The development of variable rate application of fertiliser from a fixed wing topdressing aircraft

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Abstract
New Zealand hill country has a regular requirement for application of phosphorus (P) and sulphur (S) fertilisers usually as superphosphate. There are different requirements for fertiliser within farms with flatter slopes carrying more stock and needing a greater rate than steeper slopes which carry less stock. For the last 70 years aerial application of fertiliser has been mainly uniform with one rate applied over the whole area of a block or farm. As part of Clearview Innovations (PGP), Ballance Agri-Nutrients and Ministry of Primary Industry have developed a system for fixed wing aircraft to apply variable rates of fertiliser during flights across contrasting topographic areas. This system comprises a hydraulically-operated hopper gate linked to a hopper gate controller which in turn is linked to a computer and GPS guidance system, into which a fertiliser application prescription map is inputted. The prescription map uses GPS points to delineate the boundaries between areas that are flat (0-12 degrees), easy (13-25 degrees) or steep (>25 degrees), plus non-productive areas and exclusion zones. Calculated net benefits for the same amount of product applied using either variable rate (VR) or uniform rate application show an advantage of $36 to $166/ha/yr for VR rate application for low and medium fertility farms.

Keywords: hill country, phosphorus fertilisers, variable rate, uniform rate

Key messages
- For hill farms with low soil Olsen P levels there are economic gains to be made from applying fertiliser aerially at variable rates according to slope compared with uniform applications
- There are opportunities to profitably apply nitrogen and lime at variable rates according to slope and aspect on hill farms with optimal soil Olsen P levels
- Ballance Agri-Nutrients are now offering this SpreadSmart service in the North Island.

Introduction
Hill country developed into pasture, occupies an estimated 6 million ha in New Zealand from which 65% of lambs and cattle are supplied as store or finished animals. The land is a mosaic of different slopes, aspects, soil types and depths, all of which contribute to large differences in pasture productivity. Of these factors, slope has the largest effect, while aspect changes the seasonal distribution of pasture growth and pasture species composition (Lambert & Roberts 1978). Nearly all hill soils are naturally acidic (pH 5.0-5.4) lack P and S and respond strongly to the application of N fertiliser. Up until recently, despite the large spatial variability in pasture production, fertiliser nutrients, predominantly in superphosphate, and lime have been applied at uniform rates over large areas of such hill country.

In recent years, aerial topdressing planes have been modified so that they can spread fertiliser at a variable rate. This paper outlines the development, testing and implementation of VR application of fertiliser as carried out by Super Air, a subsidiary of Ballance Agri-Nutrients.

This paper covers three aspects of the development of the SpreadSmart service. The first is the development of the aircraft hardware, the second is the development of farm prescription mapping, and the third is the measurement of on-ground and in-flight fertiliser flow characteristics in order to set hopper openings and anticipate prescription map polygon boundaries.

Aircraft and hardware development
A Cresco topdressing aircraft, was fitted with a hopper and gate as used by Farmers Air, Gisborne. The hydraulic system was designed by Murray McGregor (Flight Structures, Hamilton) and installed by Windust Hydraulics Services, Hamilton. A new joystick control system, developed by J. Whitehead Electronics (JWE) Hamilton, with push button control of the hopper gate was also installed.

An electronic gate controller unit (V3 Spreader Control Computer) developed by JWE was adopted, rather than an off-the-shelf unit, as it was considered important to be able to troubleshoot and apply any modifications necessary locally and at short notice rather than deal at distance (e.g. USA) with such issues. The controller computer was programmed with

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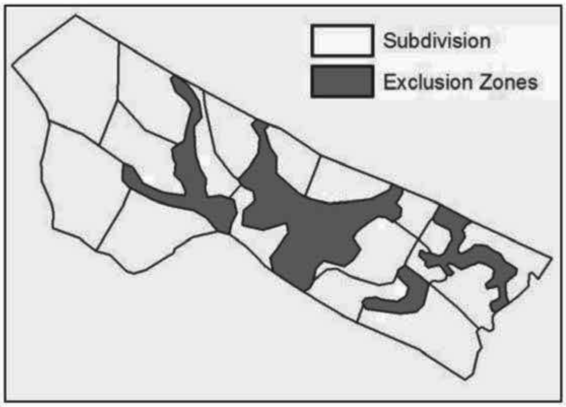

Figure 1 A GPS farm map with exclusion zones identified.

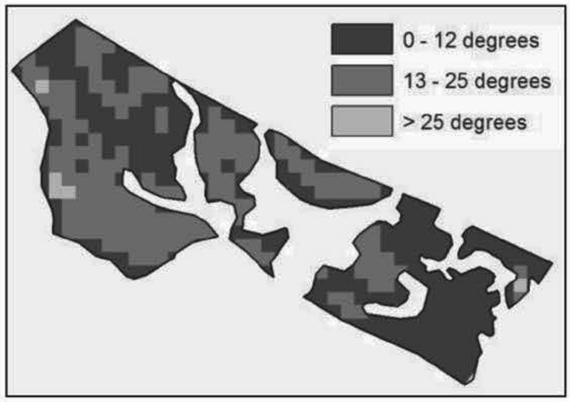

Figure 2 A GPS farm map with exclusion zones removed and slope categories identified aggregated to 45 m pixels.

fertiliser flow rate data from static hopper tests and compared with that from in-flight tests. The on-board computer compensates for speed variations to adjust hopper gate opening and aims for uniform fertiliser application within prescription mapped polygons.

A TracMap Autoboom GPS unit (www.tracmap.com) guides the aircraft on the tracks to be flown within the farm and identifies polygon boundary locations for changes in fertiliser application rate. The programme has a 'look ahead' ability to anticipate polygon boundaries and adjusts the time for fertiliser start/stop to account for fertiliser forward projection distances. This is of particular importance at exclusion zone boundaries.

Prescription mapping development

The foundation of the SpreadSmart service requires a global positioning system (GPS) based map. At the highest level the GPS map identifies the outline of the farm boundary or potential spreading area, along with exclusion zones where fertiliser is not to be applied e.g. waterways, forestry blocks or wetlands (Figure 1). At this stage the farmer may decide to apply fertiliser uniformly to some or all of the farm, or apply fertiliser at variable rates with the associated benefits from improved fertiliser efficiency. Under both uniform and variable application there is the increased surety of fertiliser being accurately excluded from specific parts of the farm.

The finalised GPS map is then run through a geographic information system (GIS) computer program to have a digital elevation model (DEM) layer placed over the mapped area. The DEM is sourced from the national database for New Zealand with a resolution of 15 m. The GPS accuracy of such maps was checked by UAR mapping of a Wairarapa farm and proved equally reliable. The DEM is categorised into slope classes of flat (0-12 degrees), easy (13-25 degrees) or steep (>25 degrees) and represented as a raster file with 45 m pixels, due to the spread capability of the aircraft (Figure 2). If desired an additional category of aspect can also be identified through the GIS process with more categories being created for variable rate fertiliser application.

Fertiliser flow tests

On-ground fertiliser flow rate tests

Superphosphate (granule size range 72% greater than 1 mm diameter; volume weight 1160 g/L) flow rate tests were conducted from an aircraft hopper with the aircraft immobile. A bag of super was hoisted by forklift and emptied into a loader bucket. The bucket then emptied the fertiliser contents into the aircraft hopper. The empty bag was held under the hopper gate in a position able to collect the total fertiliser contents of the hopper. For each of a range of hopper gate openings, from 15% to 50% open, at 5% intervals, the time taken to discharge the fertiliser load into the bag was recorded. After each measurement the aircraft was rolled forward enough to allow the forklift to remove the bag of super. This bag was weighed, again emptied into the loader bucket and the timing procedure repeated. At each % setting the actual aperture of the rear hopper door was measured (mm).

The above procedure was repeated for DAP (granule size range 95% greater than 1 mm diameter; volume weight 960 g/L) and urea (granule size range 98.5% greater than 1 mm diameter; volume weight 730 g/L). For these fertilisers the rate of flow was measured over the range of 15% to 40% open, at 5% intervals. Fertiliser flow rates were similar for superphosphate and urea but lower for DAP. Flow rate data for each fertiliser was incorporated into the V3 Spreader Control Computer.

In-flight fertiliser flow rate and projection tests

These were in three parts. The first was to measure fertiliser carryover distances from either starting or halting of fertiliser application.

These were conducted at a flat airstrip. The trial area was mapped into two adjacent parts with a defined border between them (A-B line) by taxiing the aircraft around the perimeter and logging the boundary in the on-board GPS unit. Three lines of 13 collectors each were set out parallel to the A-B line and with 10 m spacing between rows. The collectors were plastic bins with an area of 0.205 m^2. Each bin contained a mat of bubble wrap to minimise granule bounce and possible loss. The collectors were 10 m apart.

Two sets of measurements were conducted. The first was by topdressing the area approaching the A-B line then closing the hopper and measuring fertiliser carryover distance past this line. The second was by flying to the A-B line and commencing topdressing at that point, then measuring the position of the start of fertiliser application past this point. Results were compared by flying at 15 and 30 m altitude. Two passes of the aircraft were completed before fertiliser was measured for each set of conditions.

Three fertilisers were tested: superphosphate, DAP and urea.

Results indicated that at an aircraft speed of 120-130 knots and above 15 m altitude, aircraft height had little effect on stop/start distances. These were close to 50 m for superphosphate and DAP and 40 m for urea.

The second series of in-flight fertiliser flow rate tests were made by recording the time taken to empty a hopper of fertiliser at a given gate opening while topdressing a hill country block. Results were compared with results from on-ground hopper flow rate tests.

Results show that some further tests are required to accurately programme hopper settings at the highest application rates used on flat areas when VR topdressing compared with the more normal lower average rates used for overall uniform topdressing.

The third set of in-flight tests was a comparison of uniform and VR application of fertiliser to adjacent hill blocks of the same size and measuring all relevant parameters to the operation. Two sets of tests were done, one in the King Country and one in the Wairarapa. The King Country tests on two farms applied fertiliser by VR and uniform application to the same blocks. The time taken to cover the blocks by each method were similar, however, only 88% of the fertiliser was used by VR compared with uniform topdressing. Some of this would have been due to omission of exclusion zones. More fuel per tonne of fertiliser was used by VR since the topdressing times were similar but less fertiliser spread. Some of this would have been due to incomplete runs in the VR system and the need for the aircraft to revisit the endpoints to complete topdressing of the full area.

A further set of in-flight tests in the Wairarapa compared uniform and VR topdressing of adjacent similar blocks. In this test there was more fertiliser used by VR topdressing due to higher than programmed rates being applied to flatter land. Despite this the blocks selected were sufficiently similar to conclude that variable rate application of fertiliser did not incur any additional flying time or fuel usage costs per hectare compared with conventional uniform application of superphosphate. Further, in-flight on-farm tests will clarify the possible effects of differences in topography on the efficiency of VR topdressing.

The benefits from VR application of fertiliser on hill country can be both economic and environmental (SpreadSmart Plus). Avoidance of waterways and other environmentally-sensitive areas, as well as non-productive zones, can be enhanced using this technology. It is estimated that the avoidance area may comprise up to 15% of the total land.

Development of fertiliser application strategy for variable rate topdressing of hill country

The fertiliser rate to be applied to each strata of differing production potential is related to the stocking rate supported by that strata. The measurement of annual pasture production and associated stocking rate on contrasting strata on each hill country farm would be an impossible task. However, with knowledge of the average stocking rate carried by a block, the area of each strata (i.e. 0-12 degrees, 13-25 degrees and 26+ degrees slope) within that block, and an estimate of the relative productivity of each strata (e.g. 100, 66, 33 for the above strata, respectively) then the stocking rate being carried on each strata can be calculated. From this with reference to Overseer the maintenance P fertiliser rate to be applied to each strata can be derived.

The above ratio of 100:66:33 was assumed from several studies of pasture productivity on contrasting slopes (Gillingham & During 1973; Gillingham *et al.* 1998; Gillingham *et al.* 2007; Gillingham *et al.* 2008; Lambert *et al.* 1983) in different parts of New Zealand. This ratio can be varied for each farm or district if local information is available. This approach, therefore, uses a combination of actual on-farm data with general hill country pasture production research information.

Modelling of economic benefits

All legume-based hill country pasture requires P and S but because of the experimental difficulty in measuring relatively small differences in pasture growth between uniform and variable rate applications in an inherently extremely variable environment, a modelling approach was used to estimate the economic benefits.

Ballance Agri-Nutrients have developed an 'Excel' spreadsheet that uses a set of default values (Table 1), for on-farm input data (slope, Olsen P, stocking rate) and the relationship between Olsen P and relative pasture yield for flat and easy slopes. These are used to estimate the annual net benefit from application of an optimal variable rate of P and S according to slope, compared with a maintenance P and S application rate. The annual net benefit was estimated from an increase in per head production at the same stocking rate or an increase in stocking rate at the same per head production.

The calculator results (Table 2) are based on changes in per head sheep production at the same stocking rate. These changes are more positive than when the modelling is based on an increase in stocking rate at the same per head production, because there is no capital cost of extra stock incurred.

As the Olsen P levels diverge for flat and easy slopes, the net annual benefit from variable over uniform rate decreases until it is virtually similar where Olsen P levels are in the economically optimal range for each slope class. It is postulated that over time, sheep will transfer P and S from easy slopes to flatter areas where they prefer to camp. For each ratio of Olsen P ranges, net annual benefit increases with stocking rate.

Nitrogen

As slope increases, soils become shallower and unable to retain sufficient moisture for legume growth, especially on north facing slopes, so the grass-dominant pastures are more responsive to N fertiliser. An unpublished review of the literature including Gillingham *et al*. 1998, Gillingham *et al.* 2007 and Gillingham *et al.* 2008, showed that the mean efficiency of pasture response to N was 13 kg DM/kg N for pastures on slopes of 0-15 degrees compared with 26 kg DM/kg N for pastures on slopes of 15-35 degrees. This large difference in response present an opportunity to apply N to hill country at variable rates.

Lime

At four trial sites covering both north and south facing aspects, and easy (12-15 degrees) and steep (25-30 degrees) slopes under a 800 mm annual rainfall in Central Hawkes Bay. Morton *et al.* (2005) measured 11-16% annual responses in pasture DM yield to 1 tonne of lime per ha applied to shady aspects and flatter slopes where there was more legume, and soil Al levels ranged from 3.02 to 4.48 ppm. More research will be required but lime may be able to be economically applied differentially to areas with higher legume content.

Conclusions

- The development of VR topdressing of hill country is the one of the greatest technology advances since the advent of aerial topdressing in the 1940s. It now offers the opportunity to accurately apply the correct amounts of fertiliser to land areas of differing production capabilities
- This means improved fertiliser use efficiency and opportunities to increase productivity and reduce environmental impacts, as well as offering economic gains
- The SpreadSmart technology outlined here is now operating and offers farmers these advantages.

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Table 1 Default values used in variable rate spreadsheet calculator.

Value	
Capital cost of stock ($/SU)	100
Gross margin ($/SU)	70
Lamb price (S/lamb)	100
Cost of P ($/kg)	3.50
Cost of aerial application ($/ha)	15
Cost of SpreadSmart ($/ha)	6.80
Pasture utilisation (%)	70
Feed conversion efficiency for ewe liveweight gain (kg DM/kg LWG)	6
Increase in ovulation rate /5 kg gain in ewe liveweight (%)	10
Increase in lambs docked per 10% increase in ewe ovulation rate (%)	5.7

Table 2 Change in net benefit ($/ha/year) from variable rate compared with uniform rate of P and S fertiliser at different soil Olsen P ranges (μg/ml) for flat and easy slopes and overall stocking rates (su/ha).

Olsen P ranges for flat and easy slope classes for VR compared with uniform topdressing classes	Stocking rate and change in net benefit ($/ha/year)		
Flat:Easy	8 su/ha	10 su/ha	12 su/ha
6-10:6-10	83	134	166
11-15:6-10	59	80	98
16-20:6-10	41	54	67
21-25:6-10	36	47	57
16-20:11-15	-3	-2	-1

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