MARLBOROUGH DISTRICT COUNCIL

Soil Quality in Marlborough 2007 -2012

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Executive summary

Regional councils (and Unitary Councils) have a responsibility for promoting the sustainable management of the natural and physical resources of their region. One of the physical resources that we have a duty under Section 35 of the Resource Management Act (1991) to monitor and report on is soil. Specifically to report on the "life supporting capacity of soil" and to determine whether current practices will meet the "foreseeable needs of future generations". The collection of detailed soil monitoring data is therefore vital because it provides information on what effect current landuse activities are having on soil quality and whether we need to change or prioritise the way we manage the land environment. This is becoming increasingly important as landuse activities such as dairying are intensifying across New Zealand and putting pressure on our soils.

Furthermore the way soils respond to different landuse activities can affect other parts of the environment, for example water quality. This is because soils act as buffers to capture and store nutrients such as nitrogen, phosphorous and microbes, treat a range of waste products and store and filter water.

To help meet these goals the Council undertake a soil quality monitoring programme that involves collecting soil samples from a network of sites that represent the main landuse activities and soil types within the region and analysing samples for a suite of soil physical, biological and chemical properties that have been shown to be robust indicators of soil quality. The aim of this report is to summarise the current state of soil quality in the Marlborough region as determined by the results of soil analysis for the most recent sampling across a range of landuse activities and soil types.

Between 2007 – 2012, 118 soil quality monitoring sites have been sampled representing four soil orders (i.e. Brown, Pallic, Gley and Recent) and six land use activities (i.e. dairying, exotic forest, cropping, native vegetation, drystock and viticulture). Sampling results indicate that in total 48 sites met all their targets, 43 had one indicator outside their range while the remaining 27 sites had two indicators that didn't met their target range. Monitoring has highlighted that there are several soil quality issues under some land use activities.

Several of the cropping sites were found to have slightly elevated Olsen Phosphorus (P) values and most had depleted organic matter (total carbon and nitrogen) contents. Many of the cropping sites also had poor soil structure highlighted by low aggregate stability, high bulk density and low macroporosity. These findings put these soils at risk of poor aeration, impeded drainage and surface crusting all of which may potentially affect crop performance and predispose the soil to surface runoff, nutrient loss, erosion and flooding. Cultural practices in cropping soils should be encouraged which maintain or enhance soil carbon contents to stabilise or improve soil structure through the adoption of pasture phases in a crop rotation, incorporation of crop residues or adoption of direct drilling, minimum cultivation or conservation tillage techniques. While vehicle traffic movements are an integral part of cropping operations, their movements should be minimised and avoided during wet soil conditions which exacerbate the potential for soil compaction.

Half of the dairy pasture sites showed signs of soil compaction i.e. low macroporosity. The low values are likely related to heavy grazing or grazing under wet conditions where animal treading has effectively reduced the large pore fraction in soils. Low macroporposity values have been shown to negatively affect a range soil physical/chemical processes which in turn can reduce pasture dry matter production. Furthermore, it can also increase the potential for surface run-off and provide a pathway for nutrient (nitrogen and phosphorous) and microbe loss to surface waters and reduce water quality. There are a host of potential mitigation methods that can be effectively employed to prevent or minimise the affects of compaction.

Several of the dairy sites have elevated anaerobically mineralisable nitrogen and total soil nitrogen approaching the upper limits and Olsen P values higher than those required for optimal pasture production. Nitrogen and phosphorus have the potential to negatively affect water quality if they end up in surface water bodies. Efficient nutrient budget and management plans will help minimise effects and should be used by all land managers.

Furthermore cadmium concentrations at dairy pasture sites were significantly greater than other landuse activities and about double typical background concentrations found in soils. However, in the majority of cases, in the medium term concentrations are unlikely to accumulate to concentrations that will exceed proposed guideline values.

Like for the dairy sites, nearly half of the viticulture sites showed evidence of soil compaction i.e. low macroporosity and high bulk density. Most of the low macroporosity values were, not surprisingly found in soils sampled from the wheel track zone where on average values were half those found sampled under the vine. Clearly the high values in the wheel track zone are related to vehicle traffic which is subject to machinery movement to undertake activities such as mowing, spraying, harvesting and pruning. While vehicle traffic movements are an integral part of vineyard operations, their movements should be minimised and avoided during wet soil conditions which exacerbate the potential for soil compaction.

A small number of the drystock pasture sites also showed evidence of soil compaction, and a larger number had low Olsen P values. Several sites also had elevated soil fluorine, however based on the concentrations found in this study, at normal soil ingestion rates concentrations are unlikely to result in fluorine toxicity to grazing animals. Nevertheless, if soil fluorine concentrations continue to increase in the future, management should include maintaining good pasture cover, reducing stocking rates, especially during winter and withholding stock from recently fertilised pastures.

Future work should focus on re-sampling established sites to obtain four or five repeat samples to determine whether there are any trends in soil quality attributes and establishing new sites as resources allow. Many of the trends in declining soil quality can be offset by better land management practices i.e. nutrient budgets/plan, changing grazing practices during high soil moisture etc. Council should continue to educate land managers on strategies to protect the environment while achieving an economic return from the land.

Contents

1. Introduction

Regional councils (and Unitary Councils) have a responsibility for promoting the sustainable management of the natural and physical resources of their region. One of the physical resources that we have a duty under Section 35 of the Resource Management Act (1991) to monitor and report on is soil. Specifically to report on the "life supporting capacity of soil" and to determine whether current practices will meet the "foreseeable needs of future generations". The collection of detailed soil monitoring data is therefore vital because it provides information on what effect current landuse activities are having on soil quality and whether we need to change or prioritise the way we manage the land environment. This is becoming increasingly important as some landuse activities are intensifying across New Zealand e.g. dairying and putting pressure on our soils. Furthermore the way soils respond to different landuse activities can affect other parts of the environment. A good example is water quality, because soils act as buffers to capture and store nutrients such as nitrogen, phosphorous and microbes.

To help determine what effect landuse practices are having on soil quality, in 2000 the Marlborough District Council (MDC) became a participant in a national soil quality monitoring programme known as "The 500 Soils Project". At the completion of this project the MDC implemented its own soil quality monitoring programme commencing in 2008 to continue assessing the quality of soils through the Marlborough region. This programme is largely based around the framework developed as part of the national programme and is in line with soil quality monitoring currently undertaken in other regions in New Zealand.

The objectives of the soil quality monitoring programme are to:

- Provide information on the physical, chemical and biological properties of soils in order to assess overall soil health;
- Provide an early-warning system to identify the effects of primary landuses on long-term soil productivity and the environment;
- Track specific, identified issues relating to the effects of landuse on long term soil productivity;
- Assist in the detection of spatial and temporal changes in soil quality; and
- Provide a mechanism to determine the effectiveness of regional policies and plans.

2. Aim

The aim of this report is to summarise the current state of soil quality in the Marlborough region as determined by the results of soil analysis for the most recent sampling across a range of landuse activities and soil types.

3. Materials and method

3.1. Sampling sites

The soil quality monitoring programme involves collecting soil samples from a network of sites that represent the main landuse activities and soil types within the region and analysing samples for a suite of soil physical, biological and chemical properties that have been shown to be robust indicators of soil quality. The types and definition of each landuse is given in Table 1.

Table 1. Definition of each landuse category used in the soil quality monitoring programme.

Landuse	Definition
Cropping	Annual crops usually grown on a rotational system with pasture. Includes maize, barley, wheat, lucerne, peas, fodder crops and pasture for silage production.
Dairy	Pasture grazed by cattle for the purpose of milk production for use in dairy products.
Drystock	Pasture grazed by livestock other than dairy cattle. Includes sheep, beef cattle, horses, goats and other domesticated animals.
Exotic forest	Plantations of exotic tree species grown for timber production. Generally Radiata pine but can also include Macrocarpa and Douglas-fir.
Viticulture	Permanent row plantations of grapes.
Native vegetation	Native forest and scrub made up of indigenous species. Undeveloped and undisturbed by landuse.

3.2. Soil Sampling

Two types of soil samples were collected from each site. Firstly a composite sample comprising 25 individual cores taken at 2 m intervals along a 50 m transect at a depth of 100 mm (Figure 1a). These samples were used for chemical and biological soil analysis. In addition, three undisturbed soil cores (100 mm diameter by 75 mm depth) were sampled at 15-, 30- and 45-m positions along the transect (Figure 1b). The soil cores were removed as one unit by excavation around the liner, bagged and loaded into padded crates for transport to the laboratory for analysis. These soil samples were used for soil physical analysis.

Figure 1(a). Collecting a composite of core samples along a transect using a soil corer (b) One of three intact core samples taken at each site to establish the physical properties of the soil.

For cropping sites, an additional sample was also collected to assess aggregate stability. The sample was collected at the same interval as the intact cores by cutting a vertical block of soil with a spade approximately 10 cm square (10 cm high x 10 cm wide). Samples also need to be carefully handled to avoid crushing, smearing or altering the soil aggregates (Figure 2).

Figure 2. An undisturbed vertical block of soil collected for aggregate stability analysis.

3.3. Soil Quality Monitoring

A number of different soil properties were measured to assess soil quality. Soil chemical characteristics were assessed by soil pH, total carbon, total nitrogen, carbon:nitrogen ratio, Olsen P and trace element concentrations. Soil biological activity was determined by measuring anaerobically mineralisable nitrogen. Soil physical conditions were assessed using bulk density, particle density and water release characteristics which in turn were used to calculate total soil porosity, air capacity and macroporosity and at some sites aggregate stability (Table 2).

Table 2. Indicators used for soil quality assessments.

Indicators	**Soil Quality Information**
Chemical properties	
Total carbon content	Organic matter status
Total nitrogen content	Organic N reserves
Carbon:nitrogen ratio	Organic matter quality
Soil pH	Acidity or alkalinity
Olsen P	Plant available phosphate
Trace elements	Deficiency or toxicity of trace elements in soil
Biological properties	
Anaerobically mineralisable N	Microbial health. Readily mineralisable nitrogen reserves
Physical properties	
Dry bulk density	Compaction, volumetric conversions
Total porosity, air capacity and macroporosity	Soil compaction, aeration, drainage

3.4. Soil Analyses

3.4.1. Chemical

All chemical analysis was undertaken by Hills Laboratory, Hamilton. Total carbon and nitrogen were determined by dry combustion of air-dry soil. Soil pH was measured in water using glass electrodes and a 2:1 water to soil ratio (Blackmore et al., 1987). Olsen P was determined by extracting soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen, 1954) and measuring the phosphate concentration by the molybdenum blue method. Trace element concentrations in soils i.e. total recoverable copper, chromium, cadmium, arsenic, lead, mercury, nickel and zinc were determined by digesting soils in nitric/hydrochloric acid and analysing trace elements in the digest by inductively coupled plasma mass spectrometry (US EPA 200.2). Total fluoride was measured by alkaline fusion of samples with fluoride measured by an ion selective electrode.

3.4.2. Biological

Anaerobically mineralisable nitrogen was estimated by the anaerobic incubation method. The increase in NH_4-nitrogen concentration was measured after incubation for 7 days at 40 ºC and extraction in 2 M KCl (Keeney and Bremner, 1966).

3.4.3. Physical

Soil physical analysis was undertaken by Landcare Research in Hamilton. Dry bulk density was measured on soil samples extruded from cores and dried in an oven at 105°C until the weight remained constant and the sample was then weighed (Gradwell and Birrell, 1979). Macroporosity (-10 kPa) and total porosity were calculated as described by Klute (1986). Particle density was measured by the pipette method. Aggregate stability was measured by wet sieving of the 2 - 4 mm soil fraction. The mean weight diameter (MWD) of aggregates remaining on the 2 mm, 1 mm and 0.5 mm sieve is measured after sieving (Gradwell, 1972).

It is worth noting that the general definition of macroporosity has recently been expanded to cover a slightly larger range of pores sizes than the original definition. Several regional councils have adopted macroporosity measurements based on the volumetric water content at -10kPa (technically referred to as the air filled porosity). So in this report for consistency with other regions we now use the -10kPa measurement (defined in this report as macroporosity), although the -5kPa data is included for reference because this has been used and reported by the MDC and others in the past.

3.4.4. Targets and Ranges

The critical values or optimal ranges for soil indicators (with the exception of trace elements, the carbon nitrogen ratio and aggregate stability) were assessed using ‘SINDI’. This is a web-based tool designed by Landcare Research to help interpret the quality of a soil that has been sampled. SINDI allows us to i) compare soil data with information for similar soils stored in the National Soil Database ii) see how our soil measures up against the current understanding of optimal environmental and production target values and iii) learn about the effect each indicator has on soil quality and some general management practices that could be implemented to improve the soil. The critical values and optimal ranges are given in Appendix A.

The trace element results (with the exception of cadmium) have been compared against the soil limits presented in the New Zealand Water and Wastes Association (NZWWA, 2003) ‘Guidelines for the Safe Application of Biosolids to Land in New Zealand’ (referred to as the biosolids guidelines). While guidelines containing soil contaminant values like the biosolids guidelines have been written for a specific activity (i.e. biosolids application), the values are generally transferable to other activities that share similar hazardous substances. Cadmium results were compared to values in the Tiered Fertiliser Management System (TFMS) from the New Zealand Cadmium Management Strategy (MPI, 2011).

3.4.5. Statistics and Data Display

Median, minimum, maximum and 25th and 75th percentiles were calculated for soil data using STATISTICA. Where appropriate, summary data was presented as Box and Whisker plots. Figure 3 gives as example of a Box and Whisker plot. The length of each box shows the range within which the central 50% of the values fall, the centre square is the median value, with the box hinges (borders) at the 25th and 75th percentiles. The whiskers show the range of values that fall within the inner fences (but do not necessarily extend all the way to the inner fences). Values between the inner and outer fences are plotted with crosses. Values outside the outer fence are plotted with empty circles.

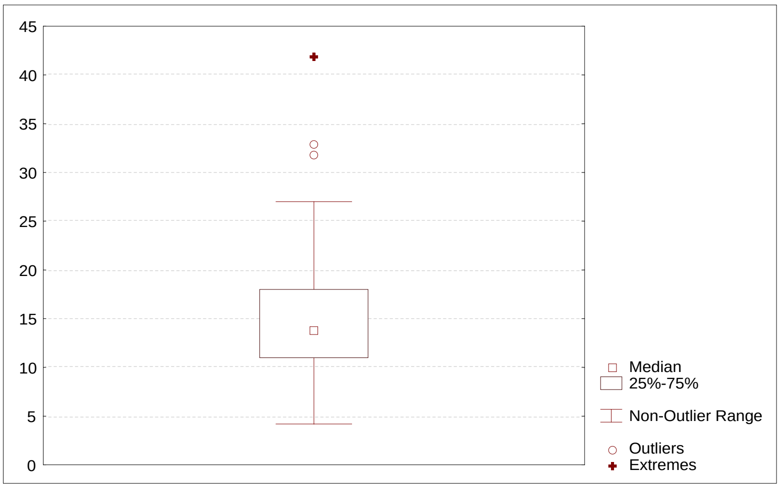

Figure 3. Example of a Box and Whisker plot.

4. Results

4.1. Sampling sites

The state of soil quality was assessed through examining the results of the most recent soil sampling across each landuse. So for example, each of the 15 cropping sites was sampled at least once between 2008 and 2012. In total 118 sites have been sampled since the soil monitoring programme commenced. Sites represent six landuse activities (Table 3; Appendix B) and four soil orders i.e. Gley, Recent, Pallic and Brown soils according to the New Zealand Soil Classification system (Hewitt, 2010). The location of each of the sampling sites is shown in Figure 4.

Table 3. Summary of the number of soil quality monitoring sites for each landuse type and the year each landuse was last sampled.

Landuse	Number of sites (total = 118)	Year last sampled
Cropping	15	2008-2012
Dairy	27	2008-2012
Drystock	19	2008-2012
Exotic forest	7	2007-2009
Viticulture	46* (21)	2008-2012
Native vegetation	4	2007-2011

*Many vineyard soils were sampled from under the vine, in the wheel track and in inter-row. In reality there were 21 unique sites.

As is the case in most regions in New Zealand, compared to the relative proportions of landuse activities by area in our region, sampling tended to be biased to the more intensive activities i.e. dairying, viticulture and cropping (Table 3). The relatively large number of vineyard sites is because different parts of the vineyard are managed differently which significantly affects soil properties. Therefore soils at most of these sites were sampled under the vine, in the middle of the inter-row, and under the wheel track area. In reality there were 21 unique vineyard sites although for analysis and reporting all data was included. In comparison, a relatively low number of sites have at present been established on either native vegetation or exotic plantation sites.

It is recommended that to allow robust statistical comparisons between different landuse, in practice the sample size for any landuse should contain at least 30 samples (Hill and Sparling, 2009). Hence any future soil quality sampling should focus on increasing the number exotic forest and native vegetation sites and to a lesser extent the cropping and drystock pasture sites.

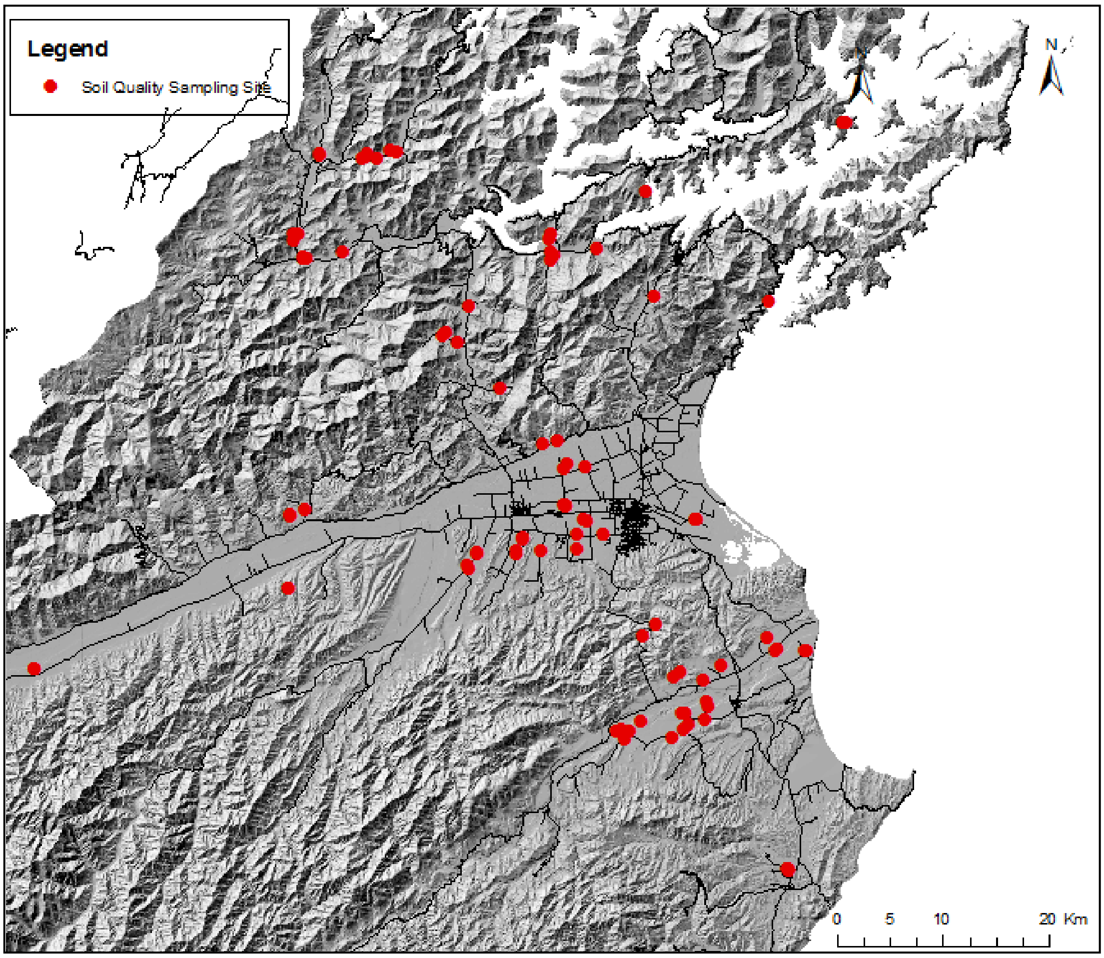

Figure 4. Location of the each of the sampling sites.

Table 4. Summary of the most recent chemical, biological and physical results from 118 soil quality monitoring sites in the Marlborough region.

		Cropping (15)	Dairying (27)	Drystock (19)	Exotic forest (7)	Vineyard (46)	Native (4)
Soil pH	Median	5.9	5.8	5.6	5.1	6.7	5.4
	Range	5.5 – 6.7	5.2 – 6.5	5.1 – 6.5	4.9 – 6.0	6.0 – 7.4	5.3 – 6.0
Total C (%)	Median	2.5	5.7	4.1	5.1	3.2	6.0
	Range	1.9 – 3.9	3.0 – 8.1	3.1 – 7.7	2.6 – 7.4	2.0 – 4.8	5.3 – 9.8
Total N (%)	Median	0.28	0.53	0.40	0.29	0.32	0.49
	Range	0.20 – 0.36	0.31 – 0.67	0.25 – 0.68	0.24 – 0.53	0.21 – 0.50	0.38 – 0.73
C:N ratio	Median	9	10	10	14	10	13
	Range	8 - 11	5 - 12	9 - 13	10 - 22	9 - 12	11 - 12
AMN (mg kg^{-1})	Median	52	191	127	71	75	154
	Range	31 - 116	87 - 345	60 - 208	34 - 107	29 - 163	126 - 175
Olsen P (mg L^{-1})	Median	33	25	14	7	17	9
	Range	13 - 80	8 - 80	4 - 36	5 - 18	5 - 48	4 - 24
Bulk Density (Mg m^3)	Median	1.40	1.06	1.17	1.09	1.35	0.95
	Range	1.23-1.60	0.81-1.34	0.96-1.34	0.79-1.38	1.06-1.61	0.73-1.22
-5kpa (% v/v)	Median	8.4	5.5	12	23.2	8.2	17.3
	Range	1.0 - 20.0	1.0-13.4	5.0-21.0	19-29.4	1.9-22.0	15.0-19.9
-10kpa (% v/v)	Median	5.8	4.2	8.0	19.9	6.0	14.7
	Range	1-16.9	0.8-11.6	2.5-19.3	17.1-26.7	0.7-20.4	13.4-17.5
Aggregate Stability (MWD)	Median	0.56					
	Range	0.37 – 1.60					

The results of soil chemical, biological and physical analyses from soils sampled at each site are given in Figures 5-17 and are discussed separately below.

4.2. Acidity

4.2.1. Soil pH

Soil pH is a measure of the acidity and alkalinity in soil. It is an important soil indicator because it affects nutrient and contaminant availability to plants and the functioning of beneficial soil macro- and micro-organisms. Most plants and soil organisms will have an optimum pH range for growth, and the pH of the soil affects which species will grow best. For example, native forest soils in New Zealand are acidic and indigenous forest species are generally tolerant of acid conditions. In contrast, introduced exotic pasture and crop species prefer less acidic conditions for optimal plant growth.

Figure 5 shows the median and range for soil pH across each landuse. All sites had soil pH values within the acceptable target for their respective landuse. Soil pH values were lowest on the exotic forestry (median pH 5.1) and native forest sites (median pH 5.4) and highest on the viticulture sites (median pH 6.7). The higher values at agricultural sites reflects the widespread use of liming products that typically follows clearance of land to increase soil pH to values adequate for intensive landuse activities.

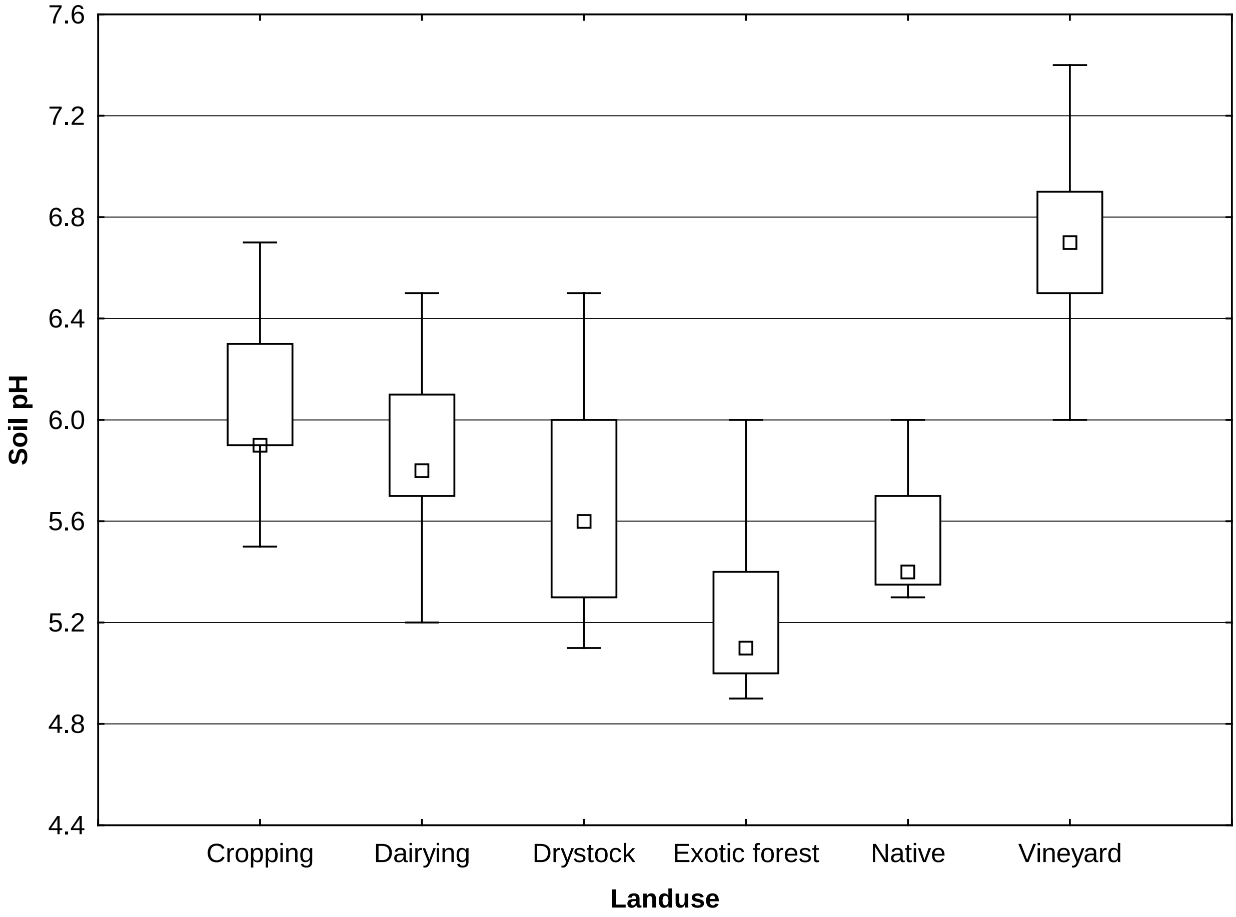

Figure 5. Box plot summarising soil pH measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

Although all sites had soil pH values within their respective soil quality target ranges, about half of the pasture sites (dairy and drystock) were outside the optimal range for pasture soils of pH between 5.8 – 6.2, considered to optimise pasture production (Roberts and Morton, 2009). These sites would benefit from an application of a liming product to increase soil pH where it has been assessed as economically viable.

4.3. Organic resources

The organic resources of soil are monitored by the indicators total carbon, total nitrogen, carbon to nitrogen ratio and anaerobic mineralisable nitrogen.

4.3.1. Total carbon

Total carbon is the total amount of carbon in soil which includes carbonates and soil organic matter carbon. Typically New Zealand soils contain only small amounts of carbonate; hence total carbon is generally considered a good measure of organic matter carbon in soil. Organic matter is important for soil quality because it helps soil retain moisture and nutrients, it contributes to a stable soil structure, it provides a source of energy for soil microbes and is a source of nutrients e.g. nitrogen, phosphorous and sulphur.

Figure 6 shows the median and range in total carbon across each landuse. Cropping sites had the lowest carbon contents (median 2.5%) while the highest values were found at the native sites (median 6.0%). All sites had total soil carbon contents within their acceptable target ranges for their respective landuse with the exception of one of the cropping sites. These results are consistent with trends observed during soil quality monitoring studies in both the Waikato and Wellington regions (Taylor et al., 2010; Sorensen, 2012) where cropping and vegetable growing sites had depleted soil carbon contents compared to carbon at native vegetation sites.

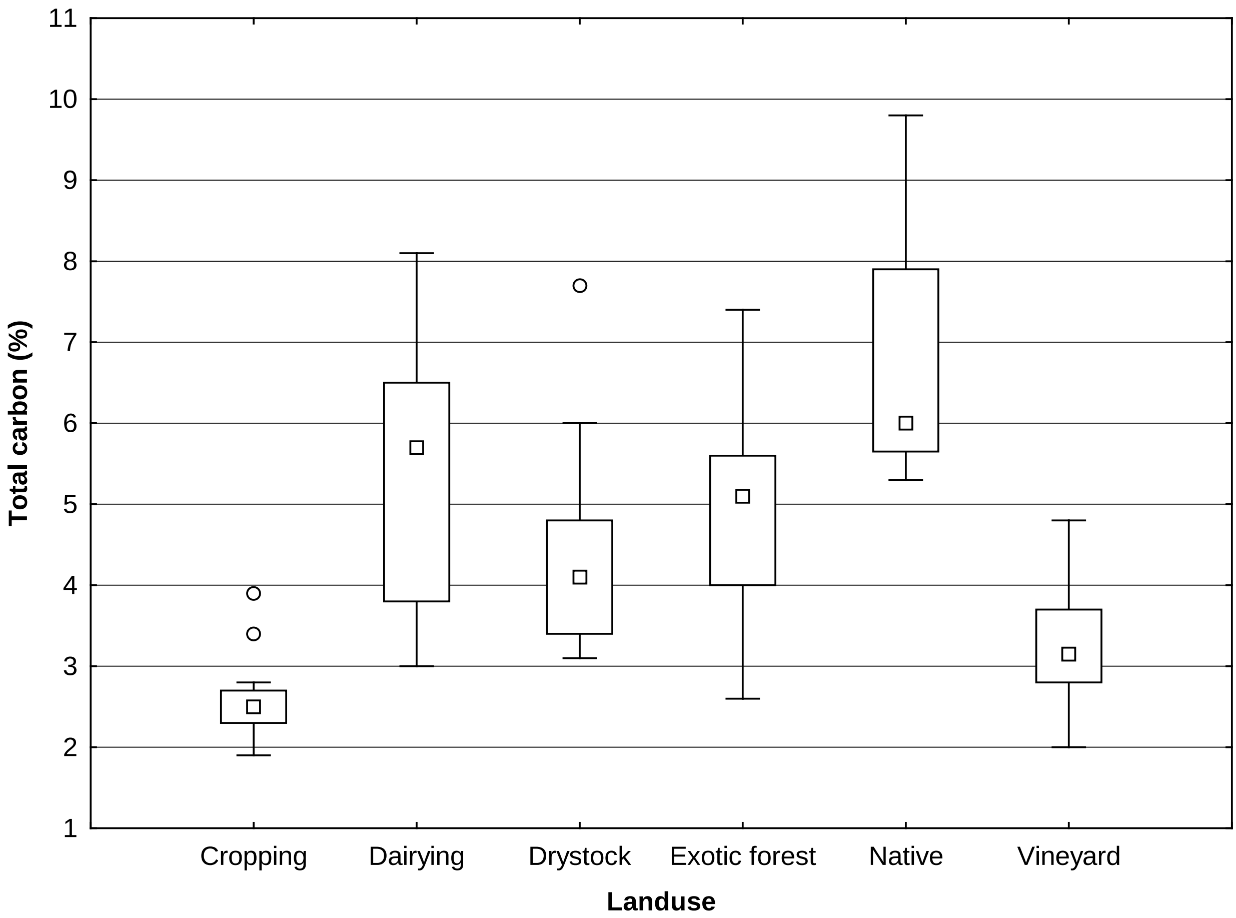

Figure 6. Box plot summarising total soil carbon measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

Despite nearly always meeting their target, about half of the cropping sites had soil carbon contents at the lower boundary of their target range. Low soil carbon (organic matter) increases the risk of soil structural degradation in soils e.g. low aggregate stability, high bulk density, low macroporosity, formation of surface crusts etc (Figure 7). In turn poor soil structure can negatively affect things like soil aeration, drainage, water infiltration rates, water holding capacity, seed germination etc. It would therefore be desirable if cultural practices are adopted to increase the amount of soil carbon in these soils, either by increasing carbon inputs or decrease the rate of decomposition of carbon. This could include adopting residue management practices that maximise carbon returns to the soil, grow cover crops rather than leaving land fallow over winter, include a pasture phase in rotations or adopt minimal tillage (Ghani et al., 2009).

Figure 7. Compacted topsoil at one of the cropping sites sampled with low soil carbon content. Note the surface crust which reduces water infiltration, can increase surface run-off and reduce seed germination.

At vineyard sites soils were sampled under the vine, in the wheel track and in the middle of the inter-row. At all but one site there were lower total carbon concentrations in soils sampled under the vine than in the inter-row. For example, at the 11 sites where samples were taken from under the vine, the wheel track and in the middle of the inter-row, total carbon values were 2.7, 3.3 and 3.5% respectively. This clearly reflects the greater inputs of carbon from vegetated inter-rows compared to under the vines which are typically sprayed to remove vegetation. The one site where there wasn't a measured difference in total carbon was where vegetation was absent from the whole vineyard (Figure 8). However it should be noted that this practice is not commonplace in vineyards in Marlborough and wouldn't be advocated for soil health reasons.

Figure 8. Vineyard site where both the vine and inter-row area have had vegetation removed.

In comparison the dairy sites had relatively high (median 5.7%) total carbon contents. Irrigated, fertilised and grazed pasture is recognised as a landuse activity whereby a significant proportion of soil carbon is added to the soil to replace that lost through decomposition, respiration and consumption.

4.3.2. Total Soil Nitrogen

Nitrogen is an essential major nutrient for plants and animals, and the store of organic matter nitrogen is an important measure of soil fertility. Typically in topsoils, organic matter nitrogen comprises more than 90% of the total nitrogen. However, organic matter nitrogen needs to be mineralised to inorganic forms (i.e. ammonium and nitrate) by soil microbes before it can be utilised by plants.

Figure 9 shows the median and range in total nitrogen across each landuse. Like for total carbon, cropping sites had the lowest nitrogen contents (median 0.28% w/w) while the highest values were at dairy pasture sites (median 0.53% w/w). All sites had total soil N contents within their acceptable target ranges for their respective landuse, although three of the dairy pasture sites had values approaching the upper limit. Like for carbon these results are consistent with trends observed during soil quality monitoring studies in both the Waikato and Wellington regions (Taylor et al., 2010; Sorensen, 2012) where cropping and vegetable growing sites had the lowest total nitrogen contents and the highest concentrations were found at dairy pasture sites.

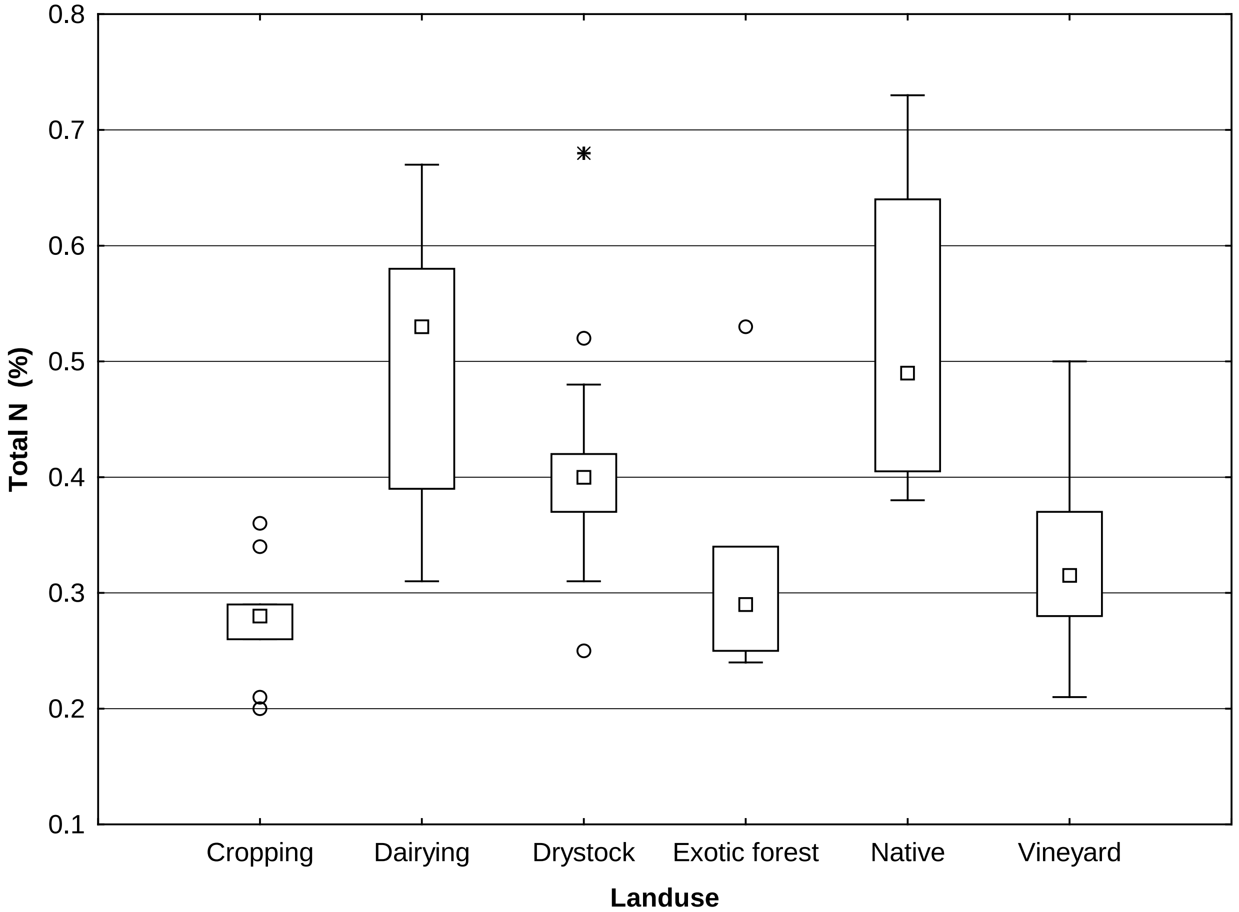

Figure 9. Box plot summarising total soil nitrogen measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

The majority of soil nitrogen (>95%) is present in soil organic matter. Therefore the low values at cropping sites reflect to a large extent the low organic matter (total soil carbon) status of these soils. In contrast, high production permanent pastures subject to fertiliser, legumes and irrigation inputs build up and maintain soil organic matter to relatively high soil nitrogen concentrations.

High concentrations of nitrogen can increase the risk of nitrogen leaching, but many other factors need to be considered. This includes the carbon:nitrogen ratio and anaerobically mineralisable nitrogen status of the soil (which will be discussed in 4.3.3 and 4.3.4), soil physical conditions i.e. is the soil shallow, soil texture, is the soil stony as well as the amount of irrigation and rainfall.

4.3.3. Carbon-nitrogen ratio

The balance of the amount of carbon to nitrogen in soil is called the carbon-nitrogen ratio (C:N). This ratio is important as a guide to the state of decomposition or likely ease of decomposition and mineralisation of nutrients i.e. nitrates and ammonium from organic residues in soils and is a measure of organic matter quality. It is therefore also a guide as to the risk of nitrogen mobility (nitrate leaching) in soil.

The results for C:N ratios for different land use activities are given in Figure 10. Results are consistent with trends observed during soil quality monitoring studies in Waikato, Wellington, Northland regions (Stevenson, 2007; Taylor et al., 2010; Sorensen, 2012) where exotic forestry and native vegetation sites have relatively higher ratios compared to other landuses.

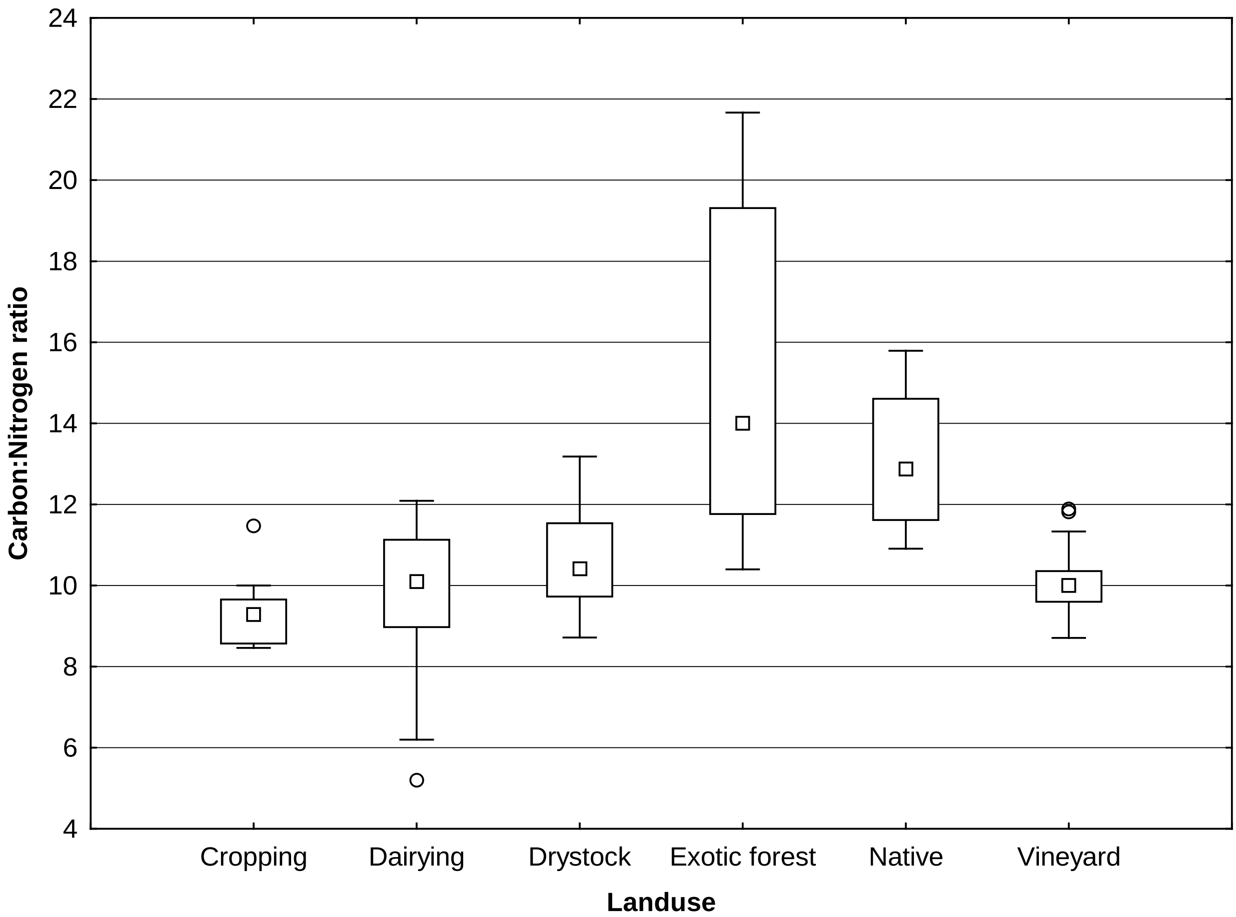

Figure 10. Box plot summarising carbon:nitrogen ratio measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

The C:N ratios of long term pasture soils are typically between 1:10 up to 1:12, which is what was measured in samples in this study. This reflects a high soil nitrogen status (Table 4), usually a result of many years of nitrogen-fixation by white clover, fertiliser inputs, deposition by grazing stock, and microbial incorporation into soil organic matter (Sparling et al., 2001). Low C:N ratios (<10) may be of concern with regard to leaching of nitrate, as low ratios suggest the storage of N in organic matter may be reaching saturation. Schipper et al. (2004) for example has estimated that within 40 years, most soils under intensive livestock farming would be near nitrogen saturation. A nitrogen saturated soil can no longer store more organic nitrogen and potentially any additional nitrogen added will be lost from the soil and may ultimately accumulate in drainage waters and aquifers as nitrate. Hence monitoring the C:N over the medium to long term will provide useful information.

In comparison, native ecosystems with few nitrogen fixing plants and low nitrogen status, often have relatively high C:N ratios that have not received any additional nitrogen inputs (e.g. by stock grazing). Low nitrogen status is desirable for native ecosystems that have indigenous plants adapted to low nutrient conditions. Higher nutrient status may not be beneficial as this could encourage the growth of undesirable, weedy species. Exotic forest soils typically have C:N ratios >15 but are variable depending on whether they have been planted directly into cleared bush, a prepared site, second or third rotation, scrub, or former pasture.

4.3.4. Anaerobically mineralisable nitrogen

Anaerobically mineralisable nitrogen is a measure of the amount of nitrogen that can be supplied to plants through the decomposition of soil organic matter by soil microbes. It is a useful measure of soil organic matter quality in terms of its ability to store nitrogen. However, the amount of anaerobically mineralisable nitrogen has also been found to correspond with the amount of soil microbial biomass – hence it is also a useful indicator of microbial activity in soils (Myrold, 1987).

Figure 11 shows the median and range in anaerobically mineralisable nitrogen across each landuse. By far the highest values were found for dairy pasture sites (median 191 mg kg^{-1}) which also had the highest soil organic mater content (i.e. total carbon and nitrogen). This median value is similar to those found in soils at dairy sites in others regions of New Zealand (Burton, 2009; Stevenson, 2007, Guinto, 2009). The lowest values were found at the cropping sites (median 52 mg kg^{-1}) which had the lowest soil organic mater content. These trends are similar to those observed during soil quality monitoring studies in both the Waikato and Wellington regions (Taylor et al., 2010; Sorensen, 2012) where dairy sites had the highest values and cropping the lowest.

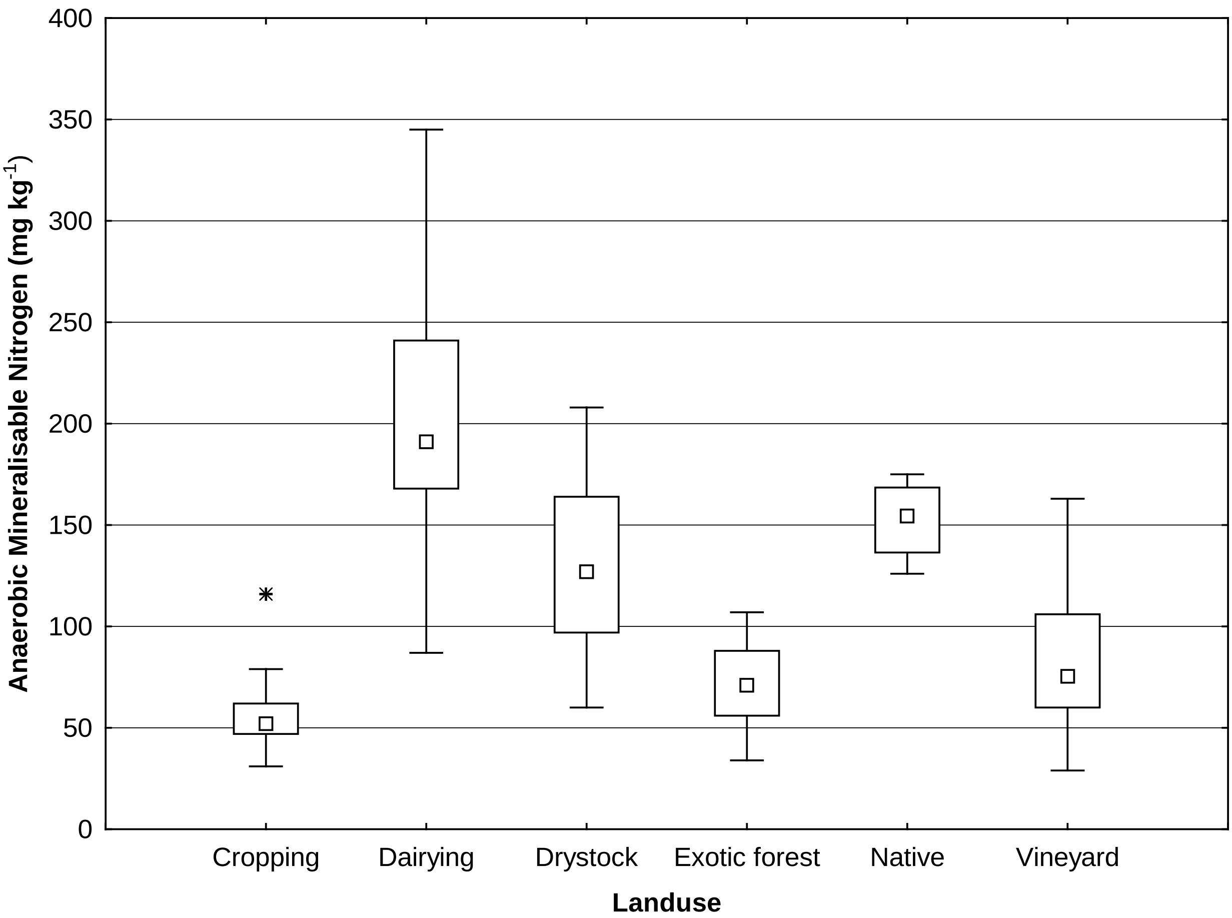

Figure 11. Box plot summarising anaerobically mineralisable nitrogen measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

All sites had anaerobically mineralisable nitrogen contents within their acceptable target ranges for their respective landuse, with the exception of the dairy pasture sites where 6 of the 27 sites exceeded the upper limit. This is likely in part a result of the higher organic matter contents of these soils where nitrogen is mineralised by soil microbes, especially given the C:N ratios.

It has been suggested that anaerobically mineralisable nitrogen is useful as an indicator of potential N leaching (i.e. nitrate) from soils. This is because it can provide an indication of N loading in soil as organic matter and plant residues are mineralised this will increase the amount of nitrate in soil solution. However as already discussed in sections 4.3.2 and 4.3.3, nitrate losses are also controlled by other factors such as soil texture and soil structure which affect the rate of water movement (drainage) in the soil and therefore the rate of nitrate loss. In addition because soils are only sampled to the 10 cm depth, it isn't necessarily going reflect what happens to the nitrate further down the soil profile where it may undergo attenuation and transformation e.g. de-nitrification, immobilisation.

4.4. Fertility

4.4.1. Olsen P

Phosphorus is an essential nutrient for both plants and animals. Only a small amount of the total phosphorus in soil is in forms able to be taken up by plants (plant available P). The Olsen P method is a chemical extractant that provides a reasonable estimate of the amount of plant-available phosphorus by measuring phosphate from soil solution and exchange surfaces. Soils with a high Olsen P status have the potential for phosphorus losses which potentially can have a negative impact on water quality.

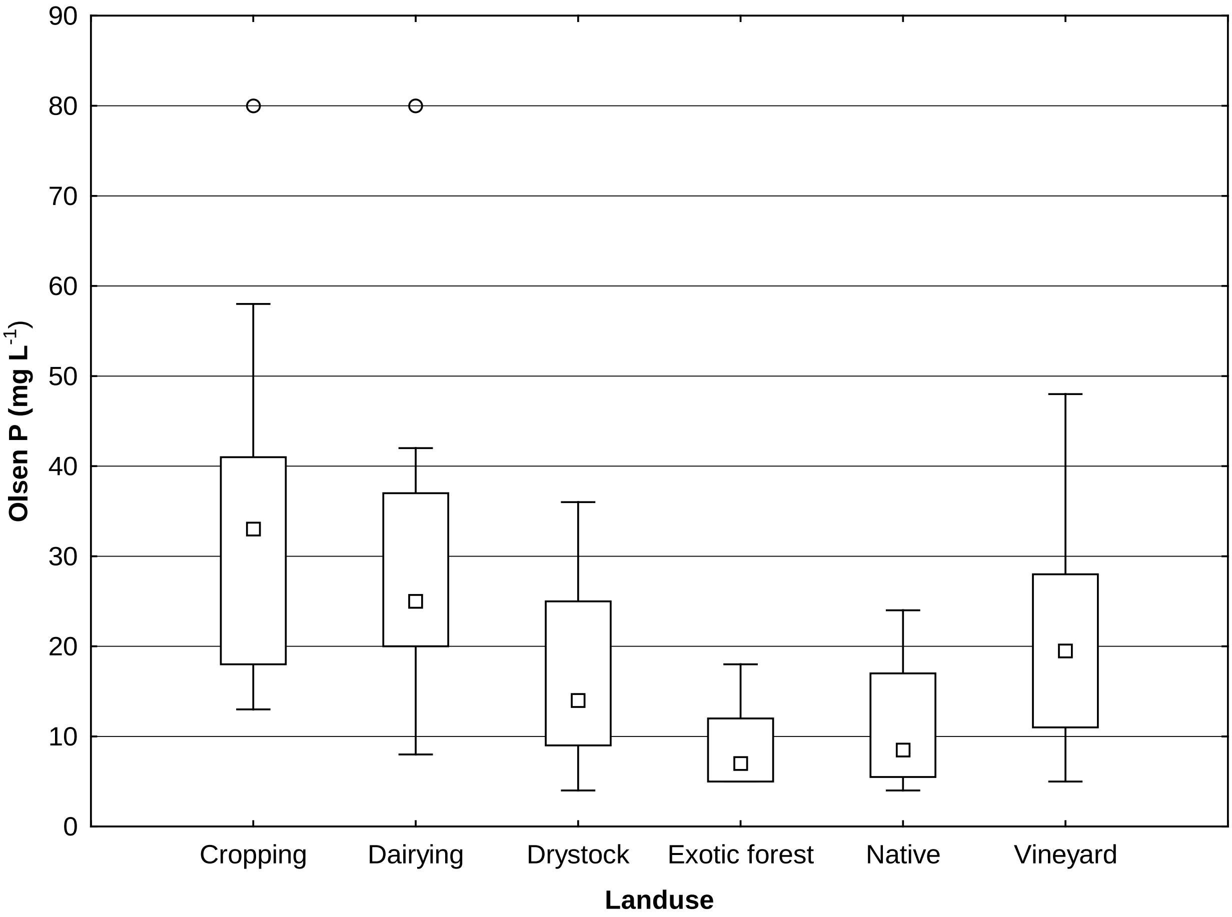

Figure 12. Box plot summarising Olsen P concentrations measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

Figure 12 shows the median and range in Olsen P across each landuse. Exotic forest and native sites had the lowest Olsen P contents while the highest values were found at the cropping sites. These trends are consistent with trends observed during soil quality monitoring studies in other regions (Taylor et al., 2010; Sorensen, 2012), although the values in Marlborough are significantly lower than those found in those regions and elsewhere such as Bay of Plenty, Auckland (Guinto, 2009; Stevenson, 2010).

No sites were found to have Olsen P concentrations that exceeded the upper targets limit of 100 mg L^{-1}. However, it should be noted that the target range is currently under review. This is partly based on the recognition that for pasture soils there is little, if any increase in relative pasture production above an Olsen P of 50 mg L^{-1} (Edmeades et al., 2006). For example, to sustain near maximum pasture production on sedimentary soils on sheep and beef farms Morton and Roberts, (2009) recommend Olsen P values of between 20 - 30 mg L^{-1} and values between 30 - 40 mg L^{-1} for high producing dairy farms, while on cropping soils values up to 40 mg L^{-1} (Nicholls et al., 2009) have been suggested. If we use these production based criteria, then two of the dairy pasture sites, one of the drystock sites and four of the cropping sites would exceed their respective upper target.

In contrast more than half of the drystock pasture and some dairy pasture and cropping sites had Olsen P values below concentrations considered optimal for maximum pasture/crop production. Phosphorous concentrations in soils can be increased relatively easily by the application of phosphate fertilisers to soil, hence these low values are not of any environmental concern but may impact on optimal crop or pasture production.

4.5. Trace Elements

Trace elements accumulate in soils either naturally through weathering of minerals contained in the soil parent material or from anthropogenic sources. While many trace elements are essential for healthy plant and animal growth, i.e. copper and zinc, at high concentrations in soils these can have a negative impact on soil fertility and plant and animal health. Furthermore, some trace elements, i.e. cadmium and arsenic are not required in soils and their accumulation can also have a negative impact on soil, plant and animal health, and in some cases there is potential for them to accumulate in the human food chain.

Table 5 summarises trace element concentrations in soils from different landuse activities. The concentrations are similar to those found in soils at other monitoring sites in other regions of New Zealand Waikato (Taylor et al, 2010); Wellington (Sorensen, 2012); Bay of Plenty (Guinto, 2011); Auckland (Curran-Cournane and Taylor, 2012). With the exception of fluorine and cadmium at dairy pasture sites, concentrations are similar to typical background concentrations found in New Zealand soils and well within suggested upper limits for trace elements in soils as suggested by the New Zealand Water and Waste Association (NZWWA, 2003). The NZWWA suggest upper soil limits are 20 mg kg^{-1} for arsenic; 1 mg kg^{-1} for cadmium; 1 mg kg^{-1} for mercury; 600 mg kg^{-1} for chromium; 100 mg kg^{-1} for copper; 60 mg kg^{-1} for nickel; 300 mg kg^{-1} for lead and 300 mg kg^{-1} zinc.

4.5.1. Fluorine

Fluorine is a naturally occurring element that has been shown to be a small (1-4% fluorine) but significant impurity in most types of phosphate fertiliser. With continuous phosphate fertiliser application, there is the potential for gradual accumulation of fluorine in soils over time.

As indicated, total fluorine concentrations were above background compared to other trace elements with concentrations ranging from 16 to 390 mg kg^{-1} with a median value across all landuse of 210 mg kg^{-1}. Natural soil fluorine concentrations depend on the soil parent material. In New Zealand, Allophanic soils formed from volcanic ash have been found to have concentrations ranging between 175- 200 mg kg^{-1}, whilst soils derived from sedimentary parent materials, such as those found in Marlborough, have been found to have lower concentrations ranging between 43 - 116 mg kg^{-1} (Loganathan et al., 2003). This indicates that some soils in Marlborough have likely received anthropogenic inputs of fluorine, in particular the dairy and drystock pasture sites which had a median fluorine concentration of 300 mg kg^{-1} and 190 mg kg^{-1} respectively.

Elevated soil fluorine is not recognised as having a negative effect on plant health, but can result in animal health issues. Grace et al. (2003) investigated the impact of soil ingestion of fluorine on the metabolism and status of grazing sheep. Based on the results of this study, at normal soil ingestion rates, soils with the range of soil fluorine concentrations found at pasture sites are unlikely to result in fluorine toxicity to grazing animals. However, if soil fluorine concentrations continue to increase in the future, management could include maintaining good pasture cover, reducing stocking rates (especially during winter), withholding stock from recently fertilised pastures and during pasture renovation and deep ploughing land which is identified as having high fluoride in the top soil layer. This effectively dilutes the fluoride by mixing it with soil below the surface layer.

4.5.2. Cadmium

Cadmium is a non-essential, naturally occurring heavy metal that is also an incidental impurity in most types of phosphate fertiliser. With continuous phosphate fertiliser application, there is the potential for gradual accumulation of cadmium in soils over time (Gray et al., 1999).

Total soil cadmium concentrations ranged from 0.04 to 1.02 mg kg^{-1} with a median value across all landuse of 0.16 mg kg^{-1} (Table 5). Median concentrations at dairy pasture sites were significantly ($P < 0.05$) greater than other landuse activities (Figure 13) where the medium concentration was 0.39 mg kg^{-1}. These values are double typical background concentrations found in soils (Roberts et al., 1994) but similar to those that have found in elsewhere in New Zealand at dairy pasture soils (Taylor et al., 2010; Guinto, 2011; Sorensen, 2012).

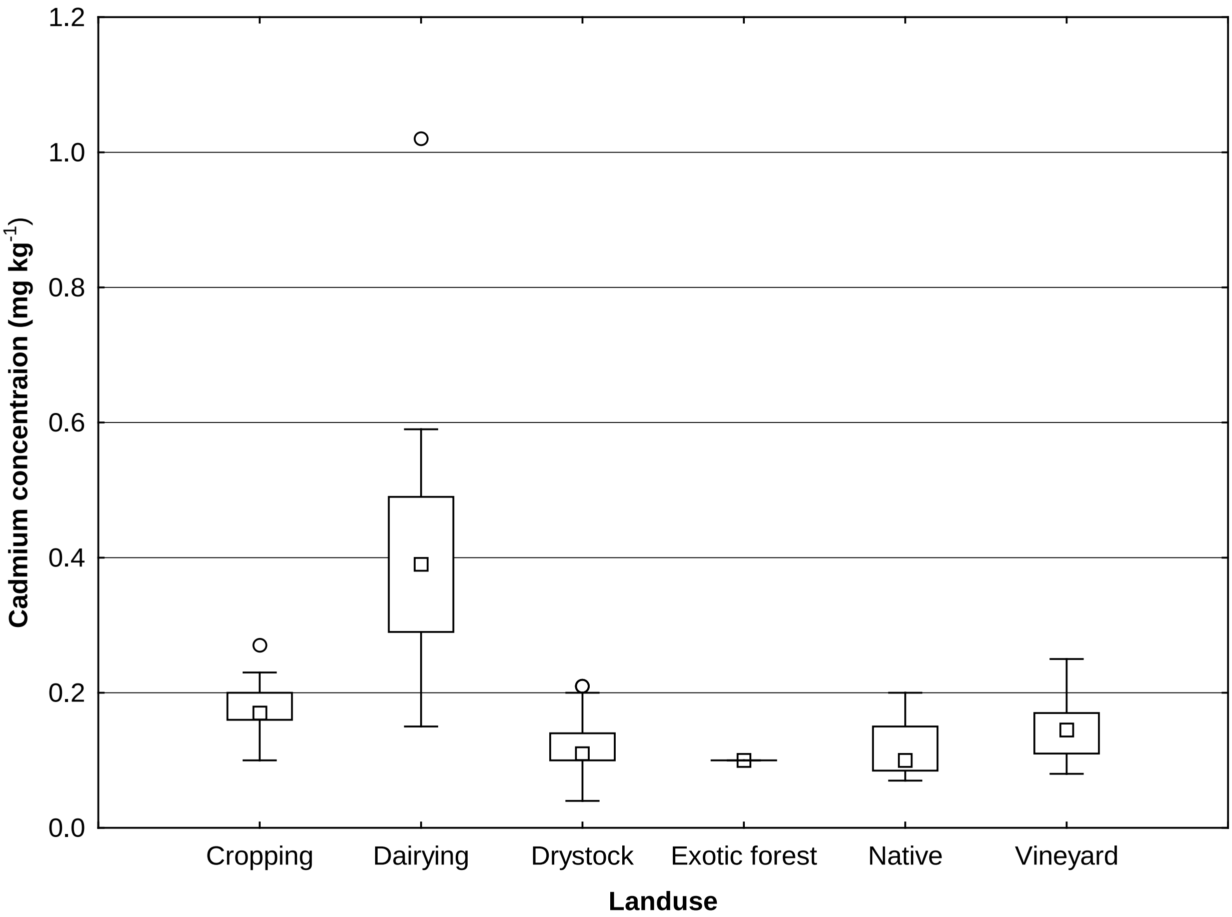

Figure 13. Box plot summarising soil cadmium concentrations measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

All but one sample (i.e. 1.02 mg kg^{-1}) had soil cadmium concentrations within thresholds developed as part of a Tiered Fertiliser Management System (TFMS) outlined in the New Zealand Cadmium Management Strategy (MPI, 2011). Although five other sites had soil cadmium concentrations approaching the 'Tier 1' trigger threshold of 0.6 mg kg^{-1}.

The TFMS is a system for linking soil cadmium concentrations to different types of management action. So for soils with cadmium concentrations up to 0.6 mg kg^{-1} (Tier 1) while there are no limits on phosphate fertiliser application, there is a recommendation that soils are tested for cadmium every five years. For soils which exceed 0.6 mg kg^{-1} but are below 1 mg kg^{-1} (Tier 2), phosphate fertiliser application rates are restricted to a set of products and application rates to manage cadmium accumulation so that cadmium doesn't exceed acceptable thresholds within the next 100 years. While soils which exceed 1 mg kg^{-1} but are below 1.4 mg kg^{-1} (Tier 3), application rates are further managed by use of a cadmium balance program to ensure that cadmium does not exceed an acceptable threshold within 100 years. While the monitoring of soil cadmium is the responsibility of regional Council, the implementation of these strategies is the responsibility of the fertiliser industry.

Table 5. Summary of total recoverable trace element concentrations (mg kg^{-1}) in soil samples in the most recent round of soil quality monitoring across each landuse.

		Cropping	Dairying	Drystock	Exotic forest	Native	Vineyard
Arsenic	Median	3	4	3	3	4	4
	Min	2	3	2	2	3	2
	Max	5	7	5	6	5	9
Cadmium	Median	0.17	0.39	0.11	0.10	0.10	0.15
	Min	0.10	0.15	0.04	0.10	0.07	0.08
	Max	0.27	1.02	0.21	0.10	0.20	0.25
Chromium	Median	22	26	16	14	37	21
	Min	11	15	8	8	8	11
	Max	29	191	21	29	85	28
Copper	Median	11	15	9	12	16	13
	Min	5	7	4	5	10	5
	Max	18	25	16	22	21	25
Nickel	Median	15	12	11	11	22	15
	Min	8	9	6	4	5	7
	Max	23	141	25	18	46	51
Lead	Median	11	12	10	11	14	10
	Min	8	9	4	6	7	8
	Max	19	20	17	14	19	19
Zinc	Median	68	62	57	46	81	62
	Min	48	41	18	22	37	43
	Max	97	220	84	75	105	111
Mercury	Median	0.03	0.07	0.04		0.02	
	Min	0.03	0.02	0.03		0.01	
	Max	0.03	0.17	0.04		0.07	
Fluorine	Median	240	300	190	140		220
	Min	160	290	100	16		140
	Max	310	310	390	250		300

4.6. Physical resources

The physical resources if soil is monitored through the indicators bulk density, macroporosity and aggregate stability.

4.6.1. Bulk density

Bulk density is the weight of soil in a specified volume and provides a measure of how loose or compacted a soil is. Loose soils may be subject to increased risk of erosion, dry out quickly, and plant roots find it difficult to get purchase and absorb water and nutrients. In contrast, compacted soils have poor aeration and are slow draining. The consequences of compacted soil may include reduced supply of air to plant roots, increased resistance to penetration that may limit root extension and germination, and reduced capacity of the soil to store water that is available to plants. Further, reduced water entry into the soil may increase water runoff over the soil surface.

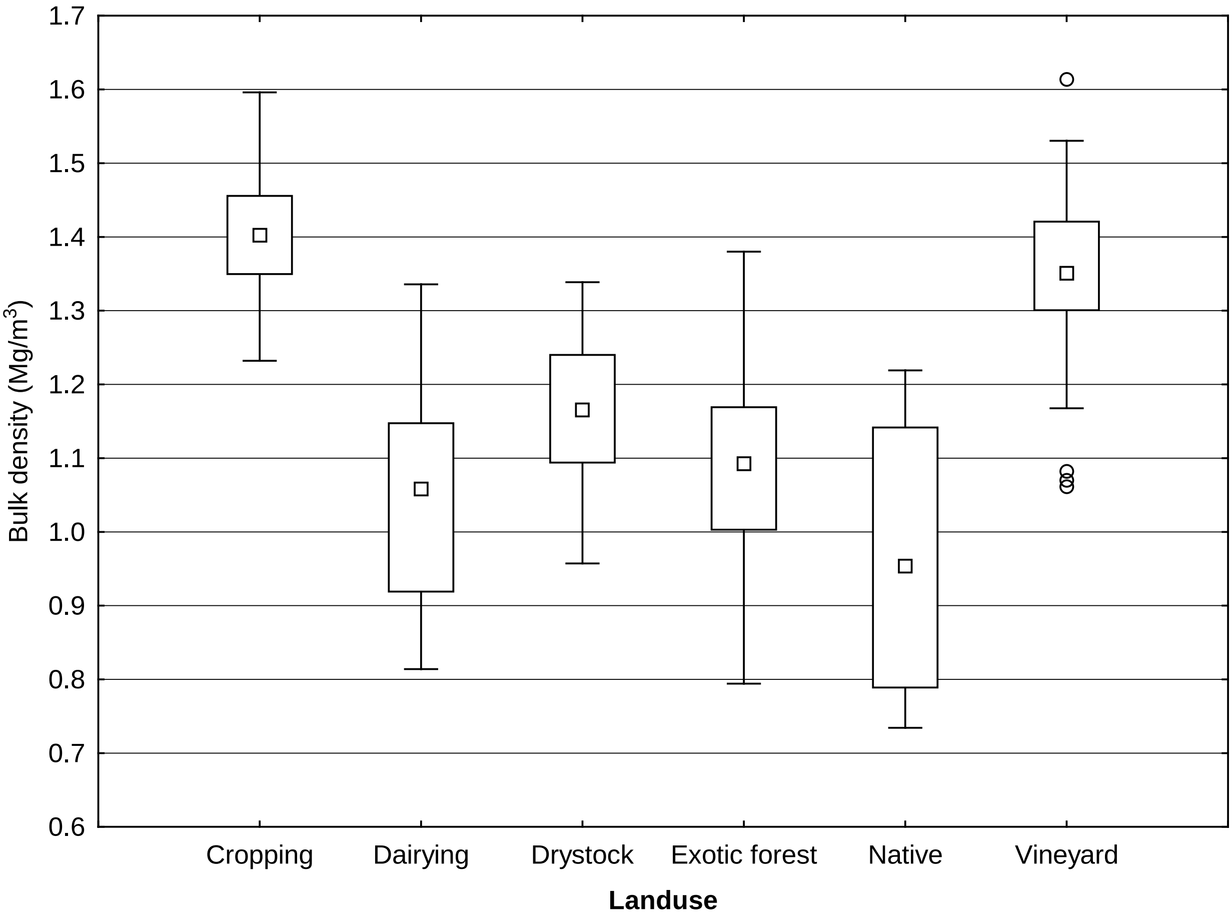

Figure 14. Box plot summarising bulk density values measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

Figure 14 shows the median and range for soil bulk density across each landuse. Median values were lowest on native sites (0.95 Mg m^3) and highest for cropping sites (1.40 Mg m^3). All the dairy, drystock, exotic forest and native sites met their target ranges for bulk density, however 11 of the cropping sites and 19 of the vineyard sites had values that exceeded the upper target range. These results are in line with what has been found nationally (Sparling et al., 2001) where mixed and arable cropping and horticulture sites recorded the highest bulk density values compared to other landuses.

In part the high bulk density values at the cropping sites are likely related to the relatively depleted organic matter i.e. total carbon contents in these soils which as discussed in section 4.3.1. It is well recognised that organic matter is an integral component in the formation and maintenance of a stable structure in soils. Furthermore, the tracking of heavy machinery in cropping operations is also likely to have contributed to elevated bulk density. For example, Figure 15 shows surface crust at one of the cropping sites sampled which potentially reduces water infiltration, can increase surface run-off and reduce seed germination.

The other soils with high bulk density values were some of the vineyards sites - often in the wheel track zone although in some instances surprisingly under the vine. Clearly the high values in the wheel track zone are related to vehicle traffic which is subject to machinery movement to undertake activities such as mowing, spraying, harvesting and pruning.

While vehicle traffic movements are an integral part of both cropping and vineyard operations, their movements should be minimised and avoided during wet soil conditions which exacerbate the potential for soil compaction (McLaren and Cameron, 1990). Furthermore, in cropping operations as already discussed cultural practices should be encouraged which maintain or enhance soil carbon contents to stabilise or improve soil structure.

Figure 15. Surface crust at one of the cropping sites sampled which potentially reduces water infiltration, can increase surface run-off and reduce seed germination.

4.6.2. Macroporosity

Macroporosity is a measure of the proportion of large pores in the soil and is along with bulk density is an indicator of soil compaction. Macropores are important for penetration of air into soil, extension of roots down into the soil and the drainage of water. Typically macropores and are the first to be lost when the soil is compacted.

The effects of soil compaction/pugging are wide ranging, both direct and indirect and the effects occur both on- and off-site. An overview of some of the potential soil, plant and environmental effects of soil compaction/pugging from animal treading is given in Figure 16.

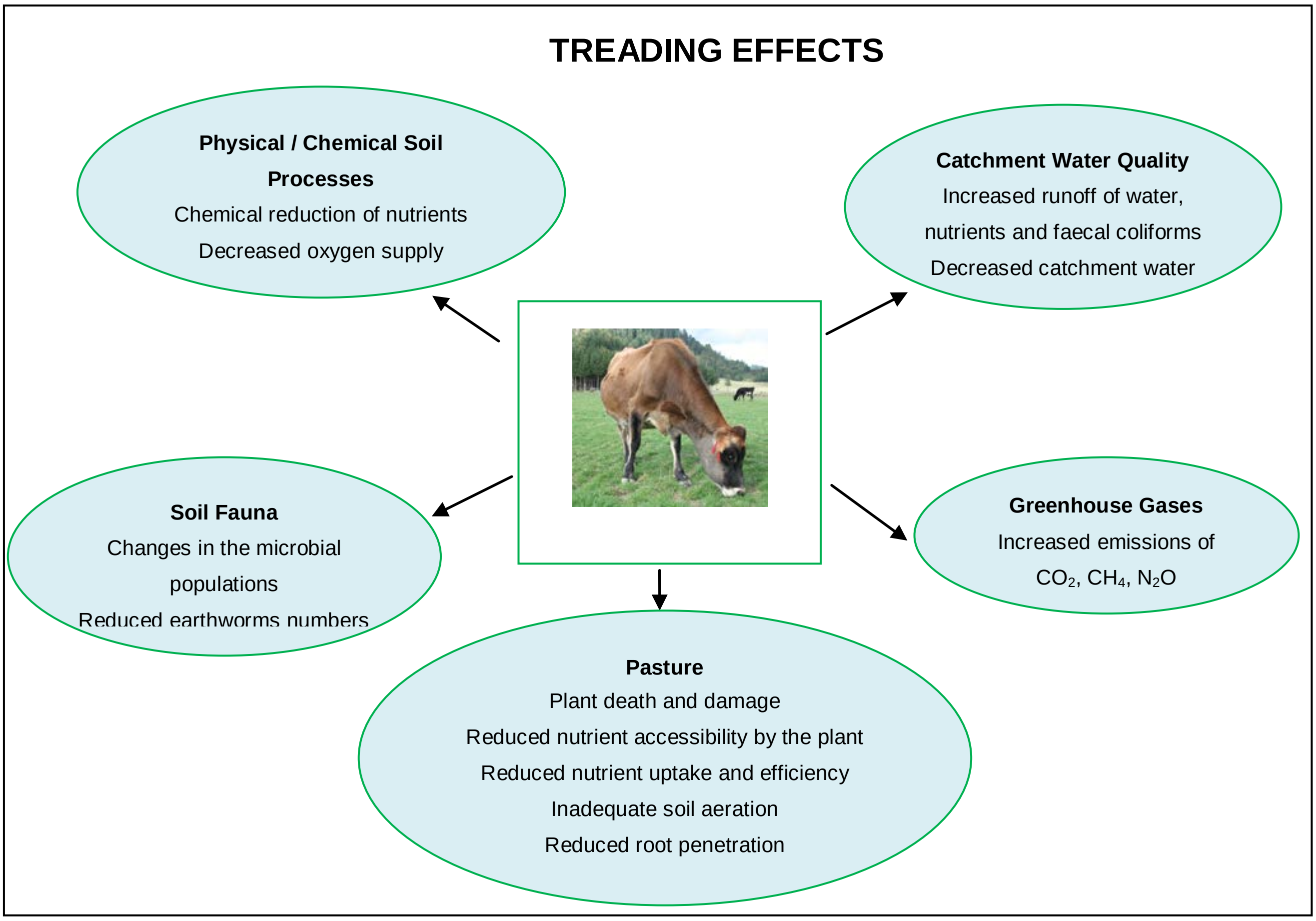

Figure 16. Potential on- and off-site effects of animal treading (adapted from Singleton et al., 2000).

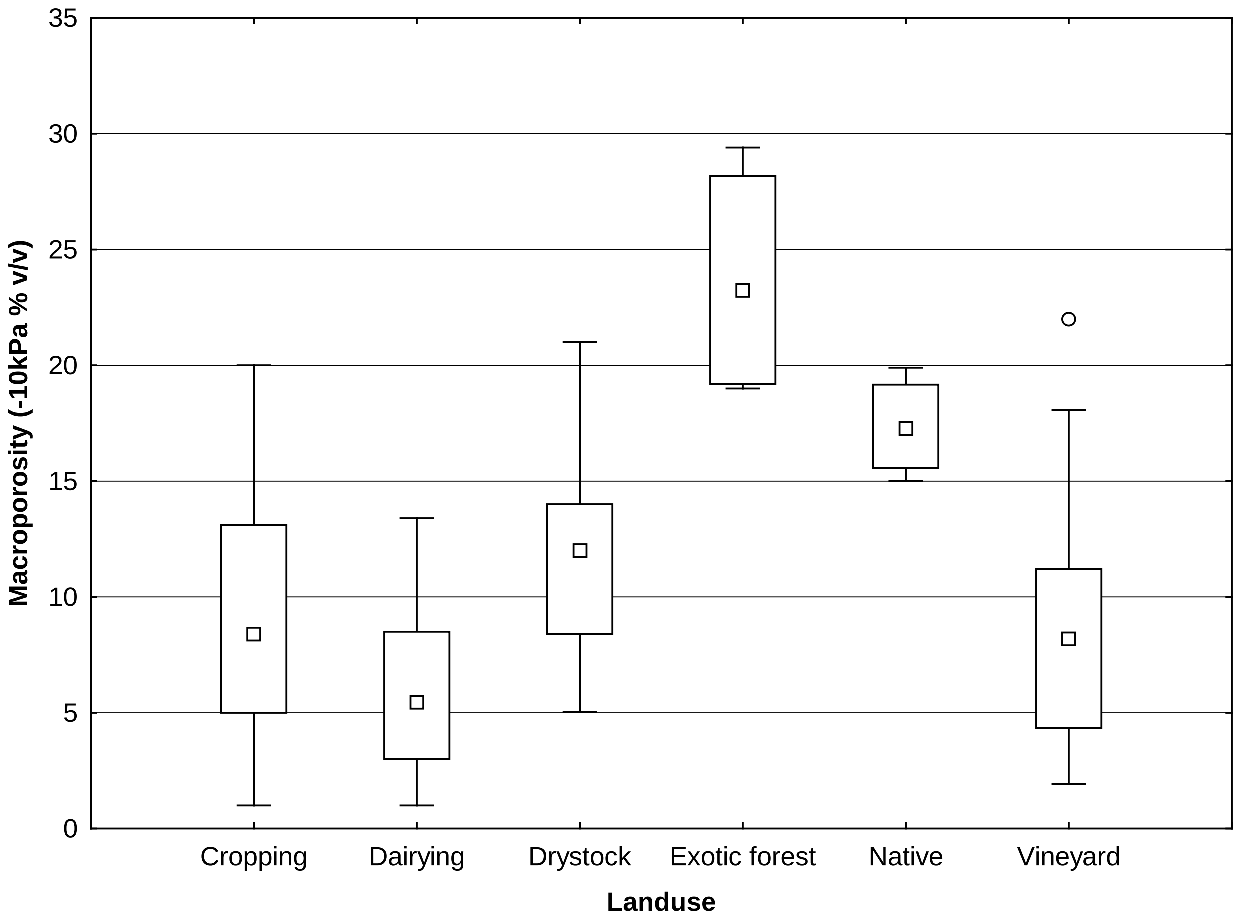

Figure 17. Box plot summarising macroporosity values measured in soil samples taken during the most recent round of soil quality monitoring for each landuse.

Figure 17 shows the median and range for soil macroporosity across each landuse. Macroporosity values were more variable than bulk density across the different land use types with varying numbers of vineyard, cropping, dairy and dryland pasture sites all having values less than the lower limit of the target range, indicating some soil compaction.

The lowest values were found at dairy pasture sites which is something which has been noted in other regions in New Zealand such as the Waikato, Auckland, Wellington (Taylor et al., 2010; Stevenson, 2010; Sorensen, 2012) and has been identified as a significant issue by the dairy industry. The low macroporosity values are likely related to heavy grazing or grazing under wet conditions where animal treading has effectively reduced the large pore fraction in soils. Research has shown that macroporosity values below a 10% threshold have been shown to adversely affect pasture production. Furthermore, low macroporosity may result in poor water infiltration which may increase overland flow and the potential for nutrient losses such as phosphorous from soils.

Low macroporosity values are typically associated with high bulk density values. While this was the case with the cropping and viticulture sites interestingly this was not observed at the dairy sites which had low macroporosity but bulk density values were within their target ranges. One possible explanation is that compaction has reduced the volume of macropores at the dairy sites, but the adequate total organic carbon at these sites is sufficient to help the soil resist overall compaction. The net result is presumably a change in the pore-size distribution, with a decrease in the macropore volume and an increase in the volume of the smaller pore sizes.

While monitoring has shown that many dairy sites show evidence of soil compaction, there are a number of potential mitigation methods that can be employed to prevent or minimise the effects of soil compaction, even on those soils not normally regarded as having a compaction problem.

Practices could include:

- on/off grazing of animals
- grazing wetter paddocks before the wet part of the season
- maintaining good pasture cover which gives better protection against pugging
- installing drainage in some areas
- use of feeding platforms
- standoff areas
- decreasing winter stock numbers by moving stock onto well drained soil types off-site
- changing to lighter weight breeds
- using the farm bike rather than heavy tractors

While there are ways of preventing/minimising the effects of soil compaction/pugging, if there is already evidence of soil compaction/pugging the effects aren't necessarily permanent and there are several remediation options available. These can include:

- Natural soil amelioration processes i.e. wetting and drying cycles, freeze and thaw cycles, plant root growth and decay and soil fauna and flora activity. Although the degree of recovery can vary from site to site depending on many factors such as previous land management practices, soil type, and climate and is often limited to a soil depth of about 10 cm and maximum of 15 cm (Drewry, 2006).
- Mechanical loosening of soil (also called subsoling or aeration) can also be effective to offset the effects of compaction/pugging (Drewry, et al., 2000; Burgess et al., 2000). In comparison to natural soil amelioration processes, mechanical loosening is effective to depths of up to 24 cm (McDowell, 2008). Although again the effectiveness is specific to soil types with some soils quickly reverting back to their original state shortly after subsoiling (Houlbrooke, 1996).
- Cultivation possibly involving growing a commercial fodder crop prior to re-sowing a new pasture is also shown to be effective.

At the cropping sites, the low macroporosity values as discussed above are likely related to the depleted organic carbon in these soils and the use of machinery, especially when soil conditions are too wet for heavy equipment - which has compressed the larger pores.

At vineyard sites, as discussed already, soils were sampled from both the vine, wheel track areas and middle of the inter-row. Most of the low macroporosity values were therefore not surprisingly found from soils sampled from the wheel track. For example, at the 11 sites where samples were taken from under the vine and under the wheel track macroporosity values were 10.1% and 4.6% respectively. The low macroporosity values at the vineyard sites are again likely related to machinery movement to undertake activities such as mowing, spraying, harvesting and pruning as discussed previously.

Based on a vine spacing of 2.4 m and a wheel track width of 0.35 m, it is estimated that on a per hectare basis 29% (2870 m^2) of the vineyard could potentially be considered as compacted (excluding headlands). As discussed, this compaction could increase the potential for reduced infiltration and surface runoff during high rainfall events and anecdotal observations suggest this could contribute to increase flooding in some areas. Although not quantified this is a possibility on sites which were previously drystock pasture which on a per hectare basis is a landuse less likely to be compacted.

4.6.3. Aggregate Stability

Aggregate stability refers to the ability of soil aggregates to resist disruption when forces such as rapid wetting and mechanical abrasion are applied. In general a soil with adequate amounts of soil organic matter will have stable soil aggregates and therefore a higher aggregate stability. A stable soil structure is important to allow water and air movement in soils and to minimise surface erosion.

Aggregate stability measurements were restricted to the majority of the cropping sites where values ranged from 0.37 to 1.60 Mean Weight Diameter (MWD) with a median value of 0.56 MWD (Table 4). Although there are no specific target ranges currently available for aggregate stability, generally any value below about 1.5 MWD is considered on the low side and likely to have a negative effect on crop production (Francis et al., 1991). Using this threshold 12 of the 13 site sampled has values below 1.5 MWD.

The low aggregate stability values in the cropping soils are likely again linked to the relatively low organic matter i.e. total carbon contents in these soils. In addition, most of the cropping sites are on Pallic soils which typically have high slaking potential (Hewitt, 2010) and are usually regarded as unsuitable for continuous cropping to due to their potential for soil structural collapse. Figure 18 illustrates a poorly structured topsoil at one of the cropping sites sampled. Note the large block and platy soil structure.

Figure 18. Compacted topsoil at one of the cropping sites.

4.7. Overall soil quality – landuse

To asses the affects of individual landuses on soil quality the sites were divided into landuse types and assesses against the relevant target ranges levels for each indicator.

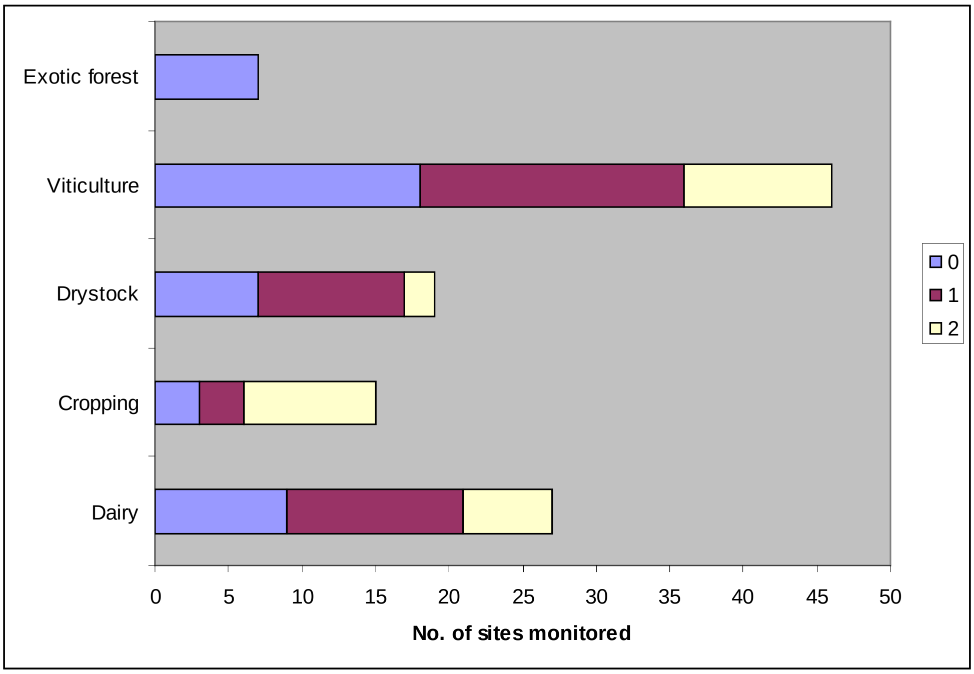

Figure 19 - Summary of compliance with target range values for seven key soil quality indicators based on the most recent round of soil monitoring across different land uses. Note there are no targets for native forest soils.

The majority of the soil quality monitoring sites were found to be in good condition when results were compared against relevant target range or critical values. Of the 118 sites sampled, 48 (41%) met all their targets and a further 43 (36%) has just one indicator outside the range. Viticulture and dairy were the landuse that numerically had the most sites not meeting their target ranges, whilst all targets were met for the limited number of exotic forestry sites sampled (although it should be noted that the impacts of forestry are often restricted to the time of harvest).

5. Summary

- Soil quality monitoring across the Marlborough region between 2007 – 2012 indicates that of the 118 sites sampled, 48 sites met all their targets, 43 had one indicator outside their range while the remaining 27 sites had two indicators that didn't met their target range.

- Monitoring has highlighted that there are several soil quality issues under some land use activities.

- Several of the cropping sites were found to have slightly elevated Olsen P values and most had depleted organic matter (Total C and N) contents. Most of the cropping sites also had poor soil structure highlighted by low aggregate stability, high bulk density and low macroporosity. These findings put these soils at risk of poor aeration, impeded drainage and surface crusting all of which may potentially affect crop performance and predispose the soil to surface runoff, nutrient loss, erosion and flooding. Cultural practices in cropping soils should be encouraged which maintain or enhance soil carbon contents to stabilise and improve soil structure.

- Half of the dairy pasture sites showed signs of soil compaction i.e. low macroporosity. The low values are likely related to heavy grazing or grazing under wet conditions where animal treading has effectively reduced the large pore fraction in soils. Low macroporposity values have been shown to negatively affect a range soil physical/chemical processes which in term can reduce pasture dry matter production. Furthermore, it can also increase the potential for surface run-off and provide a pathway for nutrient (N and P) and microbe loss to surface waters and reduce water quality. There are a number of potential mitigation methods that can be effectively employed to prevent or minimise the affects of compaction.

- Several of the dairy sites have elevated anaerobically mineralisable nitrogen, total soil N approaching the upper limits and Olsen P values higher than those required for optimal pasture production. High N and P have the potential to negatively affect water quality if they end up in surface water bodies. Implementation of nutrient budget and management plans will help minimise excessive nutrient accumulation in soils and this should be advocated to land managers across all industry sectors.

- Furthermore cadmium concentrations at dairy pasture sites were significantly greater than other landuse activities. However, in the majority of cases, in the medium term concentrations are unlikely to accumulate to concentrations that will exceed current guideline values.

- Like for the dairy sites, nearly half of the viticulture sites showed evidence of soil compaction i.e. low macroporosity and high bulk density. Most of the low macroporosity values were, not surprisingly found in soils sampled from the wheel track zone where on average values were half those found sampled under the vine. Clearly the high values in the wheel track zone are related to vehicle traffic which is subject to machinery movement to undertake activities such as mowing, spraying, harvesting and pruning. While vehicle traffic movements are an integral part of vineyard operations, their movements should be minimised and avoided during wet soil conditions which exacerbate the potential for soil compaction.

- A small number of the drystock sites also showed evidence of soil compaction, although the main issue at these sites was the low Olsen P values and in some instances elevated fluorine. Based on the results of this study, at normal soil ingestion rates, soils with the range of soil fluorine concentrations found at pasture sites are unlikely to result in fluorine toxicity to grazing animals. However, if soil fluorine concentrations continue to increase in the future, management should include maintaining good pasture cover, reducing stocking rates (especially during winter) and withholding stock from recently fertilised pastures.

6. Recommendations

- Future work should focus on re-sampling established sites to obtain four or five repeat samples to determine whether there are any trends in soil quality attributes.
- Establish new sites as resources allow.
- Many of the trends in declining soil quality can be offset by better land management practices i.e. nutrient budgets/nutrient management plans, changing grazing practices during high soil moisture etc. Council should continue to educate land managers on strategies to protect the environment while achieving an economic return from the land.

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Appendix A

Soil quality indicator target (or optimal) ranges from Hill and Sparling (2009) are outlined in the tables below along with guideline values for trace element concentrations in soil, adapted from NZWWA (2003).

Bulk density target ranges (t/m^3 or Mg/m^3)

	Very loose	Loose	Adequate	Compact	Very compact	
Semi-arid, Pallic and Recent soils	0.3	0.4	0.9	1.25	1.4	1.6
Allophanic soils		0.3	0.6	0.9	1.3	
Organic soils		0.2	0.4	0.6	1.0	
All other soils	0.3	0.7	0.8	1.2	1.4	1.6

Notes:

Applicable to all land uses

Target ranges for cropping and horticulture are poorly defined

Macroporosity target ranges (% @ -10 kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	6	10[1]	30	40
Forestry	0	8	10	30	40

Notes:

1: Revised base don Mackay et al. (2006) Applicable to all Soil Orders

Target ranges for cropping and horticulture are poorly defined

Total carbon target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	
Allophanic	0.5	3	4	9	12
Semi-arid, Pallic and Recent	0	2	3	5	12
Organic	exclusion				
All other Soil Orders	0.5	2.5	3.5	7	12

Notes:

Applicable to all Soil Orders

Organic soils by definition must have >15% total C content, hence C content is not a quality indicator for that order and is defined as an "exclusion" Target ranges for cropping and horticulture are poorly defined

Total nitrogen target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	High	
Pasture	0	0.25	0.35	0.65	0.70	1.0
Forestry	0	0.10	0.20	0.60	0.70	
Cropping and horticulture	exclusion					

Notes:

Applicable to all Soil Orders

Target ranges for cropping and horticulture are not specified as target values will depend on the specific crop grown

Anaerobic mineralisable nitrogen (AMN) target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	Excessive	
Pasture	25	50	100	200	200	250	300
Forestry	5	20	40	120	150	175	200

Cropping and horticulture	5	20	100	150	150	200	225

Notes:

Applicable to all Soil Orders

Target ranges for cropping and horticulture are poorly defined

Soil pH target ranges

	Very acid	Slightly acid	Optimal	Sub-optimal	Very alkaline	
Pastures on all soils except Organic	4	5	5.5	6.3	6.6	8.5
Pastures on Organic soils	4	4.5	5	6	7.0	
Cropping and horticulture on all soils except Organic	4	5	5.5	7.2	7.6	8.5
Cropping and horticulture on Organic soils	4	4.5	5	7	7.6	
Forestry on all soils except Organic		3.5	4	7	7.6	
Forestry on Organic soils	exclusion					

Notes:

Applicable to all Soil Orders

Target ranges for cropping and horticulture are general averages and target values will depend on the specific crop grown

Exclusion is given for forestry on organic soils as this combination is unlikely because of wind throw

Olsen P target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	
Pasture on Sedimentary and Allophanic soils	0	15	20	50	100	200
Pasture on Pumice and Organic soils	0	15	35	60	100	200
Cropping and horticulture on Sedimentary and Allophanic soils	0	20	50	100	100	200
Cropping and horticulture on Pumice and Organic soils	0	25	60	100	100	200
Forestry on all Soil Orders	0	5	10	100	100	200

Notes:

Sedimentary soil includes all other Soil Orders except Allophanic (volcanic ash), Pumice, Organic and Recent (AgResearch classification system)

Guideline values for trace element concentrations in soil, adapted from NZWWWA (2003)

Trace element	Soil Limit (mg/kg)
Arsenic (As)	20
Cadmium (Cd)	1
Chromium (Cr)	600
Copper (Cu)	100
Lead (Pb)	300
Nickel (Ni)	60
Zinc (Zn)	300

Appendix B

Table B1. Details of the soil quality monitoring sites in Marlborough region.

Site	Landuse	NZ Soil Order	Soil series	Sample location	Sample dates		
MDC1A	Vineyard	Recent	Wairau	Under the vine			Sept-2012
MDC1B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012
MDC1C	Vineyard			Middle of inter-row			Sept-2012
MDC2A	Vineyard	Recent	Wairau	Under the vine			Sept-2012
MDC2B	Vineyard			Under the wheel-track	Oct-2000	Oct-2007	Sept-2012
MDC2C	Vineyard			Middle of inter-row			Sept-2012
MDC3	Dairy	Recent	Wairau		Sept-2000	Oct-2007	Sept-2012
MDC4A	Vineyard	Pallic	Renwick	Under the vine			Sept-2012
MDC4B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012
MDC4C	Vineyard			Middle of inter-row			Sept-2012
MDC5	Cropping	Recent	Renwick		Oct-2000	Oct-2007	Sept-2012
MDC6	Drystock	Pallic	Renwick		Sept-2000	Oct-2007	Sept-2012
MDC7A	Vineyard	Pallic	Paynter	Under the vine			Sept-2012
MDC7B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012
MDC7C	Vineyard			Middle of inter-row			Sept-2012
MDC8A	Vineyard	Gley	Paynter	Under the vine			Sept-2012
MDC8B	Vineyard			Under the wheel-track	Oct-2000	Oct-2007	Sept-2012
MDC8C	Vineyard			Middle of inter-row			Sept-2012
MDC9	Dairy	Pallic	Paynter		Sept-2000	Oct-2007	Sept-2012
MDC10A	Vineyard	Recent	Omaka	Under the vine			Sept-2012
MDC10B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012
MDC10C	Vineyard			Middle of inter-row			Sept-2012
MDC11A	Vineyard	Recent	Omaka	Under the vine			Sept-2012
MDC11B	Vineyard			Under the wheel-track	Oct-2000	Oct-2007	Sept-2012
MDC11C	Vineyard			Middle of inter-row			Sept-2012
MDC12A	Vineyard	Pallic	Seddon	Under the vine			Sept-2012
MDC12B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012

Site	Landuse	NZ Soil Order	Soil series	Sample location	Sample dates		
MDC12C	Vineyard			Middle of inter-row			Sept-2012
MDC13A	Vineyard	Pallic	Seddon	Under the vine			Sept-2012
MDC13B	Vineyard			Under the wheel-track	Sept-2000	Oct-2007	Sept-2012
MDC13C	Vineyard			Middle of inter-row			Sept-2012
MDC14	Pasture	Pallic	Seddon		Sept-2000	Oct-2007	Sept-2012
MDC15	Native	Recent	Ronga		Oct-2000	Oct-2007	-
MDC16	Dairy	Recent	Ronga		Oct-2000	Oct-2007	Sept-2012
MDC17	Native	Recent	Kaituna		Oct-2000	Oct-2007	-
MDC18	Dairy	Recent	Kaituna		Oct-2000	Oct-2007	Sept-2012
MDC19	Native	Brown	Kenepuru		Oct-2000	Oct-2007	-
MDC20	Exotic forest	Brown	Kenepuru		Oct-2000	Oct-2007	-
MDC21	Exotic forest	Brown	Kenepuru		Oct-2000	Oct-2007	-
MDC22	Drystock	Brown	Kenepuru		Oct-2000	Oct-2007	Sept-2012
MDC23	Cropping	Pallic	Seddon		Oct-2000	Oct-2007	Sept-2012
MDC24	Drystock	Recent	Wairau		Oct-2000	Oct-2007	Sept-2012
MDC25A	Vineyard	Pallic	Renwick	Under the vine			Sept-2012
MDC25B	Vineyard			Under the wheel-track	Oct-2000	Oct-2007	Sept-2012
MDC25C	Vineyard			Middle of inter-row			Sept-2012
MDC26	Vineyard	Pallic	Seddon		-	-	Oct-2008
MDC27	Vineyard	Gley	Motukarara		-	-	Oct-2008
MDC28	Drystock	Gley	Motukarara		-	-	Oct-2008
MDC29	Cropping	Pallic	Warwick		-	-	Oct-2008
MDC30	Vineyard	Pallic	Sedgemere		-	-	Oct-2008
MDC31	Cropping	Pallic	Sedegemere		-	-	Oct-2008
MDC32	Cropping	Pallic	Seddon		-	-	Oct-2008
MDC33	Cropping	Pallic	Dashwood		-	-	Oct-2008
MDC34	Pasture	Pallic	Warwick		-	-	Oct-2008
MDC35	Pasture	Pallic	Jordan		-	-	Oct-2008
MDC36	Vineyard	Pallic	Jordan		-	-	Oct-2008
MDC37	Vineyard	Brown	Renwick		-	-	Oct-2008
MDC38	Drystock	Brown	Renwick		-	-	Oct-2008

Site	Landuse	NZ Soil Order	Soil series	Sample location	Sample dates		
MDC39	Drystock	Pallic	Dashwood		-	-	Oct-2008
MDC40	Dairy	Brown	Kaituna		-	-	Oct-2008
MDC41	Dairy	Brown	Rai		-	-	Oct-2008
MDC42	Exotic Forest	Brown	Pelorus Steepland		-	-	Oct-2008
MDC43	Dairy	Brown	Pelorus Steepland		-	-	Oct-2008
MDC44	Dairy	Brown	Manoroa		-	-	Oct-2008
MDC45	Vineyard	Pallic	Dashwood		-	-	Oct-2009
MDC46	Vineyard	Pallic	Sedgemere		-	-	Oct-2009
MDC47	Cropping	Pallic	Sedgemere		-	-	Oct-2009
MDC48	Drystock	Pallic	Sedgemere		-	-	Oct-2009
MDC49	Exotic forest	Brown	Hororata		-	-	Oct-2009
MDC50	Drystock	Brown	Hororata		-	-	Oct-2009
MDC51	Drystock	Brown	Kaituna		-	-	Oct-2009
MDC52	Drystock	Brown	Tuamarina		-	-	Oct-2009
MDC53	Exotic forest	Brown	Tuamarina		-	-	Oct-2009
MDC54	Drystock	Pallic	Weld		-	-	Oct-2009
MDC55	Exotic forest	Pallic	Weld		-	-	Oct-2009
MDC56	Drystock	Pallic	Warwick		-	-	Oct-2009
MDC57	Drystock	Pallic	Wither Hill		-	-	Oct-2009
MDC58	Drystock	Pallic	Haldon		-	-	Oct-2009
MDC59	Exotic forest	Pallic	Waihopai Steepland		-	-	Oct-2009
MDC60	Drystock	Pallic	Waihopai Steepland		-	-	Oct-2009
MDC61	Cropping	Pallic	Seaview		-	-	Oct-2010
MDC62	Cropping	Recent	Galtiymore		-	-	Oct-2010
MDC63	Cropping	Pallic	Marama		-	-	Oct-2010
MDC64	Cropping	Pallic	Broadbridge		-	-	Oct-2010
MDC65a	Vineyard	Pallic	Seaview	Under the vine	-	-	Oct-2010
MDC65b	Vineyard	Pallic	Seaview	Under the wheel-track	-	-	Oct-2010
MDC66a	Vineyard	Brown	Kaituna	Under the vine	-	-	Oct-2010
MDC66b	Vineyard	Brown	Kaituna	Under the wheel-track	-	-	Oct-2010
MDC67	Cropping	Recent	Wairau		-	-	Oct-2010

Site	Landuse	NZ Soil Order	Soil series	Sample location	Sample dates		
MDC68	Cropping	Pallic	Woodbourne		-	-	Oct-2010
MDC69a	Vineyard	Pallic	Woodbourne	Under the vine	-	-	Oct-2010
MDC69b	Vineyard	Pallic	Woodbourne	Under the wheel-track	-	-	Oct-2010
MDC69c	Vineyard	Pallic	Woodbourne	Middle of inter-row	-	-	Oct-2010
MDC70a	Vineyard	Recent	Wairau	Under the vine	-	-	Oct-2010
MDC70b	Vineyard	Recent	Wairau	Under the wheel-track	-	-	Oct-2010
MDC71	Cropping	Brown	Renwick		-	-	Oct-2010
MDC72	Cropping	Pallic	Brancott		-	-	Oct-2010
MDC73	Drystock	Brown	Kaituna		-	-	Oct-2010
MDC74	Dairy	Brown	Rai		-	-	Oct-2010
MDC75	Dairy	Recent	Ronga		-	-	Oct-2010
MDC76	Dairy	Brown	Rai		-	-	Nov-2011
MDC77	Dairy	Brown	Rai		-	-	Nov-2011
MDC78	Native	Brown	Rai		-	-	Nov-2011
MDC79	Dairy	Recent	Ronga		-	-	Nov-2011
MDC80	Dairy	Recent	Ronga		-	-	Nov-2011
MDC84	Dairy	Recent	Ronga		-	-	Nov-2011
MDC85	Dairy	Brown	Rai		-	-	Nov-2011
MDC86	Dairy	Brown	Pelorus		-	-	Nov-2011
MDC87	Dairy	Recent	Ronga		-	-	Nov-2011
MDC88	Dairy	Recent	Manaroa		-	-	Oct-2012
MDC89	Dairy	Recent	Koromiko		-	-	Oct-2012
MDC90	Dairy	Brown	Kaituna		-	-	Oct-2012
MDC91	Dairy	Brown	Koromiko		-	-	Oct-2012
MDC92	Dairy	Brown	Manaroa		-	-	Oct-2012
MDC93	Dairy	Brown	Koromiko		-	-	Oct-2012
MDC94	Dairy	Recent	Kaituna		-	-	Oct-2012
MDC95	Dairy	Recent	Kaituna		-	-	Oct-2012
MDC96	Dairy	Brown	Manaroa		-	-	Oct-2012