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Soil quality on ARGOS kiwifruit orchards, 2004-2005

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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 sectors (e.g. kiwifruit, dairy, sheep and beef) and between different farming systems. In the case of the kiwifruit orchards studied, those farming systems are KiwiGreen^{TM} Hort16A (often referred to and marketed as Zespri^{TM} Gold), KiwiGreen^{TM} Hayward, and Certified Organic Hayward.

Here we report the first set of results for soil quality monitoring of the ARGOS kiwifruit orchards which was carried out in 2004.

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 farming systems and where possible between agricultural sectors.

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 kiwifruit orchards are being studied. These are grouped into 12 clusters, with three orchards per cluster: one KiwiGreen^{TM} Hort16A, one KiwiGreen^{TM} Hayward, and one Certified Organic Hayward. Those three orchards are as close together as possible to minimise environmental and soil differences. Cluster one is in Kerikeri, cluster twelve in Motueka. The rest are located in the Bay of Plenty. There is a fourth property in the Kerikeri cluster (Hayward converting from KiwiGreen^{TM} to Organic) which increases the number of properties to 37.

For ARGOS work on sheep and beef properties, our approach is to monitor the two most dominant landforms on hill country clusters. An analogous approach is taken with kiwifruit, except that the two dominant “landforms” studied are the areas under the vine and between the rows. These are distinguished because we need to understand the effect of management practices on soil across the entire orchard, not just the soil under the vines. Management of these areas can be very different.

Given the large spatial variability in soil quality we have sampled from three separate blocks (or management units) on each orchard. The same blocks will be measured each time. We will sample from permanent soil monitoring sites (SMS). There are three SMS (each the size of two bays) within each block, from which all samples will be collected. Each SMS includes sampling areas for the two landforms referred to above.

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 include visual assessments of soil porosity, aggregation and area of damaged and bare soil, plus quantitative measurements of bulk density and earthworm populations. The indicators can be used individually or integrated subsequently into one or more soil quality scores. The samples for this are at the level of SMS.

Priority two measurements are soil chemical analyses for the topsoil (0-15 cm). They are mostly a suite of standard soil measurements with some additional measurements useful for interpretation. The samples for this are collected at the level of block.

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 comparison between farming systems and landforms. More detailed interpretations and a higher level synthesis are not yet possible for two main reasons. First, the ARGOS approach is to identify robust conclusions on the basis of carefully repeated measurements over several years. Second, full interpretation of soil quality differences will not be possible until detailed information is available on the bases for selection of the individual properties, plus historical and current management practices.

Nevertheless, our results so far show some interesting and exciting trends. In particular when we compare Certified Organic Hayward, KiwiGreen™ Hayward orchards and KiwiGreen™ Hort16A orchards:

- Soil bulk density was less and porosity was greater for organically managed orchards;
- Soil pH was highest on the organically managed orchards, although there was no indication pH would have limited crop production or soil biological activity on any orchard;
- Soil cation exchange capacity was higher for organic orchards - a tendency that may well be due to differences in soil pH;
- Organic orchards generally had more Ca and Mg;
- Organic orchards generally had more potentially mineralisable N, and biomass C;
- Olsen P was generally less on the organic orchards;
- Generally, the microbial population size and activity was highest in the organic Hayward orchards and lowest in the KiwiGreen™ Hayward orchards;
- Earthworm populations were highest on organic orchards and least in the KiwiGreen™ Hort16A orchards

There were also some significant differences between landforms and interactions between landforms and farming system:

- Soil between the rows was much less porous than soil within the rows particularly on the organic orchards. Similarly, soil between the rows was not as well aggregated as soil within the row, particularly on the KiwiGreen™ Hort16A orchards. These differences could be due to orchard vehicles damaging soil structure, and understorey vegetation which will contribute to improved soil aggregation through rooting action.
- On the KiwiGreen™ orchards, we found more earthworms between the rows than within the rows which caused an overall landform effect of more earthworms between the rows. Earthworm populations did not differ significantly between landforms on the organically managed properties.
- Soil pH was higher between the rows than within the rows on KiwiGreen™ Hort16A orchards, while the reverse was the case for Organic Hayward orchards.
- Under all farming systems, Olsen P was higher within the row than between the row. This is most likely an effect of fertiliser placement under the vine and P uptake by vegetation growing between rows.
- Cation exchange capacity (CEC) was affected by landform ($P<0.1$). The interaction between farming system and landform was significant. For KiwiGreen™ Hayward, CEC was higher between the rows than within the rows. There was no effect of landform in the other farming systems.

- There was more exchangeable calcium between the rows than within the rows in the KiwiGreen^{TM} orchards, which caused an overall landform effect. There was no difference between landforms in the organic farming system.
- For magnesium, there was a highly significant interaction effect of farming system and landform which was driven by high soil magnesium levels within the row on organic orchards.
- For Potassium, there was a strong landform effect and landform by farming system interaction i.e. the KiwiGreen^{TM} orchards (both Hayward and Hort16A) had higher soil potassium levels between the row than within the row; the reverse was the case for the organic orchards.
- Sulphate sulphur did not differ significantly between the main factors (farming system or landform). However, there was a significant interaction between farming system and landform ($P<0.05$) with sulphate sulphur higher between the row than within the row on organic orchards.
- Averaged across all farming systems, there was more soil organic carbon between the rows than within the rows.
- The amount of mineraliseable-N was higher between the row than within the row for all farming systems.
- Under both KiwiGreen^{TM} farming systems, there was more total N between the rows than within the rows. This contributed to an overall effect of higher N between the rows.
- Under all forms of farming system, the size of the microbial population was higher between the rows than within the rows with the difference being greater for the KiwiGreen^{TM} farming system. On the KiwiGreen^{TM} orchards, this difference could be attributed to less organic matter inputs due to herbicide use within the row. For the organic orchards, this result supports our suggestion that the single-time measures of orchard ground cover may be misleading.
- Our results show that basal respiration (a measure of microbial activity) was higher between the rows than within the rows for all farming systems.

Many of these trends may reflect differences in nutrient budgets and management of understorey vegetation as well as differences between orchards in their previous land use and time under kiwifruit. It is imperative that further information on such factors is used in the interpretation of our results before they are used to form recommendations to the industry. Detailed records of fertiliser applications and orchard management are currently being gathered and will be linked to farm maps and a GIS database.

Further analysis should consider is whether the differences in soil chemical or biological properties currently expressed on a per unit mass basis are still evident when the results are converted to kg per ha. Nutrient amounts expressed on a per unit area basis have considerable utility for ecological or crop production studies, although growers and consultants often cannot interpret them for their own purposes. The lower soil dry bulk density of organic properties may mean that the apparent differences in Ca, Mg, N and biomass C per unit mass of soil may be less or non-existent when expressed on a unit area basis.

Further attention needs to be placed on the many contrasts we observed between the soil within the rows and between the rows. Again much more information on site management and history is needed here, but the ecological implications of the strong differences we observed suggest that the effort will be well worthwhile. Any correlations found between differences in soil quality amongst landforms and the different ways that organic and

KiwiGreen™ growers manage vinelines and alleyways can give valuable leads on what drives the changes in soil quality.

Overall, it is clear that there is a great deal of scope for more detailed analysis and interpretation of these results. While much of that is well beyond the monitoring brief and budget of the ARGOS soils programme, the quality and value of the information that could emerge are sufficient to justify the considerable extra effort and expense.

Recommendations

For each orchard, nutrient budgets should be developed and tracked regularly against soil nutrient levels. As part of this, nutrient inputs should be assessed to determine the extent to which fertiliser applications are affecting differences in soil nutrient status.

The reasons for patterns of differences in soil nutrient status between the within-row and between-row areas should be investigated in detail on representative properties.

Growth of understorey vegetation should be measured (kg DM/ha) across the landforms within the soil monitoring sites. We also recommend that nutrient uptake by these swards is measured, so we can compute their likely effects on soil nutrient status, and competition with the vines for water and nutrients. Taken in conjunction with the soil results, this information will greatly assist with interpretation of crop production and orchard economic data.

Power analysis should be carried out to check the ability of the overall ARGOS design to detect differences in the soil quality parameters measured.

Principal Components Analysis should be considered to determine the most important indicators for determining treatment differences, and to help development of integrated soil quality indices that combine results from several indicators.

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1. Introduction

Soil quality is highly sensitive to land management practices, especially in horticultural production[1-7]. Accordingly, monitoring soil quality is a key component of the environmental objective of the ARGOS research programme “Pathways to Sustainability” which is investigating the environmental, social and economic impacts of different farming systems. The prime aim of this monitoring is to identify and characterise any differences in soil quality between different farm farming systems. In the case of the kiwifruit orchards studied, those farming systems are KiwiGreen™ Hort16A (often referred to and marketed as Zespri™ Gold), KiwiGreen™ Hayward, and Certified Organic Hayward. KiwiGreen™ is the main Integrated Management standard for kiwifruit growing. It regulates pesticide and herbicide inputs, and prescribes several best professional practise guidelines for social and environmental sustainability.

The effects of management on soil quality on orchards will be linked strongly to weed management and plant nutrition[8-15]. Other vegetation growing in the orchard, such as grass, has been demonstrated to compete with the fruit crop for water and nutrients, leading to a decline in fruit production[34]. On the other hand, increased organic matter inputs and rooting activity of the grass sward is likely to improve soil physical and biological properties[16]. Fruit production may be affected in other ways, for example some common orchard weeds can host pests and disease[17]. Herbicides are used for weed control under integrated production and changing to an organic fruit production system removes herbicides as a vegetation management tool. Rather than revert to cultivation (which can damage soil and crop roots) swing-arm mowers are generally preferred for established organic orchards as the most cost-effective vegetation control[18]. In New Zealand, alternative non-competitive species are currently under appraisal to replace grass as understorey vegetation on orchards.

Here we report the first set of results for soil quality monitoring on ARGOS kiwifruit orchards. 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 choice 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 ARGOS approach is to concentrate on groups (clusters) of commercial farms and orchards that are under the target farming systems. Within each cluster, the properties are as close together as possible. Given this, and the likely large spatial variability in soil quality, we chose to monitor management units (paddocks or blocks) that contain the dominant landforms within each cluster and to use permanent soil monitoring sites (SMS) within those landforms. This scheme is especially good for comparisons between agricultural sectors and farming systems (the prime aim), but it is weak for characterising whole farms. The success of long term monitoring is consistency and sampling from the permanent soil monitoring sites which have been established using similar guidelines for each of the agricultural sectors being studied.

We intend to regularly repeat the core monitoring 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 farming 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 farming systems within agricultural sectors (e.g. organic vs conventional sheep & beef farms).

Agricultural sectors, farming 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 each of the agricultural sectors being studied.

2.1.1 Agricultural Sector

This includes the Dairy, Sheep & Beef, Māori Landholdings (Ngāi Tahu) and Kiwifruit Sectors.

2.1.2 Farming system

For kiwifruit properties, the three farming systems under study are

A KiwiGreen™ Hayward (KiwiGreen™ is an integrated pest farming system for NZ kiwifruit)

B Certified Organic Hayward

C KiwiGreen™ Hort16A (often marketed and referred to as Zespri™ Gold)

2.1.3 Cluster

A cluster is a set of three properties, each under one of the three farming systems above. The properties within a cluster are within close geographic proximity with similar geomorphological landforms, soil type and climatic conditions. In kiwifruit there are 12 clusters. Cluster one is in Kerikeri and cluster 12 in Motueka with the rest in the Bay of Plenty region.

2.1.4 Property

These are the individual properties or orchards that make up the cluster. For kiwifruit we are monitoring three farming systems in 12 clusters (3 x 12 = 36 properties). In cluster one, a fourth property currently converting from KiwiGreen™ to organic farming has been added, thus bringing the total number of properties to 37.

2.1.5 Management Unit

A management unit is described as the typical land area managed by the grower on an individual basis. On kiwifruit orchards a management unit is a kiwifruit block. On sheep and beef farms, a management unit is a paddock. Three management units have been selected at random on each orchard.

For most of the orchards, we have sampled from three separate blocks. For orchards with only two blocks, we have divided the largest block in half. For orchards with just one block, we have divided the block into thirds. The same blocks (management units) will be measured each time.

2.1.6 Soil Monitoring Site (SMS)

At a single sampling time, soil properties can be quite variable within a small area. To achieve reliable monitoring, the likelihood of that spatial variation must be recognised 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. There are three SMS (each the size of two bays) within each management unit, from which all samples will be collected.

2.1.7 Landform

This term is used to describe the different geomorphology within a management unit. Geomorphic landforms for kiwifruit are the vine line (within row) and the alleyway (between row). On orchards, especially those using T-bar systems, management of these areas can be very different[9,15,19-25]. The different soil management practices can have very large effects on soil quality parameters[16]. We have sampled under the vines (within the rows) and between the rows separately as we need to understand the effect of management practices on soil across the entire orchard, not just the soil under the vines.

This approach will allow us to compare at least three blocks as well as between-row and within-row. Soil samples are collected during winter (before spring fertiliser application) at the standard sampling depth for horticultural crops (0-15 cm). This sampling depth 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.

2.2 Statistical analysis

The results were analysed using analysis of variance using Genstat version 7.1[26]. 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 farming system, which was applied at the property level. The farming system is applied across the entire property, so the management units (blocks) represent repeated measures within the property.

A two-way analysis of variance was used to analyse the results by farming system and landform, 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 property that is converting from KiwiGreen™ to organic (in cluster one) was removed as this was the only property under this form of management and statistical comparisons with other properties is not possible. Data from cluster 12 was removed from the analysis as these properties consistently gave unusual results (see Section 4.2).

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 farming 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 farming 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 (Table 1).

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: measures at each SMS

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 ongoing 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; pasture sectors only);
- 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/cm^3). This is a measure of soil compaction and defined as mass per unit volume. As mass 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[27]. 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[28].

3.2 Priority Two: soil chemical properties

These are soil chemical analyses for the topsoil and mostly a standard suite of measurements contracted out to commercial soil testing laboratories[29]. 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 horticultural crops (0-15 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. The indices are:

- **Soil pH.** This indicates the level of acidity or alkalinity of the soil sample.
- **Olsen P** (μg/ml). This is a measure of the phosphorus readily available to plants.
- **Exchangeable cations** (Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Potassium (K^+) and Sodium (Na^+)). These are the major nutrients for plant growth. These are reported as both MAF quick test units and milli-equivilents per 100g dry soil (me/100g).
- **Cation exchange capacity** (me/100g). This is a measure of the soil's capacity to hold cations and is strongly influenced by clay content and soil organic matter
- **Phosphate retention** (%). This 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). This is an indication of the nitrogen that may become available to plants through mineralisation of organic matter.
- **"Volume weight"** (g/ml). This is the mass 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[30]. Soil carbon is directly proportional to the soil organic matter (%C x 1.72 = %SOM).

3.3 Priority Three: soil microbial activity

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.

- **Microbial biomass carbon**. This is a measure of the total amount of living microbes in a soil[31]. 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.
- **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[32].
- **Metabolic Quotient.** This is the ratio between microbial biomass carbon (the size of the soil microbial population) and basal respiration (the activity of the soil microbial population). It 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 laboratory	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. 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 0-15 cm for horticultural land.

4. Results and discussion

The monitoring of kiwifruit orchards was initiated in July 2004. First the soil monitoring sites were established and samples were collected for priorities two and three. Priority one measurements were made shortly afterwards.

Results from Cluster 12 were not included in the statistical analysis. Cluster 12 was located in Motueka, on the only stony soil type for kiwifruit, and the results obtained were consistent outliers in the preliminary analyses. There were substantial problems with soil sampling in Cluster 12 (for example soil bulk density sampling was possible only for 75% of the sampling locations). Further work needs to be done (e.g. applying different techniques to measure soil bulk density) if results from Cluster 12 are to be included in future years.

Please note that interpretation of many results must remain tentative until we have had opportunity to include allowance for the previous management histories of the orchards.

4.1 Priority One: soil assessments

These measurements were conducted in both landforms (within row and between row) at each soil monitoring site.

4.1.1 Area of exposed soil and live vegetation

We found less bare soil and more live vegetation on the orchard floor under organic management than KiwiGreen™ management (Table 2 and **Table 3**). This is probably due to the use of herbicides in the latter. There was no difference in ground cover between landforms across any farming systems (**Table 3**). However these observations were made in winter and there may be landform differences at times of the year when herbicides are used to control actively growing orchard floor vegetation.

Table 2. Exposed soil surface (%) on kiwifruit orchards

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	44 ± 3 a	50 ± 3 a	47 ± 6 a
KiwiGreen™ Hayward	53 ± 3 a	60 ± 3 a	56 ± 6 a
Organic Hayward	19 ± 3 a	17 ± 3 a	18 ± 6 b
Landform Average[2]	39 ± 2 a	42 ± 2 a	41

[1] $LSD_{0.05}$ for comparisons between farming system averages = 17
[2] $LSD_{0.05}$ between landform averages = 5
$LSD_{0.05}$ for comparisons between landforms within a farming system = 8

Table 3. Soil surface (%) covered with live vegetation

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	56 ± 3 a	50 ± 3 a	53 ± 6 a
KiwiGreen™ Hayward	47 ± 3 a	40 ± 3 a	44 ± 6 a
Organic Hayward	81 ± 3 a	83 ± 3 a	82 ± 6 b
Landform Average[2]	61 ± 2 a	58 ± 2 a	59

[1] $LSD_{0.05}$ for comparisons between farming system averages = 17
[2] $LSD_{0.05}$ between landform averages = 5
$LSD_{0.05}$ for comparisons between landforms within a farming system = 8

4.1.2 Crusting, damaged soil and presence of organic thatch

There was no soil crusting observed on any of the kiwifruit orchards. Surface damage by vehicles or erosion was observed at only 73 of the 666 SMSs and was generally less than 10% of the soil surface.

There was no evidence of organic material accumulating on the soil surface as thatch.

4.1.3 Soil porosity, discolouration and aggregation

Landform had a consistent influence on soil porosity (**Table 4**). Soil between the row was much less porous than soil within the row, an effect that is probably due to compaction by orchard vehicle traffic. Within rows, soil on the organic orchards was more porous than the KiwiGreen™ managed orchards. This could be due to the influence of the extra understorey vegetation within rows on the Hayward organic orchards (cf. **Table 3**). However, as with many other results here, the apparent differences between farming systems may be influenced by orchard to orchard variations in factors such as previous land use, time since planting of the orchards, and time since any major changes in farming practices. More conclusive interpretation is not possible until we have had opportunity to examine records of orchard history.

Table 4. Percentage of scores of each porosity value on a scale of 1 (high) to 4 (low)

Farming System	Landform	Porosity value = 1	Porosity value = 2	Porosity value = 3	Porosity value = 4
KiwiGreen™ Hort16A	Between Row	2	27	46	24
	CI	0 - 20	15 – 45	29 – 65	13 – 40
	Within Row	19	40	36	4
	CI	9 - 37	25 - 58	21 - 55	1 - 17
KiwiGreen™ Hayward	Between Row	3	33	43	20
	CI	0 - 20	19 -52	27 - 62	10 - 36
	Within Row	21	30	45	3
	CI	10 - 39	17 - 49	28 - 64	1 - 16
Organic Hayward	Between Row	13	48	36	2
	CI	5 - 30	32 - 66	21 - 55	0 - 16
	Within Row	47	41	10	1
	CI	31 - 65	26 - 59	3 - 28	0 - 18

Evidence of mottling or gleying was found at only one property (property 7, cluster 3, Hayward KiwiGreen™) so it was not appropriate to attempt statistical interpretation of this variable.
In all farming systems there was a similar effect of landform on soil aggregation (

Table 5). Soil between the row was not as well aggregated as soil within the row, particularly on the KiwiGreen™ Hort16A orchards. This difference could be due to orchard vehicles damaging soil structure, and understorey vegetation which contributes to improved soil aggregation through rooting action.

Table 5. Percentage of scores of each aggregation value on a scale of 1 (high) to 4 (low)

Farming System	Landform	Aggregation value = 1	Aggregation value = 2	Aggregation value = 3	Aggregation value = 4
KiwiGreen™ Hort16A	Between Row	28	37	30	4
	CI	14 - 49	25 - 52	18 - 46	2 - 11
	Within Row	46	44	10	0
	CI	27 - 65	31 - 59	4 - 24	0 - 3
KiwiGreen™ Hayward	Between Row	38	49	13	0
	CI	22 - 59	34 - 63	6 - 27	0 - 3
	Within Row	64	32	4	0
	CI	44 - 80	20 - 47	1 - 16	0 - 3
Organic Hayward	Between Row	49	42	8	0
	CI	31 – 68	29 – 57	3 – 21	0- 3
	Within Row	71	27	1	0
	CI	51 - 86	16 - 42	0 - 16	0 - 3

4.1.4 Soil bulk density

In general, high bulk density values are undesirable, as they indicate the soil is compact and it may be difficult for water and roots to penetrate. However, in some circumstances, high bulk density is desirable since it gives the soil better ability to support traffic. In these cases it is best that the high bulk density is confined to areas that are routinely used for vehicles rather than spread widely through the orchard. For a given soil type, high bulk density values indicate low total porosity. So, the measured values of soil bulk density provide an independent check on the reliability of the porosity values obtained by visual examination of the soil (**Table 4**).

Soil bulk density was measured at both the 0-7.5 cm depth and the 7.5-15 cm depth, and corrected for moisture content. In general, soil bulk density was low at both depths measured (Table 6 and Table 7) reflecting the light ash parent materials of most of these soils. Soil bulk density increases with depth which, in non-cultivated soil, is due mostly to natural consolidation. The length of time since the land has been in permanent pasture or was last cultivated will also affect soil bulk density.

Bulk density differed significantly with both farming system and landforms. The interaction between farming system and landform was also significant.

Soil bulk density was less for organically managed orchards at both depths measured. This accords with the independent observation that soil porosity was generally higher on the organic properties (**Table 4**). This emphasizes the need for further information on site history so that we can identify how typical our results might be for the wider kiwifruit industry.

In the KiwiGreen™ orchards, soil bulk density was higher within the row than between the row for the top 7.5 cm. This created an overall landform effect of higher bulk density within the row for the 0-7.5 cm layer. The reverse is the case of the 7.5-15 cm soil layer. However the visual soil assessments found the soil less porous and less aggregated within the rows than between the rows. Information on orchard history and management techniques will greatly aid interpretation of these results. For example, it will be worth examining whether there was increased or more confined vehicle traffic on any particular class of orchards.

Table 6. Soil bulk density 0-7.5 cm (g/cm^3)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	0.35 ± 0.005 a	0.36 ± 0.005 b	0.35 ± 0.004 b
KiwiGreen™ Hayward	0.36 ± 0.005 a	0.38 ± 0.005 b	0.37 ± 0.004 c
Organic Hayward	0.33 ± 0.005 a	0.33 ± 0.005 a	0.33 ± 0.004 a
Landform Average[2]	0.35 ± 0.002 a	0.36 ± 0.002 b	0.35

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.01
[2] $LSD_{0.05}$ between landform averages = 0.01
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.01
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

Table 7. Soil bulk density 7.5-15 cm (g/cm^3)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	0.43 ± 0.004 b	0.39 ± 0.004 a	0.41 ± 0.007 b
KiwiGreen™ Hayward	0.45 ± 0.004 b	0.43 ± 0.004 a	0.44 ± 0.007 c
Organic Hayward	0.41 ± 0.004 a	0.38 ± 0. 004 a	0.39 ± 0.007 a
Landform Average[2]	0.43 ± 0.002 b	0.40 ± 0.002 a	0.42

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.02
[2] $LSD_{0.05}$ between landform averages = 0.01
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.01
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.1.5 Earthworms

Earthworm population estimates were not normally distributed and required logarithmic transformation before analysis of variance. Back-transformed averaged are presented in

Table 8. Earthworm populations were highest on organic orchards and least in the Hort16A KiwiGreen™ orchards (P<0.1). Earthworm populations did not differ significantly between landforms on the organically managed properties. We found more earthworms between the rows than within the rows of the KiwiGreen™ properties which caused an overall landform effect of more earthworms between the rows. Generally we would expect such differences to reflect substantially greater vegetation cover between the rows, which was not observed (**Table 3**). Clearly more information is needed on ground cover through the year and on site histories before we can interpret these results closely.

Table 8. Earthworm populations (number per m^2)

Farming System	Landform		Farming System Average
	Between row	Within row	
KiwiGreen™ Hort16A	23 ± 5 b	11 ± 2 a	16 ± 6 a
KiwiGreen™ Hayward	43 ± 9 b	12 ± 3 a	23 ± 9 ab
Organic Hayward	73 ± 15 a	43 ± 9 a	56 ± 21 b
Landform Average	42 ± 5 a	18 ± 2 b	27

[1]$LSR_{0.05}$ for comparisons between farming system averages = 2.9
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.4
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.8

4.2 Priority Two: soil chemical properties

4.2.1 Soil pH

We found a strong management effect on soil pH, which was highest on the organically managed orchards (Table 9). There was no significant difference between landforms, but the interaction between landform and management was highly significant. Soil pH was higher between the row than within the row on KiwiGreen™ Hort16A orchards, while the reverse was the case for Hayward Certified Organic orchards.

There is much scope for useful detailed interpretation of these results once information on site history and management is available. For instance, the higher soil pH within the row on organic orchards could be due to under vine banding of organic fertilisers such as reactive phosphate rock and chicken manure which both increase soil pH. As a further example, the slightly higher soil pH between the rows on KiwiGreen™ Hort16A orchards could be due to fertiliser spreading patterns or retention of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}) by vegetation growing between the rows (leaching of these base cations contributes to soil acidification).

Table 9. Soil pH

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	6.4 ± 0.03 b	6.3 ± 0.03 a	6.4 ± 0.05 a
KiwiGreen™ Hayward	6.5 ± 0.03 a	6.5 ± 0.03 a	6.5 ± 0.05 b
Organic Hayward	6.6 ± 0.03 a	6.7 ± 0.03 b	6.7 ± 0.05 b
Landform Average[2]	6.5 ± 0.02 a	6.5 ± 0.02 a	6.5

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.1
[2] $LSD_{0.05}$ between landform averages = 0.1
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.1
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.2.2 Olsen P

Soil Olsen P data was not normally distributed and so it was logarithmically transformed before analysis of variance. Back-transformed averages are presented in Table 10. Olsen P level was lower in the organic orchards than the KiwiGreen™ orchards.

Although we do not have full information on fertiliser history of these orchards yet, it seems likely that these differences in Olsen P reflect differences between farming systems in fertiliser use before or after establishment of kiwifruit on the land. For example, even if the KiwiGreen™ and organic orchards had the same amounts of P applied per year, we could expect Olsen P to be less on the organic orchards. Organic phosphate fertilisers (e.g. reactive phosphate rock) tend to release P over a long period of time, and the Olsen test for phosphate does not measure this slowly available P. Under all farming systems, soil Olsen P was higher within the row than between the row. This is most likely an effect of fertiliser placement under the vine and P uptake by vegetation growing between rows.

There was no interaction between management and landform effects on soil Olsen phosphorus.

Table 10. Soil Olsen P (µg/ml)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	30 ± 1 a	42 ± 2 b	35 ± 3 b
KiwiGreen™ Hayward	29 ± 1 a	38 ± 2 b	34 ± 3 b
Organic Hayward	21 ± 1 a	29 ± 1 b	25 ± 2 a
Landform Average[2]	27 ± 1 a	36 ± 1 b	31

[1] $LSR_{0.05}$ for comparisons between farming system averages = 1.3
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.1
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.1

4.2.3 Phosphate retention

Soil phosphate retention was not normally distributed so it was logarithmically transformed before analysis of variance was performed. Back-transformed averages are presented in **Table 11**.

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 farming systems in P retention. While there were some very small differences between landforms these are most likely due to chance as phosphate retention is unlikely to be affected directly by these factors.

Table 11. Phosphate retention (%)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	67 ± 0.5 b	66 ± 0.5 a	67 ± 2.3 a
KiwiGreen™ Hayward	63 ± 0.5 a	63 ± 0.4 a	63 ± 2.2 a
Organic Hayward	68 ± 0.5 b	67 ± 0.5 a	68 ± 2.4 a
Landform Average[2]	66 ± 0.3 b	65 ± 0.3 a	66

[1] $LSR_{0.05}$ for comparisons between farming system averages = 1.11
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.01
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.02
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.2.4 Cation exchange capacity

These results are presented in **Table 12**. Cation exchange capacity (CEC) was significantly affected by farming system ($P<0.05$), and perhaps also by landform ($P<0.1$). The interaction between management and landform was also significant ($P<0.05$). CEC was higher for organic Hayward than KiwiGreen™ Hayward. For the KiwiGreen™ Hayward orchards, CEC was higher between the rows than within the rows. There was no effect of landform in the other farming systems.

CEC is mainly a function of soil mineralogy, organic matter content and pH. The sampling system of using geographic clusters with one of each orchard farming system should reduce the possibility that differences between farming systems are due to effects of differences in soil mineralogy. Thus it is most likely that differences in CEC between farming systems and landforms are due to differences in pH and the nature and amount of soil organic matter. The influence of soil pH on CEC can be complex. In many soils the influence of pH is very small and can be ignored. However, an increase in pH increases CEC in soils that are high in organic matter or certain minerals like allophone that are common in volcanic soils of New Zealand[33].

The tendency for CEC to be higher on the organic orchards may well be due to differences in soil pH. A substantial number of the orchards studied were on volcanic (pumice) soils in the Bay of Plenty. Although soil organic matter concentrations did not differ much between farming systems (see below), soil pH tended to be higher on the organic properties (Table 9). The observed differences between landforms and the interaction between landform and farming systems are small and rather more difficult to explain. They should be looked at in more detail if they are confirmed in subsequent measurements.

Table 12. Cation exchange capacity (me/100g)

Farming Systems	Landform		Farming Systems Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	17 ± 0.2 a	17 ± 0.2 a	17 ± 0.4 ab
KiwiGreen™ Hayward	17 ± 0.2 b	16 ± 0.2 a	16 ± 0.4 a
Organic Hayward	18 ± 0.2 a	18 ± 0.2 a	18 ± 0.4 b
Landform Average[2]	17 ± 0.1 a	17 ± 0.1 a	17

[1] $LSD_{0.05}$ for comparisons between farming system averages = 1.1
[2] $LSD_{0.05}$ between landform averages = 0.4
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.7
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.2.5 Exchangeable Calcium

Exchangeable cation concentrations in the soil are usually expressed either as standard MAF units (which is an arbitrary scale often still used by farmers) or as milli-equivalents of cation per 100g of dry soil. Here we have presented our results both ways (

Table 13 and **Table 14**).

The amount of exchangeable calcium will be strongly affected by fertiliser use and placement, and the presence of orchard floor vegetation. Soil calcium levels were strongly affected by management and landform; the interaction between these factors was also significant. There are slight differences in statistical significances between the two reporting units. MAF units are calculated on a volume basis whereas milli-equivilents are calculated on a mass basis. The calcium levels are in the upper end of the normal range found on kiwifruit orchards (6.0 to 12.0 me/100g).

Averaged across both landforms, soil calcium was higher in the organic properties. This accords with the higher soil pH found on the organic properties (Table 9), suggesting they may have received more lime or reactive phosphate rock that is high in lime. There was more exchangeable calcium between the row than within the row in the KiwiGreen™ orchards, which caused an overall landform effect when averaged across all farming systems. There was no difference between landforms in the organic farming system. The effect of orchard farming system on soil calcium was most evident within the row. It is difficult to determine the cause of the differences without close examination of fertiliser records for all properties and a more full assessment of orchard floor vegetation growth and mowing practices.

Table 13. Exchangeable calcium (MAF units)

Farming Systems	Landform		Farming Systems Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	10 ± 0.3 b	8 ± 0.3 a	9 ± 0.4 a
KiwiGreen™ Hayward	10 ± 0.3 b	9 ± 0.3 a	9 ± 0.4 a
Organic Hayward	10 ± 0.3 a	11 ± 0.3 b	11 ± 0.4 b
Landform Average[2]	10 ± 0.2 b	9 ± 0.2 a	10

[1] $LSD_{0.05}$ for comparisons between farming system averages = 1.1
[2] $LSD_{0.05}$ between landform averages = 0.5
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.8
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

Table 14. Exchangeable calcium (me/100g)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	10.4 ± 0.04 b	9.3 ± 0.04 a	9.9 ± 0.05 a
KiwiGreen™ Hayward	10.9 ± 0.04 b	9.6 ± 0.04 a	10.3 ± 0.05 a
Organic Hayward	11.6 ± 0.04 a	12.3 ± 0.04 a	12.0 ± 0.05 b
Landform Average[2]	11.0 ± 0.02 b	10.4 ± 0.02 a	10.7

[1] $LSD_{0.05}$ for comparisons between farming system averages = 1.1
[2] $LSD_{0.05}$ between landform averages = 0.5
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.8
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.2.6 Magnesium

There was a highly significant interaction effect ($P<0.001$) of farming system and landform which was driven by high soil magnesium levels within the row on organic orchards (Table 15 and Table 16). This caused the organic orchards to have higher soil magnesium levels (averaged across landforms) than KiwiGreen™ orchards ($P<0.1$). The magnesium levels we measured are within the normal range for kiwifruit soils (1.00 to 3.00 me/100g).

Like calcium, the amount of exchangeable magnesium will be strongly affected by fertiliser use and placement, and orchard floor vegetation. Assessment of fertiliser nutrient inputs and placement and vegetation growth will be necessary to determine the cause of management and landform effects.

Table 15. Exchangeable magnesium (MAF units)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	30 ± 0.8 b	28 ± 0.8 a	29 ± 2.1 a
KiwiGreen™ Hayward	29 ± 0.8 a	28 ± 0.8 a	28 ± 2.1 a
Organic Hayward	31 ± 0.8 a	37 ± 0.8 b	34 ± 2.1 b
Landform Average[2]	29 ± 0.5 a	28 ± 0.5 a	31

[1] $LSD_{0.05}$ for comparisons between farming system averages = 6
[2] $LSD_{0.05}$ between landform averages = 1
$LSD_{0.05}$ for comparisons between landforms within a farming system = 2
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

Table 16. Exchangeable magnesium (me/100g)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	1.83 ± 0.05 a	1.74 ± 0.05 a	1.79 ± 0.12 a
KiwiGreen™ Hayward	1.80 ± 0.05 a	1.67 ± 0.05 a	1.73 ± 0.12 a
Organic Hayward	1.94 ± 0.05 a	2.26 ± 0.05 b	2.10 ± 0.12 b
Landform Average[2]	1.86 ± 0.03 a	1.89 ± 0.03 a	1.87

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.36
[2] $LSD_{0.05}$ between landform averages = 0.08
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.14Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.2.7 Potassium

There was no evidence of an overall management effect on soil potassium levels (Table 17 and Table 18). However, there was a strong landform effect ($P<0.01$) and landform by management interaction ($P<0.001$). The KiwiGreen™ orchards (both Hayward and Hort16A) had higher soil potassium levels between the row than within the row; the reverse was the case for the organic orchards. Again fertiliser records and understorey vegetative growth need to be assessed before these data are interpreted and the causes for these differences examined. In general, the soil potassium levels are at the lower end of the normal range for kiwifruit soils (0.60 to 1.20 me/100g).

Table 17. Exchangeable potassium (MAF units)

Farming Systems	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	11 ± 0.2 b	9 ± 0.2 a	10 ± 0.4 a
KiwiGreen™ Hayward	11 ± 0.2 b	10 ± 0.2 a	10 ± 0.4 a
Organic Hayward	10 ± 0.2 a	11 ± 0.2 b	10 ± 0.4 a
Landform Average[2]	10 ± 0.1 b	10 ± 0.1 a	10

[1] $LSD_{0.05}$ for comparisons between farming system averages = 1.0
[2] $LSD_{0.05}$ between landform averages = 0.3
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.5
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

Table 18. Exchangeable potassium (me/100g)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	0.74 ± 0.01 b	0.66 ± 0.01 a	0.70 ± 0.03 a
KiwiGreen™ Hayward	0.74 ± 0.01 b	0.65 ± 0.01 a	0.69 ± 0.03 a
Organic Hayward	0.69 ± 0.01 a	0.76 ± 0.01 b	0.72 ± 0.03 a
Landform Average[2]	0.72 ± 0.01 b	0.69 ± 0.01 a	0.71

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.08
[2] $LSD_{0.05}$ between landform averages = 0.2
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.03
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.8 Total base saturation

Base saturation is the total of exchangeable base cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} in meq/100g) as a proportion of CEC. It is affected by the amounts of base cations as well as factors that influence CEC (e.g. mineralogy, pH, organic matter concentration). Often, base saturation follows similar trends to exchangeable calcium (the dominant cation) and soil pH. Generally, high base saturation values are considered beneficial for crops like kiwifruit, but a simple interpretation of the impact of small changes (say <10%) is not possible because so many factors influence the values.

In our results (Table 19) total base saturation was strongly affected by farming system, and there was a highly significant ($P<0.001$) interaction between the effects of management and landform. The organic Hayward orchards had higher base saturation than KiwiGreen™ orchards, following the trends for soil pH and exchangeable Ca (Table 9, Table 14). Base saturation was higher within the row for the organic orchards while the reverse was the case of the Hort16A KiwiGreen™ orchards. We observed no difference between landforms for the Hayward KiwiGreen™ orchards.

Table 19. Total base saturation (%)

Farming System	Landform		Farming System Average
	Between row	Within row	
KiwiGreen™ Hort16A	75.6 ± 1.1 b	70.3 ± 1.1 a	72.9 ± 1.9 a
KiwiGreen™ Hayward	79.9 ± 1.1 a	76.9 ± 1.1 a	78.4 ± 1.9 a
Organic Hayward	81.8 ± 1.1 a	86.4 ± 1.1 b	84.1 ± 1.9 b
Landform Average	79.1 ± 0.7 a	77.9 ± 0.7 a	78.5

[1] $LSD_{0.05}$ for comparisons between farming system averages = 5.5
[2] $LSD_{0.05}$ between landform averages = 1.8
$LSD_{0.05}$ for comparisons between landforms within a farming system = 3.2
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.9 Sulphate sulphur

As with Olsen P, the sulphate sulphur results needed to be logarithmically transformed before conducting analysis of variance. We found no statistical differences between the main factors of management or landform (Table 20). However, there was a slight and significant interaction between farming system and landform ($P<0.05$). Sulphate sulphur was higher between the row than within the row on organic orchards only.

This test is not normally conducted for horticultural soils, so it is not possible to compare our results with normal ranges are not available for kiwifruit orchards. This test was included for future comparisons between agricultural sectors. The normal range for pastoral soils is 7 to 15 although this is based on a shallower sampling depth (7.5 cm).

Table 20. Sulphate sulphur (MAF)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	13 ± 0.5 a	14 ± 0.6 a	14 ± 1.8 a
KiwiGreen™ Hayward	12 ± 0.5 a	12 ± 0.5 a	12 ± 1.5 a
Organic Hayward	12 ± 0.5 b	10 ± 0.4 a	11 ± 1.4 a
Landform Average[2]	12 ± 0.3 a	12 ± 0.3 a	12

[1] $LSR_{0.05}$ for comparisons between farming system averages = 1.5
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.1
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.1
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.10 Soil organic carbon

There was no overall management effect but a strong ($P<0.01$) effect of landform on soil organic carbon with more between the row than within the row (Table 21). This was driven by differences in KiwiGreen™ Hort16A orchards. We found no significant interaction between the effects of farming system and landform.

Even though there wasn't a difference in ground cover at the time of the year we monitored, it is highly likely that previously there was a difference in organic matter inputs that can account for this difference in carbon content between landforms. There was no difference between farming systems despite differences in ground cover at the time of sampling (see Section 4.2). This test measures both the inert and active pools of soil carbon, and so quite large changes in carbon inputs are required before significant shifts in soil organic carbon levels can be detected.

Table 21. Soil organic carbon (%)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	5.91 ± 0.10 b	5.58 ± 0.10 a	5.75 ± 0.17 a
KiwiGreen™ Hayward	5.49 ± 0.10 a	5.27 ± 0.10 a	5.38 ± 0.17 a
Organic Hayward	5.84 ± 0.10 a	5.67 ± 0.10 a	5.76 ± 0.17 a
Landform Average[2]	5.75 ± 0.06 b	5.51 ± 0.06 a	5.63

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.49
[2] $LSD_{0.05}$ between landform averages = 0.16
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.28
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.11 Potentially mineralisable nitrogen

This test measures the amount of N that is likely to be mineralised from organic matter over a short time frame (1-2 months). We found two potentially important differences in potentially mineralisable N (Table 22):

1. A management effect - overall, values were higher in the organic orchards.
2. A landform effect - under all orchard farming systems, values were higher between the row than within the row.

The size of these differences was enough to be due to inputs from composts, N-fixation by legumes in the orchard floor vegetation or differences in the retention of N (against leaching) by orchard floor vegetation, but we do not yet have sufficient orchard information to consider these in more detail. We found no significant interaction between management and landform.

This test is not normally conducted for orchard soils, so normal ranges are not available for comparisons with our results.

Table 22. Potentially mineralisable N (kg N/ha)

Farming System	Landform		Farming System Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	94 ± 3 b	84 ± 3 a	89 ± 4 a
KiwiGreen™ Hayward	96 ± 3 b	74 ± 3 a	85 ± 4 a
Organic Hayward	115 ± 3 b	102 ± 3 a	109 ± 4 b
Landform Average[2]	102 ± 2 b	87 ± 2 a	94

[1] $LSD_{0.05}$ for comparisons between farming system averages = 13.
[2] $LSD_{0.05}$ between landform averages = 5.
$LSD_{0.05}$ for comparisons between landforms within a farming system = 8.
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.12 Total soil nitrogen

Only a small proportion of the total soil N is immediately plant available, the remainder is found in the more complex organic form. Like total organic carbon, large changes in N inputs are necessary for significant shifts in total soil N to be detected. In our results (Table 23), we found no overall differences between farming systems. However, there was a strong (P<0.01) effect of landform on total soil nitrogen. The interaction between farming system and landform was not significant. Under both KiwiGreen™ farming systems, there was more total N between the row than within the row. This contributed to an overall effect of higher N between the row. Fertiliser use, vine uptake, time of year, and the presence and management of orchard floor vegetation will strongly affect total soil N levels, and interpretation of the results awaits more information on the factors.

Table 23. Total soil nitrogen (%)

Farming System	Landform		Farming System Average
	Between row	Within row	
KiwiGreen™ Hort16A	0.48 ± 0.01 a	0.46 ± 0.01 a	0.47 ± 0.01 a
KiwiGreen™ Hayward	0.45 ± 0.01 b	0.42 ± 0.01 a	0.44 ± 0.01 a
Organic Hayward	0.47 ± 0.01 a	0.45 ± 0.01 a	0.46 ± 0.01 a
Landform Average	0.47 ± 0.01 b	0.45 ± 0.01 a	0.46

[1] $LSD_{0.05}$ for comparisons between farming system averages = 0.04.
[2] $LSD_{0.05}$ between landform averages = 0.02.
$LSD_{0.05}$ for comparisons between landforms within a farming system = 0.03.
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.2.13 Carbon to nitrogen ratio

The C:N ratio gives and indication of the type and the stage of decomposition of organic matter in the soil. Our results for organic C (Table 21) and total N (Table 23) showed very similar patterns of effects of management and landform. In consequence, we found no effect of management or landform (or interaction) on the ratio of carbon to nitrogen (C:N ratio). The average C:N ratio of 12.3 was slightly higher than usually found in pastoral soils, and reflects the woody nature (prunings etc) of the organic inputs on orchards.

4.3 Priority three: soil microbial activity

4.3.1 Microbial biomass carbon

Microbial biomass carbon represents the active portion of the total carbon pool, and it is more sensitive to changes in management practice than total soil carbon. Our data were not normally distributed, and so it required logarithmic transformation before analysis of variance could be performed. Back transformed data are presented here (Table 24).

Microbial biomass carbon was affected by management ($P<0.1$) and landform ($P<0.001$). The interaction between management and landform was also highly significant ($P<0.001$). On average across all landforms, microbial biomass was significantly lower in the KiwiGreen™ Hayward orchards than in the KiwiGreen™ Hort16A or organic Hayward orchards. We have insufficient information as yet to interpret this result and consider how generally representative it is. However, it is important to note that this result is in accord with the general, but non-significant trend for the KiwiGreen™ Hayward orchards to have less organic C, potentially mineralisable N and total N.

Under all forms of management, the size of the microbial population was higher between the row than within the row but the difference between landforms was greater on the KiwiGreen™ farming systems than organic farming. On the KiwiGreen™ orchards, this difference could be attributed to less organic matter inputs due to herbicide use within the row. For the organic orchards, this result supports our suggestion that the single-time measures of orchard ground cover may be misleading (Sections 6.1.1 and 6.1.5).

Table 24. Microbial biomass carbon (µg C/g)

Farming Systems	Landform		Farming Systems Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	312 ± 15 b	265 ± 14 a	287 ± 20 b
KiwiGreen™ Hayward	311 ± 15 b	186 ± 9 a	241 ± 16 a
Organic Hayward	320 ± 15 b	290 ± 14 a	305 ± 21 b
Landform Average[2]	314 ± 9 b	243 ± 7 a	276

[1] $LSR_{0.05}$ for comparisons between farming system averages = 1.22.
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.08.
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.15.
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

4.3.2 Basal respiration

Basal respiration is a measure of how active the soil microbial population is. Values can depend greatly on the time of year samples are taken and previous land history, and comparisons of absolute values against the literature can be hard to interpret. However, in carefully structured experiments, basal respiration is a powerful technique to compare the impacts of different treatments sampled at the same time.

Our results show that basal respiration was affected by management ($P<0.1$) and landform ($P<0.001$), although the interaction between these two factors was not significant (Table 25). Basal respiration was higher on the organically managed Hayward orchards than the KiwiGreen™ Hayward orchards. Furthermore, for all farming systems, basal respiration was higher between the row than within the row. These results are in broad accord with the results for microbial biomass carbon (see 0).

Table 25. Basal respiration (µg CO_2-C/hr/100g)

Farming Systems	Landform		Farming Systems Average[1]
	Between row	Within row	
KiwiGreen™ Hort16A	21.6 ± 0.5 b	17.9 ± 0.5 a	19.7 ± 1.2 ab
KiwiGreen™ Hayward	20.2 ± 0.5 b	17.0 ± 0.5 a	18.6 ± 1.2 a
Organic Hayward	23.6 ± 0.5 b	21.6 ± 0.5 a	22.6 ± 1.2 b
Landform Average[2]	21.8 ± 0.3 b	18.8 ± 0.3 a	20.3

[1] $LSD_{0.05}$ for comparisons between farming system averages = 3.6.
[2] $LSD_{0.05}$ between landform averages = 0.8.
$LSD_{0.05}$ for comparisons between landforms within a farming system = 1.4.
Values with the same letter within a bordered part of the table are not significantly different.
See section 4.2 for more details on data interpretation.

4.3.2 Metabolic quotient

The metabolic quotient (MQ) is the ratio between size and the activity of the soil microbial population and measures the efficiency of the microbial population as the amount of activity per population unit. This variable was not normally distributed, so required logarithmic transformation before analysis of variance could be performed. Back transformed results are presented in **Table 26**. The interaction between management and landform was significant but the main effects (Farming System, landform) were not. Under KiwiGreen™ Hayward management, MQ was higher within the row than between the row, indicating that although the microbial biomass was less within the row it was operating substantially more efficiently. We are not aware of any similar results in the literature. There was no landform effect in the other farming systems.

Table 26. Metabolic quotient (µg CO2-C/µg biomass C/hr)

Farming System	Landform		Farming System Average
	Between row	Within row	
KiwiGreen™ Hort16A	6.4 ± 0.3 a	6.1 ± 0.3 a	6.3 ± 0.5 a
KiwiGreen™ Hayward	6.3 ± 0.3 a	8.7 ± 0.4 b	7.4 ± 0.6 a
Organic Hayward	7.2 ± 0.3 a	7.0 ± 0.3 a	7.1 ± 0.6 a
Landform Average	6.6 ± 0.2 a	7.2 ± 0.2 a	6.9

[1] $LSR_{0.05}$ for comparisons between farming system averages = 1.3.
[2] $LSR_{0.05}$ for comparisons between landform averages = 1.1.
$LSR_{0.05}$ for comparisons between landforms within a farming system = 1.1.
Values with the same letter within a bordered part of the table are not significantly different. See section 4.2 for more details on data interpretation.

5. General discussion

These results are only the first in what should be a long series of measurements made on the kiwifruit orchards in the ARGOS programme. Repeated measurements over time will help to ensure the results and interpretations are robust. Furthermore, there are strong indications that more detailed measurements of some variables would greatly help interpretation of our results. Examples include measurements of orchard floor vegetation, where the single time measurements made are insufficient, and indeed appear to be in conflict with the observed values of things like microbial biomass C. Bearing in mind that soil quality can decline markedly if kiwifruit are left unmanaged[6], interaction between soil quality and vine management should be considered in the future. Factors such as thinning and pruning practices and yields may assist the interpretation of soil quality results for the kiwifruit orchards in ARGOS.

Despite these caveats, our results so far show some interesting trends. In particular when we compare Certified Organic Hayward and KiwiGreen™ Hayward orchards:

- Soil bulk density was less and porosity was greater for organically managed orchards;
- Soil pH was highest on the organically managed orchards;
- Soil cation exchange capacity was higher for organic orchards - a tendency that may well be due to differences in soil pH;
- Organic orchards generally had more Ca and Mg;
- Organic orchards generally had more potentially mineralisable N, and biomass C;
- Olsen P was generally less on organic orchards.

Many of these trends may reflect differences in nutrient budgets and management of understorey vegetation as well as differences between orchards in previous land use, and time under kiwifruit. It is imperative that further information on such factors is used in the interpretation of our results before they are used to form recommendations to the industry.

Another factor that should be considered is whether the differences in soil chemical or biological properties currently expressed on a per unit mass basis are still evident when the results are converted to kg per ha. This recalculation proved to be more difficult to achieve than expected, especially due to problems with stoniness at cluster 12. However, it can be done, and further analysis in this way will be helpful. Such figures will aid the wider physical and ecological interpretation of our results even though they can not be interpreted by most growers or consultants (who have only experience with the conventional units used in this report). The fact that soil dry bulk density tended to be least on the organic properties suggests that the apparent advantages of these properties in terms of having higher Ca, Mg, N and biomass C per unit mass of soil may be less or non-existent when expressed on a unit area basis.

Further attention needs to be placed on the many contrasts we observed between the soil within the rows and between the rows. Again much more information on site management and history is needed here, but the ecological implications of the strong differences we observed suggest that the effort will be well worthwhile.

We suggest that power analysis should be carried out on the data obtained in this study, to help calculate the power of the overall ARGOS design to detect significant differences between farming systems.

This project has used a wide range of soil quality indicators, because the information gathered has to be useful in a broad multidisciplinary framework as well as to assist the industry. Future projects with a more narrow focus than ARGOS will undoubtedly consider using a smaller set of indicators to test if there are differences between kiwifruit farming systems. Principal Components Analysis of the data we have gathered here should be considered to determine the most important indicators for determining treatment differences in such studies. Principal Components Analysis would have the additional benefit for ARGOS of helping the development of integrated soil quality indices that combine results from several indicators.

Overall, it is clear that there is a great deal of scope for more detailed analysis and use of the results presented here. This requires a substantial amount of information on the sites themselves. While much of that analysis and interpretation is well beyond the monitoring brief and budget of the ARGOS soils programme, the quality and value of the information that could emerge are sufficient to justify the considerable extra effort and expense.

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