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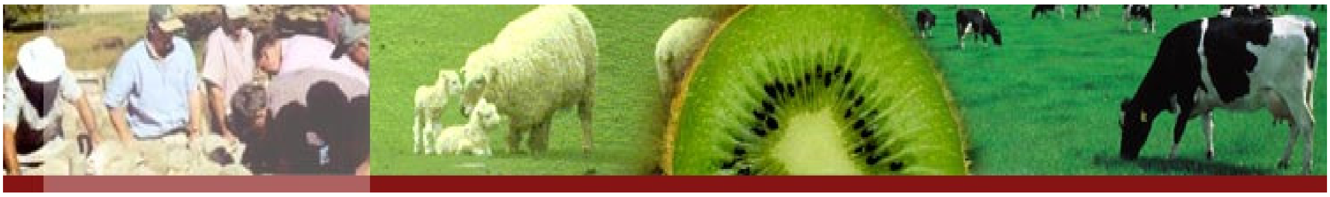

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Soil Properties on ARGOS Dairy and Sheep & Beef Farms 2005-6

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1 Executive Summary

Dairy and Sheep & Beef farms were sampled in 2005 for assessments of soil quality within differing production systems. For the Dairy sector, 10 clusters consisting of matched Converting (to organic) and Conventional farms were assessed (20 total) whilst for the Sheep & Beef sector, 12 clusters consisting of Organic, Integrated and Conventional farms were sampled (36 total). The majority of Dairy sector farms were located within the Taranaki and Waikato regions whilst Sheep & Beef farms were mainly located along the eastern half of the South Island from Marlborough to Southland.

Soil chemical tests for both Dairy and Sheep & Beef sectors revealed declining P and S test levels in Converting (to organic) and Organic farms although for Dairy, the majority of farms still exceeded recommended guidelines and the 90% percentile of producers (Olsen-P >40 mg P/ml). There was slight evidence that residual build-up of RPR may be occurring in Converting Dairy farms but none in Sheep & Beef Organic farms. Evidence of higher soil pH, soil-C and C/N ratios for Dairy Converting farms probably signifies both greater root inputs of C to SOM and less mineral-N from the withholding of N fertilisers contributing to lower rates of carbon turnover than in Conventional systems. There was no similar trend for Sheep & Beef farms, however, possibly due to the lower intensity of their systems. Dairy farm systems showed no significant differences yet in exchangeable cations but for Sheep & Beef farms there was some evidence of the longer-term changes in fertiliser use. For Organic systems there was lower exchangeable-Ca but higher exchangeable-Mg than for Conventional systems, probably from lower Ca inputs from the withholding of Ca-based fertilisers and lower stocking rates decreasing leaching losses of Mg in comparison with Conventional farms. Lower exchangeable-K values in Organic and Conventional systems were not of concern but Organic systems especially, will need to be mindful of any long-term decline.

Differences between landforms were more significant with increased P, organic-S, Total-N and exchangeable Mg, K and Na (or a combination of) in crest sites for both Dairy and Sheep & Beef farms. These increases are created mainly by nutrient transfer in excreta to stock camp sites, from slope areas in particular. Whilst these processes are well recognised, Organic farms have fewer options than Conventional farms to mitigate these effects within their farm landscapes.

Measures of biological properties showed that despite Dairy Converting farms only being 1-2 years into conversion to full Organic, there was a small, but significant, difference between the systems in microbial-C. Together with increased soil C/N ratios, this suggests that the withholding of N fertiliser in conversion to an Organic system may be leading to increased root exploration (or conversely, a reduction in root mass under heavily fertilised pastures) and greater root-C inputs leading to increases in soil microbial biomass. In the regression relationship between microbial-C and soil-C% for Sheep & Beef, Integrated farms were found to be significantly higher than for the other two systems which may be related to Integrated farms having higher overall levels of soil fertility and inputs. No differences were found for microbial C or N on a per unit weight soil-C basis despite the differing management systems having been in place for some years. Respiration results showed small, but significant, increases for basal respiration and metabolic quotient (measure of microbial efficiency) for Converting over Conventional Dairy systems but no differences after urea application. No significant differences or trends were found in respiration rates between Sheep & Beef systems.

No differences in biological properties between landforms were found for microbial-C or –N in Dairy landforms. Respiration rates were higher on slope landforms after urea application, possibly indicating greater stress on these areas. Higher metabolic quotients before and after urea application may also suggest a degree of microbial stress but this requires further corroboration. For Sheep & Beef landforms there was an increase in microbial-N on crest landforms in Conventional farms but not for Organic or Integrated farms. There were no differences between Sheep & Beef landforms in respiration rates (for soil or soil-C) or metabolic quotient.

Soil physical conditions were assessed using mainly visual soil assessment (VSA) but with most farms having generally good-to-excellent scores, finding significant differences for either Dairy or Sheep & Beef sectors was difficult. Differences approached statistical significance for soil porosity and earthworm numbers ($P \approx 0.06$) where they were higher for Dairy Converting and Conventional systems, respectively. Sheep & Beef systems had higher overall porosity and aggregation and fewer mottles than Dairy systems but like Dairy, Organic systems tended toward higher soil porosity than Integrated or Conventional that may reflect lower stocking numbers. Differences between landforms were more clear-cut and statistically significant with flat landforms in both Dairy and Sheep & Beef showing greater signs of soil compaction (reduced porosity, higher BD) and in Dairy, reduced earthworm weights.

2 Introduction

Soil is both literally and figuratively the foundation of modern agricultural and horticultural production and soil quality monitoring is a key component of the environmental and sustainability objectives of ARGOS. Assessing soil functional capacity requires measuring various soil chemical, physical and biological properties, selecting indices and setting indicator values. Although this might appear fundamental to determining “soil quality”, its a more relative measure than we might think and depends on the system under consideration. Soil quality will differ from system-to-system and region-to-region, initially because of the prevailing soil forming factors (climate, relief, topography, parent materials, organisms and time) instrumental in the soil’s development and the properties they impart to the soil. Consequently, soils will differ in their sensitivity to land management practice and their resistance to management pressures under a set of production goals (Condron *et al.* 2000; Goh *et al.* 2000; Kay *et al.* 1998; Sparling and Schipper 2004). When assessing soil quality in NZ systems we need to bear this subjectivity in mind.

Management practices likely to have the greatest impact on pastoral soils are those closely associated with soil nutrient status (different fertilizers may be used) and stocking rate (Condron *et al.* 2000; Reganold *et al.* 1993; Shannon *et al.* 2002; Stockdale *et al.* 2002). There is a restricted range of fertilizers available for organic producers and soil chemical analysis is important to determine if soil nutrient status is being sustained. Changes in soil nutrient status may affect pasture production or composition, and in turn, stocking rates or systems to accommodate changes in feed availability. Flow-on effects to soil biological processes and physical condition can occur from these changes.

Characterising differences in soil properties between different farm management systems and relating these to soil quality and sustainability is the chief objective of the soil monitoring program. This report builds on last year’s ARGOS Sheep and Beef (S&B) sampling by repeating a number of measures in 2005 and including Dairy as an additional sector in the program.

3 Monitoring approach

The 2005 program’s approach to soil quality monitoring largely mirrored that of 2004 in using a suite of chemical, biological and physical tests of soil properties in the field and laboratory to characterise soil condition. As such, this section is largely repeated from Pearson et al.’s (2005) report, albeit somewhat modified. The choice of soil quality indicators, and the techniques used for those indicators remain strongly influenced by:

The need to cover a range of biological, physical and chemical aspects using techniques that are consistently repeatable, preferably simple and can withstand scientific scrutiny;

A need for continuity wherever possible to enable historical comparisons; and

They have relevance to users and encourage them to base decisions on meaningful and reliable soil quality indicators throughout their operations.

The overall ARGOS approach is to concentrate on groups (clusters) of commercial farms that are under the target management systems and are in close proximity. To mitigate the effects of large spatial variability, paddocks were selected that represented the dominant landforms within each cluster using permanent soil monitoring sites (SMS). This scheme is especially good for comparisons between agricultural and management systems (the prime aim), but is weak for characterising whole farms. Establishing permanent long term monitoring sites and sampling and test guidelines for each sector is essential to ensure continuity and consistency are maintained throughout the ARGOS program. With expectations that the program will continue to monitor sites for between 5 and 20 years means that the robustness of comparisons needs to be ensured at an early stage, especially if the focus shifts to the effects of management systems on differences between individual farms.

3.1 Structure for describing levels of focus

The prime aims are to compare:

Between agricultural systems;

Between management systems within agricultural systems.

3.1.1 Agricultural System

This is the agricultural production systems being monitored and now includes dairy, high country and Ngai Tahu Land Holdings in addition to kiwifruit and sheep & beef farms. Dairy and sheep & beef (repeated measures) form the focus of this report.

Management System

Management systems compare the “status quo” or conventional with low input systems such as organic or those that conform to a management protocol required by the buyer for customer requirements (eg. integrated).

For dairy the management systems compared are:

Conventional

Converting (to organic)

Where Converting represents farms that are partway through the 3-year conversion process to full organic certification.

For sheep and beef properties, the three management systems are

Organic Use accredited organic production protocols and have achieved organic accreditation status.

Integrated Production is by way of industry protocols that although not to organic status, may require reduced pesticide and herbicide use, higher environmental performance and/or animal welfare standards.

Conventional Status quo

Cluster

A cluster is a set of three properties, one of each management system. The properties within a cluster are within close geographic proximity with similar landforms, soil type and climatic conditions. For dairy there are ten clusters located in Waikato (6) and Taranaki (3) and Manawatu (1). For sheep and beef agricultural system there are 12 clusters located throughout the south island from Marlborough to Southland but broadly grouped into three regions; upper (2-USI), central (5-CSI) and lower (5-LSI) South Island.

Property

Properties are the individual farms that make up the cluster. Dairy with its 10 clusters and two management systems has 20 properties. For sheep and beef, we are monitoring three management systems in twelve clusters (3 x 12 = 36 properties). Cluster 12 has an additional integrated property, taking the total number of properties to 37.

Landform

This term is used to describe the different geomorphology within a property. The principal landforms monitored here can be broadly described as river terrace (flats), hill crest (crest) and mid-slope (slope). Given the huge variation in soils and landscape across the properties being studied, here we study the two most dominant of these landforms within the cluster. For hill country clusters, the same two landforms will be studied on each property. For clusters on the Canterbury Plains, or river terraces of Taranaki and Waikato, only one landform (flats) will be studied.

Management Unit

Management unit (MU) is the smallest land area to be managed by the farmer on an individual basis and for both sheep & beef and dairy farms this constitutes a paddock. For each landform, three management units (paddocks) will be monitored. Thus on the hill country farms, six paddocks (two landforms each with three paddocks) will be monitored. On the flat land farms with only one landform present (Canterbury Plains), three paddocks will be monitored.

Paddocks or MU's were chosen randomly from farm maps but had to be stratified similarly for farms within the same cluster so that they had common slope, topography, aspect, and altitude across landforms as mush as possible. Where possible, paddocks from different areas of the farm were selected, however this was constrained by the amount of information from farm maps. Airstrip and dedicated hay or silage paddocks were excluded because of their unique land use within the farm.

Soil Monitoring Site (SMS)

Within each management unit three soil monitoring sites (SMS's) were randomly selected and their waypoints recorded for future return as permanent SMS. To qualify as a SMS all had to meet the following criteria:

Further than 5 metres from a fence

Further than 30 metres away from trees, troughs and gateways

Not a waterway, pond or swamp

Not a unique landuse e.g. rubbish site

Where more than one landform was present within a paddock, selection of SMS's were from the dominant landform. This was not achieved in 2004 which meant no comparisons of landforms could be made. Numbers of SMS's for each farm varied according to the number of landforms present multiplied by the number of paddocks (3) and the number of replicates (3) eg. farms with three landforms will have 27 SMS's. Visual soil assessment, soil bulk density and soil texture samples were taken for each SMS but for all nutrient and biological analyses the three SMS samples representing a single MU were bulked prior to analysis.

3.2 Statistical analysis

The results were analysed using analysis of variance using Genstat version 8.0 (Lawes Agricultural Trust, 2003) using an unbalanced ANOVA approach. This was necessary to gain the greatest possible number of data points and where balanced comparisons were possible, results did not generally contradict those of the unbalanced ANOVA. The data for ANOVA was structured with the following hierarchy:

Sector

Management system/Region

Landforms

Cluster number

Management unit (replicate)/ SMS's within management units (replicate)

The main factor analysed was Management system, which was applied at the property level but was cross-checked against Region to detect any significant differences due to soil locality. The management system is applied across the entire property, so the MU's (paddocks) represent repeated measures within the property. Within systems, landforms was also analysed in contrast to the previous year where it was not possible because of the mixing of soil within paddocks from different landforms.

Soil porosity, discolouration and aggregation were scored on a 1 to 4 scale (ordinal data). However more than 97% were scored at 1 or 2, so the data was converted into binary scores with scores of 1 becoming 0, and scores of 2 or more becoming 1. Soil porosity, discolouration and aggregation data was collected at the SMS level and analysed using a generalised linear mixed model (GLMM) with a binomial distribution using a similar hierarchical structure as described above. The results from the SMS's were nested within the management unit and therefore property, and considered as repeated measures.

Chemical soil tests, where appropriate, were transformed to both volume (ha; 0-7.5 cm) and weight (per kg soil) units and are presented in separate tables. Biological measurements, because of their inextricable links with soil organic matter (SOM) are presented on a per unit weight soil carbon basis. Means, coefficient of variation (CV%), and the range of values are given for each variable. Least significant differences to the 5% level ($LSD_{0.05}$) are given for data that is normally distributed. If the difference between treatment means are greater than the least significant difference, there is a less than 5% probability these differences are due to a random effect.

Soil quality indicators

In order to select the most appropriate set of soil quality indicators, we reviewed the extensive literature. We gave priority to techniques that were:

Appropriate for all the management systems to be studied in ARGOS;

Precise, reproducible and scientifically defensible;

Sensitive to management practice;

Biologically, physically and chemically meaningful in an agricultural context;

Rapid and affordable, so that good levels of replication can be achieved;

Readily adoptable for routine use by land managers;

Already well-used in the literature, so that comparisons could be made readily published results in NZ and overseas.

A range of qualitative and quantitative soil quality indicators were chosen and prioritised. The higher the priority the more essential the index is. Indicators in priorities one to three are being monitored on a regular basis at all sites. Some lower priority indicators may be used only for detailed studies at selected sites and time, to help our interpretation of trends observed in other measurements.

Soil quality at each site will be defined by the initial set of measurements. The effect of subsequent changes in management can be observed as changes in soil quality relative to the initial measurements.

3.3 Priority One

The first priority indicators are a suite of meaningful field observations that can be integrated into one or more soil quality scores. Most are qualitative or semi-qualitative visual assessments rather than quantitative, and are undertaken by the ARGOS field officers. To ensure repeatability, the field officers are trained in the same manner and calibrated against each other. Regular standardization of the visual soil assessment by the field officers (as paired observations) will be required to ensure consistency. The qualitative visual observations will be supplemented by simple quantitative measurements. Priority one measurements were conducted at each individual soil monitoring site.

Qualitative soil measurements

Key soil parameters are assessed based on pictorial comparisons. The visual parameters assessed are

Area of exposed soil (%)

Amount of soil covered in live vegetation (%)

Pasture cover (kg DM/ha)

Area of crusted soil (%) and thickness of crust

Area damaged by vehicles, stock or erosion (%) and approximate depth

Presence and thickness of surface organic thatch build up

Soil porosity (1-4 scale)

Soil discolouration by mottles or other reductomorphic features (1-4 scale)

Soil aggregation (1-4 scale)

Quantitative soil measurements

Soil bulk density (g/cm3). This is a measure of soil compaction and defined as weight per unit volume. As weight is dependent on moisture content, samples are oven-dried at 105 ^{o}C to remove all moisture, giving dry bulk densities that can be compared between locations (Blake and Hartge, 1988). Soil bulk density was measured at two depths, 0-7.5 cm and 7.5-15 cm.

Earthworm populations/m^3. These give an indication of the biological, chemical and physical fertility of a soil. Earthworms are important for breaking down and incorporating organic matter, making the nutrients available to plants. Through burrowing, earthworms also mix soil and improve soil aeration and drainage. The depth of the sampling hole varied so we have reported the earthworm populations on a per soil volume rather than area basis (Fraser *et al.* 1994).

3.4 Priority Two

These consisted of soil chemical analyses for a mostly standard suite of test indices (Blakemore *et al.* 1987) where substantial literature is available to assist interpretation.

These were contracted out to commercial soil testing laboratories with additional tests conducted by Land Research Services Ltd based at Lincoln University using established soil chemical and biological techniques. Soil samples were collected from the standard sampling depth for pasture (0-7.5 cm). This may not represent the total availability of nutrients from the entire root zone but should still be representative of plant available nutrients and chemical conditions in the soil. Priority two samples are collected at the management unit level.

Soil pH indicates the level of acidity or alkalinity of the soil sample.

Olsen P (µg/ml) is an measure of the phosphorus readily available to plant.

Exchangeable cations (Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Potassium (K^+) and Sodium (Na^+)). Calcium, magnesium and potassium are major nutrients for plant growth. These are reported as both MAF quick test units and milli-equivalents per 100g dry soil (me/100g).

Cation exchange capacity (me/100g) is a measure of the soil's capacity to hold cations and is strongly influenced by clay content and soil organic matter

Phosphate retention (%) indicates how strongly the soil will immobilize added phosphate. It is a function of the soils parent material and the presence of clay minerals or iron oxides that immobilise phosphorus.

Potentially mineralisable N (kg N/ha) is an indication of the nitrogen that may become available to plants through mineralisation of organic matter.

Volume weight (g/ml) is the weight per volume of the air dried and ground soil used by the laboratory for chemical analysis. It is sometimes referred to as "lab. bulk density" and should not be confused with field bulk density as measured in priority one.

Total organic C and N %. Organic matter is important as it supplies nutrients to the soil, improves soil physical fertility and moisture retention (Haynes and Naidu 1998). Soil carbon is directly proportional to the soil organic matter (%C x 1.72 = %SOM).

3.5 Priority Three

Priority three indicators use the same sampling depth as priority two measurements and relate to the biological activity of the soil. The indicators are described below.

3.5.1 Soluble carbon

Soluble carbon is a measure of labile organic matter and serves as an index both of available substrate for microbial respiration as well as aggregate stability (Haynes 2000). The index used is the 0.5 M K_2SO_4-soluble fraction that is obtained from the non-fumigated extraction of the soil microbial C & N method (Milne and Haynes 2004).

3.5.2 Microbial biomass carbon

This is a measure of the total amount of living microbes in a soil. Microbial biomass usually constitutes around 1-4% of total soil organic matter. In temperate climates there is often a fast rate of microbial turnover that suggests that microbial biomass is a more sensitive indicator of changes in soil organic matter than total soil carbon (C%). Microbial biomass levels will differ between soil types and land use history. Methodology is based on the method used by Jorgenson (1995) using a chloroform fumigation technique and measuring the difference in C and N content between extracts (using 0.5 M K_2SO_4), before and after fumigation. Soils were taken fresh from the field, sieved and refrigerated at 1° C.

3.5.3 Basal respiration

Soil micro-organisms recycle essential nutrients when they decompose dead plant and animal material. Hence an active microbial population is a key component of good soil quality. Measured in the laboratory, microbial respiration is a process that reflects the potential activity of the soil microbial population. Microbial respiration is the amount of carbon dioxide production over a fixed period and was measured differently in 2005 using the method as outlined by Kelliher et al. (2005). This method uses rings containing approximately 200 ml of packed soil and records CO_2 evolved under a covering cap after two minutes using a Brüer and Kjaer Trace Gas analyser. Three measurements were made over 7 days (0, 3 and 7 days) after an initial equilibration period before an application of 500 kg urea/ha as a solution was applied. Evolution of CO_2 was measured thrice more over the following week.

3.5.4 Metabolic Quotient

The ratio between microbial biomass carbon (the size of the soil microbial population) and basal respiration (the activity of the soil microbial population) is a useful indicator of the metabolic efficiency of the microbial population.

Table 1. Soil quality indicators selected for the ARGOS program (from Pearson et al. (2005)).

Priority	Indicator	Depth (cm)	Measured how?	Rationale	Possible values
1	Visual soil assessment, 9 indicators	0-30	Spade sampling and visual inspection[1]	Field measurements form a suite of meaningful observations that can be integrated into one or more soil quality scores.	Will develop and compare a range of methods to integrate the scores from the different measurements
1	Field soil dry bulk density	0-7.5 7.5-15	Samples taken using bulk density corer and sent to lab.	Values and time trends are a useful indicator of compaction. Values are essential to convert soil chemical results into nutrient contents in kg/ha	Continuous scale of values
2	Chemical properties[2]	Std[3]	Samples taken using soil corer then sent to laboratory	Values have considerable use as indicators of soil chemical fertility.	Continuous scale of values
2	Total organic C and N	Std[3]	Same samples as for chemical properties	Values have considerable use as indicators of soil biological condition, and contribution to global CO_2 balance.	Continuous scale of values
3	Microbial biomass C	Std[3]	Same samples as for chemical properties	Useful and well-accepted indicator of the amount of living material in the soil.	Continuous scale of values
3	Basal respiration	Std[3]	Same samples as for chemical properties	Useful indicator of the rate of microbial activity in the soil under standardised conditions.	Continuous scale of values
3	Metabolic quotient	Std[3]	Simple ratio of values obtained for biomass C and basal respiration.	Useful indicator of the metabolic efficiency of the microbial population.	Continuous scale of values

[1] Measurements should be made at the same date and locations.

[2] Soil pH, Olsen P, exchangeable cations and cation exchange capacity, P retention %, potentially mineralisable N, measured using NZ standard techniques

[3] The standard depth is 0-7.5 cm for pastoral farms.

4 Results

4.1 Soil Chemistry

4.1.1 System and landform

Dairy

Most of the significant differences between the soil indices tested for Conventional and Converting dairy systems on both a regional and volume basis were restricted to P and S, ($0.001<P<0.05$) and to a smaller extent, C (Table 2-7). Olsen-P, resin-P and sulphate-S were higher overall for the Conventional farm soils whilst soil pH, soil C/N ratio and soil carbon (volume basis only) were significantly higher in the Converting farm soils. The relationship between resin-P and Olsen-P was best for Converting farms but generally correlated well for both (Figure 1). To enable a better comparison, regressions lines were forced through the origin which reduced R^2 slightly for both but did not change the observation that the gradient coefficient was higher for Converting than Conventional farms although this was not statistically different. Of more significance however, was the high proportion of farms, more than 70% of Conventional and over 50% of Converting farms, above the optimal Olsen-P (30-40 mg P/L) (Roberts *et al.* 1999) and Resin-P ranges (70-100 mg P/kg soil). Only 10% of Olsen-P values from Conventional farms were less than the optimal range.

Statistically significant differences between landforms for both Conventional and Converting farms, and both weight and volume values, were generally more strongly evident. Olsen and Resin-P, soil pH, Total-N, exchangeable Mg, K and Na, and K base saturation (BS) were generally all greater, and C/N ratios lower, in crest areas compared with slope or flat areas. Another trend was for slope areas on both systems to have significantly ($P<0.05$) lower Mg levels than flat and crest areas and for declining Olsen and resin P values ($0.01< P <0.05$) on flat areas of Converting farms (Table 2 & Table 3).

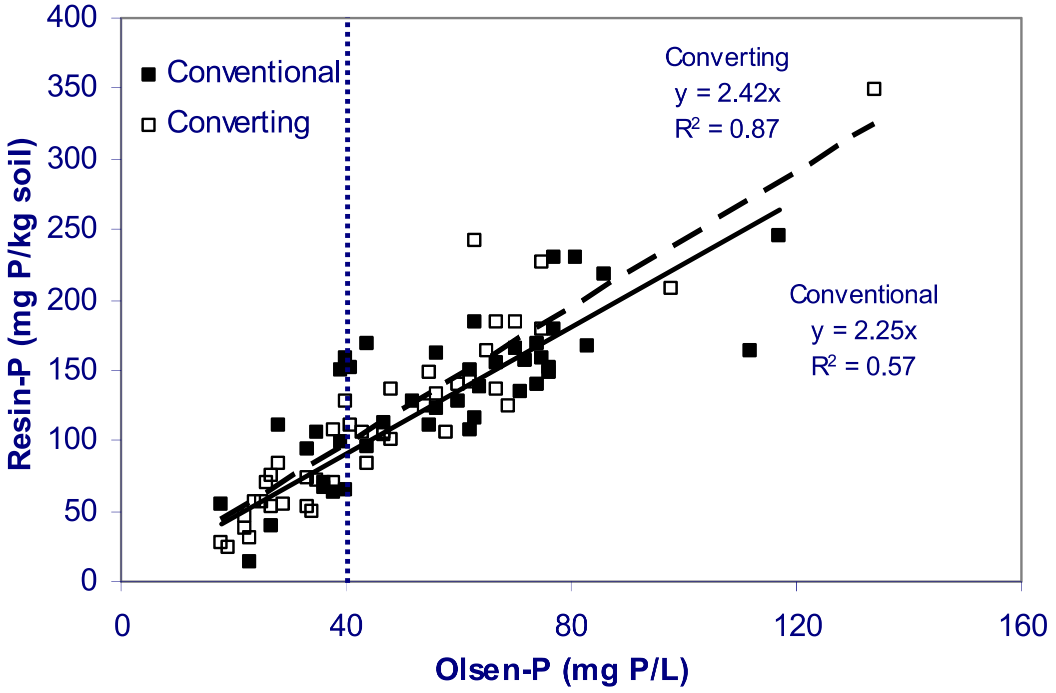

Figure 1. Relationship between Resin-P and Olsen-P test values for Conventional and Converting dairy farms. (Note: regression lines forced through origin)

Sheep & Beef

Significant differences in soil chemical properties between management systems for sheep and beef farms were strong ($P<0.001$) on both weight and volume basis for Olsen and resin P ($P<0.001$) and sulphate-S with lesser, albeit still significant, differences for exchangeable Ca, Mg and K, and anaerobic mineralisable N (per g soil nitrogen; AMN-N) (Table 5-8). Organic Sheep & Beef farms had on average available P and S values about half that of Conventional and Integrated farms, following the same trend as the Dairy Converting farms. Of the 20% of farms above optimal P guidelines (ie. >30 mg P/L) (Morton *et al.* 1994b), 95% of these were from Integrated and Conventional systems. Conversely, 85% of Organic farms had Olsen and Resin P values below optimal values (ie. <20 mg P/L and <45 mg P/kg soil, respectively. Differences in cation test values generally complemented the trends for P and S but effects varied from system-to-system. Organic soils had lower exchangeable-Ca (volume only), and greater exchangeable-Mg and Mg BS%. Magnesium values were lowest for Conventional systems ($P<0.05$) whilst exchangeable-K values were highest for Integrated systems than for the other two. The only significant differences in base saturation were for Conventional systems which had lower overall Mg BS. No significant differences were apparent in soil pH or overall BS%.

The recommended optimal limit for Olsen-P values for Sheep & Beef farms is 20-30 (Morton *et al.* 1994a) and 50-75 mg P/kg for Resin-P consequently soil test values for both were considerably lower overall than for Dairy. Only 20% of farms had Olsen-P values in excess of these guidelines with 90% of these either Integrated or Conventional farms. Conversely, over 80% of Organic farms had Olsen-P and Resin-P values below optimal guidelines.

Generally, strong significant differences between landforms were shown for P, S (sulphate-S and organic-S) and P-retention on both a weight ($0.01< P <0.05$) and volume basis ($0.001< P <0.01$) although effects between landforms varied. For Olsen-P, resin-P and sulphate-S, flat landforms had greater values than crest and slope landforms but org-S and P-retention values were greatest for crest landforms. Significant differences in total-C and total-N were also evident for weight based analysis, with values greatest for crest landforms, but these largely disappeared when calculated on a volume basis although C/N ratios remained significantly lower for crest landforms. Few firm trends were apparent in exchangeable cations between landforms with the exception of Mg ($P<0.05$) which showed a distinct difference between crest and slope landforms on both a weight and volume basis (Table 8 & Table 9). The proportion of Mg held on exchange sites (BS-Mg) was also very significantly lower ($P<0.001$) for slope landforms. and apparently at the expense of Ca BS% (Table 7). Total BS% for Ca also appeared to be significantly higher overall for flat landforms ($P<0.01$). There were no significant differences between landforms for soil pH.

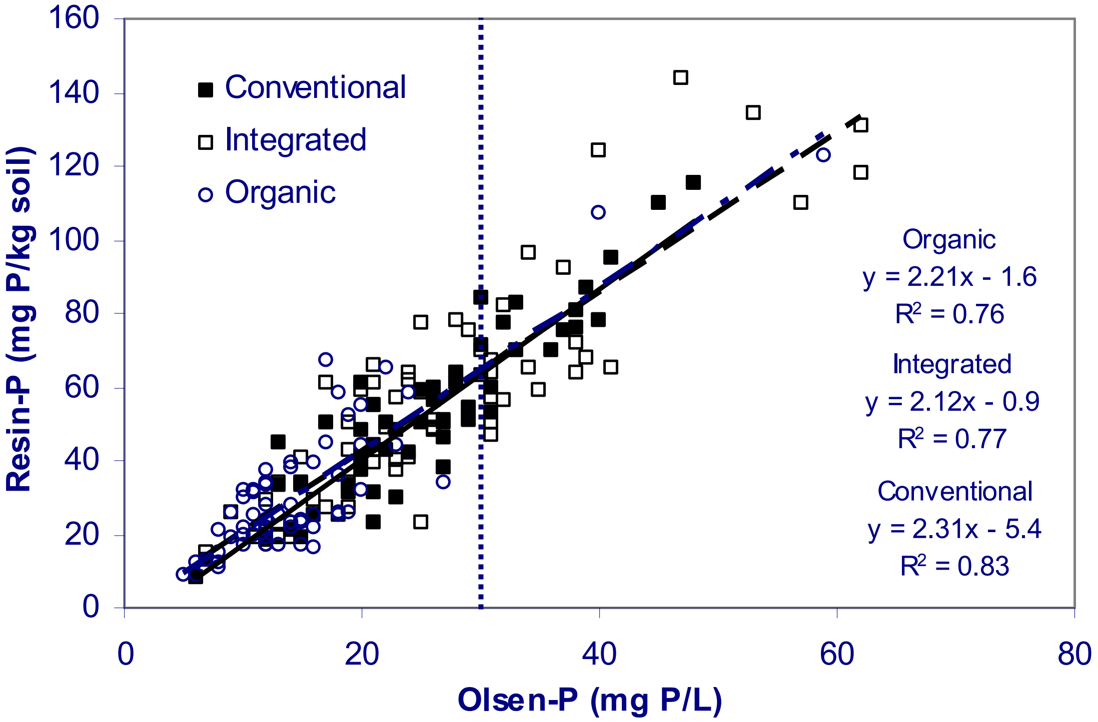

Figure 2. **Relationship between Olsen-P and resin-P indices for Conventional, Integrated and Organic Sheep & Beef farms.**

4.1.2 Region

Dairy

Only a few significant regional differences were evident in soil test indices for Dairy (Table 8-10) between Taranaki and Waikato farms, Manawatu being excluded due to low replication (ie. only one farm per system). These were limited to weight-based values ($0.001< P <0.01$) and greater total-C%, total-N%, exchangeable-Na and Na BS% for Taranaki soils compared with their Waikato counterparts. When converted to a volume basis, however, the differences in C and N values largely dissipated and were not significant. Phosphorus retention was significantly different ($P<0.05$) between regions with Taranaki soils exhibiting higher overall values.

Sheep & Beef

Of the 19 soil chemical properties tested for the Sheep & Beef farms, 13 were significantly different ($0.001< P <0.01$), on both a volume and a weight basis, between regions. Farms from the upper SI (USI) generally had lower available-P (Olsen and resin), P retention, S and organic-S, CEC, pH (albeit slightly), and total C and N than central (CSI) and lower SI (LSI) farms. In most cases the gradient for these properties was to increase with the shift south. Phosphorus (Olsen and resin), S (sulphate and organic), C, N and P retention, values were all considerably lower overall for Sheep & Beef farms than for Dairy, whilst C/N ratios were higher (Table 8 & Table 9).

4.2 Soil Biology

4.2.1 System and Landforms

Dairy

The only significant difference ($P<0.05$) for biological soil properties (excepting C/N ratio) between Dairy systems was higher microbial carbon for converting farms than their conventional counterparts (Table 4). Analysis of this difference showed two distinct relationships for conventional and converting farms although the over-riding relationship is with soil carbon (Figure 3). Differences between landforms were again, only significant ($P<0.05$) for microbial-N (per g soil-N) with values higher for slope and flat than crest landforms, especially for Converting systems (Table 4).

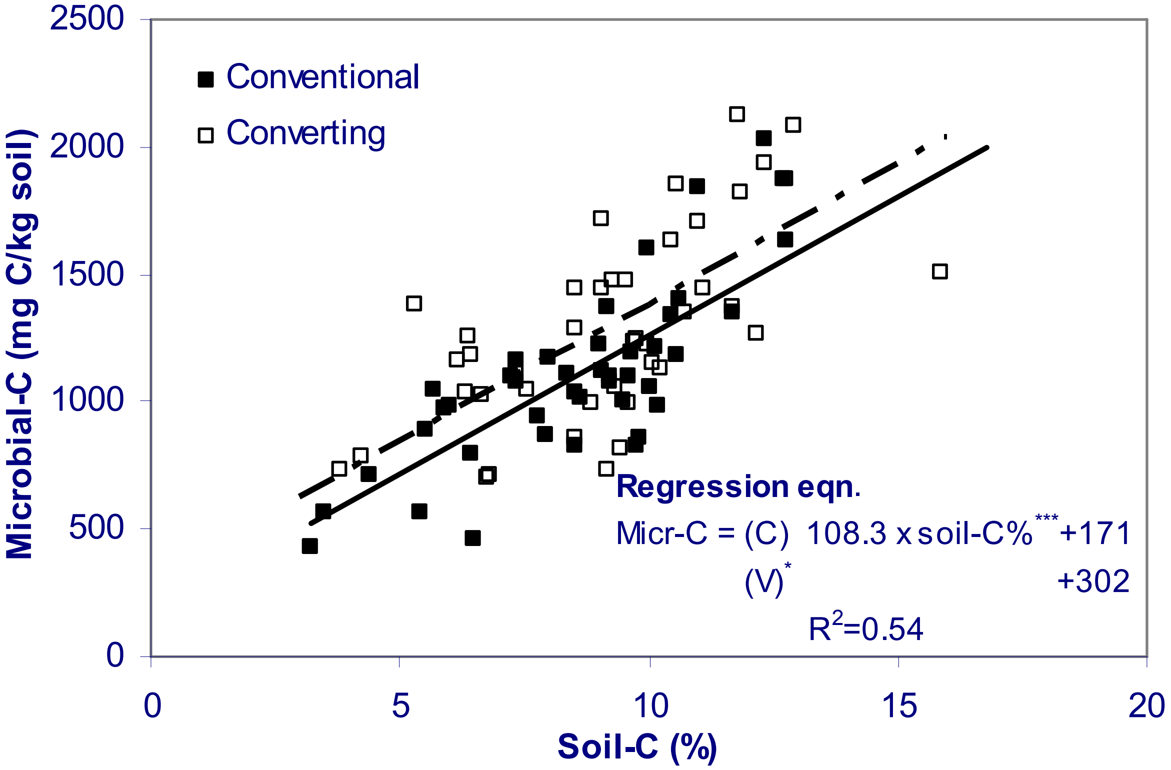

Figure 3. Regression relationship between soil-C and microbial carbon for Conventional (—) and Converting (- – -) Dairy farms.

Basal respiration was significantly higher ($P<0.05$) for the Dairy Converting system over Conventional initially but this effect disappeared by 7 days, and once urea was applied, so that they were virtually indistinguishable from each other (Figure 5). When respiration was calculated on a soil-C basis, no significant differences were apparent between systems for any time (Table 11). The metabolic quotient, a measure of respiration per unit soil biomass, was also significantly greater ($P<0.05$) for the Dairy Converting system, but as with respiration, any difference disappeared by 7 days.

Differences in respiration (on both a soil and soil-C basis) and metabolic quotient values between landscape forms were more significant ($0.05< P <0.001$) although mainly after urea application (Table 11). These showed that generally, slope values were higher after 24 hours, extending out to 7 days after application, than for crest and flat values.

Sheep & Beef

Significant differences ($P<0.05$) were apparent in the regression relationship between microbial-C and soil C% for Integrated vs. Organic systems but not Conventional, with Integrated farms showing greater microbial-C per unit weight soil-C. No significant differences were found for microbial C or N on a unit weight soil C or N basis. Differences between landforms were again, only significant ($0.001< P <0.01$) for microbial-N (per g soil-N) but in contrast to Dairy, were greater for crest than slope and flat landforms (Table 7).

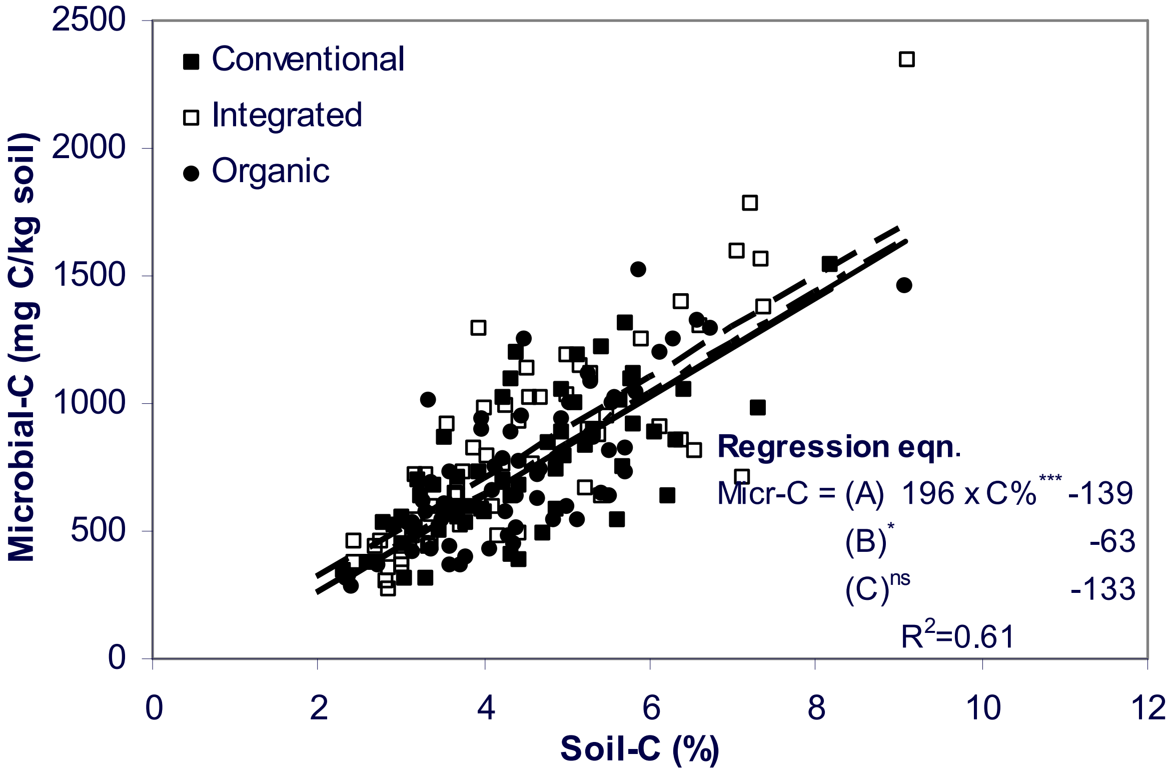

Figure 4. Regression relationship between soil-C and microbial carbon for Conventional (—) Integrated (– – –) and Organic (- – -) Sheep & Beef farms.

Although respiration means for Sheep and Beef Organic and Integrated systems were higher than for Conventional, especially after application of urea, these were not quite significant at the 5% level (Figure 5 & Figure 6). Metabolic quotient values, like respiration, were only significantly different ($P<0.05$) early on with Sheep & Beef Organic and Integrated farms higher than the Conventional farms (Table 11). Calculations for total CO_2 evolved after urea application were all less than that potentially available from hydrolysis of the urea applied (180 mg) at ≈100, 130 and 150 mg CO_2 for conventional, integrated and organic systems, respectively. There were no significant differences between landform respiration values for Sheep & Beef farms.

4.2.2 Region

Dairy

There were no significant differences in any microbial measure between Dairy sector regions (Manawatu excluded) (Table 10) and no significant difference in basal soil respiration (per unit soil or soil-C) prior to urea application (Figure 7). After application however, Waikato soils showed significantly higher respiration values on both a soil and soil-C basis after the first 24 hours and 3 days later ($P<0.001$). Calculations for total CO_2 evolved show that the areas under the peaks comprise only about two-thirds of the CO_2 chemically produced from the hydrolysis of urea (500 kg urea/ha ≅ 366 kg CO_2/ha or 180 mg CO_2/core). This probably means that the peak of CO_2 evolution either occurred prior to the first measurement, 24 hours after application or measurement errors.

Sheep & Beef

In contrast to Dairy, Sheep & Beef sector farms showed significant increases ($P<0.01$) in soluble-C and microbial-N values (on a per g soil-C and per g soil-N basis) with the shift from north to south **(**Table 10). Soil respiration for Sheep & Beef farms increased regionally in the same order: USI < CSI < LSI covering a range of 85-150 mg/core (Figure 8). However, calculations for mean total CO_2 evolved after urea application were similar to those of dairy farms (≈125 mg/core) at about two-thirds of that potentially generated by hydrolysis and in the same order as above.

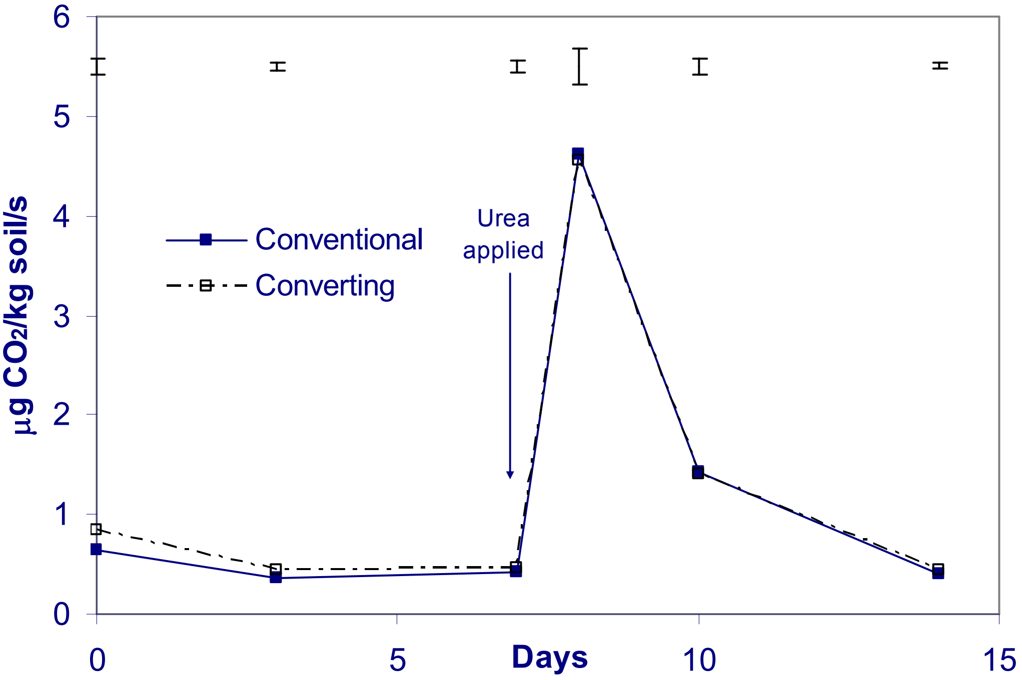

Figure 5. Respiration rates of Dairy sector soils between conventional and converting systems before and after urea application (500 kg urea /ha). LSD (5%) bars shown.

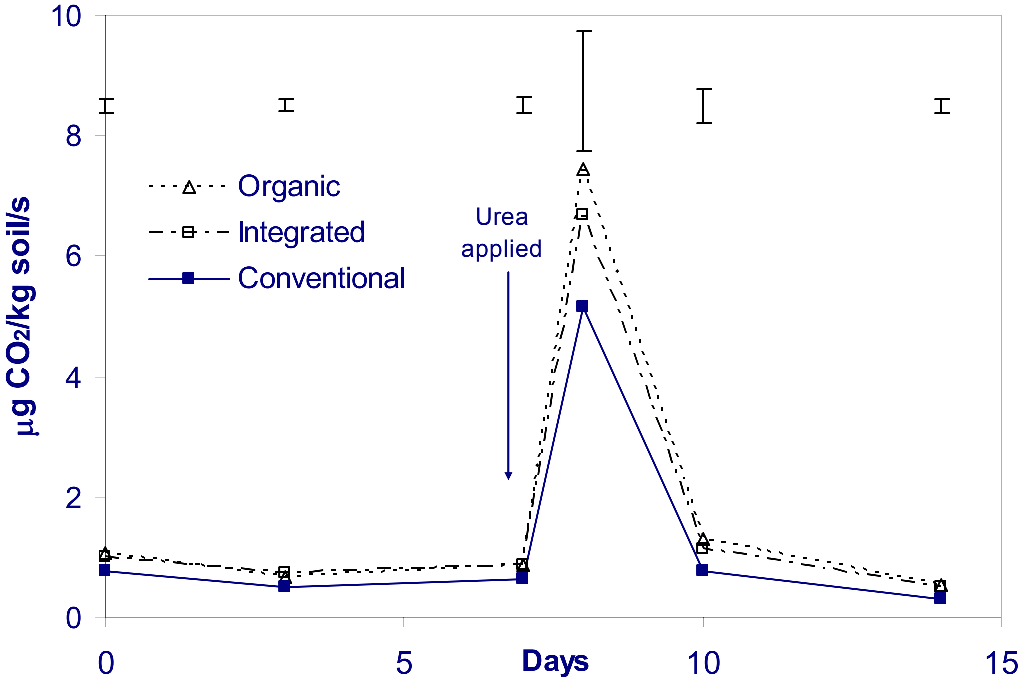

Figure 6. Respiration rates of Sheep and Beef sector soils for conventional, integrated and organic systems before and after urea application (500 kg urea /ha). LSD (5%) bars shown.

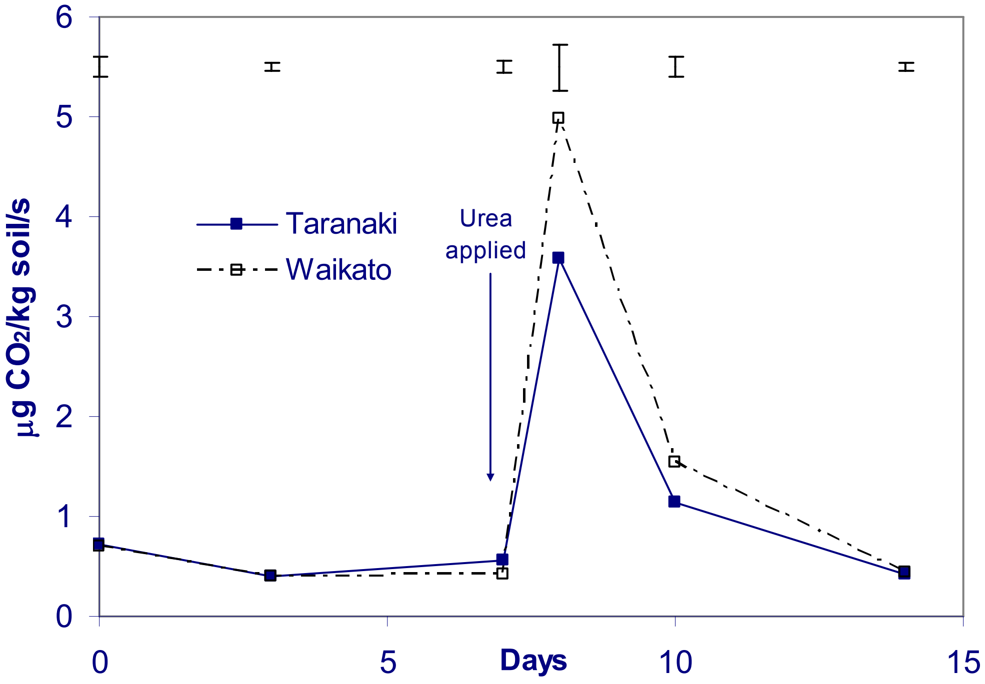

Figure 7. Respiration rate of Dairy sector soils for Taranaki and Waikato regions before and after urea application (500 kg urea /ha). LSD (5%) bars shown.

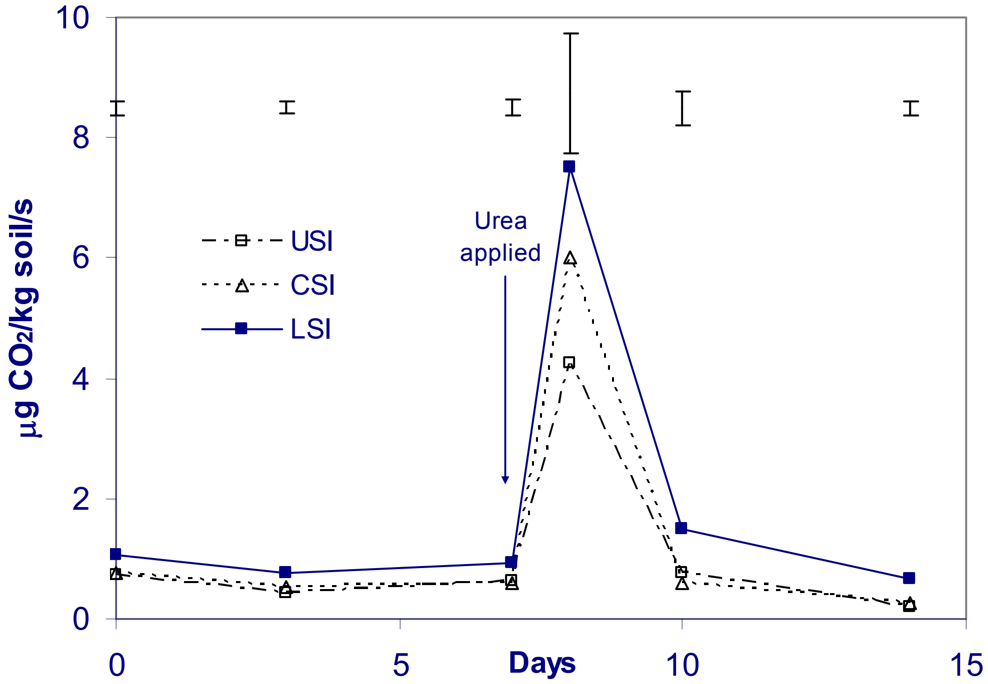

Figure 8. **Respiration rate of Sheep & Beef sector soils for Upper, Central and Lower South Island regions before and after urea application (500 kg urea /ha). LSD (5%) bars shown.**

4.3 Soil Physical Assessment

4.3.1 Systems and Landforms

Dairy

Visual soil assessments (VSA) of Dairy clusters showed no significant differences between systems for porosity, aggregation and mottle scores (Table 12) although porosity was higher overall for Converting systems and came close to significance at P=0.06 (Figure 9). There were no significant differences in bulk density (BD) between Conventional and Converting systems for either 0-7.5 cm (BD-A) or 7.5-15 cm (BD-B) depths. Earthworm weights between systems were just outside significance (P=0.06) being higher for Conventional systems overall (Table 12).

Differences between landforms for porosity were more apparent with flat sites showing significantly lower porosities ($P<0.05$) that their slope or crest counterparts but again there were no significant differences for aggregation or mottles. Differences in BD between landforms for the 7.5-15 cm depth were highly significant ($P<0.001$) with values generally increasing in the order: crest < slope < flat (Table 12). Earthworm weights showed highly significant differences ($P<0.001$) between landforms with values lowest for flat sites and crest sites generally highest.

Sheep & Beef

Visual soil assessments for Sheep & Beef clusters showed similarly no significant differences in porosity, aggregation or mottles scores between Organic, Integrated and Conventional systems although for porosity scores this was just outside 5% significance (P=0.06) (Figure 9). No significance for mottles and aggregation was, in part, due to insufficient numbers of scores greater than 1 to make specific judgments. Scores (ordinal values >1) for all three properties, however, appeared considerably lower overall than Dairy farms, although this was not specifically tested. Differences in BD between Organic, Integrated and Conventional systems were apparent for both layers with lower values overall for Organic systems but only significant (P<0.05) for the lower depth. There were no significant differences in earthworm weights between systems (Table 12).

Significant differences (P<0.05) in porosity and aggregation scores (but not mottles) were apparent between landforms with scores highest for flat sites indicating lower overall porosity and aggregation than their slope or crest counterparts (Table 12). Differences in BD between Sheep & Beef landforms were significant-to-highly-significant (0.001< P<0.05), generally increasing in the order: crest < slope < flat (Table 12). Their were no consistent or significant differences in earthworm weights between Sheep & Beef landforms.

Region

Dairy

Significant differences (P<0.05) in VSA between regions were concentrated in lower porosity (Figure 10) (>porosity scores) and greater aggregation (<aggregation scores) for Taranaki soils compared with their Waikato counterparts (Table 13). Regional differences in soil bulk density (BD) were significant (P<0.05) for the upper 0-7.5 cm of both regions with slightly lower overall BD for Taranaki soils. There was no significant difference at the 7.5-15 cm depth. Earthworm weights were significantly lower overall (P<0.05) in Taranaki farms.

Sheep & Beef

Only porosity scores were significantly different (P<0.05) between Sheep & Beef regions with scores increasing in the order: USI< CSI< LSI indicating decreasing porosity. Overall, soil aggregation and mottle scores were very low for both regions. Differences in soil BD between Sheep & Beef regions were highly significant (P<0.001) with values highest for the USI farms (Table 13). Differences in earthworm weights between regions was also highly significant (P<0.001) with weights lowest for LSI farms.

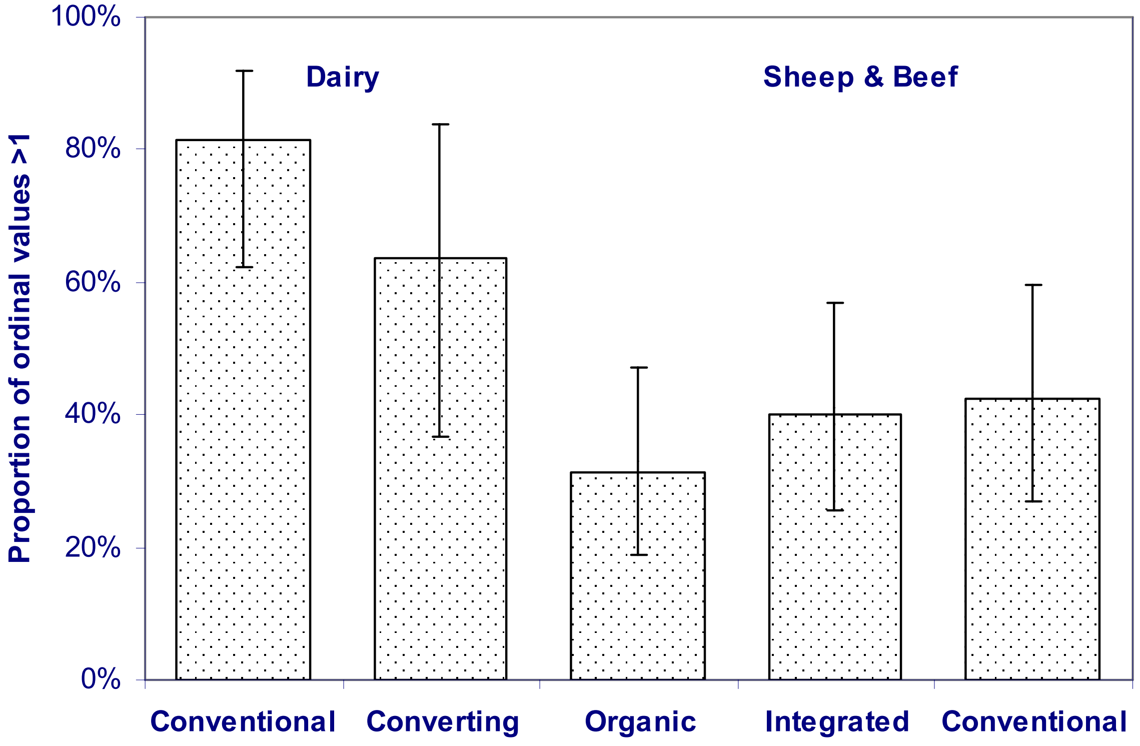

Figure 9. Porosity binomial ordinal value analysis for Dairy and Sheep & Beef systems. Error bars represent 95% confidence intervals.

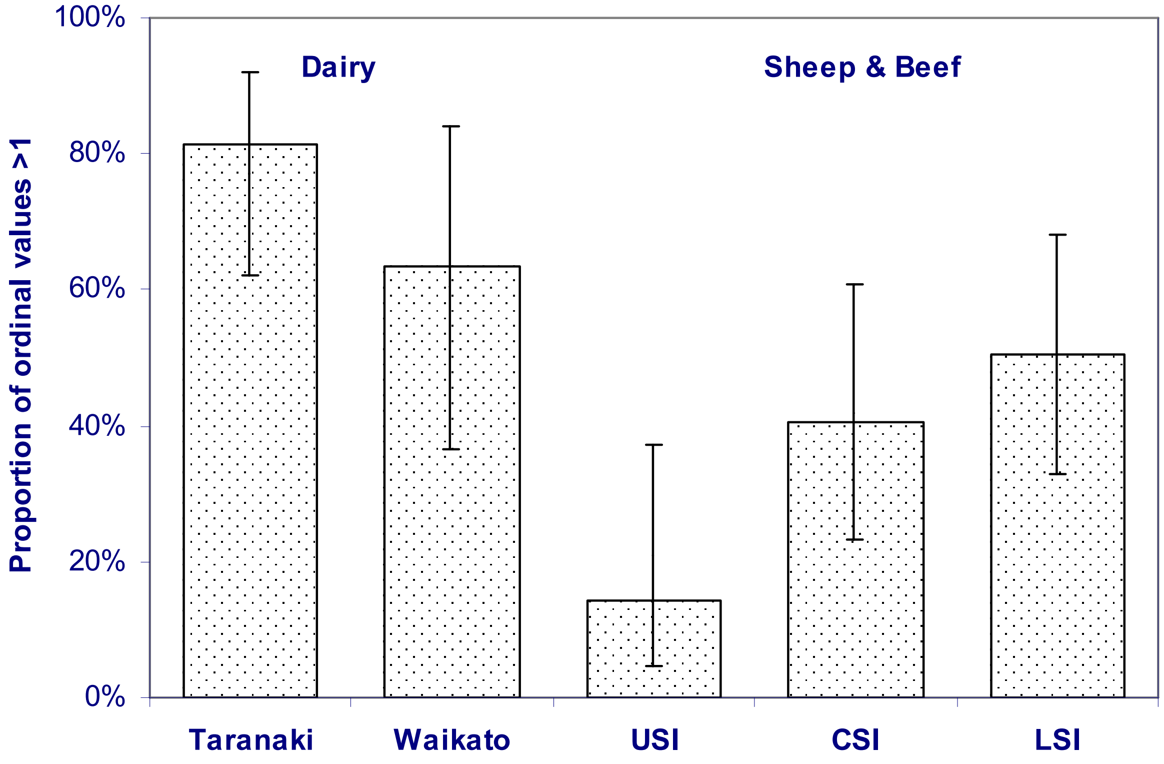

Figure 10. Porosity binomial ordinal value analysis for Dairy and Sheep & Beef regions. Error bars represent 95% confidence intervals.

Table 2. **System by Landform weight (per kg soil) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS Dairy farm soils.** **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.**

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN-N	Total-C	Total-N	C/N	CEC	Ca	Mg	K	Na
			mg P/kg soil		ASC%	mg/kg soil		g/kg soil-N	%w/w		ratio	cmol/kg soil				
Converting	crest	Mean	116.9	140.3	86.1	28.2	12.9	20.9	10.0	1.01	9.9	21.3	11.7	2.2	1.5	0.2
		Range	66-239	71-208	78-95	17-85	8-22	16.6-24.1	8.5-12.8	0.9-1.2	9.6-10.5	12-33	4.0-22	1.3-3.7	0.8-2.1	0.1-0.3
		CV%	43%	30%	6%	68%	28%	12%	13%	10%	3%	31%	58%	33%	33%	36%
	flat	Mean	62.0	88.1	73.0	16.9	11.2	29.8	9.3	0.86	10.8	22.7	14.7	2.2	1.0	0.4
		Range	32-109	30-148	25-98	8-30	7-17	13.1-65.3	3.8-15.9	0.4-1.2	9.4-13.2	10-37	3.3-27	0.9-4.0	0.4-2.1	0.2-0.7
		CV%	40%	40%	32%	33%	27%	43%	34%	32%	7%	34%	39%	41%	44%	42%
	slope	Mean	71.4	97.7	78.2	21.0	10.8	28.1	8.3	0.79	10.6	18.8	10.1	1.6	0.9	0.3
		Range	27-134	23-242	56-91	10-45	7-20	20.1-37.4	5.3-11.8	0.5-1.2	9.8-11.5	11-29	3.0-17	0.8-2.5	0.5-1.6	0.1-0.4
		CV%	53%	76%	17%	47%	35%	25%	25%	28%	5%	29%	54%	33%	36%	37%
Conventional	crest	Mean	104.4	169.3	81.6	30.2	11.3	22.9	8.8	0.88	10.0	21.0	12.0	2.1	1.3	0.2
		Range	68-143	95-230	67-89	19-50	5-15	15.2-27.8	7.2-10.6	0.7-1.1	9.3-11.2	4.0-32	1.8-22	0.7-3.9	0.5-2.2	0.1-0.4
		CV%	24%	23%	8%	35%	28%	16%	15%	15%	6%	40%	58%	49%	46%	35%
	flat	Mean	96.5	126.8	71.6	27.2	12.9	30.0	8.4	0.82	10.2	20.9	10.3	2.0	1.1	0.3
		Range	36-148	14-245	26-98	8-100	6-24	16.5-58.1	3.2-12.8	0.3-1.3	9.6-11.5	14-29	3.5-18	0.9-3.5	0.5-1.9	0.1-0.7
		CV%	31%	41%	38%	75%	36%	43%	37%	37%	5%	23%	34%	36%	32%	47%
	slope	Mean	68.8	106.9	77.7	33.7	11.1	25.7	8.5	0.83	10.3	17.8	10.4	1.3	0.8	0.2
		Range	33-123	40-184	26-95	14-73	5-32	18.0-41.0	5.5-10.5	0.5-1.0	9.5-11.5	5.0-27	1.3-20	0.7-2.3	0.4-1.8	0.1-0.3
		CV%	33%	38%	28%	49%	62%	33%	20%	20%	7%	40%	53%	30%	44%	37%
	Sig. landform		**	**	**ns**	**ns**	**ns**	**ns**	**ns**	*	**	**ns**	**ns**	*	**	***
Sig. system			**ns**	**	**ns**	**	**ns**	**ns**	**ns**	**ns**	*	**ns**	**ns**	**ns**	**ns**	**ns**
		Av. LSD	26.2	38.6	6.2	11.7	3.4	8.1	1.9	0.1	0.5	5.4	4.5	0.6	0.4	0.1

[1] P retention (ASC%) [2] anaerobic mineralisable nitrogen; g N/kg soil nitrogen

Table 3. **System by Landform volume (ha; 0-7.5 cm) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS Dairy farm soils.** **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.**

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN	Total-C	Total-N	C/N	[3] CEC	Ca	Mg	K	Na
			kg P/ha		ASC%	kg S/ha		kg N/ha	tonnes/ha		ratio	Meq/ha	kg/ha			
Converting	crest	Mean	49.6	69.4	86.1	14.2	6.4	207	49.6	5.0	9.9	106	1172	133	290	24
		Range	26-101	36-106	78-95	9-44	4-11	171-235	43-57	4-6	9.6-10.5	53-161	408-2337	70-214	137-290	14-39
		CV%	44%	29%	6%	71%	30%	10%	8%	6%	3%	32%	60%	34%	35%	32%
	flat	Mean	29.0	45.2	73.0	8.6	5.7	236	46.0	4.3	10.8	115	1506	134	205	42
		Range	17-52	17-83	25-98	5-15	4-7	131-314	26-66	2.4-5.2	9.4-13.2	65-191	427-2984	71-210	109-205	19-71
		CV%	37%	40%	32%	27%	21%	23%	19%	17%	7%	28%	39%	33%	41%	41%
	slope	Mean	31.3	57.9	78.2	12.4	6.3	246	48.2	4.6	10.6	111	1228	115	216	33
		Range	14-56	13-167	56-91	6-28	4-12	188-346	30-63	2.6-6.0	9.8-11.5	62-178	338-2395	52-212	103-216	20-42
		CV%	48%	84%	17%	50%	35%	20%	19%	22%	5%	32%	60%	38%	49%	25%
Conventional	crest	Mean	46.7	86.4	81.6	15.4	5.7	200	44.3	4.4	10.0	106	1196	127	266	21
		Range	29-65	44-143	67-89	10-27	2-9	146-258	36-52	3.2-5.2	9.3-11.2	18-152	194-2084	41-208	87-266	9-36
		CV%	28%	30%	8%	40%	32%	15%	11%	14%	6%	39%	57%	47%	51%	29%
	flat	Mean	49.0	74.4	71.6	15.3	7.0	244	44.5	4.4	10.2	120	1210	131	251	42
		Range	17-88	7-177	26-98	5-49	4-11	118-383	24-58	2.5-5.8	9.6-11.5	68-190	341-2500	51-226	111-251	15-86
		CV%	37%	52%	38%	70%	28%	28%	22%	23%	5%	30%	45%	33%	35%	48%
	slope	Mean	30.8	56.1	77.7	16.7	5.6	207	42.6	4.1	10.3	92	1074	81	163	24
		Range	14-56	18-112	26-95	9-36	2-16	155-307	34-49	3.3-5.1	9.5-11.5	22-137	117-1696	36-147	74-163	10-49
		CV%	39%	47%	28%	45%	63%	26%	10%	12%	7%	42%	51%	35%	49%	46%
	Sig. landform		***	*	**ns**	**ns**	**ns**	**	**ns**	**ns**	**	**ns**	**ns**	*	*	***
Sig. system			*	*	**ns**	**	**ns**	**ns**	*	**ns**	*	**ns**	**ns**	**ns**	**ns**	**ns**
		Av. LSD	12.4	25.4	6.2	6.0	1.6	42	6.2	0.6	0.5	29.3	510	35	80	11

[1] P retention (ASC%)

[2] anaerobic mineralisable nitrogen; g N/kg soil carbon

[3] cation exchange capacity (Meq/ha – 10^6 mole equivalents/ha)

Table 4. System by Landform means, ranges and coefficients of variation (CV%) for a suite of soil chemical and microbial test values for the ARGOS Dairy farm soils. Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.

System	Landform		pH	Ca	Mg	K	Na	Total	Soluble-C	Micr.-C	Micr.-N	Micr.-N	Microbial
				% Base Saturation					mg/g soil-C			mg/g soil-N	C/N ratio
Converting	crest	Mean	6.0	51.2	10.4	7.2	1.1	70.0	2.4	13.1	2.0	19.6	7.0
		Range	5.6-6.3	22.2-79	9.0-12	4.0-12	0.4-2.4	44.2-99	1.3-5.8	8.0-17	1.0-3.1	9.5-30	4.7-13.0
		CV%	3%	35%	12%	33%	55%	24%	53%	21%	34%	33%	33%
	flat	Mean	6.3	63.8	9.6	4.5	1.6	79.6	2.6	15.5	2.6	27.5	6.3
		Range	6.0-6.7	33.4-82	7.2-12	2.2-6	0.5-2.8	48.8-97	1.2-5.6	9.5-19	1.4-4.1	17-44	4.5-9.0
		CV%	4%	19%	15%	22%	39%	15%	41%	19%	29%	27%	23%
	slope	Mean	5.8	51.2	9.0	5.1	1.5	66.8	2.6	14.3	2.2	24.0	6.3
		Range	5.5-6.2	27.4-87	5.3-18	3.1-12	0.5-2.4	39.6-98	1.4-4.1	8.7-26	1.4-3.4	15-37	4.4-9.5
		CV%	4%	39%	42%	47%	45%	30%	29%	35%	24%	27%	23%
Conventional	crest	Mean	6.0	53.0	10.4	6.7	1.1	71.2	2.8	13.1	2.0	19.8	7.3
		Range	5.6-6.8	13.6-84	6.6-19	3.8-12	0.5-2.0	26.4-99	1.0-4.2	10.9-16	1.1-2.8	10-27	4.3-11.1
		CV%	6%	36%	38%	36%	48%	30%	33%	14%	31%	30%	33%
	flat	Mean	5.7	49.6	9.3	5.4	1.5	65.8	2.8	13.6	2.2	22.1	6.6
		Range	5.2-6.3	25.7-81	6.3-12	2.9-10	0.5-2.4	38.2-98	1.5-5.1	8.5-18	1.3-3.3	14-37	4.4-10.2
		CV%	5%	28%	22%	27%	33%	21%	27%	21%	27%	30%	27%
	slope	Mean	5.9	54.4	8.4	5.0	1.4	69.2	3.2	12.0	2.2	23.1	5.7
		Range	5.2-6.5	26.3-73	4.3-15	3.0-8	0.5-3.0	47.7-82	1.4-6.8	7.2-16	1.7-3.2	16-36	2.4-8.6
		CV%	7%	7%	35%	38%	28%	49%	44%	23%	27%	30%	29%
.	**Sig. landform**		***	ns	ns	***	ns	ns	ns	ns	ns	*	ns
Sig. system			**	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
		Av. LSD	0.2	13.0	2.3	1.6	0.5	13.0	0.8	2.5	0.5	5.5	1.4

Table 5. System by Landform weight (per kg soil) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS Sheep & Beef farm soils. Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. LSD$_{0.05}$ values shown are the average values of the ANOVA.

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN-N	Total-C	Total-N	C/N	CEC	Ca	Mg	K	Na
			mg P/kg soil		ASC%	mg/kg soil		g/kg soil-N	%w/w		ratio	cmol/kg soil				
Organic	crest	Mean	18.6	23.8	43.2	9.5	9.7	38.4	5.8	0.5	12.1	17.2	7.7	1.9	1.0	0.3
		Range	16-22	16-39	38-49	7-12	6-12	30-45	5.0-6.7	0.4-0.6	11.0-13.7	14-21	3.3-13	1.2-2.4	0.7-1.6	0.2-0.3
		CV%	58%	73%	32%	62%	50%	25%	26%	28%	7%	26%	37%	67%	51%	37%
	flat	Mean	21.8	35.7	25.9	12.4	5.1	36.0	4.0	0.4	10.9	15.7	9.5	1.6	0.7	0.2
		Range	6-71	9-123	13-51	3-32	1-10	20-54	2.3-5.7	0.2-0.6	9.5-12.4	12-26	5.3-19	0.7-5.1	0.2-1.6	0.1-0.5
		CV%	36%	39%	48%	47%	48%	21%	26%	25%	9%	26%	39%	44%	47%	36%
	slope	Mean	16.6	27.3	27.7	8.7	5.8	39.2	4.8	0.4	11.5	16.3	9.2	2.2	0.7	0.3
		Range	6-31	9-52	13-68	3-19	2-14	25-53	3.4-9.1	0.3-0.8	9.9-13.9	12-28	4.5-16	0.9-4.4	0.2-1.6	0.1-0.5
		CV%	35%	35%	32%	54%	30%	16%	28%	29%	4%	30%	53%	36%	41%	30%
Integrated	crest	Mean	32.6	52.4	39.7	17.4	10.1	38.8	5.5	0.5	10.3	19.7	9.9	2.3	1.1	0.3
		Range	24-56	27-78	18-54	8-30	7-16	32-48	3.3-7.1	0.3-0.7	9.8-10.9	11-29	4.6-18	0.9-3.6	0.5-1.6	0.2-0.5
		CV%	43%	49%	53%	61%	43%	25%	33%	29%	9%	43%	54%	88%	81%	26%
	flat	Mean	40.3	66.1	26.7	18.5	5.2	40.6	4.1	0.4	11.0	17.6	10.8	1.7	0.9	0.2
		Range	15-79	19-134	5-75	5-51	1-10	24-63	2.4-7.4	0.2-0.6	9.6-14.5	10-54	5.3-36	0.5-8.8	0.3-4.3	0.1-0.4
		CV%	60%	60%	43%	60%	54%	22%	32%	25%	11%	24%	36%	45%	53%	23%
	slope	Mean	28.8	46.2	26.3	13.1	6.3	41.7	4.7	0.4	11.2	17.3	10.3	2.0	0.8	0.2
		Range	9-98	15-144	8-48	2-33	1-16	22-56	2.8-9.1	0.3-0.6	9.9-15.2	11-28	4.5-19	1.0-4.3	0.4-2.0	0.1-0.3
		CV%	24%	27%	23%	31%	17%	11%	23%	15%	9%	19%	32%	43%	44%	28%

[1] P retention (ASC)

[2] anaerobic mineralisable nitrogen; g N/kg soil nitrogen

Table 5. cont'd

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN-N	Total-C	Total-N	C/N	CEC	Ca	Mg	K	Na
			mg P/kg soil		ASC%	mg/kg soil		g/kg soil-N	%w/w		ratio	cmol/kg soil				
		Mean	29.8	49.3	40.0	14.3	8.7	38.4	5.2	0.5	10.8	18.5	10.6	2.2	0.7	0.4
	crest	Range	22-38	25-61	24-48	10-21	7-10	30-45	4.2-7.3	0.4-0.6	9.8-12.4	14-24	6.3-17	1.0-3.7	0.3-1.0	0.2-0.5
		CV%	30%	42%	37%	45%	53%	25%	27%	24%	5%	16%	24%	40%	34%	41%
		Mean	34.0	54.3	26.3	20.5	6.1	36.0	4.3	0.4	11.3	15.7	10.0	1.1	0.6	0.2
Conventional	flat	Range	17-56	19-115	12-47	5-50	1-13	20-54	2.6-6.3	0.2-0.5	10.4-12.4	12-21	4.8-15	0.6-2.0	0.3-1.0	0.1-0.5
		CV%	38%	49%	51%	48%	41%	21%	29%	30%	9%	29%	37%	39%	52%	36%
		Mean	31.1	51.4	24.1	13.4	5.7	39.2	4.6	0.4	11.6	16.3	9.7	1.7	0.7	0.2
	slope	Range	9-53	8-95	1-56	3-32	3-12	25-53	2.3-8.2	0.2-0.6	10.0-13.6	10-27	4.1-17	0.9-3.7	0.2-1.5	0.1-0.4
		CV%	28%	28%	8%	43%	25%	16%	5%	7%	3%	5%	23%	24%	7%	16%
	Sig. landform		*	**ns**	***	**	***	**ns**	***	***	*	**ns**	**ns**	*	**ns**	***
Sig. system			***	***	**ns**	***	**ns**	*	**ns**	**ns**	**ns**	**ns**	**ns**	*	*	**ns**
		Av. LSD	10.1	19.1	9.1	8.5	2.2	6.6	1.0	0.1	0.7	3.8	3.1	0.8	0.3	0.06

[1] P retention (ASC)
[2] anaerobic mineralisable nitrogen; g N/kg soil nitrogen

Table 6. System by Landform volume (ha; 0-7.5 cm) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS Sheep & Beef farm soils. **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. LSD$_{0.05}$ values shown are the average values of the ANOVA.**

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN	Total-C	Total-N	C/N	[3] CEC	Ca	Mg	K	Na
			kg P/ha		ASC%	kg S/ha		kg N/ha	tonnes/ha		ratio	Meq/ha	kg/ha			
		Mean	10.4	16.2	43.2	6.6	6.7	256	39.9	3.3	12.1	118	1018	162	276	44
	crest	Range	8-12	13-24	38-49	6-7	4-8	164-295	36-45	2.7-4.0	11-14	104-126	543-1511	104-210	186-276	38-50
		CV%	12%	26%	32%	11%	20%	19%	8%	15%	10%	7%	44%	23%	38%	12%
		Mean	12.9	28.8	25.9	10.1	4.2	223	33.1	3.1	10.9	129	1556	155	222	45
Organic	flat	Range	5-44	8-87	13-51	3-27	1-10	77-456	20-51	1.9-4.7	10-12	98-211	823-2732	67-511	79-222	9-94
		CV%	59%	67%	48%	61%	49%	41%	23%	25%	7%	22%	33%	65%	50%	37%
		Mean	9.1	21.1	27.7	6.7	4.4	253	36.6	3.2	11.5	124	1376	201	211	48
	slope	Range	4-15	8-43	13-68	2-15	2-9	125-397	28-51	2.3-4.2	10-14	95-167	739-2097	84-462	69-211	25-86
		CV%	33%	40%	32%	47%	38%	30%	15%	17%	9%	17%	29%	46%	48%	36%
		Mean	18.4	38.3	39.7	13.0	7.5	296	40.1	3.9	10.3	145	1436	213	302	53
	crest	Range	14-29	22-48	18-54	7-24	5-10	231-339	31-49	2.9-4.7	10-11	103-200	865-2511	95-347	171-302	39-93
		CV%	28%	23%	53%	53%	22%	13%	17%	18%	4%	21%	46%	39%	34%	36%
		Mean	23.2	54.1	26.7	15.5	4.3	243	33.9	3.1	11.0	143	1757	162	287	41
Integrated	flat	Range	9-47	16-115	5-75	5-47	1-8	108-363	20-56	1.9-4.6	10-14	78-297	882-3976	55-578	100-287	13-78
		CV%	46%	48%	43%	65%	45%	33%	27%	24%	9%	30%	42%	67%	63%	31%
		Mean	15.2	35.9	26.3	9.9	4.8	266	37.3	3.3	11.2	136	1619	192	246	44
	slope	Range	5-35	13-102	8-48	2-22	1-9	156-369	27-64	2.4-4.3	10-15	92-243	727-2928	89-445	124-246	24-61
		CV%	42%	56%	23%	50%	42%	21%	24%	19%	11%	22%	34%	49%	56%	24%

[1] P retention (ASC%)

[2] anaerobic mineralisable nitrogen

[3] Cation exchange capacity (Meq/ha – 10^6 mole equivalents/ha)

Table 6. cont'd.

System	Landform		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN	Total-C	Total-N	C/N	[3] CEC	Ca	Mg	K	Na
			kg P/ha		ASC%	kg S/ha		kg N/ha	tonnes/ha		ratio	Meq/ha	kg/ha			
Conventional	crest	Mean	16.4	36.1	40.0	10.3	6.4	338	37.9	3.5	10.8	137	1577	205	197	67
		Range	12-21	22-50	24-48	8-13	5-8	279-427	29-46	2.8-4.2	10-12	110-196	1115-2745	83-363	89-197	36-101
		CV%	23%	26%	37%	20%	14%	15%	16%	14%	9%	22%	38%	52%	42%	36%
	flat	Mean	19.5	45.6	26.3	16.8	5.0	253	36.9	3.2	11.3	130	1655	111	193	41
		Range	5-36	15-102	12-47	4-34	1-11	140-390	22-52	1.9-4.5	10-12	106-178	820-2607	55-231	83-193	15-91
		CV%	33%	46%	51%	40%	49%	24%	25%	22%	5%	15%	22%	42%	36%	43%
	slope	Mean	18.1	42.0	24.1	10.9	4.5	246	36.0	3.1	11.6	129	1538	160	228	43
		Range	5-31	6-82	1-56	2-30	2-7	106-341	23-54	1.9-4.5	10-14	81-195	633-2470	91-317	81-228	25-73
		CV%	41%	52%	8%	52%	30%	23%	21%	22%	9%	23%	33%	34%	49%	35%
	Sig. landform		**	**	***	***	***	*	ns	ns	*	ns	ns	*	ns	**
Sig. system			***	***	ns	***	ns	ns	ns	ns	ns	*	*	*	**	ns
		Av. LSD	5.6	15.2	9.1	4.9	1.5	56	6.2	0.5	0.7	23.2	430	68	95	12

[1] P retention (ASC%)
[2] anaerobic mineralisable nitrogen
[3] Cation exchange capacity (meq/ha – 10^6 mole equivalents/ha)

Table 7. System by Landform weight (per kg soil) means, ranges and coefficients of variation (CV%) for a suite of soil chemical and microbial test values for the ARGOS Sheep & Beef farm soils. **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.**

System	Landform		pH	Ca	Mg	K	Na	Total	Soluble-C	Micr.-C	Micr.-N	Micr.-N	Microbial
				% Base Saturation					g C/kg soil-C			g N/kg soil-N	C/N ratio
Organic	crest	Mean	5.9	42.0	11.4	5.9	1.6	60.9	3.2	18.4	3.0	36.2	6.3
		Range	5.5-6.4	24.1-61.1	6.7-14.3	3.7-9.0	1.4-1.9	47.9-76.6	2.4-3.9	10.6-21.2	1.6-3.8	20.9-50.1	5.1-8.0
		CV%	5%	18%	49%	38%	35%	13%	16%	22%	27%	31%	17%
	flat	Mean	5.9	59.9	9.7	4.3	1.5	75.4	3.7	16.8	2.6	28.7	7.0
		Range	5.3-6.3	32.3-75.7	4.8-21.3	1.7-8.4	0.4-3.4	53.0-94.3	1.6-5.9	9.8-30.2	0.8-4.3	9.3-48.7	3.3-19.3
		CV%	4%	25%	41%	52%	38%	14%	27%	32%	31%	31%	48%
	slope	Mean	5.9	55.4	13.5	4.5	1.7	75.1	3.6	15.7	2.7	31.3	6.2
		Range	5.4-6.7	34.2-84.3	5.6-24.7	1.8-10.6	0.9-3.7	57.0-95.7	1.8-6.5	10.4-25.8	1.0-3.9	12.8-54.2	2.9-12.0
		CV%	5%	27%	52%	36%	42%	10%	35%	24%	28%	31%	34%
Integrated	crest	Mean	5.8	48.1	13.2	5.5	1.7	68.5	3.4	17.4	2.8	29.0	6.3
		Range	5.5-6.1	33.8-63.7	5.1-22.2	2.8-8.6	1.0-3.1	57.9-76.3	2.5-4.9	9.9-22.6	2.0-3.4	21.2-36.0	3.0-7.9
		CV%	3%	16%	39%	53%	36%	13%	21%	25%	19%	19%	21%
	flat	Mean	5.9	60.3	9.1	5.2	1.3	75.9	3.6	17.5	2.6	28.1	8.5
		Range	5.1-6.5	44.4-83.9	3.6-21.8	1.6-17.1	0.5-2.4	56.6-97.5	2.2-5.2	9.6-32.5	0.5-5.2	5.7-62.4	3.1-34.1
		CV%	7%	21%	42%	37%	30%	14%	18%	31%	51%	53%	72%
	slope	Mean	5.9	58.6	11.8	4.5	1.5	76.4	3.6	18.4	2.8	32.0	7.2
		Range	5.3-6.5	32.5-78.5	5.5-21.0	2.4-8.7	0.7-2.3	50.6-97.4	1.7-5.5	11.7-25.7	1.1-4.9	11.8-74.8	3.8-15.4
		CV%	5%	17%	38%	47%	22%	13%	24%	24%	35%	44%	37%

Table 7. cont'd.

System	Landform		pH	Ca	Mg	K	Na	Total	Soluble-C	Micr.-C	Micr.-N	Micr.-N	Microbial
				% Base Saturation					g C,N/kg soil-C			g N/kg soil-N	C/N ratio
Conventional	crest	Mean	5.9	56.3	12.0	4.0	2.1	74.4	3.5	19.1	3.9	42.4	5.1
		Range	5.2-6.5	43.4-69.5	6.3-16.7	1.2-6.1	1.5-2.6	64.7-88.2	2.8-4.6	8.6-27.2	2.8-5.7	28.3-64.3	2.5-9.8
		CV%	4%	14%	37%	37%	38%	13%	19%	33%	25%	26%	42%
	flat	Mean	5.9	63.4	7.0	3.8	1.4	75.6	4.0	15.4	2.3	25.5	8.1
		Range	5.5-6.5	37.7-82.2	4.1-12.9	2.0-6.5	0.6-2.9	49.1-92.5	2.3-6.2	9.4-24.5	0.7-4.1	7.3-48.1	3.8-22.5
		CV%	5%	19%	37%	44%	37%	11%	21%	24%	38%	40%	52%
	slope	Mean	5.9	59.0	10.7	4.6	1.5	75.8	3.4	17.4	2.8	31.0	7.1
		Range	5.8-6.4	27.5-76.1	5.3-21.7	1.5-8.4	0.7-2.4	53.5-95.8	1.8-4.8	9.6-25.3	1.0-4.0	2.3-48.8	2.6-20.9
		CV%	4%	22%	26%	7%	13%	16%	30%	21%	27%	34%	51%
	Sig. landform.		**ns**	**	***	**ns**	*	*	**ns**	**ns**	***	**	**ns**
Sig. system.			**ns**	**ns**	*	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
		Av. LSD	0.2	8.8	3.4	1.6	0.4	7.8	0.7	3.4	0.7	8.5	2.9

Table 8. Regional weight (per kg soil) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS sheep & beef and dairy farm soils. **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $\text{LSD}_{0.05}$ values shown are the average values of the ANOVA.**

Sector	Region		Olsen-P	Resin-P	[1]P-retn.	Sulp-S	Org-S	[2]AMN-N	Total-C	Total-N	C/N	CEC	Ca	Mg	K	Na
			mg P/kg soil		ASC%	mg/kg soil		g/kg soil-N	% w/w		ratio	cmol/kg soil				
Dairy	Taranaki	Mean	83.1	103.1	87.4	24.0	13.6	24.0	10.5	1.0	10.6	21.9	10.6	2.2	1.1	0.4
		Range	36-123	14-169	37-98	8-100	6-24	16-40	5.4-12.9	0.5-1.3	10.0-11.5	10-33	3-19	0.9-4.0	0.4-1.9	0.2-0.7
		CV%	31%	44%	19%	84%	34%	22%	21%	22%	5%	30%	41%	41%	38%	39%
	Waikato	Mean	88.4	126.1	78.5	26.9	11.4	25.4	8.8	0.9	10.3	20.3	11.9	1.9	1.1	0.2
		Range	27-239	23-245	26-95	10-85	5-32	13-49	5.3-16	0.5-1.2	9.3-13.2	4-37	1-27	0.7-3.9	0.4-2.2	0.1-0.4
		CV%	45%	45%	19%	52%	36%	31%	22%	22%	7%	33%	51%	42%	44%	39%
	Sig. region		**ns**	**ns**	*****	**ns**	**ns**	**ns**	******	******	**ns**	**ns**	**ns**	**ns**	**ns**	*******
		Av. LSD	21.0	29.3	8.4	8.2	2.3	4.2	1.1	0.1	0.4	3.8	3.2	0.4	0.3	0.1
Sheep & Beef	Upper SI	Mean	22.8	35.6	19.2	8.3	4.1	38.0	3.7	0.3	11.0	13.8	8.3	1.6	0.7	0.2
		Range	6-56	8-110	1-38	2-27	1-6	25-63	2.3-5.8	0.2-0.5	9.6-13.6	10-21	5-17	0.8-3.5	0.2-1.6	0.1-0.4
		CV%	60%	73%	37%	63%	32%	27%	22%	22%	7%	19%	30%	41%	48%	30%
	Central SI	Mean	26.9	38.6	31.6	16.6	6.6	38.8	4.1	0.4	10.8	15.1	7.7	1.7	0.8	0.2
		Range	14-56	16-115	18-75	5-45	1-12	20-58	2.4-7.1	0.2-0.7	9.6-12.4	11-24	3-17	0.5-3.7	0.3-1.6	0.1-0.5
		CV%	38%	51%	35%	53%	38%	23%	30%	32%	7%	18%	37%	60%	43%	43%
	Lower SI	Mean	31.3	53.7	28.6	15.4	6.4	41.7	5.0	0.4	11.7	18.4	11.6	1.8	0.8	0.3
		Range	11-98	13-144	5-68	3-51	1-16	20-56	2.3-9.1	0.2-0.8	9.5-15.2	11-54	6-36	0.7-8.8	0.2-4.3	0.1-0.5
		CV%	53%	54%	43%	57%	52%	18%	26%	25%	10%	30%	35%	62%	70%	29%
	Sig. region		*******	*******	*******	*******	*******	**ns**	*******	*******	*******	*******	*******	**ns**	**ns**	******
		Av. LSD	5..0	9.1	4.6	3.1	1.1	3.5	0.5	0.04	0.4	1.7	1.4	0.4	0.2	0.03

[1] P retention (ASC%)

[2] anaerobic mineralisable nitrogen; g N/kg soil nitrogen

Table 9. Regional volume (ha; 0-7.5 cm) means, ranges and coefficients of variation (CV%) for a suite of soil chemical test values for the ARGOS sheep & beef and dairy farm soils. **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.**

Sector	Region		Olsen-P	Resin-P	[1] P-retn.	Sulp-S	Org-S	[2] AMN	Total-C	Total-N	C/N	[3] CEC	Ca	Mg	K	Na
			kg P/ha		ASC%	kg S/ha		kg N/ha	tonnes/ha		ratio	Meq/ha	kg/ha			
Dairy	Taranaki	Mean	39.2	49.8	87.4	11.3	6.3	220	48.8	4.6	10.6	103	984	123	209	45
		Range	17-84	7-122	37-98	4.7-48.7	3.5-10	118-296	41-58	3.6-5.5	10.0-11.5	65-157	341-1,539	51-226	109-209	25-86
		CV%	40%	54%	19%	87%	29%	19%	10%	11%	5%	29%	37%	40%	40%	44%
	Waikato	Mean	39.6	67.9	78.5	14.3	6.1	221	46.2	4.5	10.3	109	1281	119	235	27
		Range	14-101	13-177	26-95	5.6-44	2.2-16	131-383	30-66	2.6-6.0	9.3-13.2	18-190	117-2,500	36-214	74-235	9-54
		CV%	46%	52%	19%	51%	38%	23%	15%	16%	7%	34%	51%	39%	46%	43%
	Sig. region		**ns**	**ns**	*****	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	*******
		Av. LSD	9.8	18	8.4	4.2	1.2	28	3.5	0.4	0.4	20.2	338	26	59	8
Sheep & Beef	Upper SI	Mean	12.8	30.6	19.2	7.0	3.5	208	32.4	2.9	11.0	117	1410	161	217	40
		Range	4-29	6-97	1-38	1.7-18	0.9-6	124-352	22-52	1.9-4.5	9.6-13.6	78-186	894-3,066	71-356	79-217	13-94
		CV%	61%	77%	37%	61%	34%	25%	22%	22%	7%	18%	31%	41%	47%	36%
	Central SI	Mean	15.9	31.7	31.6	13.6	5.4	242	33.1	3.1	10.8	123	1258	161	241	46
		Range	8-36	13-102	18-75	3.9-38	0.8-10	77-427	20-46	1.9-4.7	9.6-12.4	89-196	543-2,745	55-363	89-241	9-101
		CV%	39%	53%	35%	55%	36%	35%	23%	26%	7%	15%	37%	56%	39%	42%
	Lower SI	Mean	17.5	41.8	28.6	12.0	4.8	270	38.3	3.3	11.7	141	1783	165	230	46
		Range	6-47	11-115	5-68	2.4-47	0.8-10.9	106-456	23-64	1.9-4.7	9.5-15.2	80-297	835-3,976	67-578	69-230	24-91
		CV%	53%	55%	43%	59%	44%	23%	20%	20%	10%	24%	29%	58%	63%	30%
	Sig. region		**	***	***	***	***	***	***	**	***	***	***	**ns**	**ns**	**ns**
		Av. LSD	2.8	7.6	4.6	2.6	0.8	27	3	0.3	0.4	10.6	198	36	48	6

[1] P retention (ASC%)
[2] anaerobic mineralisable nitrogen
[3] Cation exchange capacity (meq/ha – 10^6 equivalents/ha)

Table 10. Regional means, ranges and coefficients of variation (CV%) for soil chemical and microbial test values for the ARGOS sheep & beef and dairy farm soils. Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. $LSD_{0.05}$ values shown are the average values of the ANOVA.

Sector	Region		pH	Ca	Mg	K	Na	BS%	Soluble-C	Micr.-C	Micr.-N	Micr.-N	Microbial
				% Base Saturation					g C,N/kg soil-C			g N/kg soil-N	C/N ratio
Dairy	Taranaki	Mean	6.0	47.9	9.8	5.1	1.9	64.7	2.5	13.6	2.3	24.1	6.1
		Range	5.6-6.7	26-82	6.3-12	3.6-6.6	0.9-2.6	38-96	1.5-5.1	8.5-18	1.3-3.4	13-37	4.4-9
		CV%	30%	28%	18%	15%	22%	21%	38%	23%	25%	25%	22%
	Waikato	Mean	6.0	55.3	9.5	5.8	1.2	71.8	2.7	13.5	2.2	22.3	6.6
		Range	5.2-6.8	14-87	4.3-19	2.2-12.3	0.4-3.0	26-99	1.0-6.8	7.2-26	1.0-3.4	9-37	2.4-13
		CV%	34%	30%	33%	41%	50%	23%	37%	24%	30%	32%	30%
		Sig. region	**ns**	**ns**	**ns**	**ns**	*******	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
		Av. LSD	0.2	8.7	1.6	1.2	0.3	8.7	0.6	1.8	0.4	3.8	1.0
Sheep & Beef	Upper SI	Mean	5.9	59.8	11.5	4.8	1.5	77.6	3.3	15.9	2.2	24.2	7.9
		Range	5.6-6.5	43-84	4.7-21	1.7-10.6	0.6-3.4	64-98	1.7-5.2	9.6-24	1.0-3.3	11-38	3.8-21
		CV%	23%	17%	35%	45%	37%	10%	25%	26%	30%	29%	46%
	Central SI	Mean	5.8	50.4	10.9	5.0	1.6	68.1	3.5	17.0	2.8	30.4	6.9
		Range	5.1-6.4	24-83	3.6-25	1.2-9.0	0.4-3.7	48-93	2.0-4.8	8.6-33	0.6-5.2	7-52	2.5-21
		CV%	30%	27%	55%	36%	39%	15%	18%	31%	37%	35%	51%
	Lower SI	Mean	6.0	63.0	9.5	4.1	1.5	78.0	3.8	17.4	2.8	32.5	7.1
		Range	5.3-6.7	37-84	4.6-23	1.5-17.1	0.5-2.9	51-97	1.6-6.5	9.4-26	0.5-5.7	2-75	2.9-34
		CV%	28%	14%	40%	51%	32%	11%	28%	24%	33%	39%	55%
		Sig. region	*******	*******	**ns**	*****	**ns**	*******	******	**ns**	******	******	**ns**
		Av. LSD	0.1	4.2	1.9	0.8	0.2	3.6	0.4	1.8	0.4	4.4	1.4

Table 11. Mean system and landform respiration and metabolic quotient values versus time (days) for Dairy and Sheep & Beef farms. Urea (500 kg/ha) applied at 7 days. **Significance of differences of means (unbalanced ANOVA): ns –not significant, * P<0.05, ** P<0.01, *** P<0.001. LSD$_{0.05}$ values shown are the average values of the ANOVA.**

Sector	**System**	**Landform**	**Respiration**						**Respiration (per unit soil carbon)**						**Metabolic quotient**					
		Days→	0	3	7	8	10	14	0	3	7	8	10	14	0	3	7	8	10	14
			μg CO_2/kg soil/s						μg CO_2/kg soil-C/s						mg CO_2/kg Bio-C/s					
Dairy	Converting	crest	0.8	0.5	0.5	4.4	1.4	0.4	7.8	5.4	5.3	44.7	14.3	4.4	1.1	0.7	0.7	5.9	1.9	0.6
		flat	0.9	0.4	0.5	4.1	1.2	0.4	12.1	5.1	5.5	51.9	15.1	4.7	1.2	0.6	0.6	5.5	1.6	0.5
		slope	0.8	0.4	0.3	5.3	1.7	0.5	9.0	4.4	4.4	68.1	21.6	6.7	1.0	0.5	0.5	7.1	2.3	0.7
	Conventional	crest	0.7	0.4	0.5	5.1	1.5	0.5	7.5	4.4	5.2	60.1	16.7	5.3	0.9	0.5	0.6	6.9	2.0	0.6
		flat	0.6	0.3	0.4	3.6	1.2	0.3	9.9	4.1	4.8	51.0	15.5	4.1	0.8	0.4	0.5	4.8	1.5	0.4
		slope	0.7	0.4	0.4	5.6	1.8	0.5	7.9	4.8	5.0	70.1	22.1	5.8	0.9	0.5	0.6	7.6	2.4	0.6
		Sig. landform	**ns**	*****	**ns**	*******	*******	*****	**ns**	**ns**	**ns**	*****	******	******	**ns**	*****	**ns**	*******	*******	******
	Sig. system.		*****	*****	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	*****	*****	**ns**	**ns**	**ns**	**ns**
		Av. LSD	0.3	0.1	0.2	0.6	0.3	0.1	6.1	1.6	1.8	17.8	5.0	1.5	0.4	0.2	0.3	0.8	0.3	0.2
Sheep & Beef	Organic	crest	1.1	0.6	0.8	6.5	0.5	0.4	18.5	10.7	13.1	115.5	8.9	6.7	1.4	0.8	1.0	8.7	0.7	0.5
		flat	1.0	0.6	0.9	6.9	1.2	0.5	19.1	12.5	14.4	128.6	18.5	6.1	1.3	0.8	1.2	9.3	1.6	0.7
		slope	1.1	0.8	0.9	8.4	1.6	0.6	18.8	10.8	11.9	118.4	17.9	7.4	1.5	1.0	1.2	11.2	2.2	0.9
	Integrated	crest	0.8	0.6	0.9	6.9	0.8	0.3	16.7	12.8	17.6	137.2	18.0	6.6	1.1	0.9	1.2	9.2	1.1	0.5
		flat	0.9	0.6	0.7	5.7	1.0	0.4	17.0	11.2	13.7	116.3	22.1	6.7	1.2	0.8	1.0	7.6	1.4	0.6
		slope	1.2	0.9	1.0	7.9	1.3	0.6	18.9	13.1	14.9	121.0	17.1	7.8	1.6	1.2	1.3	10.6	1.8	0.8
	Conventional	crest	0.7	0.6	0.7	7.1	0.5	0.4	14.0	11.4	13.5	143.3	10.0	7.3	1.0	0.8	0.9	9.5	0.7	0.5
		flat	0.8	0.5	0.6	4.7	0.7	0.3	17.7	12.3	14.3	115.3	18.3	6.0	1.0	0.7	0.8	6.3	1.0	0.3
		slope	0.8	0.5	0.7	5.1	0.9	0.3	18.3	12.0	16.3	120.7	24.7	8.3	1.1	0.7	0.9	6.9	1.2	0.5
		Sig. landform	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
	Sig. system		**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	*****	**ns**	**ns**	**ns**	**ns**	**ns**
		Av. LSD	0.5	0.4	0.6	4.2	1.2	0.5	6.6	4.6	4.9	20.8	12.2	3.2	0.7	0.6	0.8	5.6	1.6	0.7

Table 12. Mean ordinal values, bulk density and earthworm weights for systems and landforms for Dairy and Sheep & Beef sectors. **$LSD_{0.05}$ values shown, where appropriate, are the average values of an unbalanced ANOVA.**

Management	System	Landform	Porosity	Aggregation	Mottles	BD-A [2]	BD-B [2]	Earthworms
			[1]proportion of observations >1			g/cm^3		g/m^2
Dairy	Converting	Crest	0.62	0.45	0.08	0.66	0.78	306
		Flat	0.82	0.30	0.06	0.70	0.92	195
		Slope	0.42	0.24	0.05	0.79	0.90	217
	Conventional	Crest	0.75	0.28	0.04	0.67	0.81	320
		Flat	0.88	0.47	0.08	0.77	0.97	144
		Slope	0.80	0.41	0.04	0.68	0.84	331
		Sig. landform	*	ns	ns	*	**	***
	Sig. system		ns	ns	ns	ns	ns	ns
		Av. LSD	-	-	-	0.07	0.11	76
Sheep & Beef	Organic	Crest	0.26	0.03	0.00	0.93	1.00	229
		Flat	0.53	0.10	0.05	1.10	1.19	283
		Slope	0.19	0.01	0.04	1.04	1.15	250
	Integrated	Crest	0.30	0.08	0.00	1.01	1.14	227
		Flat	0.61	0.08	0.00	1.14	1.24	244
		Slope	0.31	0.05	0.00	1.08	1.21	255
	Conventional	Crest	0.40	0.05	0.00	0.99	1.06	287
		Flat	0.55	0.08	0.02	1.16	1.20	283
		Slope	0.34	0.01	0.02	1.08	1.22	250
		Sig. landform	*	*	ns	***	*	ns
	Sig. system		ns	ns	ns	ns	ns	ns
		Av. LSD	-	-	-	0.11	0.12	67

[1] proportion of ordinal values scored greater than 1 (ie. decreasing quality), significance estimated using a general linear binomial regression model (Genstat 8.0).
[2] A: 0-7.5 cm; B: 7.5-15 cm

Table 13. Mean ordinal values, bulk density and earthworm weights for regions for Dairy and Sheep & Beef sectors. **$LSD_{0.05}$ values shown, where appropriate, are the average values of an unbalanced ANOVA.**

Management	Region	Porosity	Aggregation	Mottles	[2] BD-A	[2] BD-B	Earthworms
		[1]proportion of observations >1			g/cm^3		g/m^2
Dairy	Taranaki	0.91	0.16	0.00	0.64	0.89	199
	Waikato	0.64	0.41	0.07	0.72	0.86	264
	Sig. region	*	*	ns	*	ns	*
	Av. LSD	-	-	-	0.06	0.08	58
Sheep & Beef	USI	0.14	0.01	0.02	1.18	1.29	261
	CSI	0.41	0.07	0.05	1.09	1.16	338
	LSI	0.50	0.06	0.01	1.05	1.17	215
	Sig. region	*	ns	ns	***	***	***
	Av. LSD	-	-	-	0.09	0.09	40

[1] proportion of ordinal values that are greater than 1, significance estimated using a general linear binomial regression model (Genstat 8.0).
[2] A: 0-7.5 cm; B: 7.5-15 cm

5 Discussion

5.1 Soil Chemistry

5.1.1 System and Landform

Dairy

The most obvious difference between Conventional and Converting (Dairy) was the lower P and S test values (Olsen-P, Resin-P and Sulphate-S) for the latter systems indicating the withholding of soluble P and S fertilisers. Although differences were more evident on a volume than a weight basis, the trends were similar. The greater gradient coefficient for Converting farms in the regression relationship between Resin-P and Olsen-P values (Figure 1) is most likely due to the substitution of soluble P fertilisers with sparingly soluble products such as reactive phosphate rock (RPR). These are sparingly soluble in alkali extractants such as sodium bicarbonate used in the Olsen-P test but exchangeable in the presence of cationic and anionic resin membranes used in the Resin-P test (Saggar *et al.* 1992). This may mean that the relationship between Olsen-P and Resin-P test values for Organic system farms will diverge from that for the Conventional farms in the future but at this stage the regression is sufficiently similar.

The large numbers of Converting (>50%) and particularly Conventional farms (>70%) exceeding the upper soluble-P recommendation (40 mg P/L) is of concern and indicates overuse of P fertilisers. Since even this guideline has only relevance for the 90% percentile of producers and research shows that the lower guideline of 30 mg P/L is more appropriate (Roberts and Morton 1993), it would seem that these percentages are conservative. Differences between the Dairy systems are probably due to Converting farms already having lower initial Olsen-P values (ie. less soluble P fertiliser was applied in the period leading up to conversion) rather than any rapid reduction in P status after only one or two years into the 3-year organic certification process. Whilst P values for Converting systems are obviously decreasing there is some way to go before they will enter a less than optimal phase and it will be interesting to monitor the progression.

The higher soil pH, soil-C and C/N ratios for Converting systems probably reflects lower N fertiliser use, less soil acidification and the build up of soil organic matter due to “lower quality” inputs (ie. wider C/N ratios) and less mineral-N available to maintain the rates of carbon turnover evident in Conventional systems (Marschner *et al.* 2003; McLaren and Cameron 1990). To maintain N status in Organic systems requires healthy and vigorous clover or other pasture legumes so it will be important to ensure nutrients such as K, S and P are not lacking or continuing to decline (Bolland and Gilkes 1992; Morton *et al.* 1994b; Roberts and Morton 1993; Simpson *et al.* 1988). As yet no significant differences in exchangeable cations has occurred between systems.

Differences between landforms in soil test values were more strongly evident and the generally higher values for crest areas for soil pH, P, Total-N and exchangeable Mg, K and Na and lower C/N ratios are most likely due to nutrient transfer in animal excreta (Gillingham and During 1973; Metherell 2000; Williams and Haynes 1992). There was also evidence of depletion of Mg, particularly from slope areas, and P from flat areas, of Converting farms suggesting that these areas will need closer monitoring.

Sheep and Beef

Generally, Sheep & Beef systems compared with Dairy are more extensively managed and as a consequence are less heavily fertilised. This effect is more noticeable in Organic farms where it is becoming apparent that Olsen-P values have declined and are approximately half that of Conventional and Integrated systems. The regression relationships between Olsen-P and Resin-P values for each of the three systems were almost identical with no discernible differences that might account for increased sparingly-soluble P reserves in the Organic farms. If P values continue to decline on these farms there could be some potential loss of production in the foreseeable future. Conversely, almost 30% of Conventional and Integrated farms exceed P guidelines and could reduce P application rates. Differential fertiliser rates between systems affects exchangeable cations with Organic soils having lower exchangeable-Ca, presumably from the withholding of soluble Ca-based fertiliser, and greater exchangeable-Mg and Mg BS%. Lower overall exchangeable-Mg for Conventional farms is probably in response to continual applications of Ca-based fertilisers and higher stocking rates (more urine deposition) increasing the leaching losses of Mg (Early *et al.* 1998; Rajendram *et al.* 1998). Both Organic and Conventional farms showed evidence of lowering K values although the means were well above guidelines. In Organic systems, however, the ability to rectify losses may be more difficult and will require more careful monitoring.

Whilst there were no significant differences between systems in C and N values or C/N ratios, there were significantly lower ($P<0.05$) AMN-N values for organic systems. AMN is a subset of soil-N and a measure of readily mineralisable-N suggesting that these lower values are a response to the withdrawal of fertiliser N meaning “lower quality” SOM, though this remains to be corroborated.

On both a weight and volume basis, differences in P and S values between landforms showed flat areas had higher values on average, probably reflecting differential fertiliser rates between areas of the farms. This also appears to be confirmed from increased Ca BS%, and decreased Mg BS% in flat areas, compared with the other landforms. Higher C, N, S and AMN-N values on crest landforms is evidence of nutrient transfer in excreta and although significant differences in C, N and AMN-N between landforms disappeared when calculated on a volume basis, this was probably due to lower bulk densities of the crest sites. It is likely that the lower BD is the result of greater inputs of organic matter in dung on these areas. This is backed up by the higher AMN-N values and lower Ca and total BS% for crest sites indicating that other cations, such as ammonium (NH_4^+) from dung and urine, may be occupying the soil exchange sites. Crest areas in organic farms showed significantly lower P (Olsen and resin), inorg-S and AMN than the same areas for integrated and conventional farms suggesting that excreta inputs were of lesser “quality” and reflecting input policies. Nutrient transfer between landforms is obviously a major factor that has to accounted for in any farm fertiliser policy but it would appear that Organic farms, with their lower rates of inputs, will need to be more proactive to ensure production is maintained to the required level. Provided good management is practiced, this should be achievable (Goulding *et al.* 2000). One feature which is difficult to explain is the consistently greater P retention values for crest areas over slope or flat areas for all three systems. This was also apparent for Dairy and does not seem related to Olsen P values so unless some interference is at work, we are unable to explain this at present.

5.1.2 Region

Dairy

The small number of significant differences found generally between mean test values for soils from the Taranaki and Waikato regions was not surprising as their parent materials originate from volcanic tephra created by eruptions from Mt Taranaki (Egmont) and Taupo, respectively. Those from Taranaki are andesitic in origin whilst those from the Waikato are from the Taupo eruptions and mainly rhyolitic material (Molloy 1988c; Molloy 1988d). The weathering of the former produces allophane, a Al-clay mineral that forms strong and stable OM complexes and possesses a strong affinity to adsorb P (Dahlgren *et al.* 2004). Whilst all clays help stabilise SOM (McLaren and Cameron 1990), accumulation of these stable allophanic clay-OM complexes creates large pools of passive OM (Parfitt *et al.* 1997) and hence, high OM content. Whilst soils from both regions are high in SOM, the greater allophonic content of the Taranaki soils is indicated by the higher P retention values. Increased exchangeable-Na in the Taranaki soils simply reflects their more westerly position and a greater exposure to salt–bearing winds and increased Na deposition (Dewes 1995).

Sheep and Beef

These farms covered a far wider spread of location than those for Dairy, from Marlborough to Southland, and were split into upper, central and lower South Island designations. Soils of the South Island are largely formed from sedimentary parent materials and although these vary in fertility, it is the regional gradient in both temperature and rainfall (Tomlinson and Sansom 1994a; Tomlinson and Sansom 1994b) that most influences soil properties and probably more overtly than soils from the Taranaki and Waikato regions. This seems to be borne out by the highly significant differences ($P<0.001$) for P, S, C, N, CEC and Ca values between the three regions with the gradient declining from south to north. With upper east coast generally warmer and drier than the south, rates of soil weathering are lower and soils have lower clay contents (Molloy 1988b; Molloy 1988e). The build-up of soil organic matter is also less due to the effect of moisture stress on biomass production, especially in summer and the effect this has on the rates of OM breakdown and the stabilisation of soil aggregates. Compare this to the wetter and cooler south where weathering and biomass production rates are higher and less limited by moisture deficits meaning clay content, soil-C, soil-N and CEC increase accordingly (Molloy 1988a; Molloy 1988b). In these differing production environments, farm management in the north may be less intensive and consequently, nutrient inputs are less and reflected in P, S and N test values. The converse probably applies to soils in the south but it may also be that greater clay contents of these soils allow increased sequestration of these nutrients. To some extent these are broad generalisations and apply to non-irrigated land only but they appear to have some support.

5.2 Soil Biology

5.2.1 System and Landform

Dairy

The major significant difference between systems was for increased microbial-C ($P<0.05$) (with a similar trend in microbial-N) and C/N ratios in Converting soils compared with Conventional counterparts. Grayston et al. (2004b) has also reported similar effects in unimproved and improved grasslands in Great Britain showing lower microbial-C in improved grassland. It has been similarly reported that this decrease (or increase in Organic systems) may reflect that in well fertilized pastures using high rates of N, there is a reduction in sward root mass and therefore reduced inputs of root C that is not compensated by increased inputs of above ground biomass (Lovell *et al.* 1995). Whilst there is likely to be a lower stocking rate for the Organic systems farms in the future and, therefore, lower OM inputs from excreta and plant matter returns, this has probably yet to make an impact. The increase in soil C/N ratios support this and suggest that the root and other OM returns are of “lower quality” ie. of a higher C/N ratio from with-holding of N fertiliser. These differences point to changes occurring in the Converting system farms but any trends need to be confirmed in future measurements. With Converting systems only 1-2 years into the conversion process to Organic, it seems almost premature to expect any significant differences already but may reflect that the nutrient flows in Dairy systems are large and more intensively managed (Roberts and Morton 1998) and that abrupt change produces more noticeable differences.

Basal respiration and metabolic quotient showed small but significant increases for Converting systems and may reflect increased stress on microbial populations but since microbial-C was also higher for Organic systems it may just indicate a larger respiring population. Although not significant, respiration on a per unit weight soil-C basis followed similar trends. (Table 11). After urea application no differences in respiration or metabolic quotient between systems were apparent, showing soil microbial bionmass response was similar in both.

The only significant difference between Dairy landforms in microbial properties was higher microbial-N values per unit weight soil-N on flat landforms of Converting farms although the same trend was also noticeable on a unit weight soil-C basis. This may be due to increased stocking rate or other management factor but is unclear at this time. In terms of respiration, however, rates on both a soil and unit carbon basis and for metabolic quotient showed that these were greatest on slope landforms but it is difficult to interpret these at present as it depends on whether peak CO_2 production had occurred prior to the first 24 hours. If so, it would suggest that the slope soils have been slower to respond to urea application, if not, it would suggest that a build-up of labile-C has occurred which, with the addition of N, has been respired as CO_2. Generally, labile-C and enzyme activities have been shown to be highest on camp or crest sites (Haynes and Williams 1999). Metabolic quotients can be higher however, as a response by microflora to adverse conditions such as environmental stress (Wardle and Ghani 1995).

Sheep and Beef

A significantly higher overall intercept for the Integrated regression line over the other two systems for microbial-C versus soil-C% suggests that some stimulation of microbial populations is occurring over and above Conventional and Organic systems. It would be speculative to postulate what is causing this but possibly greater overall soil fertility for Integrated farms has increased soil OM inputs. The C/N ratio was lower for Integrated (11.0) compared with the other two (not significant) but again it is difficult to confirm whether this is related. No significant differences were found between systems for microbial C or N on a unit soil-C weight basis. Generally, the few differences in soil microbial properties indicate that Sheep & Beef systems, compared to Dairy, are not as intensively managed. Whilst that does not mean there are no differences, they are not discernible in terms of the catch-all methods used to measure biomass. There is evidence to show that the distribution between fungal and bacterial micro-organisms may well be different between organic and conventional systems but it may be difficult to interpret whether these differences are significant in terms of soil quality or merely a reflection of management (Clegg 2006; de Vriesa *et al.* 2006; Grayston *et al.* 2004a). Respiration values between systems were also quite similar on both a soil weight and soil-C basis. The single significant set of T=0 metabolic quotient values did point to a higher quotient value and less efficient respiration on the Organic farms compared with Conventional (Milne and Haynes 2004) but it is difficult to establish at this stage whether this is a real trend of increased microbial efficiency or due possibly to more adverse environmental conditions (Wardle and Ghani 1995).

Calculations for total CO_2 evolved for each system showed that the peaks of CO_2 evolution may have occurred prior to the first 24 hours and at different times for each system. If this is the case, it might suggest that Conventional farms are respiring CO_2 faster than the Integrated and Organic systems, possibly because of higher intensity management. It is noteworthy that the total amount of respired CO_2 measured appeared to be considerably lower overall for the higher intensity-managed Dairy sector soils than those for Sheep & Beef indicating that the peak production of CO_2 may have been earlier for Dairy than for Sheep & Beef.

Significant increases in microbial-N values for crest landforms compared with flat and slope landforms were likely to be the result of stock transfer of excreta to crest sites. The priming effect of excreta transfer on levels of soil micro-organisms and enzymes is well documented (Haynes and Williams 1999).

5.2.2 Region

Dairy

Given soil similarities between the Waikato and Taranaki regions it was probably not surprising that differences in microbial test values were not significant. Respiration values on the other hand, showed significant differences between regions in terms of the rate of CO_2 evolution on both a soil and soil-C basis. With the peak of urea hydrolysis for both regions apparently occurring somewhat earlier than 24 hours, it would seem that the Taranaki soils are respiring CO_2 faster than the Waikato soils for which there is no obvious explanation. However, with CO_2 levels from both regions reaching background values after 14 days, its overall significance is probably small but demonstrates that differences between systems may be less than those between regions and soil classes.

Sheep and Beef

Regional differences in microbial test values were strong and probably reflect differences in soil properties between regions. The significantly higher soluble-C and microbial-N values (backed by the trend in microbial-C values) appear to demonstrate increased labile C and microbial populations with the shift south. This seems likely a function of increasing pasture production, clay contents and SOM quality through higher soil fertility (see discussion in soil chemistry) and more favourable soil moisture regimes (McLaren and Cameron 1990; Milne and Haynes 2004; Parfitt *et al.* 1997).

Upper SI farms appeared to respire CO_2 faster than CSI and LSI regions on both a soil and unit carbon basis given that the summation of the area under the peaks did not exceed that expected by way of urea hydrolysis. Why this might have been is not clear but only two sets of farms comprise the USI set so it could be an anomaly or possibly the microbial community is more efficient and primed to make use of any readily-available organic-N source.

5.3 Soil Physical Condition

5.3.1 System and Landform

Dairy

Given that the Converting farms were only part way into full organic conversion it might have been surprising if any significant differences had been apparent in terms of soil physical condition between Converting and Conventional farms. However, with soil porosity higher overall for Converting systems and almost significant at the 5% level, suggests that these farms have better soil physical management and/or lower stocking density. With the higher earthworm weights for Conventional systems also similarly, just outside significance, suggests that the higher fertility of these farms is probably underpinning higher earthworms numbers (Haynes and Naidu 1998). In terms of landform differences, flat areas within farms of both systems showed evidence of lower porosity, higher bulk density and lower earthworm weights than slope or crest areas which is consistent with the effects of increased soil compaction (Hansen and Engelstad 1999).

Sheep & Beef

Porosity, aggregation and mottles scores were considerably higher overall than for Dairy systems indicating that Sheep & Beef soils generally had better physical condition probably because of lighter treading than their dairy counterparts. Their higher overall BD's were, in part due to their sedimentary, rather than volcanic ash, derived parent materials and lower organic matter contents. Significantly lower BD's on the 7.5-15 cm layers on Organic farms probably indicates lower stocking densities compared with their Conventional and Integrated counterparts. Higher porosity generally on Organic farms was a feature of the soil physical comparisons between systems although not significant. Landform differences were similar to those for Dairy farms with flat areas exhibiting poorer physical structure than for crest and slope areas, although this did not appear to affect earthworm weights which were similar between systems for the three landforms.

5.3.2 Region

Dairy

Lower porosity, BD and earthworm weights for Taranaki farms, whilst appearing to be regionally related, are more likely to be due to the fact that the Taranaki farms are predominantly flat sites and therefore analysis is skewed by landform, rather than any regional differences.

Sheep & Beef

Higher overall porosity for USI sites is difficult to explain given their considerably higher BD's but the latter may be partly influenced by a higher proportion of stones in their soil profiles. Earthworm weights appeared to be significantly lower in the LSI sites and may be related to lower porosity in these farms overall created by their wetter soil conditions (Haynes and Naidu 1998).

6 Summary

Soil chemistry

For both Dairy and Sheep & Beef sectors, the most significant feature was the decline in P and S test values for Converting (to organic) and Organic farms compared with their Conventional counterparts. For the Dairy sector farms this not an issue as the majority of farms had P test values in excess of recommended maximum guidelines for the 90% percentile of producers (ie. >40 mg P/L) and even Converting farms at this stage were generally well in excess of recommendations. A greater correlation coefficient for Converting over Conventional farms for Resin-P versus Olsen-P values possibly signifies evidence of an early build-up of residual-P in the Converting farms using RPR. There was no such evidence however, for the Sheep & Beef sector where regression equations between Resin-P and Olsen-P values were almost identical for all three systems although P and S levels were much lower overall compared with the Dairy sector. Whilst a considerable number of the Sheep & Beef Conventional and Integrated farms (~30%) exceeded maximum guideline P values, there was evidence that P test values for some Organic farms are declining to levels that might be of future concern.

Evidence of higher soil pH, soil-C and C/N ratios for Dairy Converting farms not only signifies less available mineral-N from the withholding of N fertilisers but greater build-up of soil-C from lower organic matter over Conventional systems. There was no similar trend for Sheep & Beef farms, however, possibly due to the lower intensity and inputs of their systems. Dairy farm systems showed no significant differences yet in exchangeable cations but for Sheep & Beef farms there was some evidence of the longer-term changes in fertiliser use. For Organic systems there was lower exchangeable-Ca but higher exchangeable-Mg than for Conventional systems, possibly due to the use of Ca-based fertilisers and increased stocking rates in Conventional farms increasing leaching losses of Mg. Lower exchangeable-K values in Organic and Conventional systems were not of concern but Organic systems especially, will need to be mindful of any long-term trend.

Differences between landforms were often of more significance than effects of systems, probably because their causes have been occurring for far longer than changes in the farm systems. In the most part these differences were probably due to nutrient transfer in excreta to stock camp sites leading to increasing SOM inputs in crest landforms. These led to increased P, organic-S, Total-N and exchangeable Mg, K and Na or a combination of, for both Dairy and Sheep & Beef sectors. Again, Organic systems will have to be aware long-term of the redistributions of these nutrients within their farm landscapes.

Regional differences between Dairy sector farms were slight but those between Sheep & Beef farms were more significant as they covered a far longer range of geographic position and climate. Differences related to soils of the upper South Island being typically drier and warmer compared to the cooler, wetter and more weathered soils of the south and was reflected in the lower SI soils having significantly greater P, S, C, N, CEC and clay content values.

Soil biology

Despite the Dairy Converting systems only being 1-2 years into conversion to full Organic, a small, but significant, increase over Conventional was found in microbial-C. Together with increased soil C/N ratios, this suggests that lower mineral N inputs may be stimulating more root exploration and greater root-C inputs. A significantly higher slope intercept for Sheep & Beef Integrated in the regression relationship between microbial-C and soil-C% over the other two systems may represent the other end of the spectrum, where greater overall soil chemical fertility for the Integrated farms has increased DM response and soil OM inputs. No differences were found for microbial C or N on a per unit weight soil-C basis despite the differing management systems having been in place for some years. Respiration results showed small but significant increases for basal respiration and metabolic quotient (measure of microbial efficiency) for Converting over Conventional Dairy systems but no differences after urea application. No differences were found in respiration rates between systems for Sheep & Beef.

No significant differences or trends were found for microbial-C or –N in Dairy landforms although respiration rates were higher on slope landforms after urea application possibly indicating some increased stress on microbial populations. Higher metabolic quotient values for slope landforms before and after urea application may also reflect some increased microbial stress but requires further corroboration. For Sheep & Beef landforms there was an increase in microbial-N on crest landforms in Conventional farms from excreta transfer probably but not for Organic or Integrated farms. There were no differences between Sheep & Beef landforms in respiration rates (soil or soil-C) or metabolic quotient.

No regional differences in microbial properties were found between Dairy systems although Taranaki soils appeared to show a faster rate of respiration than Waikato soils for no obvious explanation. Differences between Sheep & Beef regions of the SI were much stronger, however, reflecting the geographic spread and increasing pasture production, clay content and SOM quality of the soils in the shift from north-to-south.

Soil physical condition

The dependence of assessing soil physical condition using mainly VSA exposed difficulties in identifying any significant differences between farm systems, mainly because soil condition in the Dairy and Sheep & Beef sectors is generally good-to-excellent. Although differences may become more evident in the intensive farming sectors as systems diverge, it is more likely that farmers readily recognise the importance of managing the soil's physical condition and failure to do so quickly becomes obvious. Where differences approached significance in a few cases ($P \approx 0.06$), these mainly related to greater soil porosity in Dairy Converting systems and higher earthworm numbers under Conventional systems. Sheep & Beef systems had higher overall porosity and aggregation, and fewer mottles, than Dairy systems but like Dairy, Organic systems tended toward higher soil porosity, probably because of lower stocking densities.

Differences between landforms were more clear-cut and statistically significant with flat landforms in both Dairy and Sheep & Beef showing greater signs of soil compaction (reduced porosity, higher BD) and in Dairy, reduced earthworm weights. Regional differences were mainly restricted to Sheep & Beef farms where porosity and aggregation decreased with the shift south and may be related to the wetter climate of the LSI farms increasing the opportunities for soil compaction.

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