Agricultural and Marketing Research and Development Trust (AGMARDT)

Progressive Farming Grant

Optimising yield and profit with precision farming

Canterbury Precision Farming Group

Report prepared by:

Dr Ian Yule
Director, New Zealand Centre for Precision Agriculture
Massey University

Murray Craighead
Nutrient Solutions
Christchurch

Executive summary

The primary objective of this research was to demonstrate the potential benefits of precision farming to arable farmers by intensively monitoring three paddocks to determine the variability within each paddock and to identify which soil, plant and management factors impact on crop yield and quality. This information was to be used to demonstrate the economic benefits of identifying different growth zones within a paddock and altering the management of each zone to maximise its potential.

The three paddocks chosen for this Canterbury-based project were:

- Howey site, a 19ha dryland downlands site at Waitohi in South Canterbury consisting of clay based soils on an upper terrace and lower flats
- West Brothers site, a 19ha irrigated paddock at Wakanui in Mid Canterbury graduating from medium to lighter soils
- Ravensdown (Seadown) site, a 6.5ha irrigated paddock at Seadown in South Canterbury consisting of very light stony soils

At each site a grid of 60 or 100 points was established using differential GPS in order to carry out individual measurements within each paddock. This was repeated for three consecutive seasons (1998/99 to 2000/01), the crops measured being typical of those normally grown on the farms. Initial measurements taken included soil fertility and soil textural characterisation. For each crop, soil moisture status, herbage dry matter and nutrient status were measured, and depending on their applicability, weed, disease and plant vigour and grain quality. This data was presented as field maps and compared with the farmer yield map obtained from a yield monitor on the header.

The crops grown in respective years (1998, 1999, 2000) were:

- Howey site: grass seed, wheat, barley;
- West Brothers site: grass seed, rape seed, wheat;
- Ravensdown (Seadown) site: wheat, peas, wheat.

Results showed that some variability was present within each paddock. The main underlying variability was in soil depth to stones (West Brothers, Ravensdown) or to clay (Howey), and subsequent variation in soil volume and the soil moisture holding capacity. While this often led to yield differences, the impact of this varied between seasons with the wetter third season being less variable than that displayed in the previous two seasons. Further, crops did not constantly perform better in one part of the paddock. In particular grass seed on two sites (Howey and West Brothers) in year one performed better on the lighter parts of the paddock but in contrast, cereals (and rape seed) on all sites performed better on the heavier textured soils or where the soil was generally deeper. As fertility was good on all sites (except potassium at Howey site) this did not really impact heavily on yield, but as demonstrated at West Brothers site the crops nutrient uptake reflected the abundance of a particular nutrient in that particular soil type within the paddock. On all three sites higher soil and herbage potassium levels negatively impacted on calcium and magnesium herbage levels, and where soils were wetter and/or soil pH was lower, manganese levels were generally higher.

In terms of yield, on the Howey site the western flats always performed better than the steep slope and plateau and generally out yielded the eastern flats. The eastern flats often showed variable plant establishment leading to yield fluctuations, as a consequence of wet patches, the best remedy for which would be to improve drainage in these areas.

At the West Brothers site, the variation in yield followed the gradual change in soil type from south to north. Wheat and rape performed better in the heavier southern part and measurements such as height and vigour reflected yield well. It may be possible to manipulate water inputs across the paddock, on these crops a greater frequency of irrigation may help seed yields in the northern part of the paddock but with ryegrass which performed better on the lighter parts it may be wiser to reduce water inputs to the heavier textured parts of the paddock to reduce late vegetative bulk.

At the Ravensdown site, yield results were initially clouded by poor wheat performance in year one and the high variability in soil depth and stone content over very small distances. The large variation in soil depth and volume makes it difficult to simply change watering rates and frequencies across the paddock as a means of improving overall paddock performance. A further major limitation to performance was the shading effect of shelterbelts on the north and eastern boundaries. These severely limited initial crop establishment and their removal or thinning is seen as the best initial step to improving grower returns. Perhaps a consequence of this establishment was in the second and third year there was a tendency for the southern part of the paddock to perform better. Although the peas grown in year two suffered from wet spring conditions but still yielded reasonably well, further economic and yield improvements could have been made by differentially applying a second herbicide spray to the southern half of the paddock as the yield potential of the most vigorous areas of plants was reduced by weed competition.

In year three, small plots consisting of various nitrogen (N) rates were laid down in 3 or 4 zones in each paddock. Where possible these zones were identified from the yield maps as areas of different crop performance. At the Howey site the best responses to extra nitrogen on barley were given on the already best performing areas of the paddock. In this season this gave a 3:1 return for an extra 46kgN/ha applied on the western flats and a 1.5:1 return to extra nitrogen on the eastern flats. It was not economic to apply extra nitrogen on the plateau. If practical, money could also have been saved by managing the steep slope as a lower input system, (e.g. lower nitrogen, lower seeding rate). At the other two sites on wheat, the addition of extra nitrogen gave the best responses in intermediate yielding areas, approximately a 2:1 payout at Wests for extra nitrogen and >3:1 at Ravensdown although the optimum nitrogen rate varied slightly for each area. These results suggested the best yielding areas were already close to their yield potential whereas the lowest yielding areas were limited by some parameter other than nitrogen, most likely soil moisture retention. While in both cases the paddocks received approximately the optimum amount of nitrogen, the results suggest the nitrogen could have been better distributed. Modern equipment such as variable rate fertiliser spreaders would allow you to do this.

In conclusion, this study highlighted the possibility offered by precision agriculture for improved returns to growers. However the interpretation of yield data is often not simple with inputs for different management zones needing to be adjusted according to the crop type grown, the seasonal conditions encountered and the level of crop management applied.

A significant knowledge base is required with information such as yield maps, soil and climatic information, crop agronomy and equipment. Good starting points include knowledge of the soil type and landscape variation present, augmented by aerial photographs, detailed soil maps and some ground truthing. Regular soil and herbage sampling of different zones further enhances the information base, providing an indication of how best to manipulate soil nutrient status and adjust other management practices to best use the information gathered. New technology such as electromagnetic scans may also add to the database. It may be that the best gains can be made in drier years where more variation occurs within each paddock.

In this particular study, one common theme across each paddock was that the underlying soil characteristics in terms of soil depth, its moisture retention and drainage play a significant role in improving grower returns. This allows inputs such as nitrogen to be altered to best suit the agronomic requirements of the particular crop. Irrigation timing, rates and frequency could also be altered but this often poses logistical problems within a paddock. Similarly with some modern spray equipment, different zones could be differentially sprayed, most likely to support nitrogen and water changes, although on small paddocks typically cropped in New Zealand this has yet to be economically proven. This study has also highlighted potential one-off changes that can be made to a paddock to improve their productivity, for example improving drainage and removing shelterbelts. However, the benefits of actions such as shelterbelt removal have to be weighed against the reasons for their presence in the first place, such as wind erosion protection.

Contents

1.0 Introduction

This three-year (1998-2000) project investigated potential financial and environmental advantages arising from adoption of site-specific farming methods.

This was achieved by identifying in-field variability, assessing the subsequent impact on yield and crop quality, and suggesting strategies that could be used to take economic advantage of this variability.

Research was carried out on three properties in Mid and South Canterbury, New Zealand. Arable crop yields and quality were compared with growth factors such as soil and plant fertility and soil moisture.

1.1 Project objectives

The specific research objectives were to maximise the benefits of precision farming by:

- Establishing the accuracy of yield mapping techniques used on the sample properties.

- Intensively monitoring three paddocks to determine the variability within each paddock and which soil, plant and management factors are impacting on crop yield and quality with a view to ultimately using this information to improve the economic performance of each paddock.

- Transferring information to the growers in the project group and other arable growers by way of field days/workshops/seminars over the period of investigation.

1.2 CD-ROM

The data-intensive nature of this project resulted in the production of many GIS-derived paddock maps of yield, soil and herbage factors. In order to present this data in a logical format a CD-ROM was designed by the New Zealand Centre for Precision Agriculture, Massey University. CD copies are available by contacting Dr Ian Yule of the NZCPA, or via FAR.

2.0 Method

2.1 Introduction

Three paddocks were monitored over a three-year period:

- D and J Howey at Waitohi (South Canterbury)
- West Brothers at Wakanui (Mid Canterbury)
- Ravensdown site at Seadown (South Canterbury)

Differential GPS (DGPS) was used to establish a sampling grid for measurements (60 or 100 points/site). Measurements included: initial soil fertility and soil depth, seasonal moisture status, herbage mass and nutrient status, seed yield, and grain quality, weed, disease and vigour assessments (where applicable). Seed yield was assessed using header mounted yield monitors. In the final year soil conductivity was also measured and small nitrogen response plots were placed in better and poorer performing parts of the paddock.

The project consisted of two distinct approaches:

- Yield mapping
  At each of the three sites paddock-scale yield maps were generated for each of the three years of the project. The project team interpreted this information in order to define the potential parameters impacting on yield within each paddock to determine the appropriate actions to take in the next season.

- Intensive soil and plant monitoring
  Soil physical characteristics, soil fertility, plant nutrition and crop development characteristics were recorded in detail within each site. Each year the data was used to generate contour maps of the spatial variability in each paddock, which when aligned with the yield maps helped to define the impact of a range of variables on the potential yield.

In years one and two the variability was measured, mapped and compared to yield and grain quality. In year three various nitrogen inputs were applied in different zones within each paddock, the zones were derived from previous yield and measured soil characteristics. The impact of various nitrogen inputs was determined from small-scale plot data. Economic analysis was undertaken on the data.

2.2 Crop and soil information

One paddock on each of the three sites (West brothers, Howey, and Ravensdown) was utilised for the project. The West and Ravensdown sites are both on light to medium soils with irrigation. The Howey site is not irrigated and is on medium textured soil. Table 2.2 below provides a list of the sites and the respective crops grown during the three-year project.

Table 2.2: Soil type and crops grown by property

Sites	Landform	Soil type	Crops grown (harvest season) 1999	2000	2001
Howey block (Waitohi)	Dry downlands	Waitohi & Waimakariri silt loams	Perennial grass seed	Feed wheat	Spring barley
West Brothers (Wakanui)	Irrigated flats	Wakanui & Eyre-Paparua silt loams	Perennial grass seed	Rape seed	Feed wheat
Ravensdown (Seadown)	Irrigated flats	Lismore stony silt loam	Milling wheat	Field peas	Feed wheat

2.3 General site description

2.3.1 Howey (19ha)

Irregularly shaped paddock, especially on the eastern boundary, this paddock is situated at Waitohi in South Canterbury. The Seven Sisters and Rangatira Valley Roads bound it on the eastern and southern boundaries respectively. At the northern end is a plateau, which drops sharply to flats with some intermediate areas of deeper soils below the slope due to slumping from the slope zone.

2.3.2 West Brothers (19.4ha)

An oblong paddock situated at Wakanui, Mid Canterbury, the long side of the paddock is orientated to the northeast. The Southern boundary borders Buttericks Rd the eastern half of which initially contained a shelterbelt. This was removed in 2000. The paddock appears flat, although it has a minor depression running north to northeast to south.

2.3.3 Ravensdown (6.4ha)

Situated at Seadown in South Canterbury, the paddock is orientated North-South with the long boundaries to the East and West. The West side is bounded by SH1 with the other three sides largely bounded by well-established shelterbelts. The paddock is essentially flat.

2.4 Soil description

2.4.1 Howey

This paddock grades from Timaru silt loams in the upper part of the paddock to Waimakariri silt loams on the flat. Both soils are at the clay end in terms of texture. As the lower slope has been eroded by cultivation the downslope area has a deeper A-horizon. The actual slope has little topsoil. The subsoil is very dense and very mottled, therefore yields and plant establishment are determined by the amount of topsoil and the difficulty plants have in extracting water from the clayey subsoil. The paddock in general ranges from 23-45cm of topsoil to clay with the deeper topsoils on the flats particularly in the South-west area. Water percolates from the base of the slope and accumulates in low-lying areas. An old water channel is evident meandering West to East across the flats further compounding this problem. Thus cold wet soils are a problem in winter on the flats, while in summer the soils tend to shrink and crack, especially where the clay content is higher. The paddock is not irrigated but has good rainfall and being in the foothills some of this falls in summer. However summer droughtiness can still be an issue. There is a strong relationship between soil depth to clay and soil moisture.

2.4.2 West Brothers

The site grades from Wakanui silt loams in the South to Eyre-Paparua shallow silt loams (some parts slightly stony) in the North. The Wakanui soils lighten as you move East to West. These changes occur gradually so there is a mixture of soils in the central part of the paddock until one soil type dominates. This and continuous cropping has meant a mixing of A and B horizons leading to slight colour and textural changes. Soil depth ranges from 20-72cm to stones with the gradation following soil type with the deepest generally in the South-east corner in the heavier Wakanui soil to the lightest in the North-east (Eyre soil) corner. In the topsoil stones only become very evident near the Northern paddock boundary. Irrigation is likely to play a larger part in yield differences than soil depth and texture.

2.4.3 Ravensdown

The site consists of Lismore stony silt soils. There is pronounced channel and bar topography running West-East parallel to the Opihi River 1km to the North. Thus soil depth varies from shallow soils to small channels of deep silt (range 20-85cm). This is highly variable over short distances. The largest area of deeper soils is a band across the upper central area but there are still significant patches in the southern half as well. The soils are very free draining with low water holding capacity (except in the channels). Soil texture is reasonably consistent so depth to stones and the percentage of stones in the profile will account for the variability in yield. The paddock is irrigated.

2.5 Sampling method

The three paddocks were grid sampled (60 or 100 points/paddock on a 40 or 50m grid) for intensive monitoring of soil, herbage, and grain parameters (see Table for a full list of measured parameters). The monitoring points were set up using a differential global positioning system (DGPS) and for convenience of sampling marker rods were added at the beginning of each season after planting.

Initial information on soil depth to clay or stones, basic soil nutrients and organic matter was collected in 1998. Annual measurements included herbage mass, nutrient status, yield and seed quality parameters, in addition to aerial photographs. Where applicable crops were also scored for height, vigour and disease. Yield was measured using a header-mounted yield monitor.

Table 2.5: Parameters measured at each site

Category	Parameter measured
Soil physical	TDR+ (up to 5 times per summer); depth to gravels or clay; soil conductivity
Soil chemical	Soil pH (in water); Available N (anaerobic incubation); soil organic matter; macronutrients (P, K, Ca, Mg)
Crop	
Herbage	Herbage nutrients (N, P, K, S, Ca, Mg, Na, Fe, Mn, Cu, Zn, B); N, P, K removed; Dry matter*
Grain	Proteins/Nitrogen; Screenings*; 1000 grain weight*
Crop vigour	Vigour; disease; weeds; height*

*measured where applicable, +Time Domain Reflectometry (to measure moisture content)

2.6 Precision Agriculture tools utilised

Implementation of site-specific farming practices required the utilisation of a variety of precision agriculture resources:

- Global positioning systems (GPS)
  Soil and plant sampling at each site was based on use of highly accurate Differential GPS. The sub-metre accurate GPS was utilised for sampling site positioning, and to enable researchers to return to the same spot for subsequent sampling.
- Yield monitors
  Harvesters were fitted with yield monitors to correlate yield with position in the paddock.
- Geographic information systems (GIS)
  SSTools was primarily employed to integrate GPS and the soil/plant data collected from each site. SSTools is a GIS program powered by the widely used ArcView software.

3.0 Results

3.1 Howey

3.1.1 Summary of results

Yields on this paddock follow soil and topographical features. With the benefit of a fourth year's yield map it is easier to identify four ‘Production zones’ as listed in Table 3.1, and shown in Figure 3.1, below. The western flats (Zone C) consistently yield better. The eastern flats (Zone D) fall into the second category but within this zone there are areas of variable yield due to ponding. These areas are therefore hindered in early season production of autumn sown crops and early sowing of spring-sown crops. Weeds are also a greater problem in these areas. In dry summers there may be some compensation in yield, as these crops will grow out better. The upper plateau tends to have average to below average yields, probably a reflection that it dries out earlier due to lower than average depth of topsoil. The slope always has the lowest yields, a reflection of the shallow topsoil, higher clay content and some water percolation zones.

Potassium levels will always be low on these soils. As it is likely to be uneconomic to apply development potassium, it is best to provide some to each crop. There seems to be scope to manipulate nitrogen inputs to suit the different areas and extra nitrogen and potassium to the western area could be an option. Opening up the drainage channels (this has commenced) and some additional subsurface drainage is likely to lift the average yield in the eastern sector.

Table 3.1: Differing growth zones at the Howey site

Zone	Characteristics	Management options
A	A plateau of low to medium yield	‘Normal nitrogen’
B	Encompassing a slope between the hill plateau and the flats this zone has less topsoil and low yields	Reduce inputs (if practical)
C	Flats of more recent alluvial soils and soil removed by cultivation from the slope. It has soils with greater depth and higher yields	Increase inputs for most crops unless dry
D	Another area on the flats where water ponds and yields vary according to weather conditions.	Adjust timings/rates to suit season (moisture), implement drainage

Figure 3.1: Aerial photo of Howey site with differing growth zones identified

3.1.2 Soil/Plant correlations

There were no strong relationships in any year between seed yield and the measured parameters, perhaps because the better yields invariably occur in the same parts of the paddock. Moisture plays an important role in the response with best performing areas less affected by changes in moisture status during the season. The intermediate performing area (bottom right flats) suffers from drainage issues and relationship changes within the season mask the responses.

The plateau has lower general yields except in a wet season. Soil type is different on the plateau and the TDR measurements indicated generally lower soil moisture content in the plough layer. Better performing areas of the paddock tend to have more or earlier dry matter which leads to increased yield with better nitrogen/protein levels in seed, rather than the dilution of nitrogen through increased yield experienced on the other higher yielding areas. Lower screenings and increased seed weight, particularly in the 2001 barley, also occurred in the better performing zones. This may suggest another parameter such as disease has influenced this crop. A classic cation relationship of soil and plant K inversely affecting Ca, Mg, and particularly, Na uptake was exhibited on this site. This relationship was seen on the other two sites but may be more obvious here due to the low K levels.

The paddock also shows the positive Manganese relationship with soil moisture and inverse relationship with soil pH as noted on the other two sites.

3.2 West brothers

3.2.1 Summary of results

The brassica seed and wheat crops performed better in heavier areas (Wakanui soil) of the paddock, as shown by vigour and dry matter yield. This trend is partially due to slightly better nutrition in these areas, in addition to greater rooting depth and water holding capacity. Subsoiling may help where excessive moisture is an issue. It would pay for the northern areas to be irrigated more (lower rates, more often), especially the northern pass (of 4). More nitrogen (early nitrogen in particular) could be applied to these crops in conjunction with this. Occasional copper sprays may be of benefit, or apply copper every 3-5 years with maintenance fertiliser.

Heavier parts of the paddock were less suited to grass seed production because they result in vegetative growth continuing later in the season, at the expense of good seed production. Given that the paddock receives the same amount of irrigation water, control of irrigation is possibly the best to control vegetative growth. Plant growth regulators also work well in this role as does timing and rate of nitrogen use (see Howey results for more data).

In all three years, and during the 2000/01 season in particular, there seems to be yield loss due to dragging of irrigation hoses damaging the crop. The south east end of the paddock used for a track and is often wet by the neighbour's irrigation. It may be beneficial to permanently grass this area and designate it as a traffic zone where irrigators and machinery can be turned. The partial shelterbelt along the road was removed in 2000 as a result of observation of reduced yields prior to this study (possibly due to bird damage and/or competition for water).

3.2.2 Soil/Plant correlations

The results identify the strong influence of soil type in this paddock. The heavier Wakanui soil has higher natural soil magnesium levels, it is wetter and deeper therefore there are often relationships with soil depth and soil moisture retention. These soils also generally have better copper levels.

Wheat and brassica crops respond best in the heavier soils and yield for example is reflected in more vigorous and higher yielding crops. This tends to lead to dilution of manganese (wheat, brassica), protein (wheat) and boron (brassica) in crops.

There are good relationships with plant cations - plant calcium, magnesium, sodium tend to be better where there are lower soil and plant potassium levels. This reinforces established knowledge. Crop removal is demonstrated by lower yield effects around the paddock boundaries as demonstrated by higher soil test values in these areas, while higher yielding areas seem more depleted in organic matter. In contrast, data shows grass seed crops respond best in the lighter soil. This is because good seed yield relates well to early dry matter (these soils warm faster in the spring and seed yield is set early). TDR data shows that lighter areas are drier thus restricting later bulk. This explains why plant growth regulators work well on grass seed crops. Relationships were weaker with grass seed than the other crops, providing an indication of how many variables can impact on seed yield.

3.3 Ravensdown site

3.3.1 Summary of results

Early establishment and good plant vigour seem important to achieving good yields on this site. Soil moisture retention is important but because of the spatial variability it is not really possible to manipulate water to different parts of the paddock, rather water should be used more regularly and at lower amounts. Nitrogen (and sulphur) is important to sustain yield (even on a legume crop), the lightness of these soils means high nitrogen inputs are required for non-legume crops on a very regular basis. This is due in part to very high stone content of the soil and subsoil.

Culturally, weeds have the potential to become a problem if early dry matter production cannot help suppress them. Establishment of autumn sown crops is affected by shading caused by shelterbelts and seedbed preparation. As a consequence the type of cultivation has been changed and it is intended to change the type of drill. The biggest change is to remove trees close to the northern boundary and reduce the tree number on the east and southern boundaries. This coupled with tighter pruning of the main line of trees within each shelterbelt will reduce shading and competition for water and reduce nesting sites for birds which cause unnecessary damage particularly in the south east corner.

3.3.2 Soil/Plant correlations

The important relationships with crop yield are weak on this site, highlighting the large variability in soil depth across the paddock and the influence of shelterbelts on establishment and early growth. While disease has impacted heavily on the early data, results show that a healthy crop is generally able to take up all nutrients well. Hence in wheat parameters such as height and vigour reflect better yield. Well-established relationships such as plant cations (plant Calcium, Magnesium, and Sodium) are better where soil Potassium is lower, are shown in wheat as they are at West site. Similarly plant Manganese is inversely related to soil pH. The pea crop highlights that peas do not like wet feet with late water restricting seed weight.

3.4 Nutrient interactions

3.4.1 Importance of soil and plant nutrients

Good crop growth depends on an adequate supply of nutrients, primarily supplied from the soil. Regular soil testing for pH and macronutrients will ensure these nutrients (bar nitrogen and sulphur) are not annually limiting, or rising/falling to a degree that they cause nutrient imbalances. In addition, individual nutrients can be of differing importance to individual crops and their importance can alter with the stage of growth and the season.

Soil and plant nutrient levels were measured for this project, and the results were compared to crop growth indicators to identify any possible correlations.

As these soils have been farmed for some time soil pH and macronutrient levels have generally been lifted to reasonable levels. Potassium (K) reserves are good on the plains but can be marginal on the foothills in the Canterbury region. New Zealand soils are not grossly deficient in plant health trace elements and their main limitation will be an induced deficiency due to high pH (as measured in water). Some areas of Canterbury may be considered marginal in Copper (Cu), Manganese (Mn), Zinc (Zn) and Boron (B).

Listed below is some background to the importance of soil and plant nutrients, the interactions that can occur between soil nutrients, and normal plant nutrient levels.

3.4.2 Nutrient interaction guide

Figure 3.4 (right) depicts potential nutrient interactions in soils for example where an increase of one nutrient may lessen the availability of another.

Listed in Table 3.4a are some of the primary interactions that can take place between soil nutrients.

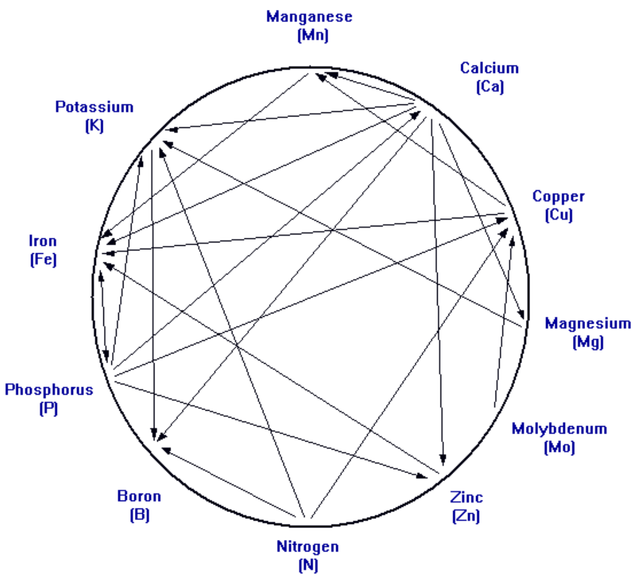

Figure 3.4: Nutrient interaction guide

Table 3.4a: Nutrient interactions

Main soil nutrient interactions	
A high level of:	**Reduces the availability of:**
Calcium	Boron and Magnesium
Potassium	Magnesium
Phosphorus	Zinc
Nitrogen	Copper

3.4.3 Guide to 'normal' herbage nutrient levels

The table below shows the 'normal levels' of plant nutrients for the four crops grown during the trial. Values usually have to be significantly below normal to be limiting to growth. Very high values may represent soil or spray contamination rather than toxicity.

Table 3.4b: 'Normal levels' of plant nutrient by crop type

Crop	Grass seed	Cereals	Brassica seed	Peas
Maturity	Active vegetative stage	Mid vegetative stage	Mid vegetative, preflowering	Preflower
Macronutrients (%)				
Nitrogen	3.5-5.0	2.5-5.0	3.5-5.5	3.0-4.5
Phosphorous	0.32-0.40	0.25-0.40	0.35-0.60	0.3-0.5
Potassium	2.0-2.8	2.2-3.8	2.8-5.0	1.8-3.0
Sulphur	0.25-0.40	0.16-0.40	0.5-0.8	0.2-0.3
Calcium	0.25-0.40	0.3-0.6	1.4-3.0	0.8-2.0
Magnesium	0.15-0.25	0.12-0.30	0.2-0.6	0.18-0.40
Sodium	0.12-0.50	<0.5	<0.5	<0.3
Micronutrients (ppm)				
Iron	50-70	30-100	50-200	40-100
Manganese	25-100	25-100	35-200	25-400
Copper	5-7	5-12	5-12	5-10
Zinc	15-25	20-50	20-70	20-50
Boron	6-12	5-10	25-40	20-40

Adapted from Reuter and Robinson 1998: Weir and Cresswell 1994; Kay and Hill 1998

3.5 Variable rate fertiliser trial

3.5.1 Background

In the last year of the project (2000/01) small ($10m^2$) plots, two per treatment were laid down in 3 or 4 different areas of each paddock based on variation observed in the previous two years. At West Brothers and Ravensdown sites the treatments compared the paddock nitrogen rate with an amount more and less than this amount. At the Howey site, being a spring crop, nitrogen had already been applied early so the response was to extra nitrogen. Sub samples of each plot were hand harvested for yield. However because of the large variation in results due to sample size, the results should be interpreted as indicative only.

The costs used in this analysis are based on urea at $395/tonne plus $8/ha to spread (application cost at the time).

3.5.2 Fertiliser trial – Results by site

Howey
Three areas were chosen, the better producing Western flats, the variably yielding Eastern flats and the average to lower yielding plateau.

Table 3.5a: Fertiliser rates and yield for Howey site

Treatment nitrogen/ha	Good Flats	Variable Flats	Plateau
Paddock average Base 105kgN, 30kgK	7.3t	7.1t	5.6t
High Extra 46kgN (cost applied $48/ha = 0.25t if barley $200/tonne	8.1t	7.5t	5.6t

Responses to extra nitrogen decreased from the highest yielding area to the lowest yielding area. It was economic to apply the extra nitrogen to the flats, especially the good areas in the West. Extra potassium was also applied to some areas.

There was no difference in yield on the flats although the plateau appeared to give some response to the extra potassium.

West Brothers
Four areas were chosen for these plots, approximately towards the North, South, East and West corners. Plots in the North, East and South corners represent the lighter and heavier soils respectively. In addition, in the Eastern sector a large area was subsoiled as ponding had previously been noted there. The East and South subplots fell into these zones.

Table 3.5b: Fertiliser rates and yield for West Brothers site

Treatment nitrogen/ha	North zone	South zone	East zone	West zone
Low 188kgN (106kgN less) (cost applied $99/ha = 0.44t$^+$)	13.0t	14.1t	11.8t	13.3t
Near paddock average Base 294kgN*	13.2t	14.2t	12.5t	14.9t
High 372kg N (extra 78kgN) (cost applied $75/ha = 0.33t$^+$)	12.6t	14.0t	13.5t	14.6t

*paddock actually received 330kgN/ha, $^+$ breakeven yield if wheat $225/tonne

On average the paddock actually received close to the most economic rate of nitrogen, but its distribution could have been improved. The southern areas with heavier soils yield the best and require less nitrogen to achieve this. In contrast the lighter soils on the North and East of the paddock have responded differently to nitrogen. There has been no response to nitrogen in the North area (this area perhaps needs more irrigation), whereas where the lighter Eastern soil has been subsoiled yield increases with increasing nitrogen. The paddock yield map also shows increasing yield relative to the previous years where the lighter soil has been subsoiled. The Western area has shown a good response to the paddock average nitrogen application but no more. These areas are medium textured and likely have good plant available water.

Ravensdown
Four areas were chosen for the plots in the North East and North West and South East and South West corners. The North East was in an area generally yielding better when in cereals and visually a better area than the other three when the plots were laid down.

Table 3.5c: Fertiliser rates and yield for Ravensdown site

Treatment nitrogen/ha	N-West zone	N-East zone	S-West zone	S-East zone
Low 138kgN (less 69kgN)	10.0t	11.2t	9.0t	9.6t
Paddock average Base 207kgN	11.0t	10.7t	9.8t	12.2t
High 276kgN (extra 69kgN) (cost applied $67/ha = 0.3t⁺)	10.4t	11.1t	12.1t	10.8t

⁺breakeven yield 0.3t if wheat $225/tonne

The north east area yielded the best with the lowest amount of nitrogen but only the southern plots responded to the extra nitrogen, in particular the south west corner. On average it was economic to apply over 200kgN but more money would have been made by from redistributing some nitrogen from the north of the paddock and applying it to the south of the paddock.

3.5.3 Conclusions from variable rate fertiliser program
Overall the results tend to suggest that the above average yielding parts of paddocks have the scope to be more responsive to nitrogen, however on lighter soils if moisture is most limiting and it can be addressed then these areas respond well to nitrogen. It may be that the heaviest parts of the paddock where moisture is less limiting are already close to meeting their yield potential.

4.0 Conclusions

Most data analysed throughout this project demonstrated the presence of variability in each paddock. The main underlying variability was in soil depth to stones (West Brothers, Ravensdown) or to clay (Howey), and subsequent variation in soil volume and the soil moisture holding capacity. While this often led to yield differences, the impact of this varied between seasons with the wetter third season being less variable than that displayed in the previous two seasons. Further, crops did not necessarily always perform better in one part of the paddock. In particular grass seed on two sites (Howey/West Brothers) in year 1 performed better on the lighter parts of the paddock but in contrast on these and the third site (Ravensdown), cereals (and rape seed) performed better on the heavier textured soils or where the soil was generally deeper. As fertility was good on all sites (except potassium at Howey site) this did not really impact heavily on yield, but as demonstrated at West Brothers site the crops nutrient uptake reflected the abundance of a particular nutrient in that particular soil type within the paddock. On all three sites higher soil and herbage potassium levels negatively impacted on calcium and magnesium herbage levels, and where soils were wetter and/or soil pH was lower, manganese levels were generally higher.

In terms of yield, on the Howey site the western flats always performed better than the steep slope and plateau and generally out yielded the eastern flats. The eastern flats often showed variable plant establishment leading to yield fluctuations, as a consequence of wet patches, the best remedy for which would be to improve drainage in these areas.

At the West Brothers site, the variation in yield followed the gradual change in soil type from south to north. Wheat and rape seed performed better in the heavier southern part and measurements such as height and vigour reflected yield well. It may be possible to manipulate water inputs across the paddock, on these crops a greater frequency of irrigation may help seed yields in the northern part of the paddock but with ryegrass which performed better on the lighter parts it may be wiser to reduce water inputs to the heavier textured parts of the paddock to reduce late vegetative bulk.

At the Ravensdown site, yield results were initially clouded by poor wheat performance in year one and the high variability in soil depth and stone content over very small distances. The large variation in soil depth and volume makes it difficult to simply change watering rates and frequencies across the paddock as a means of improving overall paddock performance. A further major limitation to performance was the shading effect of shelterbelts on the north and eastern boundaries. These severely limited initial crop establishment and their removal or thinning is seen as the best initial step to improving grower returns. Perhaps a consequence of this establishment was in the second and third year there was a tendency for the southern part of the paddock to perform better. Although the peas grown in year two suffered from wet spring conditions but still yielded reasonably well, further economic and yield improvements could have been made by differentially applying a second herbicide spray to the southern half of the paddock as the yield potential of the most vigorous areas of plants was reduced by weed competition.

In year three, small plots consisting of various nitrogen (N) rates were laid down in 3 or 4 zones in each paddock. Where possible these zones were identified from the yield maps as areas of different crop performance. At the Howey site the best responses to extra nitrogen on barley were given on the already best performing areas of the paddock. In this season this gave a 3:1 return for an extra 46kgN/ha applied on the western flats and a 1.5:1 return to extra nitrogen on the eastern flats. It was not economic to apply extra nitrogen on the plateau. If practical money could also have been saved by managing the steep slope as a lower input system, (e.g. lower nitrogen, lower seeding rate). At the other two sites on wheat, the addition of extra nitrogen gave the best responses in intermediate yielding areas, approximately a 2:1 payout at Wests for extra nitrogen and >3:1 at Ravensdown although the optimum nitrogen rate varied slightly for each area. These results suggested the best yielding areas were already close to their yield potential whereas the lowest yielding areas were limited by some parameter other than nitrogen, most likely soil moisture retention. While in both cases the paddocks received approximately the optimum amount of nitrogen, the results suggest the nitrogen could have been better distributed. Modern equipment such as variable rate fertiliser spreaders would allow you to do this.

In conclusion, this study has highlighted the possibility offered by precision agriculture for improved returns to growers. However the interpretation of yield data is often not simple with inputs for different management zones needing to be adjusted according to the crop type grown, the seasonal conditions encountered and the level of crop management applied.

A significant knowledge base is required with information such as yield maps, soil and climatic information, crop agronomy and equipment. Good starting points include knowledge of the soil type and landscape variation present, augmented by aerial photographs, detailed soil maps and some ground truthing. Regular soil and herbage sampling of different zones further enhances the information base, providing an indication of how best to manipulate soil nutrient status and adjust other management practices to best use the information gathered. New technology such as electromagnetic scans may also add to the database. It may be that the best gains can be made in drier years where more variation occurs within each paddock.

In this particular study, one common theme across each paddock was that the underlying soil characteristics in terms of soil depth, its moisture retention and drainage play a significant role in improving grower returns. This allows inputs such as nitrogen to be altered to best suit the agronomic requirements of the particular crop. Irrigation timing, rates and frequency could also be altered but this often poses logistical problems within a paddock. Similarly with some modern spray equipment, different zones could be differentially sprayed, most likely to support nitrogen and water changes, although on small paddocks typically cropped in New Zealand this has yet to be economically proven. This study has also highlighted potential one-off changes that can be made to a paddock to improve their productivity, for example improving drainage and removing shelterbelts. However, the benefits of actions such as shelterbelt removal have to be weighed against the reasons for their presence in the first place, such as wind erosion protection.

5.0 Acknowledgements

Project leader: David Howey
Science manager: Ian Yule
Agronomic coordinator: Murray Craighead
Additional organisations involved:
Ravensdown Fertiliser Co-op,
Massey University (New Zealand Centre for Precision Agriculture)

The project team would like to acknowledge the support of the following people and organisations:

David and Roger West
David and Jenny Howey
The Canterbury Precision Farming Group
Tim Phillips - Massey University, mapping
Andy Howie - Ravensdown Fertiliser Co-op, field and lab work
Tony Davoren - Hydro Services, irrigation scheduling
Clinton Rissaman - Soil characterisation
Ravensdown (Canterbury) field staff - herbage and grain sampling

This project was jointly funded by Agmardt, Ravensdown Fertiliser Co-op Ltd, Massey University and the Foundation for Arable Research (FAR)

6.0 References

Reuter, D.J. and Robinson, J.B. (eds.) 1997: Plant analysis: an interpretation manual (editors D.J. Reuter, J.B. Robinson; assistant editor C. Dutkiewicz). Collingwood, Victoria, CSIRO Publishing.

Weir, R.G. and Cresswell, G.C. 1994: Pastures and field crops. Biological & Chemical Research Institute, Melbourne.

Kay, T. and Hill, R. 1998: Field consultants guide to soil & plant analysis, R.J. Hill Laboratories Limited, Hamilton, NZ.

Appendices

Appendix A: Detailed results for Howey site

A-1: Base fertility

Soil tests were taken in 1998 well after crop establishment, 0-15cm depth at each grid point. As on the other two sites sulphate sulphur was not measured.

pH: Values varied from 5.6-6.9 with most in the 6.1-6.2 range. These did not drop too much through the three years due to higher clay contents and the lower use of nitrogen compared to the other three paddocks. In general no crop will be hindered by low pH although barley may be slightly restricted in patches while trace elements could potentially be less plant available at high pH zones.

Calcium (Ca): all values are good and reflect soil pH.

Phosphorus (P): wide range from Olsen P 14-79 although most are in the 20'. Values are lower across the slope (<20). Crops have received phosphorus each year. Soil phosphorus was particularly related to soil N, organic matter and K levels.

Potassium (K): range QTK 2-12 with most of the paddock 3-4. These are low. As the soil potassium reserves are medium these are to be expected. Potassium is expected to limit growth, hence it should be applied annually.

Magnesium (Mg): all levels are good for plant health, range QTMg 11-28.

Organic Matter (OM): levels are classified as low (3-6.5%), a reflection of the history of cropping. Soil available N levels follow a similar pattern to the organic matter.

As a general rule the upper terrace has the lowest fertility. One area below the slope and in a wetter area has the lowest pH, but the highest phosphorus, potassium, magnesium and organic matter levels.

A-2: 1998/99 Results

Crop - Autumn sown grass seed

Received: 30kgP (autumn), 188kgN split 3 times (autumn, spring)

Dry matter in October was less than at the West Brother's site due to a later sowing date and shorter variety. There was generally more growth on the central part of the flats and the plateau. Plant population and vigour was lower on the slope and in isolated wet patches.

Herbage nutrient levels were good with the exception of potassium, which was to be expected, while sodium levels fluctuated wildly but were not excessive enough to cause toxicity problems.

Herbage nitrogen was related to soil organic matter and nitrogen and to soil and plant potassium and soil phophorus levels.

Plant potassium levels tended to be lower on the slopes and the lowest part of the paddock. They were strongly related to soil phosphorus levels.

Seed yield was highest in the Western half of the paddock bar the steep slope, in particular the flats. However there was one week's difference in windrowing the paddock between this and the other half indicating this was also important in determining yield. Accordingly there was no relationship between early dry matter and yield as there was in Wests crop. However yield was inversely related to plant nitrogen (r=-0.34). Yield was best reflected by improvements in grain weight.

A-3: 1999/00 Results

Crop - Autumn sown feed wheat (Belfield)

Received: 30kgP, 39kgS (autumn), 184kgN split 3 times (September-October), plus development 60kgN, 40kgP, 40kgK, 30kgS in October

Seed yield was reasonable for a dryland site and was highest on the flats in particular the western area (Zone C) following the better soil though this is not the deeper slumped soil under the slope. As in the previous year there are pockets of lower yield in the wetter ponding areas in the east of the paddock. Measured yields for wheat in 1997/98 showed a very similar pattern. None of the fertility measures were related to yield differences although in general lower yielding areas had better protein levels. Overall, protein levels were good and there was only 2% difference across most of the paddock. Dry matter in mid October was related to protein levels rather than yield. The disease 'Takeall' may have had some impact on yields, particularly on the plateau.

Herbage samples taken just prior to the last nitrogen application at the mid vegetative stage showed very good nutrition, except for potassium. Herbage nitrogen levels tended to be better in the western part of the paddock whereas potassium levels were not. To some degree magnesium and a lesser extent calcium are better in the deeper areas of topsoil.

A-4: 2000/01 Results

Crop - Spring sown barley

Received: 30kgP, 30kgK, 22kgS and 105kgN in 2 splits (October)

Seed yields were reasonable but a lot less variable than when in other crops in the previous three years. The spring climatic conditions were very good while later as it turned quite dry, premature senescence may have evened the crop. In general the western part of the flats had consistently more of the higher yielding areas and the eastern portion had more variable areas. Grain nitrogen levels were on average suitable should malting have been an option and most did not vary greatly across the paddock. Yield was not strongly related to any measured parameter, despite early dry matter leading to a taller crop and more seed heads.

Herbage levels taken prior to ear emergence were good although potassium levels fluctuated and were generally slightly low. Soil nitrogen levels were related to grain nitrogen levels and not yield suggesting that moisture prevented full yield potential being met.

Appendix B: Detailed results for West Brothers site

B-1: Base fertility

Soil tests were taken in late winter 1998 well after crop establishment (and planter fertiliser was applied), 0-15cm depth at each grid point. Sulphate sulphur was not measured as the levels would fluctuate over the three year period of the trial and hence results would be meaningless. The crops on this site received S in their base fertiliser dressing at the beginning of each season.

pH: soil test levels ranged from 5.7-6.9 with the majority in the 6.1-6.2 range. Even allowing for a drop in pH with nitrogen use over the period of the study, none of the crops grown is likely to be restricted by low pH. There may be isolated pockets where high pH is reducing plant availability of trace elements.
Calcium (Ca): results are all good and follow soil pH.
Phosphorus levels (P): Olsen P levels range from 18-73 with the majority in the 20-30 range. The levels are slightly higher in the NW corner. The crops are unlikely to respond to P at these levels, especially given that the crops also received pre-plant P fertiliser in 1999 and 2000.
Potassium (K): range QTK 7-18 with the results tending to be higher in the lighter part of the paddock. This is to be expected as Eyre-Paparua soils have higher soil reserves of potassium and than Wakanui soils, although the Wakanui soils still have good reserves.
Magnesium (Mg): range QTMg 18-37, with most in the 20'. The lowest is in the middle of the Western boundary. All Mg levels are very good for plant and animal health. Magnesium levels are strongly related to soil type, with values highest in the Wakanui soil.
Organic Matter (OM): range 4.5-8.7, with most 5-6%. The lowest tend to be near the road along the Southern boundary. These would be classified as low a recognition of the soil and its past history of cropping. Potentially pugging is a problem in the Wakanui soils.

Individually, fertility is much higher around an old tree site (higher P, OM etc) on the western boundary.

B-2: 1998/99 Results

Crop - Autumn sown Perennial Ryegrass for seed (Nevis)

Received: 44kgP, 57kgS (autumn), 184kgN split (autumn, spring)

Dry Matter was measured in October after the crop was closed for seed production. Highest dry matter was in the lightest part of the paddock (North), probably because the soil warmed earlier in the spring and hence growth was more advanced. There was a reasonable relationship with final seed yield as compared to the heavier southern part of the paddock which kept growing. Reproductive tillers are set early, so the southern end is likely to have more late tillers, which are vegetative tillers.

Herbage
Herbage was sampled three weeks after dry matter production. Overall herbage nutrient levels are very good and they generally reflect the underlying soil type. The only trace element that could be classified as low is copper but for this crop it appears adequate. In general, soil and herbage values are related to soil values for phosphorus, potassium, calcium and magnesium, however nitrogen has a much looser relationship with soil available N and is not that strongly related to organic matter content.

Herbage nitrogen levels had started to decline by the sampling date when the crop had bulked up (by this stage all nitrogen had been applied) and there was an inverse relationship with early dry matter, ie the early growth diluted the herbage nitrogen content. Herbage phosphorus levels tend to be better in the wetter part of the paddock. They are strongly related to the calcium, magnesium, sodium levels and sulphur levels, generally a reflection of the medium textured parts of the paddock. Herbage calcium and magnesium strongly mimic each other, the lowest results being in the lowest parts of the paddock.

Potassium levels are positively related to soil nitrogen and organic matter levels and tend to be highest in the lightest part of the paddock.

Seed Yield
The higher yield on the lighter areas is consistent with our current knowledge of grass seed production and probably reflects early dry matter and setting of reproductive tillers. Yield is generally inversely related to plant N (r=-0.27) and soil moisture, probably as the wetter areas have more vegetative growth (less reproductive tillers) and the extra bulk makes it difficult to harvest all seed.

Grain weight
Grain weight is highest in the lighter and western parts of the paddock where yield and early dry matter are higher. Grain weight is negatively related to soil moisture, possibly wetter areas have late vegetative growth causing delayed maturity of seed heads.

B-3: 1999/00 Results

Crop - Autumn sown Brassica rape for seed

Received 40kgP, 95kgS (autumn), 320kgN split 5 times (July-Sept)

Seed yield was good and strongly followed the soil type with the highest yields being in the Southern (heavier) areas of the paddock. Height and density (vigour) of the crop at early bolting were good predictors of yield. Because yield followed crop density this map was the complete anthesis of that for grass seed. Soil conductivity related well to final yield.

Herbage samples taken at the same time indicated again very good crop nutrition. Brassica crops in particular respond to phosphorus and boron as well as nitrogen. Although there was a good relationship between yield and phosphorus (as there was with calcium and magnesium) there was not with boron (or potassium). As all nutrient levels were good, the crop in effect is luxuriously taking up nutrients from those areas where the particular nutrient is more abundant. The heavier Wakanui soils have higher herbage nitrogen levels reflecting high nitrogen usage, possibly accounting for why there was little relationship between yield and soil or available nitrogen. Magnesium content was positively related to most other nutrients and parameters measured. 1999/00 was known for transient magnesium deficiency in Mid Canterbury, and as magnesium forms part of the chlorophyll molecule this is partly a reflection of stop/start spring growth due to low spring temperature and lower sunshine hours.

B-4: 2000/01 Results

Crop - Autumn Sown Feed Wheat (Savannah)

Received 44kgP, 57kgS (autumn), 330kgN split 5 times (July-Oct)

The crop was sown early and this contributed to the high seed yields. As in the previous year's brassica seed crop the best yields occurred in the heavier part of the paddock. The application of subsoiling to a 100m strip across the paddock in the eastern section may have accounted for the best yielding area being greater across the paddock (see yield map). The spring weather conditions were kind with good early rain and a constant gradual increase in soil temperature. Hence the variation in yield was not as great as expected. Most of the lower yielding areas related to edge effects caused by excessive irrigation and placement of spray lines. On the eastern border lower yields could be related to compaction from farm vehicles, compounded by extra irrigation from a neighbouring paddock.

Crop height at ear emergence and early season dry matter related well to yield as did light interception and a lesser extent to head number and grain weight. This indicates that early vigour (but not excessive tillering causing too much vegetative growth) was conducive to high yield.

Grain protein levels were low to medium (not that applicable to feed wheat) and were inversely related to yield and grain weight indicating that the paddock was reasonably even in nitrogen (high nitrogen rates were used), so that high yield diluted grain protein and pinched grain had higher protein levels.

Herbage

Herbage samples were taken at ear emergence, so the levels would be expected to be at the lower end of the leaf standards presented and this follows for all the macronutrients (nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, sodium) and copper, manganese and zinc. There are odd low values dispersed across the paddock, particularly for manganese and zinc which could be related to higher pH and in general copper levels are low. This was to be expected on some lighter parts of the paddock and while a subclinical deficiency may occur in some areas, some of the reason is genetically (cultivar) related.

Soil conductivity has not been reflected in grain yield but has some relationship with dry matter. It is very strongly related to the cations (positively charged elements) in the herbage such as potassium, magnesium, calcium, sodium, zinc, and manganese.

Appendix C: Detailed results for Ravensdown site

C-1: Base fertility

Soil tests were taken in 1998 well after crop establishment, 0-15cm depth at each grid point. As on the other two sites sulphate S was not measured. The crops on this site received S in their base fertiliser at planting or in their first N topdressing.

pH: range 6-7.1, all are quite high and on this soil some areas could have low plant availability of trace elements. Otherwise pH will not hinder crop performance.
Calcium (Ca): all are good and reflect soil pH. Both Ca and pH values are higher in the southern half of the paddock.
Phosphorus (P): range Olsen P 15-52, most are in the mid 20'. These will not restrict growth, particularly as P was also applied in 1999 and 2000.
Potassium (K): range Quick Test K 5-16, and if anything the middle of the paddock has lower results. Despite some areas being 5-6 the crops grown are not expected to be responsive to K, especially as this soil has high reserves of K.
Magnesium (Mg): range Quick Test Mg 14-22, in general results are fairly even across the paddock and will not restrict plant growth.
Organic Matter (OM): range 3.2-5%. This is classified as low but is perhaps not as low as expected considering this is the lightest of the three paddocks in the study. Values highlight a gully across the middle of the paddock and in general values may be slightly higher in the southern half of the paddock.

The highest general fertility area lies near an old water trough.

C-2: 1998/99 Results

Crop - Autumn sown Milling wheat (Monad)

Received: 25kgP, 30kgS (in spring), 240kgN split 4 times (Aug-Nov)

Crop establishment was acceptable except in the North-east corner. Early (October) dry matter measurement showed the highest values in the Southern and Eastern areas, the most protected zone from cold Southerly winds in winter.

Herbage
October herbage sampling indicated plant nutrition was good. Values did not appear to vary too much across the paddock, although there was a significant area in the central north of the paddock that had higher values, in particular of trace elements. Possibly the most limiting nutrient at the time was nitrogen although further nitrogen was later applied to the crop. Nitrogen was generally higher around the edge of the paddock. This closely mimicked the soil available nitrogen levels.

Herbage calcium levels were closely related to magnesium but not to potassium. Potassium was closely related to most other nutrients, in particular phosphorus, sulphur, manganese, zinc and to a lesser extent magnesium, perhaps a reflection of the higher general fertility in the middle of the paddock.

Depth to gravel
Depth to gravel was closely related to regular soil moisture readings and to early dry matter, the latter possibly because irrigation started slightly too late.

Yield
Yields were exceptionally poor achieving only half of what the same cultivar achieved in the same paddock several years earlier. This was largely attributable to premature crop senescence in December perhaps due to some unknown disease, this despite a full plant protection programme. Observations of other Monad crops indicate that there may have been a problem in December with high ambient temperatures resulting in poor pollination. The whole paddock was affected so interpretation of results for this season is difficult. The best performing areas were on the western boundary and the central part of the paddock. Grain protein was related to yield but inversely related to grain weight indicating that pinched grain restricted yield and grain protein was not diluted out with yield. Grain weights were low (37-40mg) and grain protein very high with many above 15%. Amongst the lowest yielding areas were inside the two main gateways where bird damage was bad and on the second irrigation line where excessive crop was lodged at the southern end.

C-3: 1999/00 Results

Crop - Spring sown Field peas

Received: 22kgP, 25kgS, 33kgN (split in spring)

Field pea yields were good but had the potential to be better. Yields were higher in the southern half of the paddock. The lowest yields were at the soil extremes, in the general area of the deeper soil channel and where a stony ridge was evident, ie yields were better in the slightly lighter parts of the paddock. Crop yield was related to seed weight and higher yielding areas generally had less disease and more plant vigour. As seed weight was inversely related to soil moisture it suggests the plants did not like wet feet towards maturity.

It was the late spring was relatively wet and this was reflected in two ways; plant nutritive values and in secondary weed infestation.

In general plant nutrient uptake was poor for most nutrients, in particular potassium and boron, two nutrients to which peas are susceptible and copper. These soils are known to be marginal for copper. Boron levels were related to soil moisture conditions and may not have impacted on yield as much as they would in a dry season. Magnesium levels were also low, a reflection of the cooler, overcast conditions. As a general rule if sulphur levels were good, the level of most other nutrients was good (bar nitrogen).

Weed regrowth was worst in the southern part of the paddock where plant vigour was good, however it was the intermediate areas for vigour that ultimately yielded the best, suggesting a second weed spray would have been worthwhile. Subsequent analysis showed that a 0.3t/ha yield increase would have paid for this weed spray and would have been justified in the southern half of the paddock. Plant disease pressure was inversely related to nitrogen, phosphorus, potassium and sulphur nutrition and plant vigour. Overall climatic conditions played a large part in the results.

C-4: 2001/01 Results

Crop - Autumn sown Feed Wheat (Hussar)

Received: 30kgP, 40kgS (autumn), 207kgN split 3 times (Aug-Nov)

Plant establishment was patchy over much of the paddock and extremely poor on the North and Eastern boundaries. The reason for the poor initial establishment was very wet conditions in the lee of the shelterbelts, and subsequently less winter sun reached these parts of the paddock. Some slug damage was also experienced during this season. Subsequently these areas (along with the western boundary part of which had not been sown), were resown 6 weeks later. Despite this yields were quite good, however there was a drop in yield around the boundaries of 1.5-2 t/ha for the delayed sowing as the wheat was an English variety that required true winter vernalisation. Otherwise, the good spring conditions meant there was less variation in yield across the remainder of the paddock.

Early dry matter was reflected in the number of ears and the crop height which less directly reflected yield. Grain protein levels were low to medium, one of the lowest value areas corresponding to the lowest overall fertility point. Values fluctuated widely across the paddock indicating the variability in soil depth. The best areas had high nitrogen and general fertility and had lower grain weights.

Herbage samples taken at ear emergence were as expected at the lower end of the standards presented. As with the West crop there were some low zinc and manganese levels as well as some slightly low potassium levels. Magnesium levels although slightly low were typical of those found in Canterbury. Again if plants had good sulphur nutrition they were invariably high in other plant nutrients.

The results perhaps suggest more nitrogen could have been used on the paddock and that because the soil is light more early nitrogen is required.

Appendix D: Papers written on project

Craighead, M.D. and Yule, I.J. 2001. Opportunities for increased profitability from precision agriculture. Geospatial Information and Agriculture Conference, 17-19 July, Sydney, Australia.

Craighead, M.D. and Yule, I.J. 2001. Agronomic Interpretation of Precision Farming Maps – some results from a Canterbury Arable Farming Study. In *Precision Tools for Improving Land Management* (Eds L.D. Currie and P. Loganathan). Occasional Report No. 14. Fertiliser and Lime Research Centre, Massey University, Palmerston North. Pp 147-152.

Craighead, M.D. and Yule, I.J. 2000. Preliminary results from a precision agriculture study, Canterbury, New Zealand. Proceedings of the Australasian Soil Science Society, Lincoln University, New Zealand Nov, Vol. 2, 129-131.

Yule, I.J. 2001. The role of precision agriculture in improving land management in New Zealand. In *Precision Tools for Improving Land Management* (Eds L.D. Currie and P. Loganathan). Occasional Report No. 14. Fertiliser and Lime Research Centre, Massey University, Palmerston North. Pp 7-16.

Yule, I.J. 2001. The application of remote sensing and GIS for improving vineyard management. Geospatial Information and Agriculture Conference, 17-19 July, Sydney, Australia.

Yule, I.J. 2001. RTKGPS and Autodesk land management desktop; A powerful combination for rapid accurate surveying and land development planning. Geospatial Information and Agriculture Conference, 17-19 July, Sydney, Australia.

Yule, I.J., Pratt, J.P., Craighead, M.D. and A. Gillingham. 2000. Precision Agriculture in New Zealand. 4th Annual Symposium, *Precision Agriculture in Australasia*, August, Sydney, Australia.

Appendix E: Field Days for farmers outside the group

Ministerial visit, Rt Hon Jim Sutton - Minister of Agriculture, 10 May 2002 (Howeys)

Agmardt Precision Farming Project, FAR field day 27th November 2001 (Howeys)

Canterbury Precision Farming Project, FAR field day 30th November 2000 (Howeys)

Canterbury Precision Farming Project, FAR field day October 2000 (West Brothers)

Precision Farming, Ravensdown Seadown Open Day, 16th November 1999 (Ravensdown)