Soil Quality in the Marlborough Region in 2010

MDC Technical Report No: 11-001

Marlborough District Council

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ISBN 978-0-9864664-5-8

File Reference/Record No: E225-07/1111682

December 2010

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Acknowledgements:

The Marlborough District Council wish to thank the landowners and managers for providing access to their properties to allow soils to be sampled and supplying relevant site management information and Dr Iain Campbell for help in location of monitoring sites and soil profile descriptions.

Executive Summary

The Marlborough District Council (MDC) has a duty under the Resource Management Act (1991) to monitor and report on the "life supporting capacity of soil" and determine whether current practices will meet the "foreseeable needs of future generations". To help meet these goals the MDC undertake a soil quality monitoring programme that involves collecting soil samples from sites that represent the main land use activities and soil types in the Marlborough region, analysing samples for a suite of soil physical, biological and chemical properties that have been shown to be robust indicators of soil quality and comparing the results to recognised soil quality target values.

In this investigation, soils were sampled from 15 new soil quality monitoring sites. The sites included 4 different land use activities including cropping/rotational cropping, viticulture, dairy and drystock pasture across 11 different soil types from 3 soil orders.

Monitoring results indicate that only 6 soils met all their soil quality targets, 3 others had one indicator out of the target range while the remainder had 2 or more indicators out of the target range. The monitoring has highlighted that there are some soil quality issues under some land use activities.

Several sites showed signs of poor physical condition. This included soil compaction i.e. high bulk density, low macroporosity and low aggregate stability. These were mostly the cropping/rotational cropping sites which also often had low or depleted soil carbon contents. This puts these soils at risk of poor aeration, impeded drainage, surface crusting all which may potentially affect crop performance and predispose the soil to surface runoff, nutrient loss, erosion and flooding.

Trace element concentrations in Marlborough agricultural soils were generally low and were similar to concentrations found in other parts of New Zealand with the exception of cadmium at the two dairy sites.

It is recommended that to obtain reliable, long-term detection and prediction of trends in soil quality, at least three and preferably five points along a time sequence should be obtained. Therefore repeat monitoring of sites should be conducted in the medium-term (≈ 3 - 5 years) to determine trends over time.

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 land use activities are having on soil quality and whether we need to change or prioritise the way we manage the land environment. This is essential as not all soils are equal and some are fragile and if not carefully managed are at risk of degradation. This is becoming increasingly important as land use activities are intensifying across New Zealand and putting pressure on our soils. For example, over the last two decades cow stocking rates on dairy farms have increased by about 20% across New Zealand (LIC, 2010). Closer to home the amount of land used for viticulture in Marlborough has increased from 2,655 ha in 1997 to 23,921 ha in 2010, predominantly conversion from dryland pastoral farming which is recognised as a relatively less intensive land use activity than viticulture.

To help determine what effect land use practices are having on soil quality, the Marlborough District Council (MDC) began a monitoring programme in 2000. The monitoring programme involved collecting soil samples from a network of sites that represented the main land use 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.

Up until 2009, 60 soil quality sites had been established, sampled and results reported. However, to provide a more complete picture of soil quality in the Marlborough region, further sampling of soil is still required from more sites. This report present the results for 15 new soil quality monitoring sites that were sampled and analysed for a suite of soil physical, biological and chemical properties to determine if they meet their target ranges for soil quality.

2. Materials and Methods

2.1. Sampling Sites

Soils were sampled from 15 sites that included four different land use activities and represented 11 different soil types from 3 soil orders (Table 1).

At each site a soil pit was dug to about 1 m depth and a detailed soil profile description was undertaken to confirm the soil type and to note any salient soil features that may affect soil management i.e. rooting depth, mottling, hardpans etc. In addition, details of the site were recorded such as current landuse, present vegetation, slope, elevation, landform, parent material and soil drainage class. This information in presented in Appendix A.

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

Site Code	Soil Type	New Zealand Soil Order	Land use; management
MDC61	Seaview	Pallic	Cropping
MDC62	Galtymore	Recent	Cropping
MDC63	Marama	Pallic	Cropping
MDC64	Broadbridge	Pallic	Cropping
MDC65a	Seaview	Pallic	Pasture; Grapes – vine
MDC65b	Seaview	Pallic	Pasture; Grapes – wheel

MDC66a	Kaituna	Brown	Pasture; Grapes – vine
MDC66b	Kaituna	Brown	Pasture; Grapes – wheel
MDC67	Wairau	Recent	Wheat; Peas; Beans; Pasture
MDC68	Woodbourne	Pallic	Wheat; Peas; Beans; Pasture
MDC69a	Woodbourne	Pallic	Pasture; Grapes – vine
MDC69b	Woodbourne	Pallic	Pasture; Grapes – wheel
MDC69c	Woodbourne	Pallic	Pasture; Grapes – inter-row
MDC70a	Wairau	Recent	Pasture; Grapes – vine
MDC70b	Wairau	Recent	Pasture; Grapes – wheel
MDC71	Renwick	Brown	Pasture; Peas; Seed clover
MDC72	Brancott	Pallic	Pasture; Peas; Seed clover
MDC73	Kaituna	Brown	Pasture – sheep and beef
MDC74	Rai	Recent	Dairy
MDC75	Ronga	Recent	Dairy

2.2. 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 (Plate 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 (Plate 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.

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.

In addition at sites that are or have been cropped, samples were taken for measurement of soil aggregate stability. This involved cutting 100 mm by 100 mm by 100 mm undisturbed blocks of soil at 15-, 30- and 45-m positions along the 50 m transect.

In addition, as different parts of a vineyard are managed differently, soils were also sampled from both under the vine, in the area of the wheel tracks and one instance in the inter-row at vineyard sites.

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, total carbon, total nitrogen, carbon:nitrogen ratio, Olsen P and trace element concentrations. Soil biological activity was determined by measuring anaerobically mineralisable nitrogen (AMN). 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 (Table 2).

Table 2 Indicators used for soil quality assessment

Indicators	Soil Quality Information	Method
Chemical properties		
Total carbon content	Organic matter status	Dry combustion, CNS analyser
Total nitrogen content	Organic N reserves	Dry combustion, CNS analyser
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
Physical properties		
Dry bulk density	Compaction, volumetric conversions	Soil cores
Particle density	Used to calculate porosity and available water	Specific gravity
Aggregate Stability	Presence of soil crumbs, stable soil structure	Wet sieving the 2 - 4 mm aggregates
Total porosity, air capacity and macroporosity	Soil compaction, aeration, drainage	Pressure plates

2.4. Soil Analyses

2.4.1. Chemical

Total carbon and nitrogen were determined by dry combustion of air-dry soil using a LECO 2000 CNS analyser (Blakemore et al., 1987). Soil pH was measured in water using glass electrodes and a 2.5:1 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, 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).

2.4.2. Biological

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

2.4.3. Physical

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 (-5 kPa), air capacity (-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).

2.5. Statistics and Data Display

Where appropriate, data were expressed on a weight/volume or volume/volume basis to allow comparison between soils with differing bulk density.

2.6. Targets and Ranges

Target ranges for individual soil indicators 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 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.

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. The two physical measurements i.e. bulk density and macroporosity were the indicators most often not meeting their soil quality target. In contrast, soil pH, total N and AMN targets were met at all sites.

The significant number of sites not meeting their target for macroporosity is similar to what has been previously found at soil quality monitoring sites (Marlborough District Council, 2007; 2008; 2009) and is what has been found nationally where soil compaction i.e. low macroporosity and high bulk density is recognised as a key soil quality issue (Ministry for the Environment, 2010).

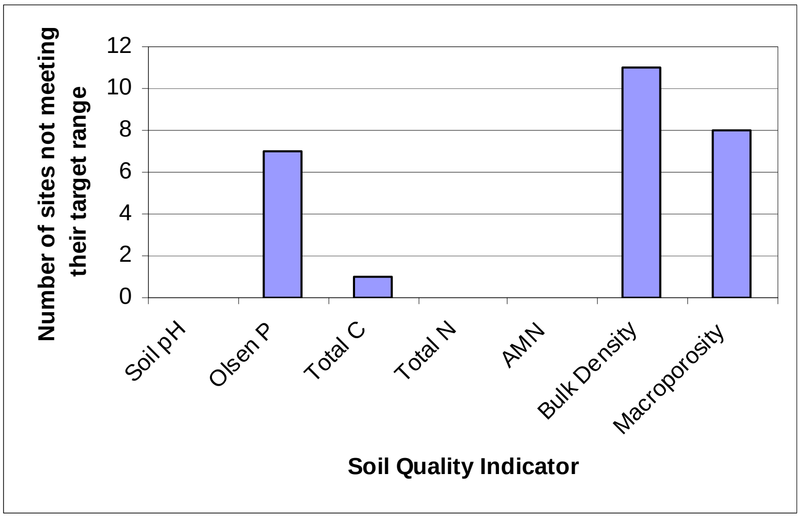

Figure 1 The number of sites not meeting their target range for a specific soil quality indicator

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

3.2. 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. For example, most 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.

As indicated in Figure 1, all sites had soil pH values within the acceptable target for their respective land use. However two sites, the drystock pasture site (MDC73) and one of the dairy sites (MDC74) had soil pH values which were at the lower end of their target range (Table 3). The ideal pH range for pasture soils (excluding peat soils) is 5.8 – 6.0 (Morton and Roberts, 2004) which maximises nutrient availability. An increase in soil pH can be readily remediated by the application of a lime product.

3.3. Total Soil 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 and it provides a source of energy for soil microbes.

All sites had total soil carbon contents within acceptable target ranges for their respective land use activity (Figure 1) with the exception of one of the cropping sites MDC62 which was below the target (Table 3). Six of the other cropping/rotational cropping sites had depleted total carbons contents that approached the lower end of the desired target range. It is well recognised that soils with low carbon contents are more susceptible to a breakdown of soil structure which puts soils at risk of things like poor aeration, impeded drainage and surface crusting (Plate 2). In turn this increases the potential for surface run off and nutrient losses such as phosphorous from soils as well as increased opportunity for sheetwash erosion and also flooding. This will increasingly become an issue if carbon contents continue to decrease further in these soils over time.

Plate 2 Surface crust at one of the cropping sites sampled which potentially reduces water infiltration, can increase surface run-off and reduce seed germination.

In addition, three of the four vineyard sites sampled under the vine also had total soil carbon contents at the lower end of the desired target range. Under the vine there are often only limited inputs of organic matter (i.e. carbon), probably from mown grass clippings from the inter-row and some pruning material. Plant material present under the vine is often killed off by the application of broad spectrum herbicides such as glyphosate.

Table 3 Chemical and biological characteristic of soils sampled in the Marlborough Region 2010

Site Code	Land use	Soil Type	Soil pH	Olsen P (µg cm^{-3})	Total C (mg cm^{-3})	Total N (mg cm^{-3})	C:N ratio	AMN (µg cm^{-3})
MDC61	Cropping	Seaview	6.7	100	**53**	6	10	113
MDC62	Cropping	Galtiymore	6.2	39	28	3	10	71
MDC63	Cropping	Marama	6.5	54	38	4	9	91
MDC64	Cropping	Broadbridge	6.4	50	38	4	10	72
MDC65a	Vineyard - vine	Seaview	6.3	**22**	43	4	14	79
MDC65b	Vineyard - wheel	Seaview	6.4	**20**	51	5	11	105
MDC66a	Vineyard - vine	Kaituna	6.7	34	34	4	9	150
MDC66b	Vineyard - wheel	Kaituna	6.9	36	42	4	12	205
MDC67	Rotational cropping	Wairau	5.9	**20**	30	3	14	75
MDC68	Rotational cropping	Woodbourne	5.9	**26**	32	4	10	73
MDC69a	Vineyard - vine	Woodbourne	6.7	53	37	4	10	79
MDC69b	Vineyard - wheel	Woodbourne	6.9	78	49	5	9	117
MDC69c	Vineyard - inter-row	Woodbourne	6.8	36	47	4	10	111
MDC70a	Vineyard - vine	Wairau	6.5	**18**	29	3	10	72
MDC70b	Vineyard - wheel	Wairau	6.7	43	57	6	12	160
MDC71	Rotational cropping	Renwick	5.8	**22**	35	4	11	76
MDC72	Rotational cropping	Brancott	5.9	**25**	38	4	12	68
MDC73	Drystock Pasture – sheep/beef	Kaituna	5.4	19	47	4	13	142
MDC74	Dairy	Rai	5.6	46	67	6	14	173
MDC75	Dairy	Ronga	5.8	26	53	5	15	163

Bold – outside optimal range for the site’s specific soil order and land us

3.4. 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.

All sites had total soil nitrogen contents within acceptable target ranges for their respective land use activity (Table 3).

3.5. Carbon:Nitrogen Ratio

The balance of the amount of carbon: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.

All sites had C:N ratios within acceptable target ranges for their respective land use activity (Table 3).

3.6. 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. A high Olsen P value in soil may result in phosphorus losses from soil which potentially can have a negative impact on water quality.

Olsen P concentrations varied about 5-fold between sites with the lowest value found at one of the drystock pasture sites i.e. MDC73 and highest value at one of the cropping sites i.e. MDC61 (Table 3). As indicated in Figure 1, seven sites had Olsen P values out of the desired target range, all below their target. 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 major concern.

3.7. 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 the 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.

Anaerobically Mineralisable Nitrogen concentrations varied 3-fold between sites with the lowest values typically found on the cropping sites and the highest values found on the pasture sites (Table 3). All values were within their target range for their respective land use activity. Anaerobically Mineralisable Nitrogen values above the target is regarded as important as it can potentially lead to water quality issues if nitrogen is lost from soil as nitrate, primarily through leaching.

3.8. 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.

In total eleven soils had bulk density values that did not meet the desired target (Figure 1) and six that were approaching the upper target limit (Table 4) with bulk density values too high. This included seven of the eight cropping/rotational cropping sites that had bulk density values which exceeded the desired target range or were approaching the upper limit. In part the high bulk density values at the cropping sites are related as discussed in section 3.3 to the relatively low total carbon contents in these cropping soils which were below or at the lower boundary of the desired range. However, the tracking of heavy machinery in cropping operations has also likely significantly contributed to elevated bulk densities of these soils as well as continuous cropping without a pasture phase at some of the sites sampled.

The other sites with high bulk density values were some of the vineyards sites - often in the wheel track zone. This is likely related to vehicle traffic in this zone 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 cultural practices 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.

3.9. Macroporosity

Macroporosity is a measure of the proportion of large pores 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 and are the first to be lost when the soil is compacted.

Eight sites did not meet their target for macroporosity (Figure 1) with values too low. These included four of the eight cropping/rotational cropping sites and in the wheel tracks of the inter-row at the vineyard sites (Table 4). In addition two of the cropping/rotational cropping sites and one of the dairy sites has values approaching their lower limits.

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 which has compressed the larger pores. Plate 3 shows the soil structure at one of the cropping sites sampled. Note the massive/blocky soil structure which reduces drainage, can increase surface run-off and impedes root extension.

Plate 2 Compacted topsoil at one of the cropping sites sampled

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.

3.10. 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 made at seven of the eight cropping/rotational cropping sites with values ranging from 0.37 to 0.72 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). The low aggregate stability values in the cropping soils are likely again linked to the related to the relatively low total carbon contents in these soils. Furthermore, several of the cropping sites are on Pallic soils which typically have high slaking potential (Hewitt, 1993) and are usually regarded as unsuitable for continuous cropping to due to their potential for soil structural collapse.

Table 4 Physical characteristic of soils sampled in the Marlborough Region 2010

Site Code	Land use	Soil Type	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Total porosity (% v/v)	Macro-porosity (%v/v)	Air-filled porosity (%v/v)	Aggregate Stability (mwd)
MDC61	Cropping	Seaview	**1.55**	2.61	40.6	**1.0**	1.0	**0.43**
MDC62	Cropping	Galtiymore	**1.46**	2.66	45.4	9.0	12.0	**0.49**
MDC63	Cropping	Marama	**1.60**	2.64	39.6	**1.3**	2.1	**0.39**
MDC64	Cropping	Broadbridge	**1.42**	2.61	45.8	**3.5**	5.0	**0.37**
MDC65a	Vineyard - vine	Seaview	1.25	2.60	51.8	11.9	14.2	n.d.
MDC65b	Vineyard - wheel	Seaview	**1.42**	2.60	45.3	**1.5**	3.5	n.d.
MDC66a	Vineyard - vine	Kaituna	1.27	2.68	52.8	9.1	10.8	n.d.
MDC66b	Vineyard - wheel	Kaituna	1.32	2.66	50.2	**3.7**	3.8	n.d.
MDC67	Rotational cropping	Wairau	**1.45**	2.63	45.1	**5.8**	8.7	**0.61**
MDC68	Rotational cropping	Woodbourne	**1.38**	2.62	47.3	6.8	8.4	**0.72**
MDC69a	Vineyard - vine	Woodbourne	1.32	2.63	50.0	8.4	10.0	n.d.
MDC69b	Vineyard - wheel	Woodbourne	**1.40**	2.61	46.4	**1.6**	3.3	n.d.
MDC69c	Vineyard - inter-row	Woodbourne	1.06	2.57	58.7	9.7	11.5	n.d.
MDC70a	Vineyard - vine	Wairau	**1.45**	2.65	45.4	9.6	11.8	n.d.
MDC70b	Vineyard - wheel	Wairau	**1.51**	2.62	42.5	**2.9**	5.4	n.d.
MDC71	Rotational cropping	Renwick	**1.36**	2.59	47.4	6.9	10.2	**0.56**
MDC72	Rotational cropping	Brancott	1.34	2.59	48.3	9.6	13.1	n.d.
MDC73	Pasture	Kaituna	1.18	2.63	55.3	9.4	11.9	n.d.
MDC74	Dairy	Rai	0.86	2.43	64.7	8.1	11.0	n.d.
MDC75	Dairy	Ronga	0.89	2.50	64.5	7.8	10.6	n.d.

n.d. not determined

Bold – outside optimal range for the site's specific soil order and land use

3.11. 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 the monitoring sites. On average concentrations were 4 mg kg^{-1} for arsenic, 0.23 mg kg^{-1} for cadmium, 20 mg kg^{-1} for chromium, 15 mg kg^{-1} for copper, 15 mg kg^{-1} for lead, 15 mg kg^{-1} for nickel and 76 mg kg^{-1} for zinc. These concentrations are similar to those found in soils in other regions of New Zealand (Auckland Regional Council, 1999; Greater Wellington Regional Council, 2005; Canterbury Regional Council, 2006). In fact, with the exception of cadmium at the two dairy sites, concentrations are similar to typical background concentrations found in New Zealand soils and are well within suggested upper limits for trace elements in soils as suggested by the New Zealand Water and Waste Association.[1]

The two dairy sites had cadmium concentrations significantly higher than background concentrations with site MDC74 at the NZWWA, 2003 limit of 1 mg kg^{-1}. The source of cadmium in these two soils is most likely phosphate fertiliser which has been shown to contain cadmium as an incidental impurity. Whilst the elevated Cd concentration at site MDC 74 is significant, the risk of plant uptake, which is the main exposure pathway for this bio-toxic heavy metal is relatively low because of the high soil carbon content and pH, which minimises its plant availability.

[1] New Zealand Water and Waste Association suggest upper soil limits of 20 mg kg^{-1} for arsenic; 1 mg kg^{-1} for cadmium; 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 (NZWWA, 2003).

Table 5 Trace element concentrations in soils sampled in the Marlborough Region 2010

Site Code	Land use	Soil Type	As ($mg\ kg^{-1}$)	Cd ($mg\ kg^{-1}$)	Cr ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Pb ($mg\ kg^{-1}$)	Ni ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
MDC61	Cropping	Seaview	4	0.20	23	13	12	18	78
MDC62	Cropping	Galtiymore	5	< 0.10	19	14	11	18	54
MDC63	Cropping	Marama	4	0.12	22	13	11	18	67
MDC64	Cropping	Broadbridge	3	0.18	23	11	12	17	77
MDC65a	Vineyard - vine	Seaview	4	0.13	25	13	12	18	84
MDC65b	Vineyard - wheel	Seaview	4	0.14	24	13	11	17	78
MDC66a	Vineyard - vine	Kaituna	6	0.25	15	20	12	14	111
MDC66b	Vineyard - wheel	Kaituna	5	0.19	15	20	11	14	76
MDC67	Rotational cropping	Wairau	4	0.17	21	14	12	16	60
MDC68	Rotational cropping	Woodbourne	5	0.23	22	18	18	19	87
MDC69a	Vineyard - vine	Woodbourne	5	0.17	22	18	19	18	86
MDC69b	Vineyard - wheel	Woodbourne	6	0.18	20	19	51	17	88
MDC69c	Vineyard - inter-row	Woodbourne	5	0.16	20	17	17	16	71
MDC70a	Vineyard - vine	Wairau	4	0.13	20	20	11	15	72
MDC70b	Vineyard - wheel	Wairau	4	0.14	20	24	11	15	61
MDC71	Rotational cropping	Renwick	< 2	0.17	11	6	9	9	65
MDC72	Rotational cropping	Brancott	2	0.16	11	7	10	9	64
MDC73	Pasture	Kaituna	4	0.14	13	16	12	11	78
MDC74	Dairy	Rai	4	**1.02**	26	14	15	10	70
MDC75	Dairy	Ronga	5	0.53	28	14	15	13	86

Bold – exceeds recommended guideline value (NZWWA, 2003)

4. Summary

- Monitoring results indicate that only 6 out of 20 soil samples met all their soil quality targets, 3 others had one indicator out of the target range while 11 soils had 2 or more indicators out of the target range. The monitoring has highlighted that there are some soil quality issues under some land use activities.

- Several sites showed signs of soil compaction i.e. high bulk density and low macroporosity. These were mostly the cropping/rotational cropping sites which also often had low or depleted soil carbon contents and low aggregate stability. These results put these soils at risk of poor aeration, impeded drainage and surface crusting all which may potentially affect crop performance and predispose the soil to surface runoff, nutrient loss, erosion and flooding.

- Trace element concentrations in Marlborough agricultural soils, with the exception of cadmium at two dairy sites, were 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.

- There should be more intensive monitoring for cadmium on pasture farm sites to determine how widely and to what concentrations cadmium has accumulated on pasture soils.

- It is also recommended that repeat monitoring of these risk sites be conducted in the medium-term (≈ 3-5 years) to determine the rate of change over time.

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Appendix A

Site and Soil Descriptions

Sample name: MDC61
Soil Name: Seaview
Location: 11.5 km SW of Seddon and 500m North of Marama Road
GPS Coordinates: E1678720 N5383122
Land use: Cropping
Topography: Terrace
Elevation: 176m
Slope: 2°
Soil material: Deep loess
Soil drainage: Well
Date sampled: 4/10/10

Horizon	Thickness (cm)	Soil description
App	0 - 15	dark greyish brown (10YR 3/3) silt loam, moderately developed medium and coarse blocky; structure; weak soil strength; friable; few medium roots
Ap	15 - 24	dark greyish brown (10YR 3/3) silt loam; massive breaking to coarse blocky structure; slightly firm soil strength; brittle; few fine roots
AB	24 - 33	yellowish brown (10YR 5/4) and dark greyish brown silt loam; moderately developed medium blocky structure; slightly firm soil strength; brittle; very few roots
Bw1	33-50	yellowish brown to light olive brown (10YR 5/4-2.5Y 5/4) silt loam; moderately developed coarse blocky structure; firm soil strength; brittle; 5% yellowish red (5YR 4/6) mottles;
Bw2	50 - 70	yellowish brown (10YR 5/4) silt loam; moderately developed coarse blocky structure; 10% yellowish red (5YR 4/6) fine distinct mottles; firm soil strength; brittle
Bw(g)	70-85	yellowish brown (10YR 5/4) heavy silt loam; moderately developed coarse blocky structure; 20% olive (5Y 5/3) and 10% yellowish brown (10YR 5/8) medium prominent mottles; firm soil strength; brittle
Bx	85-90+	dark yellowish brown (10YR 4./4) silt loam; moderately developed coarse prismatic structure; 20% olive (5Y 5/3) and 10% dark reddish brown (5YR4/3) coarse prominent mottles; very firm soil strength

Sample name: MDC62
Soil Name: Galtymore
Location: 11.7 km SW of Seddon and 1.1 km North of Marama Road
GPS Coordinates: E1678003 N5383561
Land use: Cropping
Topography: Terrace
Elevation: 129m
Slope: 0°
Soil material: Sandy alluvium
Soil drainage: Well
Date sampled: 4/10/10

Horizon	Thickness (cm)	Soil description
A	0-18	dark brown (10YR 3/3) sandy loam; weakly; developed fine polyhedral and blocky structure; very weak soil strength; friable; few fine root
2b A	18-27	very dark greyish brown (10YR 3/2) sandy loam; weakly developed medium blocky structure; weak soil strength; friable; few fine roots
2b B	27-41	olive brown (2.5Y 4/4) fine sand; apedal; single grain; very weak soil strength; very friable; very few roots
3 b A	41-57	dark brown to very dark greyish brown (10YR 3/2-10YR 3/3) sandy loam; weakly developed fine polyhedral structure; very weak soil strength; very friable
3 b B	57-80	light olive brown (2.5Y 5/6) sandy loam; weakly developed fine blocky structure; weak soil strength; very friable
3 b C	80-90	olive brown (2.5Y 4/4) coarse sand; loose; 5% yellowish brown (10YR 5/6) fine distinct mottles;
	on	stony gravel

Sample name: MDC63
Soil Name: Marama
Location: 11.7 km SW of Seddon and 0.9 km North of Marama Road
GPS Coordinates: E1678588 N5383720
Land use: Cropping
Topography: Terrace
Elevation: 144m
Slope: 0º
Soil material: Alluvium
Soil drainage: Well
Date sampled: 4/10/10

Horizon	Thickness (cm)	Soil description
A	0-21	very dark greyish brown (10YR 3/2) silt loam; weakly developed fine polyhedral and medium blocky structure; weak soil strength; friable; few fine roots
AB	21-32	very dark greyish brown and dark yellowish brown (10YR 3/2+ 10YR 4/4) silt loam; moderately developed medium and coarse blocky structure; weak soil strength; friable; few fine roots
Bw1	32-55	dark yellowish brown (10YR 4/4) silt loam; moderately developed coarse blocky structure; weak soil strength; friable; very few fine roots
Bw2	55-75	olive brown to dark yellowish brown (2.5Y 4/4-10YR 4/4) fine sandy loam; weakly developed coarse blocky structure; brittle
BC	75-85+	olive brown (2.5Y 4/4) sand; apedal; single grain; loose 60% medium to coarse stones
	on	gravel

Sample name: MDC64
Soil Name: Broadbridge
Location: 12 km SW of Seddon and 30m north of Marama Road
GPS Coordinates: E1678787 N5382739
Land use: Cropping
Topography: Terrace
Elevation: 129m
Slope: 0°
Soil material: Colluvium
Soil drainage: Moderate
Date sampled: 5/10/10

Horizon	Thickness (cm)	Soil description
A	0-24	very dark greyish brown (10YR 3/2) silt loam; weakly developed fine polyhedral and medium blocky structure; slightly firm soil strength; friable to brittle; very few fine roots
AB	24-33	very dark greyish brown and dark yellowish brown (10YR 3/2 + 5/4) silt loam; 2% fine distinct yellowish brown (10YR 5/6) mottles; moderately developed medium blocky structure; weak soil strength; brittle; very few fine roots
Bw1	33-46	yellowish brown (10YR 5/4) silt loam; 5% olive (5Y 5/3) and 10% yellowish red (5YR 4/6) medium distinct mottles; moderately developed medium blocky structure; slightly firm soil strength; brittle
Bw2	46-65	dark yellowish brown (10YR 4/4) clay loam; 10% light olive brown (2.5Y 5/4) and 5% olive (5Y 5/3) medium distinct mottles; moderately developed coarse to very coarse blocky structure; firm soil strength; brittle
Bw(g)	65-80	olive brown (2.5Y 4/4) clay loam; 20% pale olive (5Y 6/3) and 15% yellowish red (5YR 4/6) medium and coarse mottles; moderately developed coarse to very coarse blocky structure; firm soil strength; brittle
BC(g)	80-100+	dark yellowish brown (10YR 4/4) sand; 20% pale olive (5Y 6/3) and 15% yellowish red (5YR 4/6) medium distinct mottles; apedal; single grain; loose

Sample name: MDC65
Soil Name: Seaview
Location: 10.5 km SW of Seddon and 0.6 km North of Marama Road
GPS Coordinates: E1679242 N5383506
Land use: Vineyard
Topography: Terrace
Elevation: 171m
Slope: 3°
Soil material: Loess
Soil drainage: Moderately well
Date sampled: 5/10/10

Horizon	Thickness (cm)	Soil description
A	0-23	very dark greyish brown (10YR 3/2) silt loam; moderately developed fine polyhedral structure; weak soil strength; friable; many fine and few medium roots
AB	23-34	very dark greyish brown and dark yellowish brown (10YR 3/2+ 10YR 4/4) silt loam; moderately developed fine polyhedral and medium blocky structure; slightly firm soil strength; friable many fine and few medium roots
Bw1	34-55	dark yellowish brown to light olive brown (10YR 5/4-2.5Y 5/4) silt loam; 1% yellowish red (5YR 5/6) fine faint mottles; moderately developed fine polyhedral and coarse blocky structure; slightly firm soil strength; brittle; few fine roots
Bw2	55-70	dark yellowish brown to light olive brown (10YR 5/4-2.5Y 5/4) silt loam; 20% olive (5Y 5/4) and 10% dark yellowish brown (10YR 4/6) fine distinct mottles; moderately developed medium blocky structure; slightly firm soil strength; brittle; few fine roots
Bwt	70-90	yellowish brown (10YR 5/6) clay loam; 45% olive (5Y 5/3) and 40% yellowish red (5YR 4/6) medium prominent mottles; strongly developed coarse blocky structure; firm soil strength; brittle; few fine roots
Bx	90-100+	olive (5Y 5/3 55%) and yellowish red (5Y 4/6 45%) coarse blocky and extremely coarse prismatic structure; very firm soil strength; brittle

Sample name: MDC66
Soil Name: Kaituna
Location: Nth side of the Wairau River, 4.2 km ENE from SH 6 and approx 200m N of Kaituna-Tuamarina Rd
GPS Coordinates: E1671064 N5410489
Land use: Vineyard
Topography: Fan
Elevation: 30m
Slope: 2°
Soil material: Fine sediment over gravel
Soil drainage: Well
Date sampled: 6/10/10

Horizon	Thickness (cm)	Soil description
A	0 - 23	dark brown (10YR 3/3) silt loam; moderately developed fine polyhedral structure; weak soil strength; friable; many fine and few medium roots
AB	23 - 30	dark brown (10YR 3/3) and dark yellowish brown(10YR 4/6) heavy silt loam; 4% fine stones; weakly developed fine polyhedral structure; weak soil strength; friable; many fine and few medium roots
Bw1	30 - 45	dark yellowish brown (10YR 4/6) clay loam; 2% fine stones; moderately developed fine polyhedral and medium blocky structure; slightly firm soil strength; brittle; few fine roots
Bw2	45 - 55	dark yellowish brown (10YR 4/6) sandy clay loam; 4% fine stones; moderately developed medium blocky and polyhedral structure; slightly firm soil strength; brittle; few fine roots
BC	55-70+	dark yellowish brown to olive brown (10YR 4/6-2.5Y 5/6) sand; 25% fine to coarse stones; apedal; single grain; loose

Sample name: MDC67
Soil Name: Wairau
Location: East side of Jacksons Road, approx 500m N of Middle Renwick Road
GPS Coordinates: E1673316 N5404689
Land use: Rotational grazing
Topography: Floodplain
Elevation: 13m
Slope: 0°
Soil material: Unconsolidated layered alluvium
Soil drainage: Well
Date sampled: 5/10/10

Horizon	Thickness (cm)	Soil description
A	0-22	very dark greyish brown (10YR 3/2) silt loam; weakly developed fine and medium polyhedral structure; weak soil strength; friable; many fine roots
AB	22-29	very dark greyish brown and light olive brown (10YR 3/2+ 2.5Y 5/4) silt loam; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots
BC	29-52	olive brown (2.5Y 4/4) silt loam to fine sandy loam; weakly developed medium blocky structure; very weak soil strength; very friable; many fine roots
C	50-74	olive brown (2.5Y 5/4) sandy loam; apedal; earthy; very weak soil strength; few fine roots
bA	74-86	very dark greyish brown (10YR 3/2) silt loam; moderately developed medium polyhedral structure; weak soil strength; very friable; few fine roots
bC	86-90cm+	olive brown (2.5Y 5/4) sandy loam; apedal; earthy; very weak soil strength; very few roots

Sample name: MDC68
Soil Name: Woodbourne
Location: East side of Jacksons Road, approximately 550m N of Middle Renwick Road
GPS Coordinates: E1673359 N5404882
Land use: Rotational grazing
Topography: Floodplain
Elevation: 15m
Slope: 0°
Soil material: Loamy alluvium over gravel
Soil drainage: Well
Date sampled: 6/10/10

Horizon	Thickness (cm)	Soil description
A	0-22	very dark brown (10YR 3/2) silt loam; moderately developed fine and medium polyhedral structure; many fine roots
AB	22-32	very dark brown and brown to dark brown (10YR 3/2+ 10YR 4/3) silt loam; moderately developed medium polyhedral structure; weak soil strength; friable; few fine roots
Bw1	32-46	brown to dark brown (10YR 4/3) silt loam; moderately developed coarse blocky structure; weak soil strength; friable; few fine roots
Bw2	46-63	brown to dark brown (10YR 4/3) clay loam; weakly developed medium and coarse blocky structure; slightly firm soil strength; friable; few fine roots
BC	63-80	brown to dark brown-olive brown (10YR 4/3-2.5Y 4/4) silt loam; weakly developed medium polyhedral structure; slightly firm soil strength; brittle; very few fine roots
C	80-90+	olive brown (2.5Y 5/4) sand; apedal; single grain

Sample name: MDC69
Soil Name: Woodbourne
Location: Jacksons Road, west side approximately 500m N of Middle Renwick Road
GPS Coordinates: E1673207 N5404873
Land use: Vineyard
Topography: Floodplain
Elevation: 16m
Slope: 2°
Soil material: Silty alluvium
Soil drainage: Well
Date sampled: 6/10/10

Horizon	Thickness (cm)	Soil description
A	0-26	very dark greyish brown (10 YR 3/2) silt loam; strongly developed fine polyhedral structure; weak soil friable; many fine and medium roots
AB	26-32	very dark greyish brown (10 YR 3/2) and dark yellowish brown (10 YR 4/4) silt loam; moderately developed fine and medium polyhedral structure; weak soil strength; friable; many fine and few medium roots
Bw1	32-48	dark yellowish brown to olive brown (10YR 4/4-2.5Y 4/4) silt loam; moderately developed medium and coarse blocky structure; slightly firm soil strength; brittle; many fine and few medium roots
Bw2	48-70	light olive brown (2.5Y 5/4) clay loam; moderately developed coarse blocky structure; slightly firm soil strength; brittle; few fine roots
Bw3	70-90+	olive brown (2.5Y 4.4) clay loam; weakly developed coarse blocky structure; slightly firm soil strength; brittle; few fine and few medium roots

Sample name: MDC70
Soil Name: Wairau
Location: West side of Jacksons Road, approximately 500m N of Middle Renwick Road
GPS Coordinates: E1673248 N5404666
Land use: Vineyard
Topography: Floodplain
Elevation: 19m
Slope: 0°
Soil material: Recent silty alluvium
Soil drainage: Well
Date sampled: 6/10/10

Horizon	Thickness (cm)	Soil description
A	0-25	very dark greyish brown (10YR 3/2) silt loam; moderately developed fine polyhedral structure; weak soil strength; very friable; many fine roots
AB	25-33	very dark greyish brown and olive brown (10YR 3/2+ 2.5Y 4/4) silt loam; moderately developed fine and medium polyhedral structure; weak soil strength; very friable; many fine roots
BC	33-65	olive brown (2.5Y 4/4) silt loam; weakly developed fine and medium blocky structure; weak soil strength ;friable; many fine and few medium roots
b A	65-80	very dark greyish brown (10YR 3/2) silt loam; moderately developed medium polyhedral structure; weak soil strength; friable; few fine roots
b Bw	80-95+	olive brown (2.5Y 4/4) silt loam; weakly developed medium blocky structure; weak soil strength; friable; very few fine roots

Sample name: MDC71
Soil Name: Renwick
Location: Approximately 3 km S of Renwick and 150m W of Brookby Road
GPS Coordinates: E1669255 N5401549
Land use: Rotational grazing
Topography: Floodpain
Elevation: 56m
Slope: 0°
Soil material: Slightly gravelly silty alluvium over gravel
Soil drainage: Well
Date sampled: 7/10/10

Horizon	Thickness (cm)	Soil description
A	0-18	brown to dark brown (10YR 4/3) heavy silt loam; 2% medium stones; weakly developed fine polyhedral and coarse blocky structure; slightly firm soil strength; brittle; many fine roots
AB	18-26	brown to dark brown and yellowish brown to light olive brown (10YR 4/3- 10YR 5/6 - 2.5Y 5/6) silt loam; 5% medium stones; moderately developed medium and coarse blocky structure; slightly firm soil strength; brittle; many fine roots
Bw1	26-37	yellowish brown to light olive brown (10YR 5/6-2.5Y 5/6) silt loam; 5% medium stones; moderately developed coarse blocky structure; slightly firm soil strength; brittle; few fine roots
Bw2	37-57	light olive brown (2.5Y 5/6) sandy loam; 20% medium to coarse stones; weakly developed coarse blocky structure; friable; very few fine roots
BC	57-75+	light olive brown (2.5Y 5/6) sand; 60% fine to coarse stones; loose

Sample name: MDC72
Soil Name: Brancott
Location: Approximately 2.8 km S of Renwick and 150m W of Brookby Road
GPS Coordinates: E1669326 N5401681
Land use: Rotational pasture
Topography: Floodplain
Elevation: 50m
Slope: 0°
Soil material: Slightly gravelly clayey alluvium
Soil drainage: Moderate
Date sampled: 7/10/10

Horizon	Thickness (cm)	Soil description
A	0-20	brown to dark brown (10YR 4/3) silt loam; 2% medium stones; developed medium and coarse blocky structure; slightly firm soil strength; brittle; many fine roots
AB	20-28	brown to dark brown and light olive brown (10YR 4/3 + 2.5Y 5/6) silt loam; weakly developed coarse blocky structure; slightly firm soil strength; brittle; many fine roots
Bw1	28-50	light olive brown (2.5Y 5/6) clay loam; 10% dark yellowish brown and light olive brown (10YR4/4 +2.5Y 5/4) fine distinct mottles; moderately developed coarse blocky structure; firm soil strength; brittle; few fine roots
Bw2	50-65	light olive brown (2.5Y 5/6) clay loam; 2% fine stones; 2% light grey (2.5Y 7/2) and 15% yellowish brown fine and medium distinct mottles; moderately developed coarse blocky structure; firm soil strength; brittle; very few fine roots
Bx	65-85+	dark yellowish brown (10YR 4/4) silt loam; 4% fine stones; 10%brown (10YR 5/3) and 20% yellowish brown (10YR 5/6) medium prominent mottles with pale brown (10YR 6/3) coatings in cracks; moderately to strongly developed coarse prismatic structure; very firm soil strength; brittle

Sample name: MDC73
Soil Name: Kaituna
Location: N side of Wairau River and Kaituna-Tuamarina Road and 6.8km NNE from SH 6
GPS Coordinates: E1672512 N5410817
Land use: Pasture
Topography: Fan
Elevation: 30m
Slope: 2°
Soil material: Weakly weathered silty colluvium
Soil drainage: Well
Date sampled: 7/10/10

Horizon	Thickness (cm)	Soil description
A	0-25	brown (10YR 3/3) silt loam; 1% fine stones; moderately to strongly developed fine and medium polyhedral structure; weak soil strength; friable; abundant fine roots
AB	25-32	brown and yellowish brown (10YR 3/4+ 10YR 5/6) silt loam; 1% fine stones; moderately to strongly developed fine polyhedral structure; weak soil strength; friable; many fine roots
Bw1	32-46	light olive brown (2.5Y 5/6) silt loam; 3% fine stones; moderately developed fine polyhedral structure; weak soil strength; friable; many fine roots
Bw2	46-60	light olive brown (2.5Y 5/6) heavy silt loam; 2% yellowish brown (10YR 5/6) fine distinct mottles; 2% fine stones; moderately developed coarse blocky structure; weak soil strength; friable; few fine roots
Bw3	60-85+	light olive brown (2.5Y 5/6) clay loam; 5% yellowish brown (10YR 5/6) fine distinct mottles; 3% fine stones; moderately developed coarse blocky structure; slightly firm soil strength; brittle; few roots

Sample name: MDC74
Soil Name: Rai
Location: 9.2 km ENE of Rai Valley, S side of Opouri Rd and near Kaiuna Stream
GPS Coordinates: E1657444 N5438093
Land use: Dairy
Topography: Terrace
Elevation: 78m
Slope: 2°
Soil material: Partly weathered silty alluvium over gravel
Soil drainage: Well
Date sampled: 13/10/10

Horizon	Thickness (cm)	Soil description
A	0-21	dark yellowish brown (10YR 4/4) silt loam; 2% medium and coarse stones; strongly developed fine and medium polyhedral structure; slightly firm soil strength; friable; profuse fine roots
AB	21-30	dark yellowish brown and yellowish brown (10YR 4/4+ 10YR 5/6) silt loam; 2% medium and coarse stones; strongly developed fine and medium polyhedral structure; weak soil strength; very friable; many fine roots
Bw1	30-55	yellowish brown (10YR 5/6) silt loam; strongly developed fine and medium polyhedral structure; weak soil strength; very friable; many fine roots
Bw2	55-75	yellowish brown (10YR 5/8) silt loam; 2% medium and coarse stones; moderately developed fine and medium polyhedral structure; weak soil strength; very friable; few fine roots
BC	60-85+	light olive brown to yellowish brown (2.5Y 5/6-10YR 5/8) sandy loam; 40% coarse to very coarse stones; weakly developed fine polyhedral structure; very friable

Sample name: MDC75
Soil Name: Ronga
Location: 8.6 km East of Rai Valley on the N side of Opouri Road, 100m from Opouri River
GPS Coordinates: E1656745 N5438210
Land use: Dairy
Topography: Terrace
Elevation: 72m
Slope: 3°
Soil material: Weakly weathered gravelly alluvium
Soil drainage: Well
Date sampled: 13/10/10

Horizon	Thickness (cm)	Soil description
A	0-12	dark yellowish brown (10YR 4/6) silt loam; 2% medium stones; strongly developed medium polyhedral structure; weak soil strength; friable; profuse fine roots
AB	12-16	yellowish brown and dark yellowish brown (10YR 5/6 + 10YR 4/6) silt loam; 10% medium stones; moderately developed fine and medium polyhedral structure; weak soil strength; very friable; profuse fine roots
Bw1	16-23	yellowish brown (10YR 5/5) sandy loam; 15% fine and medium stones; weakly developed fine polyhedral structure; very weak soil strength; very friable; many fine roots
BC	23-45	light olive brown (2.5Y 5/6) sand; 20% fine and medium stones; weakly developed fine polyhedral structure; very weak soil strength; very friable; many fine roots
C	46-80+	light olive brown to dark yellowish brown (2.5Y 4/6-10YR 4/6) coarse sand; 20% fine and medium stones; apedal; single grain; loose; few fine roots