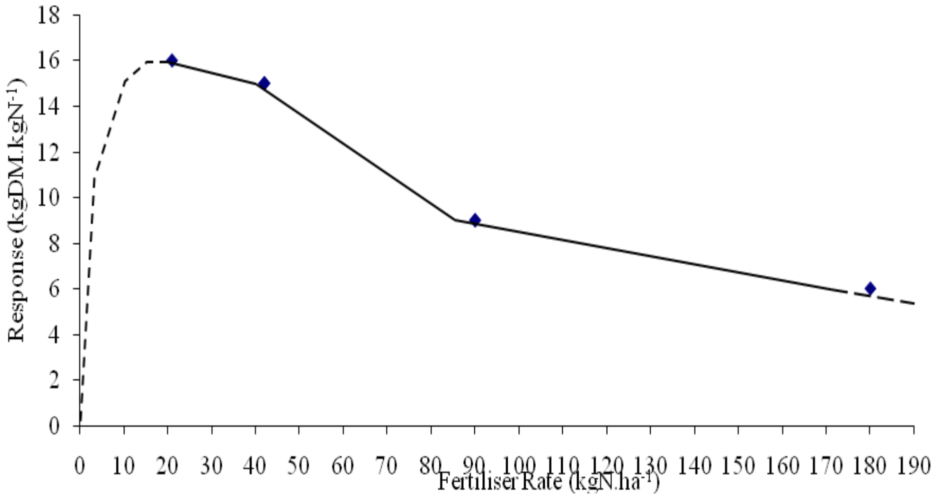

Figure 10: Nitrogen response curve from Ball and Field (1982).

The dry matter responses for nitrogen response are tabulated for each method in Tables 5 and 6, the dry matter response for DAP using the phosphorus response and the commonly used Ball and Field response curve are shown in Table 7. The alternative nitrogen dry matter response decision tree model was; 82% of the response curve and was not used to quantify the response as it is modelled for an application of 50 kg N ha^{-1} which is twice that was applied. The cost and benefit of the application and the opportunity cost lost through a poor spread are calculated; using the dry matter conversion factor of 16.6 already obtained see Table 7.

In Figure 11 the phosphate response decision tree, (Figure 8), has been applied to Limestone Downs based on Olsen P and rate of fertiliser applied. The responses for each area are summed and form the P response in dry matter produced in Table 7.

Similarly the N response tree, Figure 9 has been applied in a similar manner and the results appear in Table 5. Here the decision tree was split based on Olsen P. The N response curve, Figure 10 has response measured by application rate and demonstrates diminishing returns. The results of the addition of the various responses are incorporated in the N response of Table 7.

Table 5: Response to N application based upon Zhang & Tillman (2009) decision tree model, based on application Figure 3.

Application Rate Kg N ha^{-1}	Area ha	Tonnes DAP applied	Response Actual	Response Targeted Ball & Field	Response Zhang & Tillman Tonnes DM	Targeted Response Zhang & Tillman Tonnes DM
8.7	26.2	1.3	24	15.9	5.4	3.6
16.1	1652.1	147.8	24	15.9	638.4	422.9
25.6	598.9	85.2	13.9	15.9	213.1	243.7
35.2	43.1	8.4	13.9	15.9	21.1	24.1
49.4	44.2	12.2	13.9	15.9	30.4	34.7
8.7	1.1	0.1	7.2	15.9	0.1	0.2
16.1	83.6	7.5	7.2	15.9	9.7	21.4
25.6	265.1	37.7	7.2	15.9	48.9	107.9
35.2	29.1	5.7	7.2	15.9	7.4	16.3

Table 6: Response to N application based upon Ball & Field response curve, based on application Figure 2.

Application Rate Kg N ha^{-1}	ha	Tonnes DAP	Response Actual	Response Targeted	Response Ball & Field Tonnes DM	Targeted Response Ball & Field Tonnes DM
8.7	27.1	1.3	12.3	15.9	2.9	3.7
16.1	1734.5	155.1	15.4	15.9	430.1	444.0
25.6	866.6	123.2	15.8	15.9	350.5	352.7
35.2	72.5	14.2	14.9	15.9	380.2	405.8
49.4	47.1	12.9	12.9	15.9	30.0	37.0

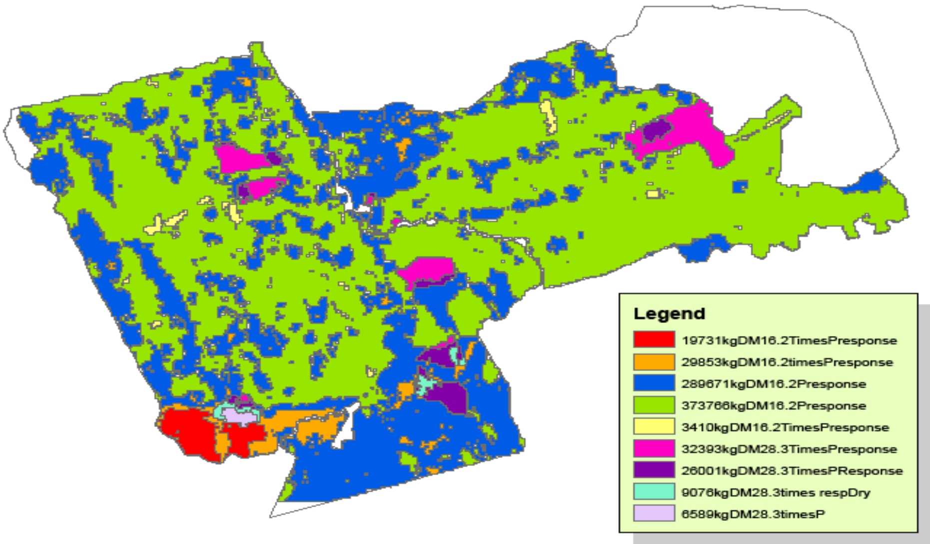

Figure 11. Dry Matter response based on decision tree (Zhang et al 2009)

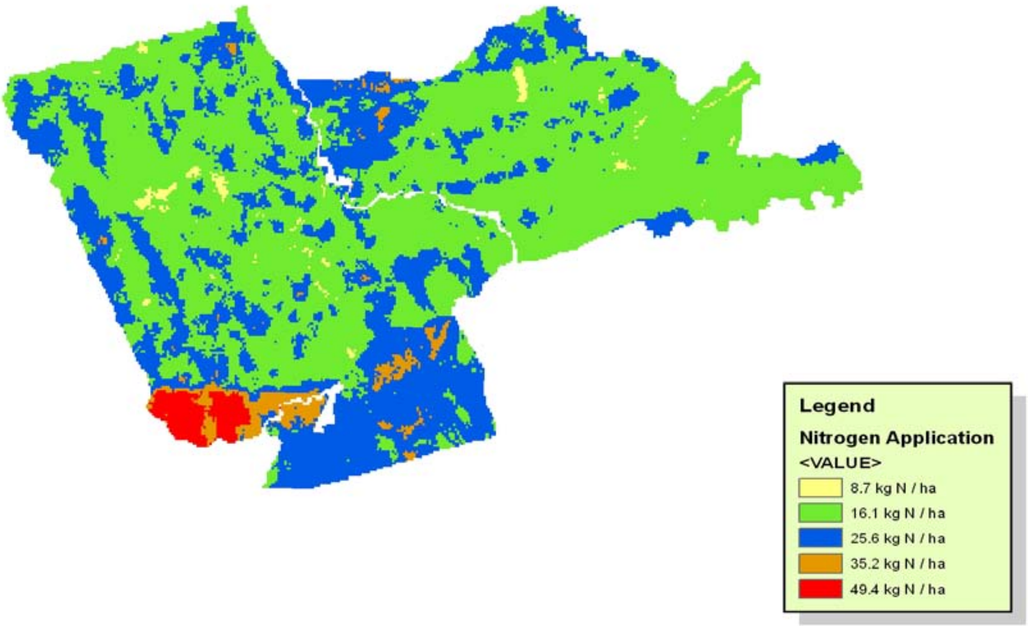

Figure 12. Nitrogen requirement (kg N ha^{-1}) map based on Ball and field (1982)

Table 7: Cost benefit analysis of application to achieve 20 kg N and 22 kg P application.

	DAP
Tonnes of product used	307
Cost ($)	280,905
Application cost ($)	38,375
Actual Response DM (N) tonnes	1,194
Actual Response DM (P) tonnes	791
Value Carcass Weight ($)	550,060
Target response DM tonnes	2,284
Actual Benefit ($)	230,780
Target Benefit ($)	313,636
Difference target – actual ($)	82,855

Discussion

This case study used a GIS system to predict farm pasture production with the background knowledge of farm inputs, farm nutrient status, weather, topography and aspect. With this information a farm dry matter conversion factor of 16.6 kg dry matter to 1 kg lamb carcass weight was established to evaluate the cost and benefits of farm fertiliser inputs. A farm nutrient budget was produced using Overseer ® and to maintain current nutrient status, inputs of fertiliser amounting to 13% of farm gate income are required.

A decision tree mining fertiliser response system was used to evaluate the response to a fertiliser application modelled on an actual application measured in 2005. This is the only whole farm fertiliser application data available using aircraft; therefore it can not be compared to other topdressing applications.

The cost of poor application (difference – actual) was over two times the cost of application, as seen in Table 7, which suggests that there are likely to be benefits in improving application quality by reducing the difference between targeted and actual application, even if this increases application cost.

Two systems of measuring fertiliser response were compared each of which has advantages and disadvantages.

The N response model used in Table 6 and Figure 13 is based on a response curve which has the benefit of recognising that there is a law of marginal returns in respect of fertiliser application (Ball and Field, 1982). This model is merely a response curve and does not examine application timing, rainfall, slope or other factors which may influence N response.

Whereas, the N response model used in Table 5 and Figure 14 is based on the decision tree model Zhang and Tillman (2007). This has the advantage of examining the many natural factors which have an affect on N response. They found that timing had the greatest influence on response, the best results being obtained from applications of N in August and September. The amount of P applied over the preceding five years, the amount of rainfall, the slope and temperature after application also have an influence on N response. However, the work was carried out at one application rate 50 kg N ha^{-1} and the effects of marginal returns are ignored. This is a weakness of the decision tree modelling work as it produces a response which remains constant for all application rates.

Research has been undertaken in improving the efficiency of fertiliser inputs through the use of variable rate application technology (VRAT), Murray (2007) and Yule *et al*, (2008). The use of computer controlled fertiliser release may have benefits exceeding those calculated in this research if it also eliminates the cost of poor spread quantified in this case study.

Conclusions

The dry matter conversion on hill country is less than that achieved from pastures on flatter areas with little contour. This can be quantified through a conversion factor, in this case study it is valued at $0.28 compared to meadow hay at $0.38 in situ or $0.42 processed as hay.

The reason for this is undoubtedly due to less desirable pasture species with lower nutritional value out-competing the more nutritious legumes and grasses which are more easily established on flatter areas; Waghorn and Clark, (2004).

The elasticity in demand for topdressing services, Grafton *et al*, (2010) coincides with fluctuations in fertiliser prices and farm gate prices. However, the percentage spent by farmers on fertiliser tends to remain constant, Davison and Williams (2010). From this it can be concluded that those areas requiring aircraft application of fertiliser are the first to withdrawn from fertiliser application by farmers; whilst those areas which can be fertilised from the ground generally continue to receive inputs.

Hill country with low soil phosphorus levels re-sown in rye grass clover mixes responded well to capital inputs of sulphur and phosphorus, Morton *et al*, 1998. Dry east coast hill country which because of moisture constraints are difficult to establish all but the hardiest legumes, also responded well to nitrogen inputs. The value of the dry matter response has been quantified at $0.28 and in both cases the response far outweighed the cost. As nitrogen, phosphorus and sulphur are components of protein those farming food animals require these inputs so that they are present in the pasture feed. There is no economic reason to withdraw these inputs.

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