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Soil quality on ARGOS sheep & beef farms, 2004-2005

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Table of contents

Executive summary

Soil quality is highly sensitive to land management practices. Accordingly, monitoring soil quality is a key component of the environmental objective of ARGOS. The prime aims of this monitoring are to identify and characterise any differences in soil quality between agricultural systems (e.g. kiwifruit, dairy, sheep and beef) and between different farm management systems. In the case of the sheep and beef farms studied, those management systems are organic, conventional and integrated.

Here we report the first set of results for soil quality monitoring of the sheep and beef farms in ARGOS.

The overall approach is to concentrate on groups (clusters) of commercial farms that are under the target management systems and are in close proximity.

We made a suite of measurements between July and September 2004, with the intent to repeat this monitoring regularly for at least five and maybe up to 20 years. Changes in soil quality over time will be compared between management systems and where possible between agricultural systems.

Soil quality varies a great deal within landscapes, farms and paddocks. Accordingly we developed a systematic soil sampling regime based on clearly defined levels of focus. Thirty seven sheep/cattle farms are being studied. These are grouped into 12 clusters, with three farms per cluster: one organic, one integrated and one conventional. Those three farms are as close together as possible to minimise environmental and soil differences. There is an extra property in cluster 12 which increases the number of properties to 37.

Our approach is to monitor the two most dominant landforms on hill country clusters. For clusters on the Canterbury Plains, only one landform (flat river terraces) will be studied. Landforms are broadly described as river terrace, hill crest and mid slope. We will study the two most dominant landforms found within the cluster. For each landform, three paddocks (management units) are monitored on each farm.

To minimise random errors between years generated by sampling different areas of soil, we have established permanent Soil Monitoring Sites (SMS) within each management unit, from which all samples will be collected. There are three SMS within each management unit (paddock). Farms with two landforms and six paddocks being monitored will have 18 SMSs. Farms with only one landform and three paddocks monitored will have 9 SMSs. Soil samples are collected from the standard sampling depth for pasture (0-7.5 cm)

A range of qualitative and quantitative soil quality indicators were chosen and prioritised. These form a suite of chemical, biological and physical tests made in the field and laboratory. Indicators in priorities one to three are being monitored on a regular basis at all sites.

Priority one measurements are made at each individual soil monitoring site. They include visual assessments of soil porosity, aggregation and estimated area of damaged and bare soil, as well as quantitative measurements of soil bulk density and earthworm populations. These indicators can be used individually or integrated subsequently into one or more soil quality scores.

Priority two samples are soil chemical analyses for the topsoil (0-7.5 cm). They are mostly a standard suite of soil measurements, but some additional measurements useful for interpretation are also being conducted. The measurements are made on aggregated samples collected from each management unit.

Priority three indicators relate to soil biological activity, and use the same samples that are collected for priority two measurements. The measurements are microbial biomass

carbon, basal respiration, and the ratio between these two parameters (a useful indicator of the efficiency of the microbial population).

Our interpretation of the data available so far is limited to a preliminary (and cautious) comparison between management systems. More detailed interpretations and a higher level synthesis are not yet possible for three main reasons.

- First, the ARGOS approach is to identify robust conclusions on the basis of carefully repeated measurements over several years.
- Second, the recommended sampling methodology was incompletely applied in the first sampling season. The need to collect soil samples urgently (before farmers applied spring fertilisers and before SMSs had been established) meant that soil was pooled from across whole paddocks, sometimes including more than one landform. Samples for priority two and three measurements will be repeated next year using soil only from fixed SMSs. The pooling of soil samples and budget limitations meant that we did not make priority three measurements in this first year of sampling, and the statistical analysis of priority one and two measurements will be less powerful because they cannot use landform as a factor.
- Finally, full interpretation of soil quality differences will not be possible until detailed information on the history and current management of the individual paddocks are available. Detailed records of recent fertiliser applications, pasture and stock management on individual paddocks are currently being gathered and will be linked to farm maps and a GIS database.

In general there was little evidence of poor soil structure. Minor soil crusting was detected in 2 of the 195 paddocks sampled. Damage to the soil surface from stock treading was observed in only ten paddocks and a surface thatch of organic material was found in only nine paddocks.

In the initial set of measurements made, few soil quality parameters differed significantly between management systems. The main difference we found was that soil phosphate status (Olsen P) was about 10µg/ml lower on organic properties than conventional properties. This may be enough to noticeably reduce pasture productivity, which needs to be checked. Similar results have been found by other researchers comparing organic and conventional farming properties. Often on organically managed properties inputs of nutrients such as P are insufficient to replace nutrients removed by farming products (e.g. cropping or stock grazing).

If soil phosphorus affects pasture production and therefore organic matter inputs to the soil, then in turn this may affect other soil factors and processes that are sensitive to organic matter inputs.

Readily available sulphur levels were lower under organic management than conventional and integrated. This difference may be due to differences in fertiliser applications although sulphate sulphur levels can be extremely variable.

Recommendations

Soil sampling must be repeated next year, but it is essential that it commences only after soil monitoring sites are located on the correct landform within each management unit (paddock).

Fertiliser records should be collected from the farmers to determine nutrient inputs. It is likely that fertiliser inputs are the main driver for differences in nutrient levels between management systems.

Nutrient outputs should be assessed by determining pasture production. These assessments will also help indicate if lower soil phosphorus levels on organic properties are affecting pasture production.

Priority three (microbial) measurements should be conducted to determine if any differences in pasture production (and therefore organic matter inputs) are affecting labile soil organic matter pools. Changes in total organic carbon will be more difficult to detect.

Nutrient budgets for each management unit (paddock) should be developed using the Overseer™ nutrient budgeting model. These results will indicate if there is a positive, neutral or negative nutrient balance, and how soil nutrient status may change in future.

Extractable organic sulphur should be considered as an additional test to the very variable sulphate sulphur test.

1. Introduction

Soil quality is highly sensitive to land management practices (Karlen et al. 1994; Reicosky & Forcella 1998; Campbell et al. 1999; Haynes & Tregurtha 1999; Saviozzi et al. 2001; Sparling & Schipper 2002; Buman et al. 2004). Accordingly, monitoring soil quality is a key component of the environmental objective of Agriculture Research Group On Sustainability (ARGOS) research which is investigating the social, economic and environmental consequences of different farming systems in New Zealand. The prime aim of this monitoring is to identify and characterise any differences in soil quality between different farm management systems. In the case of the sheep and beef farms studied, those management systems are organic, conventional and integrated.

The largest effect of management practices on pastoral soils is likely to be associated with soil nutrient status (different fertilizers may be used) and stocking rate (Reganold et al. 1993; Condron et al. 2000; Shannon et al. 2002; Stockdale et al. 2002). There is a restricted fertilizer range available for organic producers, and soil chemical analyses are important to determine if soil nutrient status is being sustained. Depending on the amount of change in soil nutrient status, pasture production or composition may also be affected. If stocking rate is changed to accommodate changes in feed availability, then soil bulk density and treading damage may be also affected.

Here we report the first set of results for soil quality monitoring of the sheep and beef farms in the ARGOS research programme. Interpretations of the results are by necessity somewhat preliminary; an important intent of the project is to build towards strongly reliable conclusions on the basis of carefully repeated measurements over several years.

2. Approach overview

In ARGOS, soil quality monitoring consists of making a suite of chemical, biological and physical tests in the field and laboratory. Visual and tactile examination of the soil in the field is the prime tool. It is complemented with a combination of standard and innovative laboratory techniques. The choices of indicators, and the techniques used for those indicators, are strongly influenced by:

- The need to cover biological, physical and chemical aspects of soil quality with techniques that can withstand scientific scrutiny;
- The need for continuity, so wherever possible results can be compared to historical information for New Zealand soils;
- A desire to encourage growers and consultants to use low-tech but reliable and meaningful 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 each other. Given this, and the likely large spatial variability in soil quality, we chose to monitor paddocks that represent 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 it is weak for characterising whole farms. The success of long term monitoring relies on consistency and sampling from permanent soil monitoring sites which have been established using guidelines developed for all agricultural systems.

We intend to repeat routine monitoring regularly for at least five and maybe up to 20 years. Time trends that may appear in the results will help us to make the more detailed and robust comparisons mentioned above. Also, in some years it may be possible to carry out some more intensive measures on specific farms to test sharp hypotheses about the effects of the management systems and differences between individual farms.

Crop & Food Research have designed the soil monitoring project, but all field sampling has been the responsibility of the ARGOS environmental team and field officers.

2.1. Structure for describing levels of focus

The prime aims are to compare:

- Between agricultural sectors (e.g. sheep & beef vs kiwifruit);
- Between management systems within agricultural systems (e.g. organic vs conventional sheep & beef farms).

Agricultural systems, management systems and individual properties are complex things to compare, and soil quality can vary a great deal in time and space. So, to achieve our prime aims on a limited budget we must be very careful to specify the levels of focus for sampling. The levels of focus in the work we adopted are explained below. Similar structures have been developed for all agricultural systems being studied.

2.1.1. Agricultural System

The agricultural production systems being monitored in this case are the sheep & beef farms participating in the ARGOS programme.

2.1.2. Management System

For the sheep and beef properties, the three management systems are

A	Organic
B	Integrated
C	Conventional

2.1.3. 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 the sheep and beef agricultural system there are 12 clusters located throughout the south island from Marlborough to Southland.

2.1.4. Property

Properties are the individual farms that make up the cluster. 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.

2.1.5. 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, hill crest and mid slope. Given the huge variation in soils and landscape across properties, we are studying the two most dominant of these within each cluster. For each hill country cluster, the two landforms which are the most dominant across all three farms will be studied. For clusters on the Canterbury Plains, only one landform (flat river terraces) will be studied.

2.1.6. Management Unit

Management unit is described as the smallest land area to be managed by the farmer on an individual basis. On sheep and beef farms, a management unit is 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.

Unfortunately paddocks were not chosen randomly because farm maps were not available. Paddock selection was based on common slope, topography, aspect, altitude across landforms within a cluster. 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.

It was intended that soil indicators collected at the management unit (paddock) level (for priorities two and three, see sections 3.2 and 3.3) would be a composite of samples collected from three permanent soil monitoring sites located within each paddock. However due to pressure to sample prior to fertiliser application, paddocks were sampled using a random zig zag pattern.

2.1.7. Soil Monitoring Site (SMS)

At a single sampling time, soil properties can be quite variable within a small area. To achieve reliable monitoring, spatial variation must be recognised and managed in the sampling system. This will allow time trends to be distinguished from random effects generated by sampling different areas of soil. Our approach to this problem is to establish permanent soil monitoring sites (SMS) within each management unit, from which all samples will be collected.

There are three SMS located randomly within each management unit (paddock), and 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

Although a paddock is selected within a landform (slope, crest or river terrace), often there is more than one landform present in a paddock. It was intended that the soil monitoring sites would be located on the designated landform within that paddock. However the SMSs were mixed across landforms within paddocks, which removed the possibility of interpreting the effect of landform on soil quality indicators.

Farms with two landforms and six paddocks monitored will have 18 soil monitoring sites. Farms with only one landform and three paddocks monitored will have 9 soil monitoring sites.

2.2. Statistical analysis

The results were analysed using analysis of variance using Genstat version 7.1 (Lawes Agricultural Trust, 2003). The data was structured with the following hierarchy

- Clusters
- Properties within clusters
- Landforms within properties
- Management units within landforms
- SMS within management units

The main factor analysed was management system, which was applied at the property level. The management system is applied across the entire property, so the management units (paddocks) represent repeated measures within the property. It is not possible to determine the effect of land form on soil quality because soil was sometimes mixed amongst land forms within the same paddock (see above). Therefore we only analysed the data by management system (i.e organic, integrated and conventional).

A one-way analysis of variance was used to analyse the results by management system, using clusters as replicates. Because the clusters are spread over a wide geographic area, blocking by cluster removes the variation due to cluster location. The additional integrated property in cluster one was excluded to allow a balanced analysis.

Soil porosity, discolouration and aggregation were scored on a 1 to 4 scale (ordinal data). However most 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. These binary scores then allow analysis to be made comparing the proportion of scores of 2 or 3 in each management unit. 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 SMSs were nested within the management unit and therefore property, and considered as repeated measures.

In the tables of results (see next section), standard error of the mean is given after each mean (mean ± SEM). Average values for management system with the same letter are not significantly different. Least significant differences to the 5% level ($LSD_{0.05}$) are given for data that is normally distributed. If the difference between treatment means is greater than the least significant difference, there is a less than 5% probability these differences are due to a random effect. Least significant ratios ($LSR_{0.05}$) are given for logarithmically transformed data. If the ratio between treatment means is greater than the least significant ratio, there is a less than 5% probability these differences are due to random variation.

3. 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 could 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.

3.1. 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.

3.1.1. 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 gleying (1-4 scale)
- Soil aggregation (1-4 scale)

3.1.2. 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°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/m3. 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. We have reported the earthworm populations on a per soil volume rather than area basis (Fraser et al., 1999).

3.2. Priority Two

These are soil chemical analyses for the topsoil and mostly a standard suite of measurements (Blakemore et al., 1987) that we contracted out to commercial soil testing laboratories. There is a substantial literature available to assist interpretation. Additional measurements useful for interpretation are being conducted by Crop & Food Research. Soil samples are collected from the standard sampling depth for pasture (0-7.5 cm). This may not represent the availability of nutrients from the entire root zone but can still provide valuable information about 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 a 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 level of clay minerals or iron oxides present 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 (Sheldrick 1986). Soil carbon is directly proportional to the soil organic matter (%C x 1.72 = %SOM).

Unfortunately, priority two samples were collected using transects across the paddock rather than composite samples collected from the soil monitoring sites. This was forced by the pending application of fertilisers before the SMSs had been established. Samples should be collected from the SMSs next year, but the difference in sampling approaches will mean that the results cannot be compared with this year's data.

3.3. Priority Three

Priority three indicators use the same sampling depth and soil samples as used for priority two measurements, and relate to the biological activity of the soil. The indicators are described below. Due to the non-standard sampling method used in this first sampling, we have chosen not to test the priority three indicators. These measurements will be conducted next sampling round when samples are collected from the soil monitoring sites.

3.3.1. Microbial biomass carbon

This is a measure of the total amount of living microbes in a soil (Vance et al., 1987). 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 total soil organic matter than total soil carbon. Microbial biomass levels will differ between soil types and land use history.

3.3.2. 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 (Anderson, 1982).

3.3.3. 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 programme.

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 of integrating the scores from the different measurements
1	Field soil dry bulk density	0 - 7.5 7.5 - 15	Samples taken using soil 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 CO2 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. Good training is crucial!

[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 - 7.5cm for pastoral farms

4. Results and discussion

The samples for priority two measurements were collected from July to October 2004, before spring fertiliser applications. Priority one measurements were conducted from September 2004 to February 2005.

Please note, the pooling of some soil samples across several landforms in some paddocks has limited the interpretation of the data to cautious comparisons at the level of the management system. We cannot use landform as a factor in the statistical analysis, so testing of the main farming systems null hypothesis is now not as powerful. Furthermore, the samples were not collected at the soil monitoring sites, so the sampling pattern cannot be repeated in exactly the same way for future trend analysis. Finally, it is inadvisable to attempt a detailed or wide ranging interpretation of the soil results yet, because mapping of the hill country farms is not yet complete, and information on the bases for farm selection is not available to us.

4.1. Priority one –soil assessments

These measurements were conducted at each soil monitoring site.

4.1.1. Area of exposed soil, live vegetation (%), crusted soil (%) and damaged soil (%), and the presence and thickness of surface organic thatch build up

There was very little variation in these visually estimated variables. Ground cover was more affected by paddock usage, for example cropped paddocks had more bare soil than those in permanent pasture. On average across all properties, there was 11% bare soil and 88% covered in live vegetation. The remaining 1% was covered in dead vegetation. Soil crusting was evident in only two of the monitored paddocks. Both of these were in a pea crop (properties 6A and 6C). Damage to the soil surface from stock treading was observed in only ten paddocks and a surface thatch of organic material was only found in nine paddocks (average thatch thickness of 1 cm).

4.1.2. Soil porosity, discolouration by mottles or gleying, and aggregation (1-4 scale)

The porosity, discolour, and aggregation score results were in the range 1 to 3, with most of the results being scores of 1, and few scores of 3 (Table **2**). These scores were converted into binary scores with scores of 1 becoming 0, and scores of 2 or more becoming 1. The proportion of scores of 2 or greater did not differ significantly between the different management systems.

Table 2. Frequency of scores for soil porosity, discolouration and aggregation measured at all soil monitoring sites.

Score	Porosity	Discolouration	Aggregation
1	395	538	474
2	157	22	75
3	13	2	13
4	0	0	0
missing	5	5	5

Table 3. Proportion (%) of scores greater than 2 for each management system

Management	Porosity	Discolouration	Aggregation
Conventional	28	2	11
Integrated	20	3	7
Organic	33	5	12
Significance	NS	NS	NS

4.1.3. Soil bulk density and earthworm populations

These results are presented in Table 4. We detected no significant differences between management systems in soil bulk density at either depth. Earthworm populations were not normally distributed and required logarithmic transformation before analysis of variance was performed. Back-transformed averages are presented for this variable. Although on average earthworm populations were 25% less under organic management than conventional management, this difference was not significant at *P*=0.05.

Table 4. Soil bulk density and earthworm populations.

Management	Soil bulk density 0-7.5 cm (g/cm^3)	Soil bulk density 7.5-15 cm (g/cm^3)	Earthworms (no./m^3)
Conventional	1.16 ± 0.03	1.29 ± 0.02	1490 ± 150
Integrated	1.13 ± 0.03	1.25 ± 0.02	1280 ± 130
Organic	1.12 ± 0.03	1.28 ± 0.02	1120 ± 110
Significance	NS	NS	NS
LSD $_{0.05}$	0.08	0.06	LSR$_{0.05}$ = 1.34

4.2. Priority two – soil chemical properties

Priority two measurements are conducted at the management unit (paddock) level. These samples were collected using random transects across the paddock rather than as intended using composite samples collected from the soil monitoring sites.

4.2.1. Soil pH, Olsen P and P retention

These results are presented in Table 5.

Usually, variation in P retention is mostly influenced by soil type (the amount and type of soil minerals which are responsible for fixing phosphorus). In the experimental design we aimed to minimise the risk of different soil types on soil properties masking the effects of management. The way we sought to do this was by using clustered properties, carefully selected landforms within clusters, and an appropriate statistical model. We appear to have been successful in this so far as we detected no differences between management systems in P retention.

We detected no significant effect of management on soil pH, and soil pH was in the normal range for pastoral soils.

Soil Olsen P was not normally distributed and required logarithmic transformation before analysis of variance was performed. Back-transformed averages are presented for this variable. Olsen P was less on organic farms than on conventional or integrated farms, and this could be due to the types of phosphate fertilisers used. Organic phosphate fertilisers (e.g. reactive phosphate rock) tend to release phosphorus over a long period of time, and the Olsen test for phosphate does not measure this slowly available P. Olsen P for organic farms is less than the normal range for pastoral soils of 20 to 30 µg/ml.

Table 5. Soil pH, Olsen P (µg/ml) and phosphorus retention (%).

Management	Soil pH	Olsen P (µg/ml)	P Retention (%)
Conventional	6.0 ± 0.05	24 b ± 2	27± 2
Integrated	5.9 ± 0.05	24 b ± 2	26± 2
Organic	6.0 ± 0.05	14 a ± 1	28± 2
Significance	NS	$P<0.001$	NS
LSD $_{0.05}$	0.1	$LSR_{0.05} = 1.25$	5

4.2.2. Exchangeable calcium, magnesium and potassium

Values for these variables were not normally distributed and required logarithmic transformation before analysis of variance. Back-transformed averages are presented (Table 6, Table 7). The variables were analysed using both reporting units (MAF units calculated on a volume basis and milli-equivalents calculated on a weight basis)

There was no significant effect of management system on any of the exchangeable cations. The observed levels of calcium, magnesium and potassium are within the normal range for pastoral soils.

Table 6. Exchangeable cations reported using MAF quick test units.

Management	Calcium (MAF)	Magnesium (MAF)	Potassium (MAF)
Conventional	8 ± 1	22 ± 2	10 ± 1
Integrated	8 ± 1	27 ± 2	10 ±
Organic	7 ± 1	26 ± 2	9 ± 1
Significance	NS	NS	NS
LSR $_{0.05}$	1.22	1.30	1.46

Table 7. Exchangeable cations reported using milli-equivalents per 100g.

Management	Calcium (me/100g)	Magnesium (me/100g)	Potassium (me/100g)
Conventional	8.6 ± 0.8	1.25 ± 0.11	0.63 ± 0.08
Integrated	8.3 ± 0.8	1.49 ± 0.13	0.71 ± 0.09
Organic	7.4 ±0.7	1.47 ± 0.13	0.59 ± 0.08
Significance	NS	NS	NS
LSR $_{0.05}$	1.19	1.29	1.44

4.2.3. Sulphate sulphur, cation exchange capacity and total base saturation

Sulphate sulphur and cation exchange capacity (CEC) were not normally distributed and required logarithmic transformation before analysis of variance. Back-transformed averages are presented for these variables. Sulphur levels were less under organic management than conventional and integrated. This difference may be due to differences in fertiliser applications although sulphate sulphur levels can be extremely variable. Organic sulphur is a more stable measure of soil sulphur availability. The normal range of sulphate sulphur for pastoral soils is 7 to 15.

There was no effect of management on either CEC or total base saturation (Table 8). This absence so far of an observed difference between management systems is of course not unequivocal, but neither is it surprising. Cation exchange capacity is a function of soil mineralogy and organic matter content. So far we can detect no differences between management systems in terms of soil organic C and the sampling system using geographic clusters should reduce the effect of differences in soil mineralogy. Base saturation is the total of exchangeable base cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) as a proportion of CEC, and neither the concentrations of these cations nor CEC differed significantly between management systems.

Table 8. Sulphate sulphur, cation exchange capacity and total base saturation.

Management	Sulphate sulphur (MAF)	CEC (me/100g)	Total Base Satn (%)
Conventional	8 ± 0.8 a	15 ± 1	74 ± 2
Integrated	10 ± 1.0 a	15 ± 1	74 ± 2
Organic	6 ± 0.6 b	14 ± 1	73 ± 2
Significance	$P<0.01$	NS	NS
LSD $_{0.05}$	LSR $_{0.05}$ = 1.33	LSR $_{0.05}$ = 1.13	6

4.2.4. Potentially mineralisable nitrogen, organic carbon and total nitrogen

Potentially mineralisable nitrogen is not often measured on pastoral soils, so information on normal ranges is not available. This test measures the amount of N that is likely to be mineralised from organic matter over a short time frame (1-2 months). There is no evidence for differences in potentially mineralisable N between the management systems.

Total carbon and nitrogen were not normally distributed and required logarithmic transformation before analysis of variance. Back-transformed averages are presented. There was no significant effect of management on either variable (Table 9), the carbon to nitrogen ratio (average of 12.1) was also unaffected by management system (results not presented).

Table 9: Potentially mineralisable nitrogen, organic carbon and total nitrogen.

Management	Pot. Min. N (kg N/ha)	Organic carbon (%)	Total nitrogen (%)
Conventional	231 ± 7	4.76 ± 0.14	0.39 ± 0.01
Integrated	241 ± 7	4.52 ± 0.13	0.38 ± 0.01
Organic	223 ± 7	4.61 ± 0.14	0.38 ± 0.01
Significance	NS	NS	NS
LSD $_{0.05}$	21	0.42	LSR $_{0.05}$ = 1.09

5. General discussion

Few soil variables differed significantly between the management systems. The main difference we observed between management systems was in soil Olsen P, which was significantly lower on organic properties. This result is supported by a review comparing organic and conventional farming systems (Condron et al., 2000). Condron et al. suggest the cause of such differences can be explained by the nutrient budgets. Conventionally managed farms tended to have neutral or positive nutrient budgets, whereas organically managed properties had a net removal of nutrients. The application to organic properties of organic fertilisers such as compost, phosphate rock and elemental sulphur can result in a positive nutrient budget. However it must be remembered that most of the nutrients in these products, especially compost, is only slowly available to plants and may affect the Olsen P values slowly.

Compared to the conventional and integrated management properties, there was less sulphate-S in the soils sampled from the organic properties. The sulphate-S has a reputation for being rather variable, and we suggest that future interpretation of soil nutrient concentrations would be enhanced if extractable organic sulphur should be considered as an additional test. Nevertheless, the sulphate-S results reported here deserve further comment. A major source of S under conventional and integrated management is superphosphate fertiliser, so the measurements of sulphate S offer some support for the hypothesis that Olsen P was least on the organic properties because the conventional and integrated properties tended to have more positive nutrient budgets due to fertilisers. Unfortunately a direct test of this is not possible until we have detailed information on management practices at each study site.

Pasture production is strongly affected by soil phosphorus levels (Sinclair et al., 1997), which may in the long term affect soil organic matter inputs. As soil biological activity is dependant on organic matter inputs, microbial biomass carbon and respiration rates may also be affected. The turnover time of soil microbial biomass is less than one year (Paul 1984) so it responds more rapidly to management changes than total organic carbon. We found no evidence of difference in soil organic carbon between management systems but this test represents both the inert and active pools of soil carbon, and large changes in organic matter inputs are required before significant shifts in soil organic carbon levels can be detected. Earthworms are sensitive to changes in management practices and populations tended to be lower under organic management than conventional management but the differences were not significant at $P=0.05$. The pooling of soil from more than one landform within paddocks, and strictures on funds, led us to abandon the complete measurements of other biological properties (microbial biomass carbon and basal respiration).

Use of the 2004 soil data for long term trend analysis will only be possible from the subsample of paddocks with only one landform present (all the Canterbury Plain clusters and some of the hill country ones). It may also eventuate that landform has very little effect on soil quality measures, in which case all the 2004 data will be more comparable with future years sampling. However, soil quality is likely to vary even within the same landform with location, so gathering soil from the same SMS will help reduce sampling variance.

We strongly recommend that the soil sampling is carried out again next year, following the sampling protocols developed. Also pasture production measurements should be carried out and related to soil quality measures. Analysis of the soil and pasture production results then should pay careful attention to the possibility that lower soil P availability on the organic properties has limited pasture productivity and organic matter returns to the soil, thereby potentially changing the soil earthworm and microbial communities. Nutrient budgets for each management unit (paddock) should be developed using the Overseer™ nutrient budgeting model. These results will indicate if there is a positive, neutral or negative nutrient balance, and suggest how soil nutrient status may change in future.

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