MARLBOROUGH DISTRICT COUNCIL

Soil Quality in the Marlborough Region in 2016

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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. Under Section 35 of the Resource Management Act (1991), one of the physical resources that we have a duty 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". To help meet these goals, the Council undertakes 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 both the current state of, and the long-term trends in, soil quality in the Marlborough region as determined by the results of soil analysis from sampling across a range of landuse activities and soil types.

In this investigation, soils were sampled from twenty monitoring sites that included 15 dairy sites, one dry stock site, one unfarmed pasture site and three under native lowland forest. These sites represented 7 different soil types from 2 soil orders.

This year's results indicate that in general, the soils are in good condition with most soil quality indicators for most sites falling within target ranges. However, 80% of sites reported soil compaction measurements outside the target range. These results put these soils at risk of poor aeration and impeded drainage which may potentially affect pasture production and predispose the soil to surface runoff, nutrient loss, erosion and flooding. While soil compaction isn't permanent, it clearly should be avoided and remediated where necessary. A range of beneficial management options to prevent and remediate soil compaction are outlined in the report.

Soil compaction is also of concern when long-term trends are analysed. Soil compaction is occurring across all farming landuses including Dairy, Pastoral, Cropping and Viticulture. Long-term trends also show elevated Nitrogen and Phosphorus measures as well as, loss of soil organic matter. The combination of soil compaction, elevated nutrient levels and loss of organic matter indicate a heightened risk of nutrient loss to water. Nutrient loss to water often leads to deteriorating water quality in both groundwater and surface waterways.

Long term trends for most Trace Elements are well within target ranges. However, Cadmium levels are a concern. Dairy levels are elevated and other farmed landuses show rising levels. While levels are not likely to exceed target ranges in the short-term, continued use of phosphate fertiliser will mean levels will continue to rise and continued monitoring will be required.

This report also makes recommendations regarding the Soil Quality Monitoring programme itself. The aim of these is to ensure improved data reliability and better representation of all landuses.

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1. Introduction

Regional councils have a responsibility for promoting the sustainable management of the natural and physical resources of their region. Under Section 35 of the Resource Management Act (1991), one of the physical resources that we have a duty 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 and viticulture 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 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 throughout 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 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.

A network of 96 soil quality monitoring sites has been established over the last 10 years in Marlborough. This report presents results for 20 sites previously sampled in 2011 and 2012 and discusses if they meet their target ranges for soil quality. Data has now been gathered for long enough to begin looking at long-term trends or changes in soil quality.

2. Materials and Methods

2.1. Sampling Sites

Soils were sampled from 20 sites previously sampled in 2011 and 2012. They include 15 dairy sites, three sites under native lowland forest, one dry stock site and one ungrazed pasture site. Three sites scheduled for sampling this year were not sampled as land had been cultivated in preparation for conversion to another landuse. The sampled sites represent 7 different soil types from 2 soil orders (Table 1).

Table 1 Soil type, soil classification and land use management of sites sampled in Marlborough

Site Code	Soil Type	Soil Order*	Land use; management
SOE_Soils_Site_03	Wairau	Recent	Backyard; ungrazed pasture
SOE_Soils_Site_15	Ronga	Recent	Lowland forest
SOE_Soils_Site_16	Ronga	Recent	Dairy; grazed
SOE_Soils_Site_17	Kaituna	Recent	Lowland forest
SOE_Soils_Site_18	Kaituna	Recent	Drystock; grazed
SOE_Soils_Site_76	Rai	Brown	Dairy; grazed
SOE_Soils_Site_77	Rai	Brown	Dairy; grazed
SOE_Soils_Site_78	Rai	Brown	Lowland forest
SOE_Soils_Site_79	Ronga	Recent	Dairy; grazed
SOE_Soils_Site_80	Ronga	Recent	Dairy; grazed
SOE_Soils_Site_84	Ronga	Recent	Dairy; grazed
SOE_Soils_Site_85	Rai	Brown	Dairy; grazed
SOE_Soils_Site_86	Pelorus	Brown	Dairy; grazed
SOE_Soils_Site_87	Ronga	Recent	Dairy; grazed
SOE_Soils_Site_88	Manaroa	Brown	Dairy; grazed
SOE_Soils_Site_89	Koromiko	Recent	Dairy; grazed
SOE_Soils_Site_90	Kaituna	Brown	Dairy; grazed
SOE_Soils_Site_91	Koromiko	Recent	Dairy; grazed
SOE_Soils_Site_95	Kaituna	Brown	Dairy; grazed
SOE_Soils_Site_96	Manaroa	Brown	Dairy; grazed

*New Zealand Soil Classification

2.2. Soil Sampling

Three 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 (Plate 1a). These samples were combined into one large sample and used for chemical and biological soil analysis. A second set of 5 cores taken along the same transect at 10m intervals (10, 20, 30, 40, 50m) were collected and individually bagged to provide samples for microbial ecology study. 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 (Plate 1b). These 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. Samples were collected from mid-October to early November. Most sites had reasonable soil moisture conditions.

Plate 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.

2.2.1. Changes to sampling sites

It can be expected that changes to sites and transect locations will continue as landuse and landscapes continue to change. Monitoring these changes are part of the core reason for this project, as such, transects and sites can be expected to change through the years.

The majority of the sites sampled in this round are being sampled for the second or third time. This means some sites are now up to 15 years old and may have changed markedly from the original. Field notes from past sampling rounds help staff to locate the original transects so samples can be replicated as closely as possible. However, it has not been possible to replicate exactly the location of the original transect on some sites. Reasons for this include large changes in vegetation (especially in forested areas), errors in GPS location markers and unclear field notes. Where transects could not be located accurately, a new transect was established as closely as possible to the original using the original site photographs. New transects were documented with explicit notes and photographs to ensure location in the future. New transects were established on Sites 03, 15, 17 & 78 this year.

2.2.2. Viticulture sampling sites

Because of the economic importance and scale of viticulture in Marlborough, it was decided in 2012 that vineyard monitoring should encompass 3 samples per vineyard site. Samples are taken from under the vines, in the wheel tracks and in the interrow region. This is done to allow the impact various management practices to be evaluated. These include:

- Under row
  - banding of fertiliser
  - herbicide applications
  - maintenance of bare ground

  - absence of traffic
  - irrigation
  - transfer of interrow mowings
- Wheel tracks
  - soil compaction
- Interrow
  - inputs of organic matter including prunings
  - lower rates of fertiliser
  - rainfall inputs only

2.3. Soil Quality Measurements

A number of different soil properties were measured to assess soil quality. Soil chemical characteristics were assessed by soil pH, Olsen P and trace element concentrations. Soil biological activity was determined by measuring anaerobically mineralisable nitrogen, total carbon, total nitrogen and carbon: nitrogen ratio. 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 Filled Porosity and macroporosity (Table 2). Additional microbial samples will be analysed in the future to provide insight into soil ecological properties. This work will be reported on later as results become available.

Table 2 Indicators used for soil quality assessment

Indicators	Soil Quality Information	Method
Chemical properties		
Soil pH	Acidity or alkalinity	Glass electrode pH meter,
Olsen P	Plant available phosphate	Bicarbonate extraction, molybdenum blue method
Trace elements	Deficiency or toxicity of trace elements in soil	Acid digestion
Biological properties		
Anaerobically mineralisable N	Readily mineralisable nitrogen reserves	Waterlogged incubation at 40 ºC for 7 days
Total Carbon	Organic matter status	Dry combustion, CNS analyser
Total Nitrogen	Organic N reserves	Dry combustion, CNS analyser
Carbon: Nitrogen Ratio	Decomposition rate of organic matter	Calculated from above
Physical properties		
Dry bulk density	Compaction, volumetric conversions	Soil cores
Particle density	Used to calculate porosity and available water	Specific gravity
Total porosity, air capacity and macroporosity	Soil compaction, aeration, drainage	Pressure plates

2.4. Soil Analysis

Descriptions of the different soil analysis process are detailed below. In general, analysis follows the processes described by Hill and Sparling, 2009 for soil quality parameters and Kim and Taylor, 2009 for Trace element analysis.

2.4.1. Chemical Analysis

All chemical analysis was undertaken by Hills Laboratory, Hamilton. Soil pH was measured in a 1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. Soil phosphorus is determined with Olsen extraction followed by Molybdenum Blue colorimetry. Trace element determination made by Nitric/hydrochloric digestion followed by ICP-OES (Hills, 2016).

2.4.2. Biological Analysis

Biological analysis was carried out by Hills Laboratory, Hamilton. Anaerobically mineralisable nitrogen was estimated Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. Total carbon and nitrogen were determined by dry combustion of air-dry soil (Hills, 2016).

2.4.3. Physical Analysis

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). Air Filled Porosity (-10 kPa) and total porosity were calculated as described by Klute (1986). Particle density was measured by the pipette method.

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 air filled porosity), although the -5kPa data is included for reference because this has been used and reported by the MDC and others in the past.

2.4.4. Targets and Ranges

To aid in the interpretation of soil quality indicators, an expert panel (in several workshops) developed guidelines for the seven soil quality indicators now commonly used by regional councils (Hill and Sparling 2009). The panel determined target ranges for the assessment of soil quality (e.g. very low, optimal, very high etc.) for the predominant soil orders under different land uses. The interpretative ranges from Hill and Sparling (2009) are presented in Appendix A. However, Olsen P targets have recently been revised from those reported in Hill and Sparling (2009) with new target values reported in Taylor and Mackay (2012) and used in this report (Appendix A).

The trace element results (except for Cd) 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) (Appendix A). 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 (MAF, 2010).

2.4.5. Data Display

Readers of previous Soil Quality reports will note a number of changes in the presentation of the data. Firstly, the names of the sites have been changed in order to provide better referencing in the Council computer database. Sites were previously labelled using an "MDC" number e.g. MDC 15. These have now been renamed *SOE_Soils_Site15*. The number of each site remains the same. Vineyard sites are labelled *SOE_Soils_Site63a_vine, b_wheel* or *c_interow*.

The second change in data presentation from previous reports has been to present data in groups according to soil order or landuse. This change allows the reader to more clearly understand how a soil conforms to its target values which are set according to soil order or landuse. These two factors have the greatest influence on soil quality. Readers can refer to Appendix A for target ranges of soil quality indicators. Information on the New Zealand Soil Classification can be found at https://soils.landcareresearch.co.nz/describing-soils/nzsc

As mentioned in section 2.4.3, for reasons of consistency, previous Soil Quality reports used the term Macroporosity to refer to soil pore measurements. However, these measurements used data more correctly called Air Filled Porosity. This report now refers to Air Filled Porosity -10kPa to clarify which measurement is being used.

For the first time, this report discusses changes in soil quality indicators over time. This is done to improve the understanding of soil quality changes on a regional basis. This has allowed the determination of some key issues for land managers to be aware of. See section 4 for further details.

Where appropriate, data were expressed on a weight/volume or volume/volume basis to allow comparison between soils with differing bulk density. Olsen P values are reported in different units (μg/cm^3) than previous reports to account for differences in soil bulk density.

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3. Results and Discussion

3.1. Comparison of Target Ranges

Figure 1 shows the number of sites not meeting their target for a specific soil quality indicator. pH &Olsen P (1 site each), Trace elements (One element each for 2 sites), AMN (4 sites) and Air Filled Porosity (16 sites) were the indicators not meeting their soil quality target. In contrast, Total C, Total N, C: N ratio and bulk density targets were met at all sites.

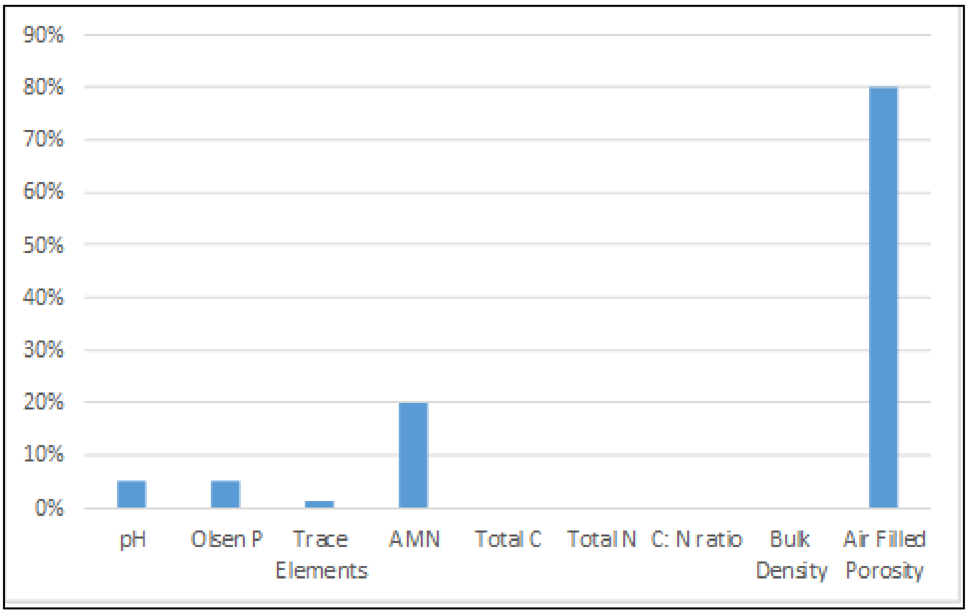

Figure 1. The percentage of sites not meeting their target range for a specific soil quality indicator

The results of soil chemical, biological and physical analyses from soils sampled at each site are given in Tables 3, 4 and 5 respectively and are discussed separately below.

3.2. Soil Chemical results

Results of soil chemical analysis (pH, Olsen P and Trace elements) are reported in Table 2. Each of the chemical properties is discussed individually. The target values appropriate to the relevant soil order can be found in Appendix A.

3.2.1. 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 in 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.

As indicated in Table 3, all sites had soil pH values within the acceptable target for their respective land use. Site 03 shows a pH at the high end of its target range. As one of the original sites, this location has reported a high pH consistently since 2000. Comparable soils within the wider SoE study (Recent, Wairau soils; Sites 01,02,03 & 70) also consistently report high pH values leading to the conclusion that soil parent material is a likely cause of high pH on these sites although it is noted that Wairau soils with grazing landuses have reported lower pH values.

3.2.2. 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.

Olsen P concentrations varied about 6-fold between sites. The lowest and highest values were found in lowland native forest sites (Sites 78 & 17). The maximum Olsen P target for all soils is set at 50 µg/cm^3 (Taylor and Mackay, 2012). Table 3 shows no Sites exceed the target ranges for their land use.

Two sites (86 &87) had Olsen P values below concentrations considered optimal for maximum pasture/crop production. Both sites had higher Olsen P scores in their last sample indicating removal of P either through farming practice or natural processes. Phosphorus 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 (Edmeades, et.al 2006). In general, Olsen P values in this sampling round were lower than optimal on many sites. As a result, optimal production levels may not be achieved.

It is noted that one Lowland Forest site (Site 17) recorded a high Olsen P score of 43. This is a significant departure from the previous samples from this site in 2000 & 2007 and has skewed the 5-year rolling average for Native Forest landuse. Several other differences are noted in the sample results for this site as well. The field notes indicate that the transect was changed for this sample due to unclear location instructions from previous visits. The 2016 sample should be regarded as an outlier amongst the Lowland Forest sites. It is suggested that it is resampled in 2017 to verify results.

3.2.3. 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 3 summarises trace element concentrations in soils from the monitoring sites. On average concentrations were 4.3 mg kg^{-1} for arsenic, 0.3 mg kg^{-1} for cadmium, 52 mg kg^{-1} for chromium, 19.3 mg kg^{-1} for copper, 17.8 mg kg^{-1} for lead, 30 mg kg^{-1} for nickel, 0.19 mg kg^{-1} for mercury and 64 mg kg^{-1} for zinc. These **average** concentrations are within the suggested upper limits for trace elements in soils as suggested by the New Zealand Water and Waste Association (Appendix A). Concentrations are also similar to those that have been found in soils in other parts of New Zealand (Auckland Regional Council, 1999; Greater Wellington Regional Council, 2005; Canterbury Regional Council, 2006; Curran-Cournane and Taylor,2012) and what has previously found in Marlborough (Gray, 2011b) with the exception of Nickel and Chromium which were on average higher.

For both Chromium and Nickel, the elevated concentrations were largely influenced by high values in two soil types. Both the Ronga and (to some extent) Rai soils located in the central Rai and Pelorus valleys show elevated levels of both Ni and Cr (Figure 2). Elevated concentrations of these heavy metals have been found in these soils in other investigations of trace element concentrations in soils (Gray, et al., 2011) and in previous Soil Quality monitoring rounds. In particular, two Sites (79 & 80) report levels that exceed guidelines. This is consistent with previous samples from these sites. The source is most likely the soil parent material, possibly serpentine minerals which are known to contain elevated concentrations of both these trace elements.

For Cadmium, average concentrations in farmed soils were approximately double typical background concentrations found in soils. Un-farmed soils such as native forest samples show only background levels of Cd (Figure 3). The source of Cadmium is most likely phosphate fertiliser which has been shown to contain cadmium as an incidental impurity (Roberts, Longhurst and Waller, 2004).

The levels found in farmed soils are similar to those that have found in the past for dairy pasture soils in Marlborough and what has been found elsewhere in New Zealand (Taylor et al., 2010). While no sites had Cd concentrations above the suggested 0.6 mg kg^{-1} trigger value set in the Tiered Fertiliser Management System (TFMS) outlined in the New Zealand Cadmium Management Strategy (MAF, 2010), three sites are approaching that limit (Sites 84,85 &86). All three sites are located on the same farm. On these sites Cadmium levels have fallen by approx. 10% in the 5 years since the last sampling date. See section 4.4 for further discussion.

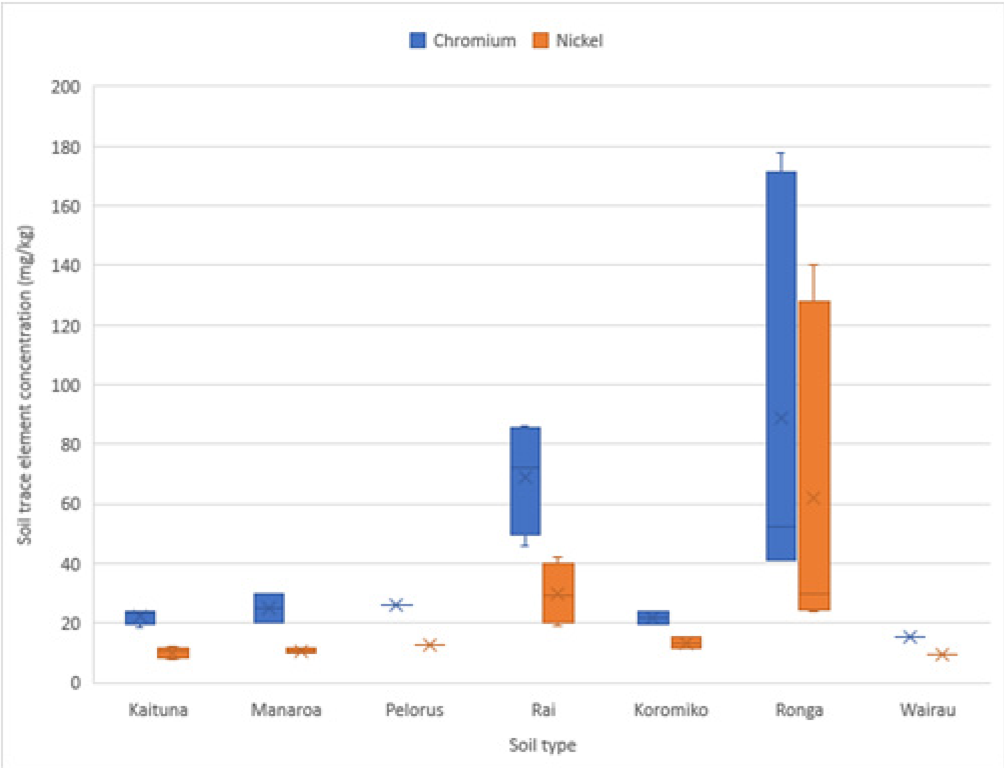

Figure 2. Soil Chromium and Nickel concentrations by soil type. Note elevated concentrations in Rai and Ronga Soils compared with other soil types.

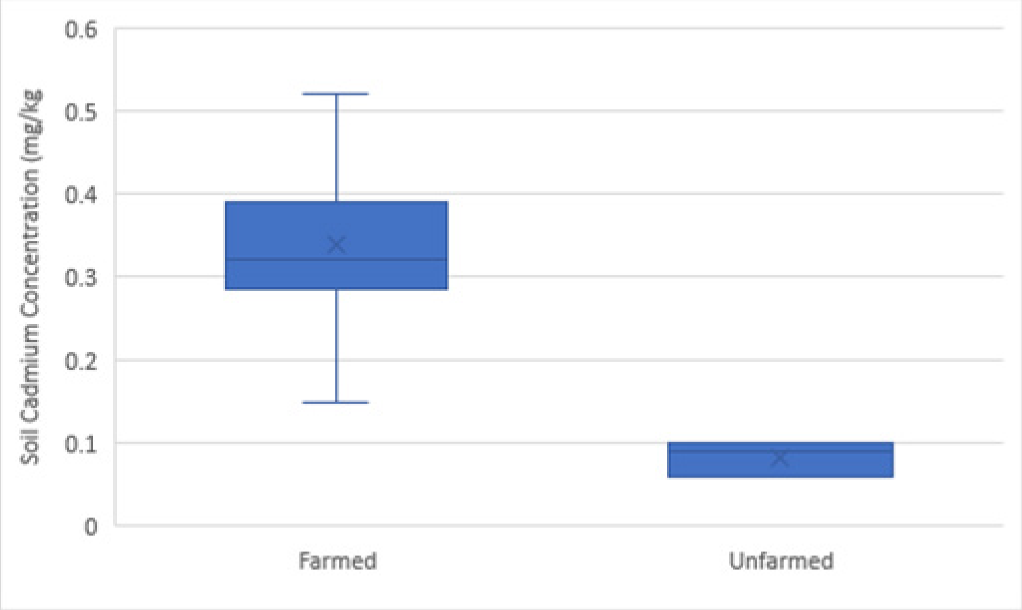

Figure 3. Soil Cadmium concentrations by Landuse. Note the difference between 'Farmed'(Dairy, Drystock, pasture) and 'Unfarmed' (Native forest) Landuses.

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Table 3 Soil Chemical results. Soil pH, Olsen P, Trace Elements

Site	Soil type	Soil Order	Landuse	pH	Olsen P (ug P/cm3)	Trace Elements Zn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	As (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Hg (mg/kg)	Cd (mg/kg)
SOE_Soils_Site90	Kaituna	Brown	Dairy; grazed	5.9	25	61	24	24	6	12.8	10.6	< 0.10	0.31
SOE_Soils_Site95	Kaituna	Brown	Dairy; grazed	5.9	22	36	12	18.5	3	9.1	8.1	< 0.10	0.28
SOE_Soils_Site88	Manaroa	Brown	Dairy; grazed	5.9	41	52	16	30	4.3	11.5	11.6	< 0.10	0.38
SOE_Soils_Site96	Manaroa	Brown	Dairy; grazed	6.3	36	54	15	20	4.6	11.1	9.8	< 0.12	0.27
SOE_Soils_Site86	Pelorus	Brown	Dairy; grazed	5.9	18	67	20	26	5.3	12.7	12.9	< 0.11	0.44
SOE_Soils_Site76	Rai	Brown	Dairy; grazed	5.9	36	46	15	60	5.3	10.5	24	< 0.12	0.4
SOE_Soils_Site77	Rai	Brown	Dairy; grazed	5.9	37	55	17	84	4.8	9.7	35	< 0.12	0.29
SOE_Soils_Site85	Rai	Brown	Dairy; grazed	5.9	32	70	20	46	5.9	11.9	19.2	< 0.10	0.52
SOE_Soils_Site78	Rai	Brown	Lowland forest	5.5	5	93	20	86	4.2	11.2	42	0.19	0.06
SOE_Soils_Site18	Kaituna	Recent	Drystock; grazed	6.4	24	58	16	24	3.7	11.7	10.2	< 0.11	0.32
SOE_Soils_Site17	Kaituna	Recent	Lowland forest	5.3	43	65	15	23	2.9	13.2	12.1	< 0.11	0.1
SOE_Soils_Site89	Koromiko	Recent	Dairy; grazed	5.9	33	56	20	19.9	4.2	10.8	11.4	< 0.12	0.32
SOE_Soils_Site91	Koromiko	Recent	Dairy; grazed	6.2	30	60	18	24	4.5	10	15.5	< 0.10	0.29
SOE_Soils_Site16	Ronga	Recent	Dairy; grazed	5.6	25	74	23	51	5.7	12.8	29	< 0.12	0.36
SOE_Soils_Site79	Ronga	Recent	Dairy; grazed	5.8	34	61	26	169	4.9	9	**124**	< 0.10	0.23
SOE_Soils_Site80	Ronga	Recent	Dairy; grazed	6.2	27	71	34	178	4.7	10.1	**140**	< 0.10	0.37
SOE_Soils_Site84	Ronga	Recent	Dairy; grazed	6.1	32	67	20	41	4.7	12.3	24	< 0.12	0.48
SOE_Soils_Site87	Ronga	Recent	Dairy; grazed	6	13	65	19	41	4.4	12	25	< 0.10	0.35
SOE_Soils_Site15	Ronga	Recent	Lowland forest	5.2	14	73	20	54	5.6	15	31	< 0.10	0.09
SOE_Soils_Site03	Wairau	Recent	Backyard; Ungrazed pasture	**6.6**	31	92	16	15.2	4.3	17.8	9.5	< 0.10	0.15

Values in red indicate above target range, Values in Blue indicate below target range

3.3. Soil Biological Results

Results of soil biological analysis (Anaerobically Mineralisable Nitrogen, Total Nitrogen, Total Carbon and C:N ratio) are reported in Table 2. Each of the biological properties is discussed individually. The target values appropriate to the relevant soil order can be found in Appendix A.

3.3.1. Anaerobically Mineralisable Nitrogen

Anaerobically Mineralisable nitrogen (AMN) 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 AMN 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).

It has been suggested that AMN is useful as an indicator of potential N leaching (i.e. NO_3^--N) 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 NO_3^--N in soil solution. However NO_3^--N 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 NO_3^--N loss. In addition, because soils are only sampled to the 10-cm depth, it isn't necessarily going to accurately reflect what happens to the NO_3^--N further down the soil profile e.g. denitrification.

Anaerobically Mineralisable Nitrogen concentrations varied widely between sites with the lowest values found on unfarmed sites. Two sites had values which were higher than their target range and two were lower. Dairy grazed sites have significantly higher values compared to unfarmed sites due to increased organic matter inputs in the form of pasture grasses, manure and urine (Figure 4). Given the significantly higher AMN values on Dairy grazed sites that soil solution nitrate Nitrogen (NO_3^-N) will be higher on these sites. As most the sampled sites are located in high rainfall areas, it is likely that NO_3^--N leaching will be taking place on many of these sites. Tools such as Overseer can be used to estimate these losses.

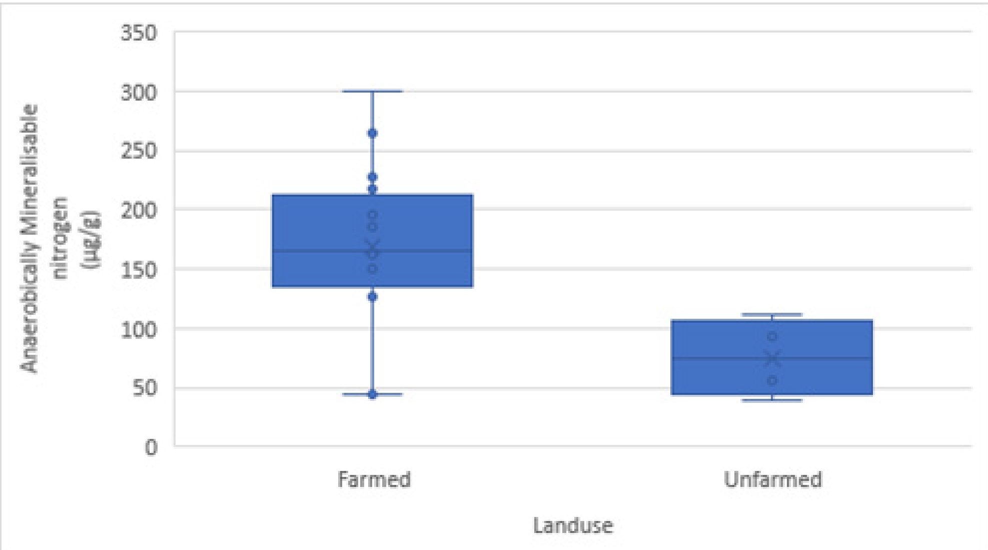

Figure 4. Anaerobically Mineralisable Nitrogen. Farmed landuses include dairy and pasture. Unfarmed are forestry sites.Farmed site values are driven by higher AMN in Dairy soils suggesting increased risk of nitrate leaching.

3.3.2. Total Carbon

Total Carbon in soil 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 health because it aids in the retention of moisture and nutrients, contributes to a stable soil structure, provides a source of energy for soil microbes and is a source of nutrients e.g. N, P and Sulphur (S). In contrast, low soil C increases the risk of structural degradation in soils e.g. low aggregate stability, high bulk density, low macroporosity, formation of surface crusts.

All sites had total soil carbon contents within acceptable target ranges for their respective land use activity. It is normal for soils under long-term, high producing pastures to accumulate carbon. Figure 5 shows the variation in soil Total Carbon according to soil type. While there are no significant differences between soil order, soil type shows that Rai soils hold significantly more carbon than other soils sampled in this round. This may be a function of increased soil age and chemical ability to hold organic matter compared with other soils in the sampling group.

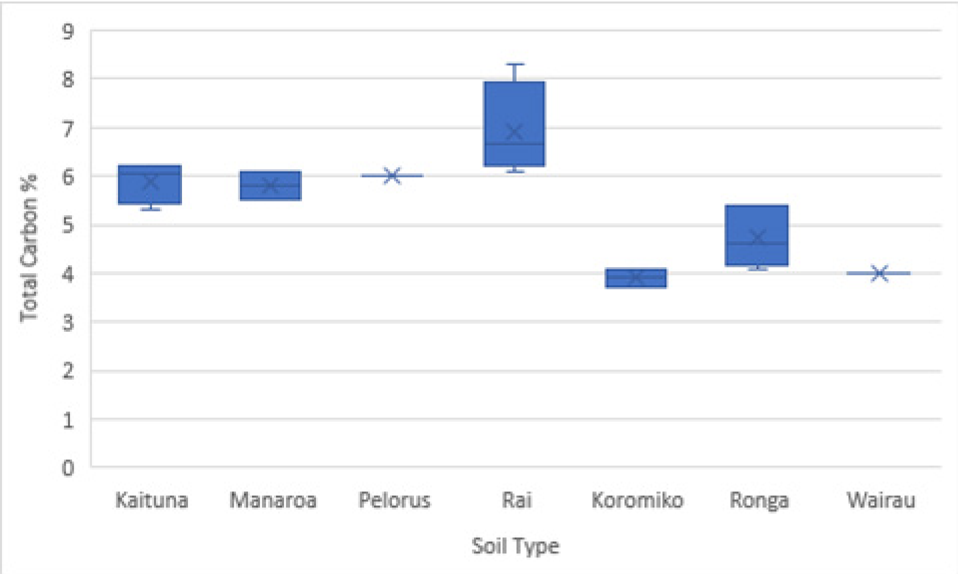

Figure 5. Landuse Total Carbon. Note elevated levels in Rai and Ronga Soils.

3.3.3. Total 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 or lost from soil by leaching.

All sites had total soil nitrogen contents within acceptable target ranges for their respective land use activity. Examination of total N figures show Brown soils retain more organic matter compared with Recent soils (Table 4, Figure 6). Deeper investigation shows that all the Brown soils in the study had higher Total N levels but that this was especially the case with the Rai soils. The increased age of Brown Soils compared to Recent soils has allowed increased accumulation of organic matter.

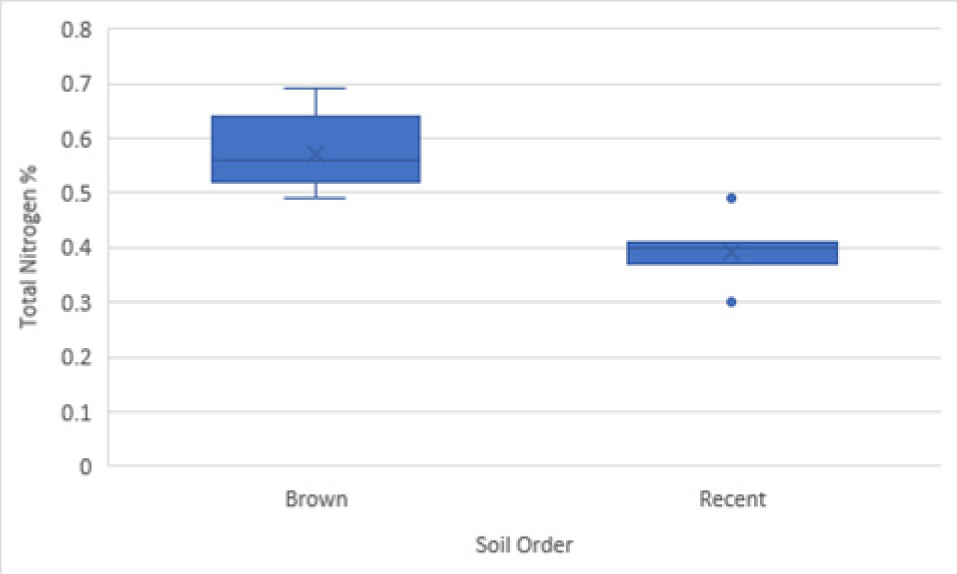

Figure 6. Total Nitrogen content of Recent and Brown soils.

3.3.4. 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 to the risk of N mobility (nitrate leaching) in soil. As C: N ratio increases above 10:1 (Nitrogen becomes scarce in relation to Carbon), Nitrogen is immobilised (taken up) by soil microbes. The soil solution N concentration falls and the risk of nitrogen leaching decreases (Havlin et al, 2013). Nitrogen cycling then becomes more dependent on microbial activity.

All sites had C: N ratios within acceptable target ranges for their respective land use activity (Table 4). No significant differences in C:N ratio are noted in the data for this sampling round. However, Lowland forests show a slight tendency to a higher C: N ratio compared with other landuses.

Table 4. Biological results, AMN, Total C, Total N and C: N ratio

Site	Soil type	Soil Order	Landuse	AMN µg/g	Total Carbon %	Total Nitrogen %	C:N Ratio
SOE_Soils_Site90	Kaituna	Brown	Dairy; grazed	164	6.2	0.59	10.5
SOE_Soils_Site95	Kaituna	Brown	Dairy; grazed	185	6.2	0.49	12.7
SOE_Soils_Site88	Manaroa	Brown	Dairy; grazed	164	5.5	0.53	10.4
SOE_Soils_Site96	Manaroa	Brown	Dairy; grazed	196	6.1	0.56	10.9
SOE_Soils_Site86	Pelorus	Brown	Dairy; grazed	265	6	0.53	11.3
SOE_Soils_Site76	Rai	Brown	Dairy; grazed	217	8.3	0.69	12.0
SOE_Soils_Site77	Rai	Brown	Dairy; grazed	162	6.5	0.56	11.6
SOE_Soils_Site85	Rai	Brown	Dairy; grazed	299	6.8	0.69	9.9
SOE_Soils_Site78	Rai	Brown	Lowland forest	111	6.1	0.51	12.0
SOE_Soils_Site18	Kaituna	Recent	Drystock; grazed	**45**	5.3	0.5	10.6
SOE_Soils_Site17	Kaituna	Recent	Lowland forest	40	5.9	0.4	14.8
SOE_Soils_Site89	Koromiko	Recent	Dairy; grazed	127	4.1	0.37	11.1
SOE_Soils_Site91	Koromiko	Recent	Dairy; grazed	167	3.7	0.31	11.9
SOE_Soils_Site16	Ronga	Recent	Dairy; grazed	**45**	5.4	0.49	11.0
SOE_Soils_Site79	Ronga	Recent	Dairy; grazed	129	4.1	0.37	11.1
SOE_Soils_Site80	Ronga	Recent	Dairy; grazed	151	4.4	0.41	10.7
SOE_Soils_Site84	Ronga	Recent	Dairy; grazed	227	5.4	0.4	13.5
SOE_Soils_Site87	Ronga	Recent	Dairy; grazed	165	4.2	0.3	14.0
SOE_Soils_Site15	Ronga	Recent	Lowland forest	56	4.8	0.4	12.0
SOE_Soils_Site03	Wairau	Recent	Backyard; Ungrazed pasture	93	4	0.37	10.8

, Values in Blue indicate below target range

3.4. Soil Physical Results

3.4.1. 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.

All sites were within the target range for bulk density which is assessed according to soil order (Table 5). While few differences are evident in the data, there is a tendency for lowland forest soils to have lower bulk density than other landuses. Rai soils also tend toward lower bulk density readings reflecting the significantly higher soil organic matter (soil carbon) in the these soils which is known to help develop and maintain good structure in soil. Note that the physical data for Site 17 reflects similar changes as noted for the chemical data. This will also be a result from the changed transect and resampling is recommended.

3.4.2. Air Filled Porosity

Air Filled Porosity is a measure of the proportion of large pores (macropores) in the soil. Macropores are important for penetration of air into soil, extension of roots down into the soil and drainage of water. Typically, macropores are the first to be lost when the soil is compacted. It is generally accepted that when Air Filled Porosity represents less than 10% of the total soil porosity, plant growth will be affected (Mclaren and Cameron, 1996)

Only one of the farmed sites meets its target (>10%) for Air Filled Porosity (Figure 7). Low Air Filled Porosity at some dairy pasture sites has been noted previously in Marlborough (Gray, 2011a) and has been observed in other regions of New Zealand (Taylor et al., 2010; Fraser and Stevenson, 2011; Stevenson, 2010; Sorensen, 2012). The Ministry of the Environment recently summarised nationwide regional council soil quality data and found only 22% of dairy sites met the required standard (MfE, 2016). 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.

The unfarmed sites in this study displayed Air Filled Porosity values well above their target (8% - Forestry, 10% pasture). These soils have remained largely undisturbed and have retained or developed improved macropore size through time. Note that site 17 was removed from the data displayed in Figure 6 due to unexpected changes in this data point. As noted above, the changed transect is the likely reason.

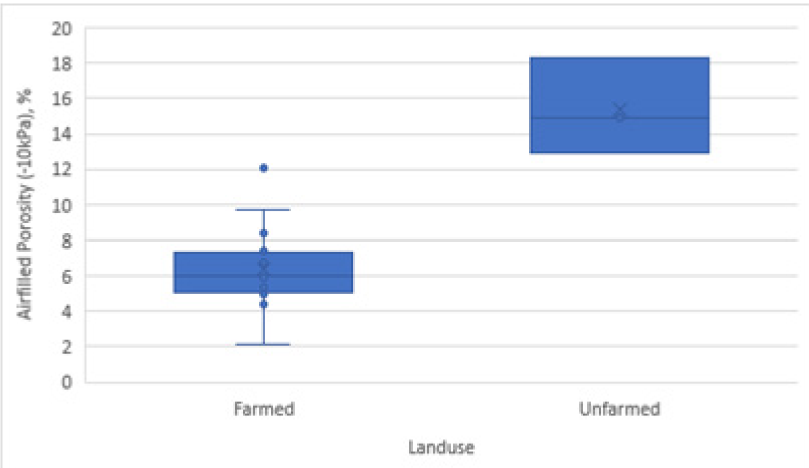

Figure 7. Comparison of Air Filled Porosity. Note the differences between 'Farmed' and 'Unfarmed' landuses. Lowland forest Site 17 value from removed from data, see text.

Table 5: Physical characteristic of soils sampled in the Marlborough Region 2016

Site	Soil type	Soil Order	Landuse	Dry Bulk Density (Mg/m3)	Air Filled Porosity (-10kPa) (%, v/v)	Macro Porosity (-5kPa) (%, v/v)
SOE_Soils_Site90	Kaituna	Brown	Dairy; grazed	0.98	6.80	4.50
SOE_Soils_Site95	Kaituna	Brown	Dairy; grazed	1.15	4.40	4.55
SOE_Soils_Site88	Manaroa	Brown	Dairy; grazed	0.97	5.40	3.20
SOE_Soils_Site96	Manaroa	Brown	Dairy; grazed	1.09	5.93	3.67
SOE_Soils_Site86	Pelorus	Brown	Dairy; grazed	0.97	7.47	4.27
SOE_Soils_Site76	Rai	Brown	Dairy; grazed	0.90	9.70	7.50
SOE_Soils_Site77	Rai	Brown	Dairy; grazed	1.01	12.07	9.40
SOE_Soils_Site85	Rai	Brown	Dairy; grazed	0.93	6.23	4.03
SOE_Soils_Site78	Rai	Brown	Lowland forest	0.85	18.33	16.33
SOE_Soils_Site18	Kaituna	Recent	Drystock; grazed	1.08	5.00	2.70
SOE_Soils_Site17	Kaituna	Recent	Lowland forest	1.09	3.00	2.50
SOE_Soils_Site89	Koromiko	Recent	Dairy; grazed	1.18	6.17	4.07
SOE_Soils_Site91	Koromiko	Recent	Dairy; grazed	1.19	2.10	2.20
SOE_Soils_Site16	Ronga	Recent	Dairy; grazed	1.02	5.03	2.70
SOE_Soils_Site79	Ronga	Recent	Dairy; grazed	1.23	5.77	3.53
SOE_Soils_Site80	Ronga	Recent	Dairy; grazed	1.10	8.33	6.13
SOE_Soils_Site84	Ronga	Recent	Dairy; grazed	1.16	5.07	3.13
SOE_Soils_Site87	Ronga	Recent	Dairy; grazed	1.16	6.23	3.87
SOE_Soils_Site15	Ronga	Recent	Lowland forest	0.93	12.93	10.30

Values in red indicate above target range, Values in Blue indicate below target range

4. Changes in Soil Quality through time

4.1. Introduction

The Soil Quality monitoring program seeks to fulfil the Marlborough District Council's legislative responsibilities under the RMA to report on the "life supporting capacity of soil" and to determine whether current practices will meet the "foreseeable needs of future generations". Soil quality and landuse are also key drivers in water quality. As a result, it has been a long-term goal of the MDC to report on regional-scale changes in soil quality to inform debate about environmental impacts of human activities in our region.

To meet these goals and obligations, we seek to answer three questions related to indicators for soil health. These include:

- What is the state and change of soil quality (based on soil order or land use)?

- To what extent and timeframe will the level of indicator meet a target or critical level?

- What are the main drivers that influence state and change (anthropogenic and non-anthropogenic)?

The initial national 500 soils program was established in 2000. Since that time data has been gathered from 96 sites throughout Marlborough. With a 5-year re-visit interval between sampling, it has taken until 2016 for sufficient data to be gathered to allow some analysis of trends in soil quality.

The methodology for this process is to use 5 year rolling averages for each soil indicator on each landuse (M. Taylor, Pers. Comm., 2017). All the data from the previous 5 years is included in any given years average (i.e. 2016 data is averaged with all data since 2012). This data is then presented by landuse. The aim of this is to provide a regional overview of soil quality. This is a simple methodology and there are discrepancies in some data. These are noted where appropriate in the text. For some landuses (Native & Exotic Forest especially) the number of samples and frequency of sampling is insufficient. This has led to excessive influence of outlier values with some graphs unduly biased as a result. It is suggested that the number of sites and the frequency of monitoring in all landuses is reviewed prior to the next sampling round. Ideally, the number of each type of site should be proportional to the regional landuse percentage. Sampling frequency should reflect the nominal 5 yearly sampling cycle, that is, one-fifth of sites should be sampled per landuse per year.

Three key issues have been identified in this initial attempt to quantify changes in soil quality over time. These include the risk of nutrients being lost to waterways (especially Nitrogen and Phosphorous), the decline in soil organic matter under some landuses and the potential risks of trace element contamination for some landuses.

4.2. Nutrient loss to water

Nutrients lost from land into waterways represent a detriment to both systems. Nutrients lost from land causes it to become less fertile and requires that fertiliser be used in order to maintain productivity. This becomes a significant expense to farmers. Often nutrients are manufactured and imported so require large amounts of energy to create and ship. When lost nutrients reach waterways, they can promote growth of unwanted biological growths including plants and bacterial slimes. These can choke waterways and cause loss of habitat for fish and other plant species. Loss of nutrients into groundwater can lead to human health issues when that water is used for drinking (Boyd, 2015). Given Marlborough's reliance of groundwater resources for both drinking and irrigation water this is a potentially serious issue for the region.

Nutrients are lost to water in two main ways. Leaching is the loss through soils beyond the reach of plant roots into deeper soil layers. These nutrients may eventually reach groundwater or drain into waterways. Total Nitrogen and Anaerobically Mineralisable N is monitored to evaluate the risk leaching may pose to water. The second pathway of loss is via surface runoff. Phosphorous is most susceptible to this pathway as it is carried on soil particles. Assessment of soil compaction is also important to ascertain the ability of water to infiltrate or runoff any given soil surface. Bare or very loose soils are vulnerable to leaching and erosion (runoff). Compacted soils prevent water (and fertiliser) infiltration and promote runoff (Mclaren & Cameron, 1996).

4.2.1. Phosphorus risk

In General, soils in Marlborough have moderate P levels. Monitoring has shown that most sites have Olsen P levels well within the target ranges. Of note, is the elevated levels of Olsen P found in the more intensive farming systems of dairy, cropping and viticulture (Figure 8). These soils will pose more risk of runoff than the less intensive farming systems shown simply because of the elevated P concentration.

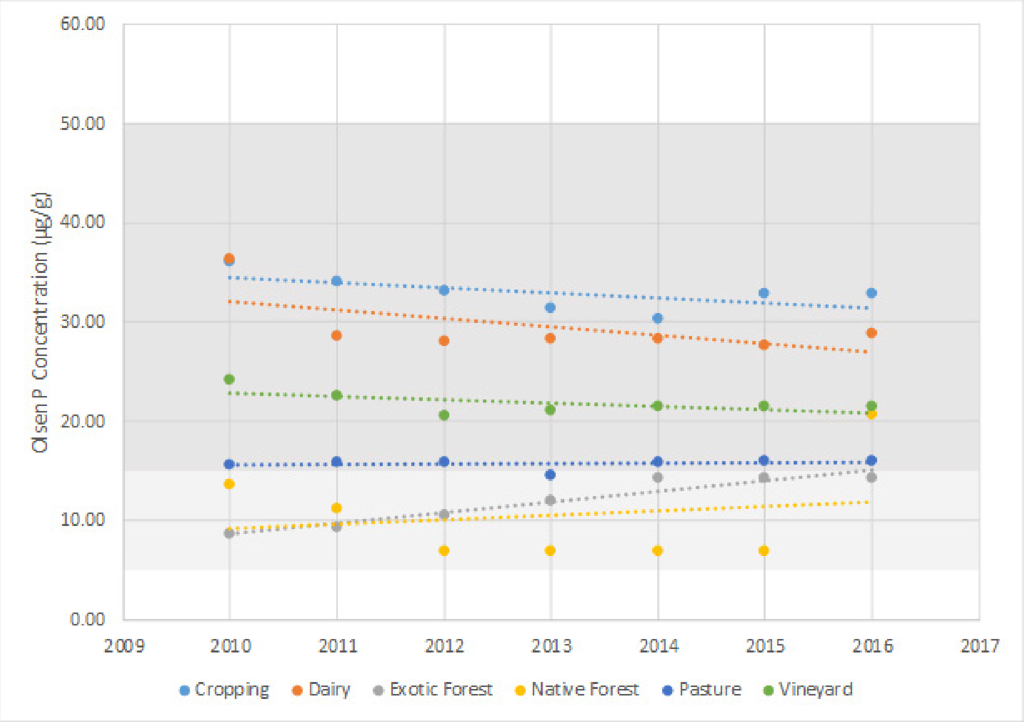

Figure 8. Regional Olsen P averages by Landuse. Target range Forestry – 5 to 50 µg/g. Target range Pasture - 15 to 50 µg/g.

Cropping system risk depends mainly on the type of cultivation practice used to sow crops, the length of time land is left bare before sowing and weather during this time. Risk on Dairy farms is posed by the volume of dung left on the soil surface and the ability of the soil to assimilate this prior to rainfall or irrigation. Also of concern is the pugging of soils in wet conditions and residual grass cover left following grazing. These contribute to runoff risk of P by increasing soil compaction and by reducing the vegetation's ability to hold soil together under erosive conditions. Vineyard risk is lower but practices such as banding fertiliser, maintaining bare soil year-round (undervine, interrow or both) and planting on slopes can increase P runoff risk.

There has been extensive national and international research to show that as soil P concentrations increase, the risk to waterways can also increase (McDowell et al. 2003). On the back of these findings, a range of P mitigation strategies have been identified and tested to minimise P loss from soil to water. Some of these include achieving the optimal soil P test, use of low soluble P fertilisers, sediment traps, grass buffer strips, constructed wetlands, and application of amendments to sorb P in soil and drainage water (McDowell, 2012). Regular soil testing, and implementation of nutrient budget and management plans will help minimise excessive nutrient accumulation in soils and potential losses from soils and this is advocated to land managers.

4.2.2. Nitrogen risk

The risk Nitrogen poses to water quality is assessed by two tests. The Total N test reports the complete content of N in the soil. This includes both the mineral and organic matter content. Anaerobically Mineralisable N reports the ability of soil microbes to make readily available N by decomposing organic matter in the soil.

We see in Figures 9 &10 that farm systems that involve animals (Dairy and Pasture) report higher rates of AMN and total N compared to non-animal farm systems (Cropping, Viticulture, Forestry). This reflects increased fertiliser input, the increased production of easily decomposed organic matter (dung) and mineral N in urine. While both production systems are well within the target ranges on a regional basis, these measures can be highly variable on a spatial (farm to farm, paddock to paddock) and temporal (day to day, season to season) basis. Elevated levels in these farm systems indicate that they pose greater risk to water quality than the non-animal systems. When variables such as slope, seasonal weather conditions, stocking rate, effluent disposal regimes, fertiliser application rates and frequency are included, there are likely be locations that do exceed the target ranges.

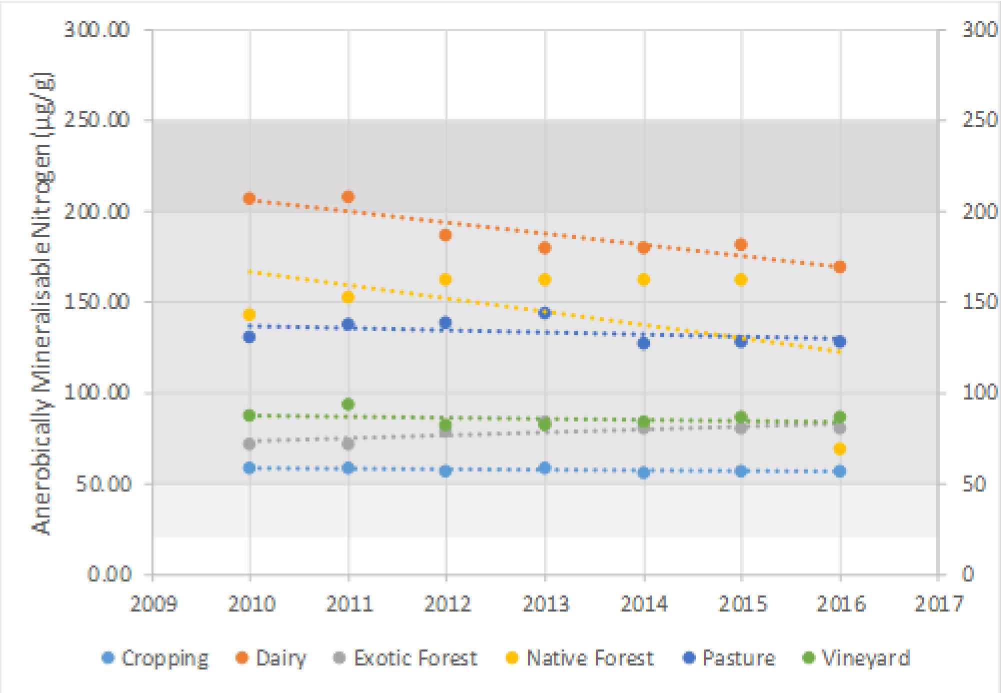

Figure 9. Anaerobically Mineralisable Nitrogen by landuse. Note the Native forest trendline is biased by a single value collected in 2012. A more accurate trendline would lie between the 100 to 150 µg/g region. Exotic forestry is similarly biased and a more accurate trendline would lie around 70 µg/g. ***Target range viticulture and cropping 20 to 200, Pasture 50 to 250 µg/g.***

Non-animal farm systems (Cropping, Viticulture and Forestry), show Total N and AMN levels toward the bottom of the target bands. As will be seen in section 4.3, this is a result of lower organic matter content in these soils. It should be noted that cropping and horticulture have no general target ranges specified for Total N. This is due to the large number of possible crops, each with its own target range. The lower levels of AMN found in the non-animal systems is likely to reduce the soils ability to produce Nitrogen from organic matter. To compensate, farmers will likely require increased nitrogen fertiliser inputs. This may lead to increased risks to water from nitrogen loss depending on management practices such as application rates and timing.

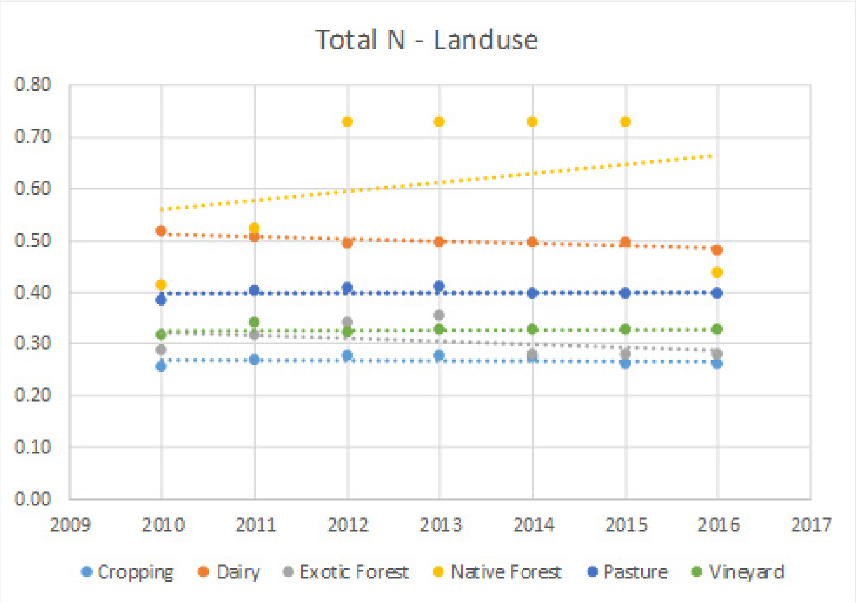

Figure 10. Total Nitrogen by landuse. Note the Native forest trendline is biased by a single value collected in 2012. A more accurate trendline would lie around the 0.45% region. *Target value forest 0.1 to 0.7%, Target value pasture 0.25 to 0.7%*

Viticulturists should note that AMN levels under vine are reported to be around half of those found in the interrow (Figure 11). Potential causes for this are likely to be increased organic matter inputs into the interrow area or reduction in OM due to herbicide use under vine. This pattern is repeated for Total Carbon measurements.

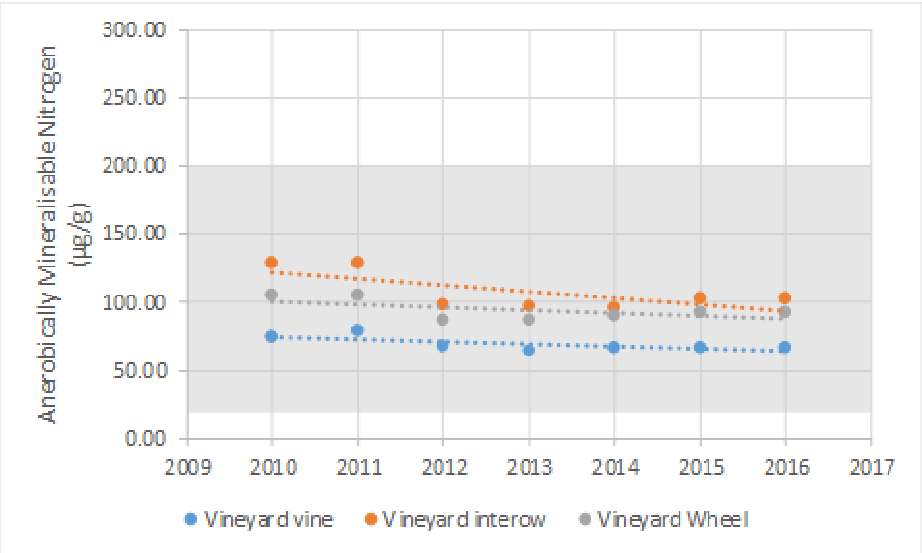

Figure 11. Vineyard AMN. Note the reduced levels of undervine AMN compared with interrow AMN.

4.2.3. Soil compaction risks

Soil compaction increases the risk of nutrient loss to water due to its role in increasing runoff. Soil compaction is measured by Bulk Density and Air Filled Porosity. Bulk Density measures the weight of a given volume of soil. It includes the pore space in that volume of soil and is strongly influenced by management practices that compact the soil (reduce pore space). Air Filled Porosity measures how much of the soil is normally filled by air (as opposed to water) at field capacity and represents a pore size of approximately 30µm in diameter (Mclaren & Cameron, 1988).

There are a range of potential soil, plant and environmental effects of soil compaction/pugging. One of the most important is the effect on crop/pasture production. For example, animal grazing and treading, particularly in wet conditions, can affect pasture yield directly through leaf burial in mud, crushing, bruising and a reduction in dry matter production (Nie et al., 2001). For both crops and pasture, indirect effects include restriction of root penetration and radial growth of roots in dense soils, reduced aeration, increased water logging potential due to slower ability to drain, reduced nutrient availability and compacted layers that may impact on water infiltration and hence the amount of water storage in a soil. A decrease in the proportion of large pores can also lead to reduced infiltration of water which increases the potential for surface runoff of water. If this runoff contains nutrients i.e. N, P or contaminants (i.e. bacteria), this may negatively impact on stream and lake water quality (Ngyen et al., 1998; McDowell et al., 2003).

The long-term trends in soil compaction in Marlborough mirror national trends (MfE 2016. pp. 84). Farmed systems have higher Bulk Density and lower Air Filled Porosity (AFP). Figures 12 and 13 illustrate the differences compared to non-farmed (forest) systems. Cropping and Viticulture report the most compact soils but for different reasons. Cropping soils have the highest Bulk Density readings but very low AFP (with large variability in samples). This would indicate that both large and small pore spaces have been damaged by repeated cultivation. Cropping soils are also vulnerable to soil erosion when soils are cultivated prior to planting.

Soil compaction in Viticulture by contrast is driven by trafficking of wheel tracks along rows (Figures 14 &15). This repeated trafficking has removed the large soil pores but not small soil pores hence the lower Bulk density readings compared to Cropping soils. It should be noted that Soil Quality measurements are confined to in-vineyard sites. Vineyard headlands could reasonably be expected to have similarly compact soils due to high vehicle traffic. This would increase the area vulnerable to runoff

It is a similar story in pasture-based landuses. Both Dairy and Pasture systems show reasonable Bulk Density readings but very low and declining AFP. This will be due to treading damage by livestock compacting the large soil pores but not small pores. Combined with the raised levels of Nitrogen and Phosphate noted above, Marlborough's soil compaction presents a quite high risk of nutrient loss to water. Even though both N&P are within the target ranges, the level of soil compaction increases the risk of loss of these nutrients to water. Risk is increased when other factors such as slope, seasonal weather conditions, stocking rate, effluent disposal regimes, fertiliser application rates and frequency are considered.

There are a number of potential mitigation options that can be employed to prevent or minimise the effects of soil compaction. For pasture soils, some 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 and/or standoff areas; decreasing winter stock numbers and moving stock onto well drained soil types off-site (Burgess, et. al, 2000). For cropping soils, maintaining practices that increase soil organic matter are important as well as minimising activity on soils during wet soil conditions that will compress and disrupt soil structure (Ghani, et.al, 2009). For Viticulture, mitigation is more difficult due to the need to traffic rows frequently for various canopy management operations. Maintaining grassed wheel tracks and using mechanical loosening techniques may help in the short-term. Longer term solutions include raising soil organic matter levels and changing management techniques to minimise trafficking (multifunction machinery, over-row machinery).

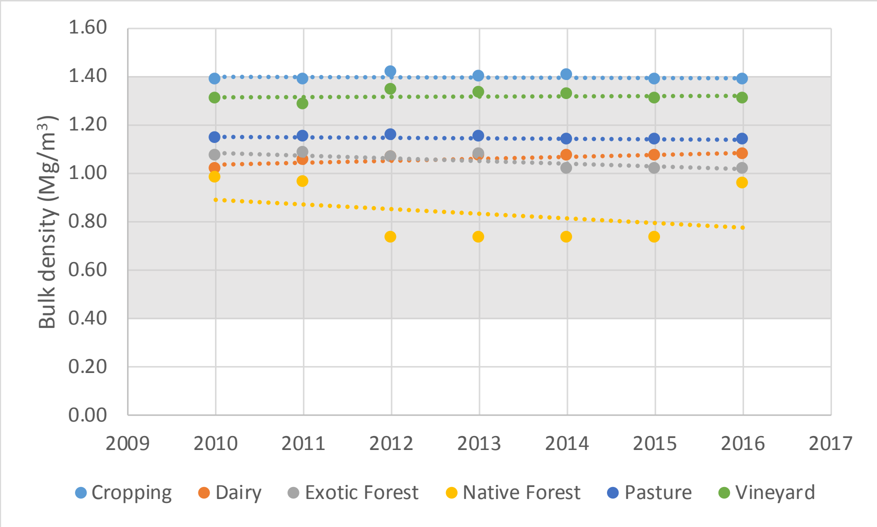

Figure 12. Bulk Density by landuse. Note the Native forest trendline is biased by a single value collected in 2012. A more accurate trendline would lie around the 0.96 Mg/m^3 level

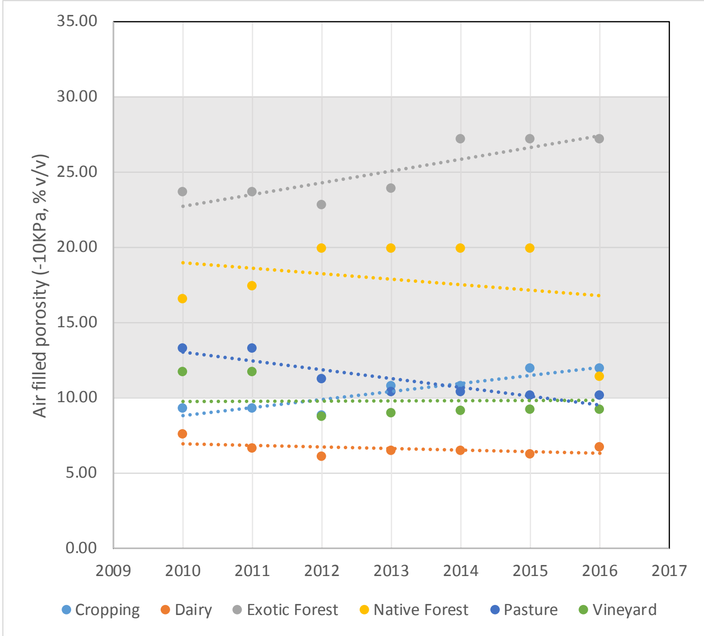

Figure 13. Air Filled Porosity by landuse. Notwithstanding compromised data, Forest landuses have better AFP compared to farmed landuses. Many farmed landuses show AFP below the target range of 10%

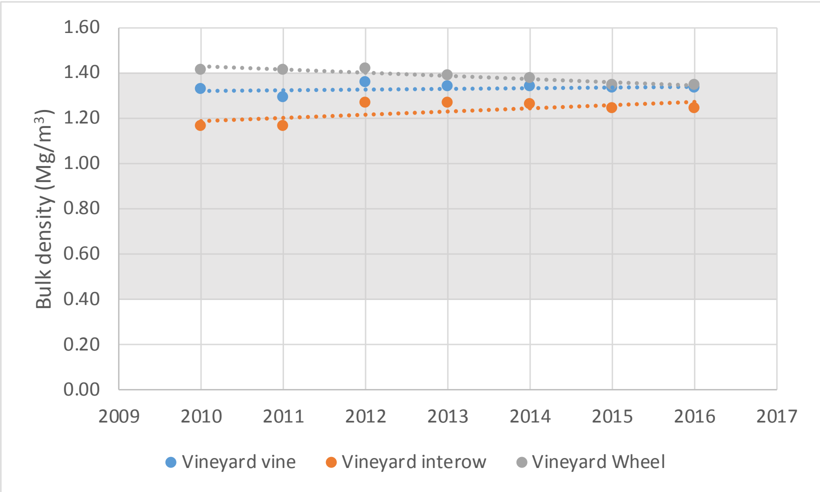

Figure 14. Vineyard Bulk density. Vineyard Bulk density is driven by wheel track compaction

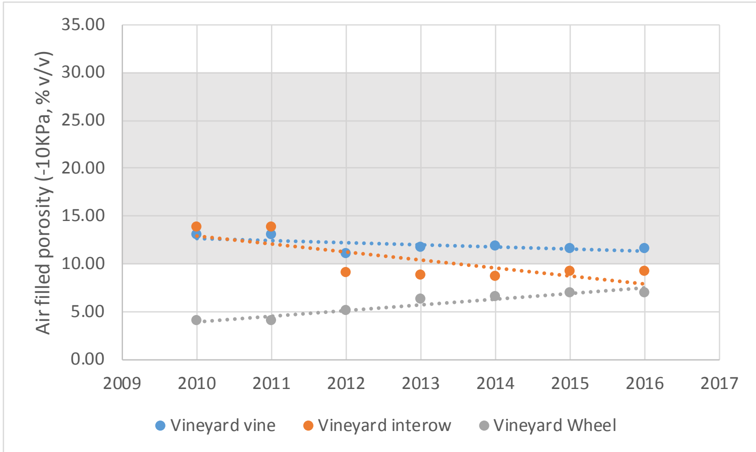

Figure 15. Vineyard Air Filled Porosity. Vineyard wheel tracks are some of the most compacted soils in Marlborough

4.3. Loss of Soil Organic Matter

Soil Organic Matter is plays a significant role in the structural stability of soils as well as provision of Nitrogen and Carbon for use by soil microbes and plants. 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 (Plate 2). In turn, poor soil structure can negatively affect things like soil aeration, drainage, water infiltration rates, water holding capacity, seed germination etc. In addition, loss of soil organic matter reduces the soils ability to retain nutrients from leaching and hold soil particles against runoff or erosion (Ghani, et. Al, 2009). These changes all have implications both for farm productivity and water quality.

The indicator for organic matter status is Total Carbon. While this indicator has not dropped below the target values for any landuse, it is noticeable that farmed landuses have lower OM levels than Native forest (Figure 16). We could regard the higher Native forest level of around 6% as the pre-farming benchmark for soil organic matter (notwithstanding the acknowledged data deficiencies). Although both data series are compromised by single outlier values and insufficient frequency of data collection, it is interesting to note the difference between Total C content of Exotic and Native Forest soils. Exotic forest reports C levels around 60% of Native forest levels. This is most likely due to historic land clearance and erosion prior to Exotic forest planting.

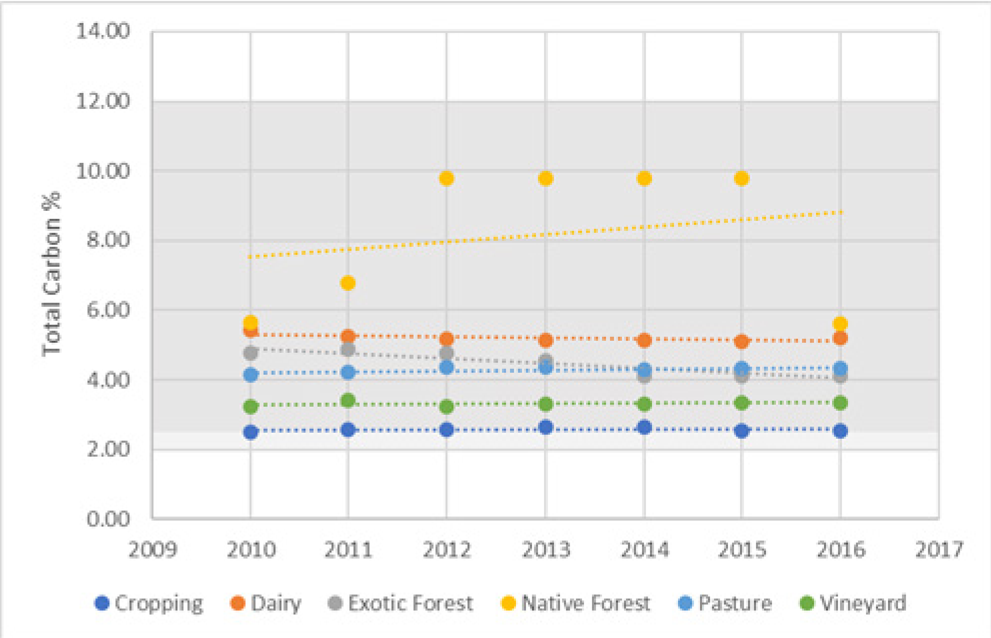

Figure 16. Total Carbon by Landuse. Native forest trendline is compromised by an outlier value in 2012. A more accurate trendline would lie around 6%. *Target range 2 to 12% depending on soil order*

One landuse (Cropping) reports consistently low organic matter levels and this may have serious implications for soil and water quality. Cropping sites have the lowest carbon contents of the measured landuses. These results are consistent with trends observed during soil quality monitoring studies in both the Waikato and Wellington regions (Taylor, 2015; Sorensen, 2012) where cropping sites had depleted soil carbon contents compared to carbon at native vegetation sites. Most of the cropping sites had soil carbon contents at the lower boundary of their target range. Land managers need to adopt cultural practices that increase the amount of soil carbon, either by increasing carbon inputs or reducing the rate of decomposition of carbon. Such practices include 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 (Francis et al., 1991). These practices all help to reduce leaching and runoff and as such have a beneficial effect on downstream water quality and soil organic matter levels.

Plate 2. Compacted topsoil at one of the cropping sites sampled with low soil carbon content (2012). Note the surface crust which reduces water infiltration, can increase surface run-off and reduce seed germination.

In comparison to cropping sites, the dairy sites had higher total carbon content. It is well understood that soil under pasture will accumulate Carbon. If the pasture is under a higher rainfall regime, irrigated, and fertilised, production of organic matter is increased and rates of accumulation increase in response. This carbon can replace that lost through cultivation, decomposition, respiration and consumption.

4.4. Trace Element Contamination

The Soil Quality Monitoring program reports on many different trace elements found in soils (MDC, 2007a; MDC 2007b). Many of these elements are toxic elements that are known to cause human and animal health problems (e.g. lead, mercury, cadmium and arsenic). The purpose of this is to inform Council of the risks of contamination from these elements. Monitoring has shown that there is little trace element contamination evident in most Marlborough soils. As mentioned earlier, Rai and Ronga soils have naturally elevated levels of Nickel and Chromium (Table 3).

The only other trace element of concern is Cadmium. The main issue with Cadmium is its accumulation through time and future landuse change. A number of landuses (Viticulture, Cropping, Pasture) show a slow increase in their cadmium content over time including Pasture, Cropping and Viticulture (Figure 17). The Tiered Fertiliser Management Strategy (TFMS) is a system for managing soil Cd concentrations with different types of management action. For soils with Cd 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 Cd 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 specific set of products and application rates to manage Cd accumulation to ensure Cd concentrations don't exceed acceptable thresholds within the next 50 years. For 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 Cd balance program to ensure that Cd does not exceed an acceptable threshold within 50 years. While the monitoring of soil Cd is the responsibility of Regional Councils, the implementation of these strategies is the responsibility of the fertiliser industry.

At current rates, the TFMS strategy Tier one level (0.6 mg kg^{-1}) would not be exceeded by Viticulture, Cropping or Pasture landuses before 2066 (using the 50-year threshold time). However, because different landuses have different Maximum Residue Levels for Cadmium, landuse change could lead to contamination. For example, a soil that has accumulated Cd under a pasture or vineyard regime that is then converted to vegetable production (Cropping) may have sufficient Cd to cause contamination problems in product. Understanding this, and given the high levels seen in some sites, it is suggested that land users test their soils for Cadmium regularly and prior to landuse change.

The situation with Dairy Cadmium levels is more problematic. The regional average levels are already concerning. See section 3.2.3. It should be noted that while the dairy trendline is down at present, there is considerable statistical error in this. Only minor changes in future sample results could cause the trendline to shift up or down and improvements are recommended to the sampling regime to reduce error margins. If Dairy cadmium levels were to increase at the same rate as Pasture levels, TFMS tier one would be exceeded around 2030.

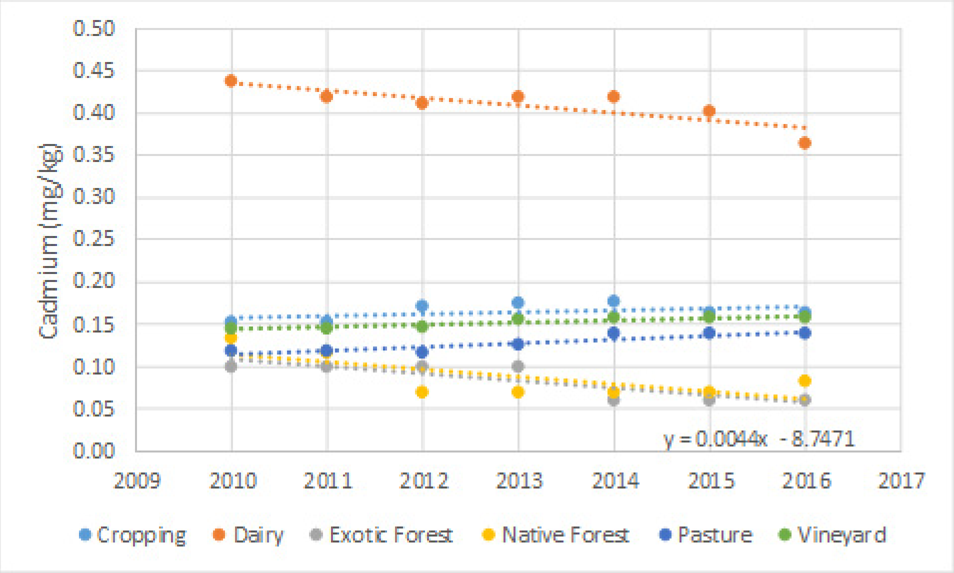

Figure 17. Cadmium levels by landuse. Concentration limit is 0.6mg/kg for Tier 1 of TFMS.

5. Future Considerations

It has been 17 years since the Soil Quality Monitoring program began with the 500 Soils program. Since that time there has been much discussion between various agencies about the aims and methodology of the program. With the recent publication of a report from the Environmental Monitoring and Reporting land and soil indicators workshop (Weeks and Collins, 2015), some direction has been given to these discussions. Future Soil quality monitoring by the Marlborough District Council may need to be expanded to include issues such as:

- Land cover, land use and land fragmentation
- Soil processes and properties
    - Soil Quality and health (Currently covered)
    - Trace elements (Currently covered)
    - Nutrient use and loss (first discussed in this report)
    - Peat loss
- Soil movement and protection
    - Soil stability / erosion
    - Suspended sediment
    - Riparian characteristics
- Community contribution / participation
    - Impact and response
    - Primary production and tourism
    - Public health
    - Culture and recreation

Some aspects of these requirements may be covered under Hazardous and Industrial Land use (HaIL) legislation or Water Quality Monitoring and will be reported on separately from Soil Quality. With these increased requirements in mind, there have been several changes to land use in Marlborough that may require increased focus for soil quality monitoring. These might include:

- Industrial and agricultural waste disposal techniques e.g. winery and dairy waste disposal sites
- Changes to land use such as dairy or vineyard conversions
- Disturbance to land such as large scale vegetation clearance e.g. forest harvesting
- Riparian strip management techniques e.g. Streamside planting, fence line or drain spraying

Ideally, an expanded Soil Quality Monitoring program would be conducted in conjunction with Council water monitoring to provide a better overview of land use effects on the wider environment.

6. Summary

Results for the 2016 Soil quality Monitoring round showed that the majority of sites sampled were in good condition and reported results within the target ranges. The most concerning aspect of this year's results are the number of sites that have compacted soils. Eighty percent of sites showed low Air Filled Porosity indicating a reduction in pore space in the soil. These were noted across all soil types sampled but only on farmed land. Forest sites reported both low Bulk Density and high Air Filled Porosity indicating no soil compaction.

A number of changes have been made to the 2016 Soil Quality report. These include changes to presentation and analysis. A new section has been introduced to discuss the long-term trends in Soil Quality. Results from this section mirrored findings from other regions. These findings include extensive soil compaction on all farmed landuse types, low soil organic matter levels in Cropping and Viticulture and elevated Cadmium levels especially in Dairy landuse. Elevated Nitrogen and Phosphate levels in many landuse types combined with soil compaction raises the risk of nutrient losses to water. Of special note to the Marlborough region is the level of severe soil compaction that exists within vineyards.

With the introduction of the long-term analysis, a number of issues have been isolated regarding the collection of data for soil quality reporting. These include unclear location of some sites, excessive influence of data outliers from historic sampling, insufficient sample numbers for some landuses and inadequate frequency of sampling. In addition, a number of changes have been suggested for Soil Quality Monitoring nationally to more closely align regions. It is recommended that the sampling program is reviewed with these issues in mind prior to the next sampling round in October 2017.

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8. Appendix A. Soil Target Values

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). Olsen P values as set by Taylor and Mackay (2012).

Bulk density target ranges (t/m³ or Mg/m³)

	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 based on 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**	>50
Pasture on Pumice and Organic soils	0	**15**	35	**50**	>50
Cropping and horticulture on Sedimentary and Allophanic soils	0	**20**	50	**50**	>50
Cropping and horticulture on Pumice and Organic soils	0	**25**	60	**50**	>50
Forestry on all Soil Orders	0	**5**	10	**50**	>50

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