CONNECTING NORTH ISLAND HILL COUNTRY FARMERS NUTRIENT REQUIREMENTS WITH SOIL MAPPING UNITS

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Introduction

Agricultural primary production accounts for nearly 50% of New Zealand's export earnings (Ministry of Agriculture and Fisheries – MAF, 2009b), with approximately 37% of New Zealand's land area under pastoral land uses (Ministry for the Environment – MfE, 2007). The North Island (NI) accounts for approximately 43% of the total pastoral land area in New Zealand, and approximately 30% (3.5 million ha) of the NI under pastoral land use is hill country (MfE 1997). North Island hill country farming operations are based on sheep (meat and wool production) and/or beef production; on better quality hill country a large proportion of young stock are sold fat, while on hard hill country most stock are sold in "store" condition. Agricultural land use has undergone substantial intensification in recent decades leading to significant productivity gains. In the NI hill country this has been mainly due to improvements in live stock-breeding, improved grazing through subdivision fencing, improved pasture species, and capital fertiliser dressing. Generally the improvements in hill country farm productivity have resulted from a combination of all these factors.

Managing soil nutrients is key to improving production in New Zealand pastoral agriculture as New Zealand soils generally have low natural nutrient status and tend to be acidic. Fertiliser and lime additions are therefore vital to improving and maintaining pastoral production. As fertiliser costs are often the single largest annual farm expenditure on hill country farms, profitability could be improved significantly with more efficient fertiliser use through technologies that allow fertiliser placement to be targeted to areas where the greatest benefit may be achieved (Murray and Yule, 2007a). There are also potential environmental benefits through targeted fertiliser use such as reduced fertiliser runoff.

Soil fertility tests (pH, macro nutrient and trace element analysis) can be utilised to ensure an optimum rate of fertiliser application; if the spatial distribution of soils at the farm scale is known, selected sites can be sampled for soil testing, that are representative of different soils occurring on the farm and (assuming the technology is available) fertiliser applied differentially to areas with different nutrient requirements. A prerequisite to targeting fertiliser to a particular soil type is the availability of and access to farm-scale soil maps.

Soils of NI hill country have not been mapped in enough detail (scale or resolution of individual map units) for current soil maps to be particularly useful as management tools for fertiliser planning and decision making by consultants and farmers. Through much of the NI hill country there is a mosaic of soils derived from soft rock (Tertiary sediments), hard rock (Greywacke, Argillite), and tephric parent materials. These soils have widely differing physical and chemical properties, and therefore have different fertiliser requirements in order to realise their optimum productivity under pastoral land use.

The most important parameters that influence hill country productivity are climate (temperature, rainfall, and solar radiation), slope, aspect, altitude, soil type, and grazing management. These parameters can be used to model pasture response to fertiliser across the landscape at a farm scale. To determine block-specific fertiliser requirements a hill country farm map can be broken into various response blocks, depending on the above parameters and farm specific data. For example: steep land unlikely to respond favourably to fertiliser (and contributing significantly to nutrient runoff), moderate slopes that have potential if fertiliser requirements are met (dependant on soil type), easy slopes where most benefit of fertiliser can be gained (dependant on soil type), and stock camps where fertility is not limiting (no fertiliser required – soil type will determine at what point fertility may be a limitation). Detailed soil maps can be produced at scales useful for farm management, and made available as GIS layers, by utilising existing soil information, modelling based on soil landscape relationships and spatial inputs, including high resolution DEMs and remote sensing, together with low intensity field sampling and validation.

This paper, which will discuss how hill country farmers could realise higher profitability through improved soil spatial information, will draw on two case studies. It will be argued that while improved soil information may lead to greater farm profitability, this will be conditional on the availability of a value chain that encompasses the development of, access to, and implementation of the new soil information in conjunction with other sources of information and emerging technologies.

Objectives

Contribute to decision making about investment in NI hill country farm scale soil mapping by:

- describing a potential value chain linking improved soil information with improved farm profits
- estimating a cost per hectare of producing detailed soil spatial information for NI hill country useful at the farm scale, using Waikoha Station as a case study
- discussing the value of farm-scale soil spatial information in the context of nutrient management, using Waikoha Station and Limestone Downs as case studies
- commenting on the operationalisation of the value chain.

Case studies: Waikoha Station and Limestone Downs

Waikoha Station is situated in the Waikato region, approximately 30 km south-east of Raglan. The Station is dissected by the Kapamahunga Ranges, which have slopes from steep land (>35°) through to easy rolling land, with small areas of flats formed from alluvial deposition. The Kapamahunga Ranges rise from about 25 m (Waipa River) up to 324 m at the highest point on Waikoha Station. The geology of the region comprises Tertiary sandstone, siltstone, and limestone overlaying Triassic/Jurassic sand stones and siltstones – greywacke (Kear and Schofield, 1976). A series of faults run north and north-west, mostly along the western margins of the Tertiary rocks. Tephra deposits of the Hamilton Ash Formation, including the uppermost Mairoa Ash member, mantle the landscape to a depth of several metres in the flat to rolling country, but thinning out and disappearing on steeper slopes (> 20–30°). A complex pattern of soils has developed in this landscape, with distribution explained largely by erosion or deposition of parent materials (Bruce, 1978).

Limestone Downs is a 2500-ha hill country farm running sheep and beef. It is situated 15 km south of Port Waikato in the northern Waikato region, and is approximately 100 km north-west of Waikoha Station. Soils on the property are similar to many of the soils mapped on Waikoha Station; however, the terrain is generally easier and of a lower altitude than Waikoha Station. Murray and Yule (2007a and b) and Murray, Yule and Gillingham (2007) modelled productivity and economic returns under a number of different scenarios targeting fertiliser needs to specific land units on Limestone Downs. Expenditure and revenue calculations were based on the Ministry of Agriculture and Forestry's national sheep and beef budget model for 2005 (MAF, 2009a), with the sheep to cattle ratio based on Limestone downs stock records. The authors used decision tree analysis to model productivity based on a number of input parameters that were determined to be most important in predicting potential yield from hill country pasture (Zhang et al, 2004). Land units were mapped based on fertiliser requirements determined by the productivity model.

The Value Chain

Investment in new soil information can be justified if the data and maps underpin an information value chain in which value is added in stages (Craemer and Barber, 2007). Craemer and Barber (2007) propose a number of such stages from fundamental R&D that builds knowledge capability, through to discovery, development, and deployment that results in a commercially available product or service (Figure 1). The potential value chain identified for achieving greater farm cash surplus from new soil information for NI hill country is illustrated in Figure 2. Existing soil knowledge is expected to support the discovery of new soil information that may come about through an improved understanding of processes and relationships i.e. pedotransfer functions and soil landscape relationships. This new soil information may then be developed with GIS and modelling to produce digital soil maps (McBratney et al., 2003) that, if used with other information and technology, e.g. soil tests, production models and precision agriculture technologies such as variable rate application technology (VRAT), may have commercial applications (deployment). In order to realise the potential of greater productivity from their hill country (impact), farmers will rely on all the links in the value chain from basic soil knowledge to improved production being connected.

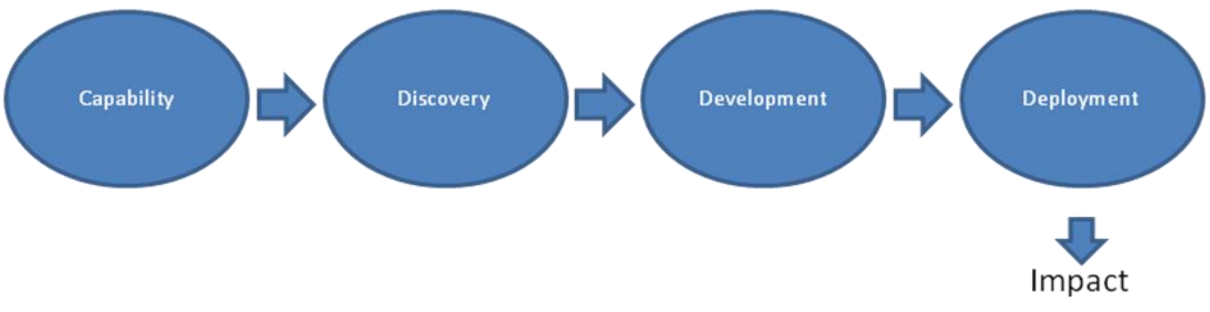

Figure 1. A basic value chain (modified from Craemer and Barber, 2007).

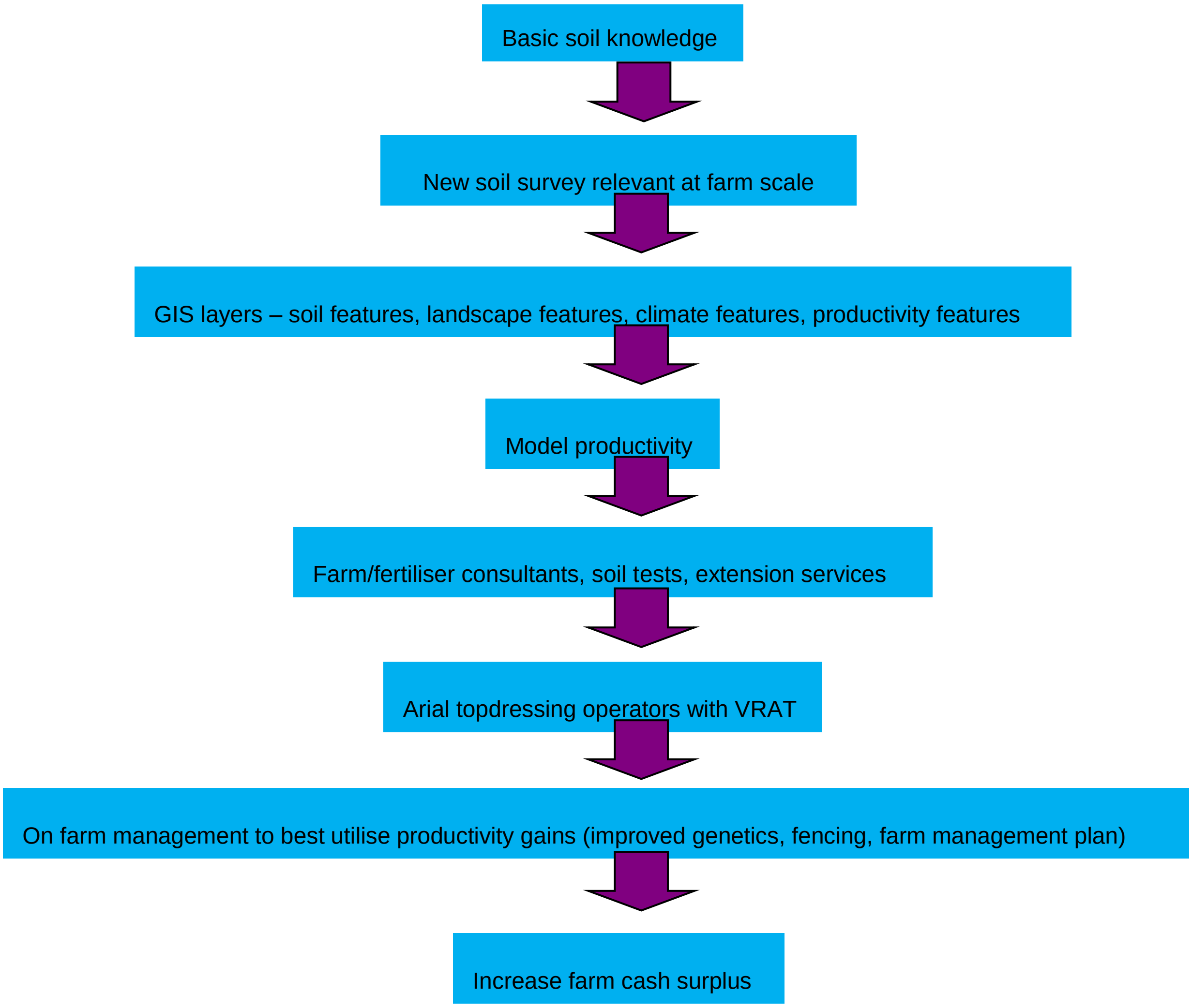

Figure 2. Proposed value chain to achieve greater farm cash surpluses from new soil surveys.

Cost of farm-scale soil mapping

In 2009 a detailed farm scale map of soil distribution on Waikoha Station was produced covering an area of approximately 3500 ha. The cost per hectare of mapping is calculated from time spent reviewing relevant soil (Bruce, 1978) and geological (Kear and Schofield, 1976) surveys of the region, costs associated with field work, and time spent developing the map as a GIS layer. The resulting map contained enough detail that individual soil mapping units could be identified in order to apply variable rates of fertiliser across the farm.

The cost of the soil survey on Waikoha Station was broken down as follows: approximately 40 hours were spent in the field, mostly becoming familiar with the landscape and soils, thereby building an understanding of soil-landscape relationships. Another 30 hours (office-based) were spent researching the soils and geology of the region, and developing the soil map as a GIS layer. At \$130 hour^{-1} labour costs, plus additional costs such as vehicle running and aerial photographs, the total cost of the soil map was \$10,000, or approximately \$3 ha^{-1}.

The Waikoha soil map was produced as an individual farm map, but this type of mapping would most likely be carried out on a larger scale (district or region) to be most cost effective and have the greatest utility. This is particularly relevant in regions where existing soil survey information is sparse. The cost per hectare would drop substantially if larger areas were mapped, although this will depend on the quality of spatial information already available and the terrain being mapped. The cost of producing the Waikoha map may under estimate the costs in less accessible regions with little existing soil information, as access was relatively easy and there was an existing 1:63 000 soil map coverage – Soils of Part Raglan County (Bruce, 1978).

Value of farm scale soil information
The value of farm-scale soil information is discussed for the Waikoha station and Limestone Downs case studies in the context of improved nutrient management.

Waikoha station
The costs of soil mapping have been estimated in the previous section.

The benefits from using the generated soil maps for improved soil nutrient management are estimated based on a comparison of the application and fertiliser costs involved in targeted (with variable rate application technology (VRAT)) and blanket fixed rate applications. Variable rate application technology on topdressing aircraft is being developed (New Zealand Centre for Precision Agriculture) which can deliver variable rates of fertiliser at a ground resolution of 18 × 18 m (Murray and Yule, 2007b). Variable rates of fertiliser are delivered to specific hill country land units by aircraft with VRAT by uploading relevant farm specific GIS information and using GPS technology. Although a fully automated VRAT (FVRAT) system for aerial topdressing (including continuous adjustment of fertiliser application rate) is not yet available for commercial application, Murray and Yule (2007b), estimating a $50,000 installation cost and one year payback period, assumed a 20% overhead on standard hourly topdressing costs. Standard topdressing costs are presented by Grafton et al. (2010), and for this case study, the application cost of a Cresco aircraft fitted with FVRAT was calculated to be $96t^{-1}(assuming an average flight distance of 5 km and application rate of 160kg^{-ha}).

There is approximately 3000 ha of hill country on Waikoha Station; of this approximately 450 ha has been mapped as purely Allophanic soils, 470 ha as a composite of Allophanic/non-Allophanic, the remainder has non-Allophanic soils. The Allophanic soils have high (>84%) phosphate retention (P-ret), while the remaining soils have low (10–59%) to medium (60–84%) P-ret. According to Cornforth (1998), drystock pasture (easy hill country) with a stocking rate of 10 su ha^{-1} requires maintenance dressings of 16, 13 and 10 kg ha^{-1} of P for high, medium and low P-ret soils respectively. At $310 t^{-1} (2010 figures) for super phosphate (9% P content) and assuming $96^{-t} application costs, this translates to $72.18, $58.64 and $45.11 ha^{-1} for high, medium, and low P-ret soils respectively. If soil fertility was increased with additional developmental dressings of P so that Olsen P was lifted to an optimum level, for example from 10 to 16, there would be an additional cost of $297.73, $216.53, and $135.33 ha^{-1} for high, medium and low P-ret soils respectively to purchase and apply the required amount of super phosphate. Table 1 presents costs of various fertiliser application scenarios and illustrates that if fertility was increased by 6 units, and if fertiliser was targeted to specific soil types, the cost would be $671,292, compared with $1,065,978 with one application rate based on high P-ret. These scenarios demonstrate the potential savings possible if fertiliser is targeted to the P retention classes of soils on the farm relative to broadcast high applications, and would be useful for planning fertility maintenance and development strategies for the farm.

Changes in fertiliser costs can be significant, for example, between 2007 and 2010 the cost of super phosphate approximately doubled. As fertiliser is often the single largest on-farm expenditure for hill country farmers, changes in fertiliser costs may have significant affects on cash surpluses. If fertiliser becomes more expensive the cost savings associated with targeted applications relative to blanket high applications will increase, e.g., as fertiliser is used more efficiently. Furthermore, the value of soil information increases as soil variability increases, i.e. if there is no variability there is no advantage over blanket application.

Table 1: Hypothetical fertiliser and application cost for Waikoha Station for targeted applications to specific soil types based on Phosphate retention (rates sourced from Cornforth 1998), and blanket applications at either high (blanket-high) or low P-ret rates (blanket-low).

	High P-ret	**Med P-ret**	**Low P-ret**	**Total**	**Blanket high**	**Blanket low**
Ha	450	472	2,078	3,000	3,000	3,000
Maintenance cost	$32,479	$27,680	$93,739	$153,897	$207,996	$129,997
Development cost[1]	$133,977	$102,201	$281,216	$517,394	$857,982	$389,992
Maintenance + Development	$166,456	$129,881	$374,955	$671,292	$1,065,978	$519,989

[1] Based on raising Olsen P 6 units

The cost of producing the GIS soil map layer estimated at $10,000 would likely be recovered in the first year from fertiliser cost savings, or assuming a 20-year useful life for the soil map the cost would be recovered at $500 per annum. For Limestone Downs (discussed below), Murray and Yule (2007b) calculated cash surpluses of $9–100^{-ha} for the different VRAT scenarios over and above the blanket application scenario that was currently being used. Translating this to the Waikoha case study, if targeted application is compared with blanket-low rates for maintenance dressing, annual production would need to increase by $24,400 to break even ($23,900 extra for fertiliser and spreading costs and $500 for the soil map). For the 922 ha of high or med P-ret soils this would require an additional $26.47^{-ha} or 0.2–0.5 su^{-ha} (assuming returns of between $100 and $50^{-su}), that is, increasing production (current carrying capacity of 10 su^{-ha}) on these soils by ~2–5%.

With lower mapping costs, higher fertiliser costs or greater variability of soils the payback period for a detailed farm soil map would be lower. Furthermore with the expansion of the scope of the benefits to include environmental ones (lower nutrient run-off) the attractiveness of the investment in new soil information would further increase.

Limestone Downs

Murray and Yule (2007a) modelled and compared various productivity and economic outputs at Limestone Downs under six different fertiliser application scenarios. The benchmark was scenario A – blanket application; D was blanket application with increased application rate; the rest were variable applications (simple and full) at different application rates (standard, increased, reduced). The authors emphasised that financial benefits would be dependent on many variables such as feed utilisation (fencing, stock management), climatic conditions, and pasture quality that relate to how well targeted fertiliser application can be used to increase productivity.

In the economic impact assessment of the scenarios modelled by Murray and Yule (2007b), scenario D (blanket application/increased rate) had a decrease in farm cash surplus ($381/ ha^{-1} vs $386 ha^{-1}) compared with scenario A (blanket application), whereas all variable rate (VRAT) scenarios showed increased cash surpluses ranging from $9 to $101 ha^{-1} over and above scenario A. With all on-farm costs associated with the VRAT scenarios including $1,500 for developing the prescription GIS map from spatial datasets included in the cost assessment (Murray and Yule 2007b), the increased cash surpluses indicate that the cost of farm-scale soil information would be recovered in the first year even under the poorest performing VRAT scenario. For this 2500-ha property the use of VRAT based on farm-scale soil information translated to an up to $252,500 additional cash surplus.

Operationalising the value chain

Manderson and Palmer (2006) pointed out that there are many examples where soil information has been available and has not been taken up by farmers. Craemer and Barber (2007) identified information failure as a significant barrier to use of soil information by land managers, and Manderson and Palmer (2006) illustrates this:

> Even when reliable soil information is available, it is not always sought by farmers…farmers may not know the information exists or where and how it can be accessed. Similarly, soil information is not sought out and used when end-users have no sure place for the information in their decision-making processes, or the information is not in a readily understandable form (p. 397).

The benefit of farm-scale soil maps outlined in our case studies is only realised if the value chain operates by connecting farmers with relevant technology, infrastructure, and expertise. Therefore the key to technology uptake will be providing extension programs that would convince farmers of the value of soil information and its application in conjunction with high quality data relevant to the farmer. In New Zealand, there is limited soil information at a spatial scale useful to farmers. Economies of scale will likely dictate how soil information is best developed, but it is unlikely this will be at the individual farm level, particularly if this information is to have multiple uses, for example by Territorial Local Authorities (TLAs). To provide a farm-soil-mapping service would require institutional knowledge and infrastructure that is currently with Crown Research Institutes (CRIs), However, it is unclear whether these institutions could develop the sort of timely and cost-effective services to farmers on demand, and manage this capability without significant public funding or whether the provision of such services part of their core purpose or business. Investment by private enterprise is unlikely if there is a perception that farmers are unwilling to pay. Public/private sector funding collaboration may be the most effective means of providing farm-mapping capability. This might help ensure uniformity of spatial data across the country rather than a patchwork of inconsistent information that may be disjointed above the farm scale. Improving regional soil map coverage – S-map (Lilburn et al., 2004) – that can then be used as a base (1:50 000 scale) to further develop detailed (1:10 000 – 1:25 000) individual farm maps containing specific detailed information may offer a way forward. It will be necessary to involve other institutions to develop precision agriculture, for example, VRAT, which is also likely beyond the scope of private sector investors alone.

Conclusion

Case studies of two Waikato farms were used to illustrate the potential benefit to hill country farmers from having detailed soil information at a scale that is relevant for managing soil nutrient status. There could be considerable savings in fertiliser expenditure by identifying where Allophanic and non-Allophanic soils occur, to target fertiliser application (presuming the technology exits) to suit the nutrient requirements of the various soils. A convincing argument can be made that improving existing soil information can allow quick recovery of the original investment and it can generate positive return. However, this will require an operational value chain adding value at the farm level. Other inputs of information and technology need to occur in conjunction with production of the relevant soil maps.

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