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Soil Quality in the Marlborough Region 2013

RE500/2014/016

March 2014

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Report prepared for Marlborough District Council

March 2014

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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 they have a duty under Section 35 of the Resource Management Act (1991) to monitor and report on is soil, specifically to report on the “life supporting capacity of soil” and to determine whether current practices will meet the “foreseeable needs of future generations”. The collection of detailed soil monitoring data is therefore vital because it provides information on what effect current landuse activities are having on soil quality and whether they need to change or prioritise the way the land environment is managed. This is becoming increasingly important as some landuse activities are intensifying across some parts of New Zealand (e.g. dairying) putting pressure on our soils. Furthermore the way soils respond to different landuse activities can affect other parts of the environment. A good example is water quality, because soils act as buffers to capture and store nutrients such as nitrogen, phosphorus and microbes.

To help determine what effect landuse practices are having on soil quality, in 2000 the Marlborough District Council (MDC) became a participant in a national soil quality monitoring programme known as “The 500 Soils Project”. At the completion of this project the MDC implemented its own soil quality monitoring programme commencing in 2008 to continue assessing the quality of soils 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 in order to assess overall soil health;
- Provide an early-warning system to identify the effects of primary landuses on long-term soil productivity and the environment;
- Track specific, identified issues relating to the effects of landuse on long term soil productivity;
- Assist in the detection of spatial and temporal changes in soil quality; and
- Provide a mechanism to determine the effectiveness of regional policies and plans.

The aim of this study is to report on the results of the second round of soil sampling on a range of sites that were originally established and sampled in 2008 and analysed for a suite of soil physical, biological and chemical properties – indicators of soil quality.

2. Materials and methods

2.1 Samples sites

Soils were sampled from the same sites that were established and sampled in 2008 (Gray, 2009) with two exceptions. Site MDC42 under exotic forestry was not sampled as it is recommended that it is only necessary to re-sample exotic forestry sites up to every 10 years (Hill and Sparling, 2009). Site MDC38 was also not sampled as the drystock pasture landuse present in 2008 has been converted to a vineyard in the intervening 5 years since the last sampling; a vineyard site established on the Renwick soil type (i.e. site MDC37) is already included in sampling programme. A summary of the soil type, soil classification and landuse of the soil quality monitoring sites sampled are given in Table 1.

Table 1. Soil type, soil classification and landuse of soil quality monitoring sites.

Site code	Year established	Soil Order*	Soil series	Landuse	Sample location
MDC26a	2008	Pallic	Seddon	Vineyard	Under the Vine
MDC26b	2008				Under the wheel track
MDC26c	2008				Middle of the inter-row
MDC27a	2008	Gley	Motukara	Vineyard	Under the Vine
MDC27b	2008				Under the wheel track
MDC27c	2008				Middle of the inter-row
MDC28	2008	Gley	Motukara	Drystock	
MDC29	2008	Pallic	Warwick	Cropping; Peas	
MDC30a	2008	Pallic	Sedgemere	Vineyard	Under the Vine
MDC30b	2008				Under the wheel track
MDC30c	2008				Middle of the inter-row
MDC31	2008	Pallic	Sedgemere	Cropping; Spinach	
MDC32	2008	Pallic	Seddon	Cropping; Lucerne	
MDC33	2008	Pallic	Dashwood	Cropping; Peas	
MDC34	2008	Pallic	Warwick	Drystock; Lucerne	
MDC35	2008	Pallic	Jordan	Drystock	
MDC36a	2008	Pallic	Jordan	Vineyard	Under the Vine
MDC36b	2008				Under the wheel track
MDC36c	2008				Middle if the inter-row
MDC37a	2008	Brown	Renwick	Vineyard	Under the Vine
MDC37b	2008				Under the wheel track
MDC37c	2008				Middle if the inter-row
MDC39	2008	Pallic	Dashwood	Drystock	
MDC40	2008	Brown	Kaituna	Dairy	
MDC41	2008	Brown	Rai	Dairy; DSE applied	
MDC43	2008	Brown	Pelorus	Dairy	
MDC44	2008	Brown	Manaroa	Dairy	

*New Zealand Soil Classification

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 to a depth of 100 mm. 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 . 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.

At the cropping sites, an additional sample was also collected to assess aggregate stability. The sample was collected at the same interval as the intact cores by cutting a vertical block of soil with a spade approximately 10 cm square (10 cm high x 10 cm wide).

2.3 Soil quality indicators

A number of different soil properties were measured to assess soil quality. Soil chemical characteristics were assessed by soil pH, total carbon (C), total nitrogen (N), C:N ratio, Olsen Phosphorus (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, and at some sites aggregate stability (Table 2).

Table 2. Indicators used for soil quality assessments.

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

2.4 Soil analysis

2.4.1 Chemical

All chemical analysis was undertaken by Hills Laboratory, Hamilton. Total C and N were determined by dry combustion of air-dry soil. Soil pH was measured in water using glass electrodes and a 2:1 water to soil ratio (Blackmore et al., 1987). Olsen P was determined by extracting soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen, 1954) and measuring the phosphate concentration by the molybdenum blue method. Trace element concentrations in soils i.e. total recoverable copper (Cu), chromium (Cr), cadmium (Cd), arsenic (As), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) 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-nitrogen 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

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

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

2.5 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 & 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 (2011) and used in this report (Appendix A).

The trace element results (with the exception of 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 (MPI, 2011).

2.6 Statistics analysis and presentation

Total C, total N, AMN and Olsen P are expressed on a gravimetric basis to allow comparison with their respective target ranges. To determine comparisons in soil quality indicators between soils sampled in 2008 and 2013, data were tested for normality and a paired t-test performed. All statistical analysis was undertaken using Minitab version 16.2.

3. Results and discussion

3.1 Comparison of target ranges

Figure 1 shows the percentage of sites not meeting their target for a specific soil quality indicator. It should be noted that because the vineyard landuse was sampled in three locations (i.e. vine, wheel track and inter-row) at each site, it was decided that if any of the soil quality indicators in any of the three sample locations did not meet their respective target, the site was noted as non-compliant for that indicator.

Results show that two measures of soil organic resources i.e. total C and total N were within target ranges at all sites sampled, while soil pH, AMN and bulk density exceeded targets at one site (6%) and macroporosity at two sites (12%). The exception was Olsen P which was outside the target range at 10 sites (59%), although as will be discussed in section 3.7, only four sites exceeded the target for Olsen P with the remainder below the target range.

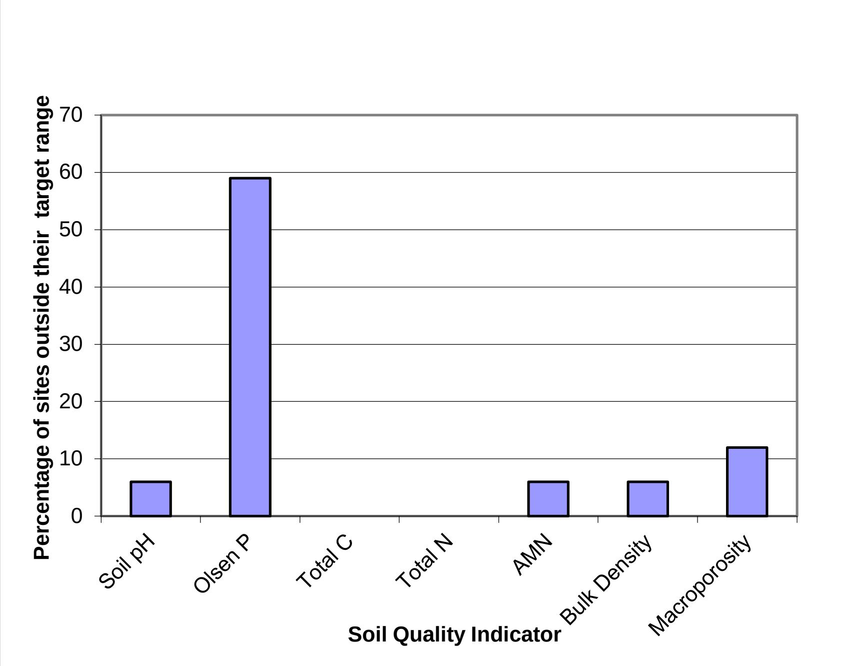

Figure 1. The percentage of sites not meeting their target range for a specific soil quality indicator.

The results of soil chemical, biological and physical analyses from soils sampled at each site are given in Appendix A and Tables 3, 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 to plants and the functioning of beneficial soil macro- and micro-organisms. Most plants and soil organisms will have an optimum pH range for growth, and the pH of the soil affects which species will grow best.

Table 3 indicates that with the exception of site MDC28, all sites had soil pH values within the acceptable target for their respective landuse. Site MDC28 had a pH value which exceeded the target range for soils under pasture. A high soil pH potentially reduces nutrient availability in soils, in particular P, although natural soil process i.e. breakdown of soil organic matter will result in a decrease soil pH over time.

3.3 Total Carbon

Total C is the total amount of C in soil which includes carbonates and soil organic matter C. Typically New Zealand soils contain only small amounts of carbonate; hence total C is generally considered a good measure of organic matter C 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).

Table 3 indicates that all sites had total soil C contents within their acceptable target ranges for their respective landuse. However, despite meeting their target, two of the four cropping sites (MDC29, MDC31) and one of the vineyard sites (MDC30 previously cropped) had soil C contents at the lower boundary of their range. Low soil C (organic matter) increases the risk of soil structural degradation e.g. low aggregate stability, high bulk density, formation of surface crusts. In turn, poor soil structure can negatively affect physical properties such as soil aeration, drainage, water infiltration rates and water holding capacity which can influence seed germination etc. It would therefore be desirable if cultural practices are adopted to increase the amount of soil C in these soils, either by increasing C inputs or decrease the rate of decomposition of C. This could include adopting residue management practices that maximise C returns to the soil, grow cover crops rather than leaving land fallow over winter, include a pasture phase in rotations or adopt minimal tillage (Ghani et al., 2009).

3.4 Total Nitrogen

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

As for total C, all sites had total N contents within acceptable target ranges for their respective landuse activity (Table 3).

3.5 Carbon to Nitrogen ratio

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

Although there are no specific soil quality target ranges for the C:N ratio, results were in the range generally considered acceptable (Table 3). For example, the C:N ratios measured in samples in this study were between 1:10 up to 1:12, which is typical of long term pasture soils. This reflects a high soil N status (Table 3), usually a result of many years of N-fixation by white clover, fertiliser inputs, deposition by grazing stock, and microbial incorporation into soil organic matter (Sparling et al., 2001).

3.6 Anaerobically Mineralisable Nitrogen

Anaerobically mineralisable nitrogen is a measure of the amount of N 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 N. 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).

All sites had AMN contents within their acceptable target ranges for their respective landuse, with the exception of one of the dairy pasture sites (MDC40) which marginally exceeded the upper limit (Table 3). In general the dairy sites typically had higher values than other landuses which is likely in part a result of the higher organic matter contents of these soils where N is mineralised by soil microbes, especially given the C:N ratios.

Table 3. Soil chemical, physical and biological characteristics of soils sampled in 2013. Data highlighted in bold represent values outside the recommended target range. Red values are below the target range while blue values exceed the recommended target range. n.d. not determined.

Site code	Landuse	Soil type	pH	Olsen P	AMN	Total C	Total N	Bulk density	Macroporosity (-10kPa)	Aggregate Stability	Macroporosity (-5kPa)	C:N ratio
				(mg/L)	(mg/kg)	(%)	(%)	(Mg/m3)	(% v/v)	(mwd)	(% v/v)	
MDC26a	Vineyard	Seddon	6.8	22	57	3.7	0.35	1.3	16.7		14.6	10.7
MDC26b			6.8	21	80	3.6	0.33	1.3	**5.7**		4.4	10.9
MDC26c			6.6	24	84	4.0	0.36	1.3	6.0		4.2	11
MDC27a	Vineyard	Motukara	6.5	19	97	3.7	0.36	1.1	12.1		10.3	10.2
MDC27b			6.6	31	122	4.2	0.43	1.2	10.8		9.4	9.7
MDC27c			6.7	12	131	3.9	0.42	1.1	13.5		12.0	9.4
MDC28	Drystock	Motukara	**7.0**	24	198	5.5	0.56	0.9	18.9		17.1	9.9
MDC29	Cropping	Warwick	6.1	**57**	51	2.6	0.28	1.2	24.0	0.51	21.4	9.4
MDC30a	Vineyard	Sedgemere	6.4	25	62	2.4	0.26	1.4	12.5		10.8	9.3
MDC30b			6.0	22	59	2.7	0.26	**1.5**	8.9		7.0	10.3
MDC30c			6.3	23	92	3.3	0.32	1.3	12.2		10.6	10.2
MDC31	Cropping	Sedgemere	6.4	35	59	2.7	0.28	1.3	19.2	0.38	17.2	9.7
MDC32	Cropping	Seddon	6.4	35	64	3.1	0.32	1.3	15.7		14.0	9.6
MDC33	Cropping	Dashwood	6.1	**47**	63	3.8	0.31	1.3	17.5	0.54	15.6	12.4
MDC34	Drystock	Warwick	6.2	**14**	104	3.6	0.38	n.d	n.d		n.d	9.7
MDC35	Drystock	Jordan	6.6	**10**	154	4.1	0.37	1.1	8.9		6.7	11.1
MDC36a	Vineyard	Jordan	6.7	**8**	62	3.2	0.33	1.3	10.2		8.6	9.6
MDC36b			6.6	**12**	86	3.4	0.35	1.3	7.0		5.8	9.7
MDC36c			6.7	**6**	123	3.8	0.37	1.2	7.7		5.7	10.1
MDC37a	Vineyard	Renwick	6.6	**41**	90	3.6	0.38	1.2	17.9		16.0	9.3
MDC37b			6.5	**52**	96	3.5	0.37	1.2	15.9		14.7	9.4
MDC37c			6.3	**37**	118	3.8	0.40	1.2	20.9		19.2	9.4
MDC39	Drystock	Dashwood	6.1	**6**	120	3.9	0.36	1.3	9.9		5.0	10.7
MDC40	Dairy	Kaituna	6.0	**43**	**267**	5.4	0.54	1.2	7.1		5.4	9.9
MDC41	Dairy	Rai	6.2	23	185	5.8	0.56	0.9	7.1		5.0	10.4
MDC43	Dairy	Pelorus	5.3	**7**	172	5.5	0.59	0.9	16.4		13.6	9.4
MDC44	Dairy	Manaroa	5.8	**14**	176	3.8	0.42	1.1	**4.0**		1.8	8.9

3.7 Olsen P

Phosphorus is an essential nutrient for both plants and animals. Only a small amount of the total P 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 P by measuring phosphate in soil solution and exchange surfaces.

Four sites had Olsen P values above their target range (Table 3). These included two of the cropping sites (MDC29, MDC33), a dairy site (MDC40) and a vineyard site (MDC37). 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; McDowell et al. 2004). 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, restricted grazing, low rate effluent application to soil, stream fencing, sediment traps, grass buffer strips, constructed wetlands, and application of amendments to sorb P in soil and drainage water (McDowell, 2012). Implementation of nutrient budget and management plans will help minimise excessive nutrient accumulation in soils and potential losses from soils and this should be advocated to land managers.

In comparison two dairy sites (MDC43, MDC44), three of the drystock sites (MDC34, MDC35, MDC39) and one of the vineyard sites (MDC36) had Olsen P values below concentrations considered optimal for maximum pasture/crop production. 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.

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, are subject to rapid drying, and plant roots may find it difficult to get purchase and absorb water and nutrients. In contrast, compacted soils have poor aeration and are slow draining.

All sites had bulk density values within their acceptable target ranges for their respective landuse with the exception of the wheel track region in one of the vineyard sites (MDC30b) which exceeded the upper limit (Table 3). At vineyard sites, soils were sampled from the vine, wheel track zone and middle of the inter-row in an attempt to capture the effects of how these different zones are managed within a vineyard. Clearly the high bulk density values in the wheel track zone are related to vehicle traffic which is subject to machinery movement to undertake activities such as mowing, spraying, harvesting and pruning. While vehicle traffic movements are an integral part of both cropping and vineyard operations, their movements should be minimised and avoided during wet soil conditions which exacerbate the potential for soil compaction (McLaren and Cameron, 1990).

3.9 Macroporosity

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

All but two sites met their target for macroporosity (Table 3). The two that did not included one of the dairy sites i.e. MDC44 and the wheel track area of one vineyard site i.e. MDC26b. Low macroporosity on dairy pasture soils has been noted previously in these soils in Marlborough (Gray, 2011) and has been observed in other regions of New Zealand including the Waikato, Auckland, and Wellington (Taylor et al., 2010; Stevenson, 2010; Sorensen, 2012). 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.

There are a range of potential soil, plant and environmental effects of soil compaction/pugging from animal treading. One of the most important is the effect on 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). 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 also compacted layers 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 a., 1998; McDowell et al., 2003).

There are a number of potential mitigation options that can be employed to prevent or minimise the effects of soil compaction at pasture sites, even on those soils not normally regarded as having a compaction problem. 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.

If soil compaction/pugging is already evident, the effects are not necessarily permanent with several remediation options available. These can include (i) natural soil amelioration processes i.e. wetting and drying cycles, freeze and thaw cycles, plant root growth and decay and soil fauna and flora activity; (ii) mechanical loosening of soil (also called subsoiling or aeration) (Drewry, et al., 2000; Burgess et al., 2000) and (iii) cultivation possibly combined with growing a fodder crop prior to re-sowing a new pasture.

At vineyard sites, not surprisingly, in all instances soils sampled from the wheel track has lower macroporosity values than those found under the vine and in the inter-row, although only one site had a value below its respective target value (Table 3). 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 restricted to three of the cropping sites where values ranged from 0.38 to 0.54 Mean Weight Diameter (MWD) (Table 3). Although there are no specific target ranges currently available for aggregate stability, generally any value below about 1.5 MWD is considered low and likely to have a negative effect on crop production (Francis et al., 1991). Using this threshold, all three sites sampled have values below what is considered desirable for optimal crop growth.

The low aggregate stability values in the cropping soils are likely to be linked to the relatively low organic matter i.e. total C contents in these soils. In addition, most of the cropping sites are on Pallic soils, which typically have high slaking potential (Hewitt, 2010) and are usually regarded as unsuitable for continuous cropping to due to their potential for soil structural collapse.

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. Cu and Zn, 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. Cd and As 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 4 summarises trace element concentrations in soils. The concentrations are similar to those found in soils at other monitoring sites in other regions of New Zealand including those found previously in Marlborough (Taylor et al, 2010; Guinto, 2011; Sorensen; 2012; Curran-Cournane and Taylor, 2012; Gray, 2013). With the exception of Cd at three of the dairy pasture sites (MDC40, MDC41, MDC44) and one of the cropping sites (MDC29), concentrations are similar to typical background concentrations found in New Zealand soils and well within suggested upper limits for trace elements in soils as suggested by the New Zealand Water and Waste Association (NZWWA, 2003) limits given in Appendix A.

Cadmium is a non-essential, naturally occurring heavy metal that is also an incidental impurity in most types of phosphate fertiliser. With continuous phosphate fertiliser application, there is the potential for a gradual accumulation of Cd in soils over time (Gray et al., 1999). All but one sample (i.e. 0.64 mg kg^{-1} at site MDC41) had soil Cd concentrations within thresholds developed as part of a Tiered Fertiliser Management System (TFMS) outlined in the New Zealand Cadmium Management Strategy (MPI, 2011). The TFMS is a system for linking soil Cd concentrations to different types of management action. So 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 set of products and application rates to manage Cd accumulation so that Cd does not exceed acceptable thresholds within the next 100 years. For soils exceeding 1 mg kg^{-1} but 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 100 years. While the monitoring of soil Cd is the responsibility of Regional Council, the implementation of these strategies is the responsibility of the fertiliser industry.

Table 4. Trace element concentrations (mg/kg) in soils sampled in the Marlborough Region 2013.

Site code	Landuse	Zn	Cu	Cr	As	Pb	Ni	Hg	Cd
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
MDC26a	Vineyard	78	15	29	3.2	10	21	0.03	0.18
MDC26b		73	15	28	3.3	10	21	0.03	0.17
MDC26c		78	16	29	3.3	10	21	0.03	0.2
MDC27a	Vineyard	77	18	29	4.2	19	30	0.06	0.18
MDC27b		69	18	29	4.2	18	29	0.06	0.16
MDC27c		64	17	27	3.9	18	28	0.06	0.17
MDC28	Drystock	66	16	26	3.6	17	25	0.06	0.21
MDC29	Cropping	71	8	20	2.6	10	15	0.03	0.32
MDC30a	Vineyard	66	11	30	3.0	10	19	0.03	0.18
MDC30b		62	10	24	2.8	10	16	0.04	0.17
MDC30c		65	11	28	2.9	10	18	0.03	0.18
MDC31	Cropping	62	10	27	2.8	10	17	0.04	0.17
MDC32	Cropping	73	12	28	2.9	10	21	0.03	0.21
MDC33	Cropping	70	6	25	2.9	9	14	0.02	0.15
MDC34	Drystock	68	8	28	2.5	10	18	0.03	0.19
MDC35	Drystock	37	5	20	2.1	8	11	0.04	0.14
MDC36a	Vineyard	50	9	22	2.5	9	12	0.03	0.10
MDC36b		38	9	18	2.5	8	10	0.03	0.11
MDC36c		37	8	16	2.2	8	10	0.03	0.10
MDC37a	Vineyard	72	11	25	3.7	11	16	0.02	0.21
MDC37b		64	10	22	2.5	11	14	0.02	0.21
MDC37c		65	10	19	2.5	11	14	0.02	0.21
MDC39	Drystock	54	7	27	3.0	9	14	0.02	0.09
MDC40	Dairy	56	15	22	2.8	10	11	0.03	0.48
MDC41	Dairy	63	23	62	4.8	12	24	0.13	0.64
MDC43	Dairy	68	22	30	4.1	12	11	0.08	0.27
MDC44	Dairy	58	16	21	3.7	10	14	0.04	0.34

3.12 Changes in soil quality since 2008

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 (Wheeler and Edmeades, 1991). Because only one set of data has been collected since the sites were established and sampled in 2008, trends cannot be determined. Nonetheless, soil quality values measured at two sample dates can provide a useful snapshot of change over the 5 years interval. The mean change in soil quality indicators for soils sampled in 2008 and again in 2013 are presented in Table 5. It should be noted that because soils were only sampled in the zone of the wheel track of vineyards sites in 2008, comparisons were made to soils sampled from this zone in 2013.

There were only two statistically significant changes in soil indicators between sampling dates. There was an increase in soil Cd concentration at the vineyard sites reflecting the soil application of phosphate fertiliser which contain Cd as an incidental impurity, as discussed in section 3.11. However, despite this increase in soil Cd, concentrations remain in line with typical background concentrations found in New Zealand soils, generally <0.20 mg/kg.

The other significant difference was an increase in soil macroporosity values at the dairy sites. Whilst values are still on the low side for three of the four dairy sites, the increase is a positive outcome. As discussed, soil compaction is a concern across intensive landuse in all parts of New Zealand, and can potentially result in a range of both production and environmental issues.

Table 5. Mean changes in soil quality indicators for sites sampled in 2008 and 2013. * significant level of change (*$p < 0.05$).

Site code	Landuse	pH	Olsen P	AMN	Total C	Total N	Aggregate stability	Bulk density	Macroporosity	Cd
			mg/L	(mg/kg)	(%)	(%)	(mwd)	Mg/m3	-10kPa (%v/v)	(mg/kg)
MDC26b	Vineyard	-0.1	-3	-59	-0.20	0.33		0.5	-12	0.07
MDC27b	Vineyard	0.3	18	-3	0.20	0.43		0.2	-11	0.06
MDC30b	Vineyard	0.0	-3	24	0.40	0.26		-0.1	0	0.04
MDC36b	Vineyard	-0.2	1	-22	0.00	0.35		0.4	5	0.01
MDC37b	Vineyard	-0.4	22	-33	-0.40	0.37		0.8	5	0.04
	Mean	-0.1	7	-19	0.00	0.35		0.3	-3	0.04*
MDC29	Cropping	-0.1	16	20	0.30	0.28	-0.1	0.0	10	0.05
MDC31	Cropping	0.2	-1	26	0.30	0.28	-0.1	0.0	-1	0.00
MDC32	Cropping	0.1	-8	-15	0.60	0.32		-0.3	8	0.01
MDC33	Cropping	0.6	-33	1	-0.10	0.31	-1.0	0.4	13	-0.01
	Mean	0.2	-7	8	0.28	0.30	-0.4	0.0	7	0.01
MDC28	Drystock	1.2	-3	71	-0.50	0.56		1.1	-2	0.11
MDC34	Drystock	0.1	-15	-16	-0.20	0.38		0.6	-15	0.04
MDC35	Drystock	1.2	-4	37	0.90	0.37		-0.5	-4	0.03
MDC39	Drystock	0.1	-1	-7	-0.40	0.36		0.8	-2	-0.01
	Mean	0.7	-6	21	-0.05	0.42		0.5	-3	0.04
MDC40	Dairy	0.0	3	-23	0.70	0.54		-0.2	4	0.05
MDC41	Dairy	0.1	2	-160	-0.60	0.56		1.2	2	0.05

MDC43	Dairy	0.1	-2	4	-0.90	0.59		1.5	3	0.01
MDC44	Dairy	-0.4	6	-12	0.00	0.42		0.4	2	0.09
	Mean	0.0	2	-48	-0.20	0.53		0.7	3*	0.05

4. Summary

Monitoring has highlighted that there are several soil quality issues under some land use activities, although in the majority of instances these can be reversed with appropriate management.

- The primary issue is high Olsen P values found at four sites across three different landuses. High soil P has the potential to negatively affect water quality if it ends up in surface water bodies. Implementation of nutrient budget plans will help minimise excessive nutrient accumulation in soils, while farm management plans can help identify source areas for P accumulation and present site specific mitigation methods that could implemented on farm. These options should be advocated to land managers across all industry sectors.

- Low aggregate stability, high bulk density along with organic matter concentrations at the lower end of the desired target range is also a potential issue at the cropping sites. This has resulted in poor soil structure at these sites which may potentially negatively affect crop performance and predispose the soil to surface runoff, nutrient loss, erosion and flooding. Cultural practices which maintain or enhance soil C contents to stabilise and improve soil structure should be encouraged in cropping soils.

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

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

5. Recommendations

- Future work should focus on re-sampling these and other established sites to obtain as a minimum four or five repeat samples to determine whether there are any discernable trends in soil quality indicators.

- Many of the trends in declining soil quality can be offset by better land management practices i.e. nutrient budgets/nutrient management plans, changing grazing practices during high soil moisture etc. Council should continue to educate land managers on strategies to protect the environment while achieving an economic return from the land.

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7. Appendix A

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

Olsen P target ranges from Hill and Sparling (2009) are no longer used. Updated targets from Taylor (2011) are now used and presented below.

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

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

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**

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

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

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	4	**5**	5.5	7.2	**7.6**	8.5
Cropping and horticulture on Organic	4	**4.5**	5	7	**7.6**	
Forestry on all soils except Organic		**3.5**	4	7	**7.6**	
Forestry on Organic soils	exclusion					

Olsen P target ranges (units not reported) from Taylor (2011)

Landuse	Soil type	Suggested Olsen P target
Pasture, horticulture and cropping	Volcanic	20-50
Pasture, horticulture and cropping	Sedimentary and Organic soils	20-35
Pasture, horticulture and cropping	Raw sands and Podzols with low AEC	5
Pasture, horticulture and cropping	Raw sands and Podzols with medium AEC and above AEC	15-25
Pasture, horticulture and cropping	Other soils	20-45
Pasture, horticulture and cropping	Hill country	15-20
Forestry	All soils	5-30

Guideline values for trace element concentrations in soil, adapted from NZWWA (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

Soil moisture release data 2013 – Landcare Research

Marlborough District Council Soil Quality Monitoring 2013
Moisture Release Results
Job: 682208-0047
January 2014

Lab Number	Cient ID	Liner Number	Initial Water Content	Dry Bulk Density	Particle Density	Total Porosity	Macro Porosity	Air Filled Porosity	Vol. WC 5kPa	Vol. WC 10kPa	Vol. WC 100kPa	Vol. WC 1500kPa	Readily Available Water	Total Available Water
			(%, w/w)	(t/m3)	(t/m3)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)
HP5825a	MDC26a/1	1131	27.8	1.28	2.65	51.8	14.4	16.7	37.4	35.1	28.7	17.1	6.4	18.0
HP5825b	MDC26b/1	1042	32.2	1.36	2.62	48.3	2.7	3.9	45.6	44.4	37.8	18.0	6.7	26.4
HP5825c	MDC26c/1	1242	34.5	1.30	2.63	50.5	4.0	6.0	46.6	44.5	37.1	17.0	7.5	27.5
HP5826a	MDC26a/2	1233	28.9	1.30	2.63	50.5	12.3	14.1	38.2	36.4	30.6	17.4	5.8	19.0
HP5826b	MDC26b/2	1580	40.7	1.16	2.59	55.4	7.4	9.0	48.0	46.4	41.4	15.9	5.0	30.4
HP5826c	MDC26c/2	1571	37.2	1.24	2.62	52.7	5.3	6.9	47.4	45.8	40.3	17.0	5.5	28.9
HP5827a	MDC26a/3	1057	24.9	1.28	2.64	51.6	17.2	19.3	34.4	32.3	26.1	16.6	6.3	15.7
HP5827b	MDC26b/3	1367	32.2	1.37	2.64	48.2	3.2	4.2	45.0	44.0	38.2	18.2	5.7	25.8
HP5827c	MDC26c/3	1596	39.2	1.25	2.61	52.2	3.4	5.1	48.9	47.1	41.4	17.2	5.7	29.8
HP5828a	MDC27a/1	1602	39.9	1.13	2.60	56.7	10.7	12.6	46.0	44.1	37.6	18.8	6.5	25.3
HP5828b	MDC27b/1	1624	40.2	1.14	2.57	55.7	9.3	10.9	46.4	44.8	38.0	20.6	6.8	24.1
HP5828c	MDC27c/1	1078	41.8	1.07	2.59	58.7	12.6	14.4	46.1	44.3	37.8	17.3	6.5	26.9
HP5829a	MDC27a/2	1709	36.9	1.22	2.62	53.6	8.8	10.4	44.8	43.2	37.9	20.2	5.3	23.0
HP5829b	MDC27b/2	1726	40.2	1.14	2.59	55.9	9.3	10.6	46.6	45.3	39.0	19.6	6.3	25.6
HP5829c	MDC27c/2	1375	38.8	1.15	2.61	56.1	10.6	12.1	45.4	44.0	38.6	18.1	5.4	25.9
HP5830a	MDC27a/3	1541	43.2	1.09	2.63	58.6	11.3	13.2	47.3	45.4	38.9	18.5	6.5	26.9
HP5830b	MDC27b/3	1568	37.5	1.17	2.61	55.0	9.6	11.0	45.4	44.0	38.0	18.4	6.0	25.6
HP5830c	MDC27c/3	1241	38.1	1.12	2.59	56.8	12.8	14.1	44.0	42.7	38.4	17.9	4.3	24.8
HP5831a	MDC28a	1504	34.8	0.99	2.62	62.3	18.7	20.1	43.5	42.2	35.3	18.0	6.8	24.2
HP5831b	MDC28b	1648	53.8	0.90	2.60	65.3	14.2	16.3	51.1	49.0	41.2	18.9	7.8	30.1
HP5831c	MDC28c	1564	47.3	0.88	2.58	65.8	18.5	20.4	47.4	45.4	39.1	18.6	6.3	26.8
HP5832a	MDC29a	1274	19.7	1.24	2.65	53.4	23.2	25.4	30.1	28.0	23.6	14.5	4.4	13.6
HP5832b	MDC29b	1576	19.2	1.25	2.63	52.5	18.8	22.3	33.7	30.2	23.6	14.3	6.6	15.9
HP5832c	MDC29c	1039	20.3	1.21	2.61	53.7	22.1	24.4	31.7	29.3	25.2	13.3	4.1	16.0
HP5833a	MDC30a/1	1256	23.5	1.30	2.62	50.5	13.5	15.1	37.0	35.4	30.9	17.0	4.5	18.5
HP5833b	MDC30b/1	1081	15.7	1.49	2.62	43.3	6.5	8.3	36.8	35.0	26.9	17.7	8.1	17.3
HP5833c	MDC30c/1	1668	24.3	1.31	2.61	49.6	9.7	11.4	40.0	38.2	32.6	17.6	5.6	20.6
HP5834a	MDC30a/2	1086	24.0	1.37	2.63	47.8	9.0	10.6	38.8	37.2	32.6	18.7	4.6	18.6
HP5834b	MDC30b/2	1303	18.3	1.46	2.61	43.9	6.4	8.4	37.5	35.5	26.9	18.4	8.5	17.0
HP5834c	MDC30c/2	1200	23.3	1.32	2.62	49.6	11.9	13.6	37.7	36.0	30.7	17.0	5.3	19.0
HP5835a	MDC30a/3	1071	19.2	1.40	2.62	46.6	10.0	11.9	36.6	34.7	29.3	18.1	5.5	16.7
HP5835b	MDC30b/3	1073	16.2	1.47	2.63	44.3	8.0	10.0	36.3	34.3	25.5	18.0	8.8	16.3
HP5835c	MDC30c/3	1072	20.2	1.41	2.65	46.8	10.2	11.7	36.5	35.1	29.7	18.1	5.5	17.1
HP5836a	MDC31a	1513	21.3	1.31	2.64	50.6	17.5	19.2	33.1	31.4	26.7	15.1	4.7	16.3
HP5836b	MDC31b	1629	21.0	1.28	2.63	51.2	16.3	18.4	34.9	32.8	26.4	15.2	6.4	17.6
HP5836c	MDC31c	1727	21.9	1.29	2.66	51.5	17.7	20.0	33.7	31.5	26.6	14.8	4.8	16.6
HP5837a	MDC32a	1173	24.0	1.29	2.65	51.2	14.2	15.8	37.1	35.4	29.3	16.9	6.1	18.4
HP5837b	MDC32b	1567	25.5	1.26	2.62	51.8	13.5	15.0	38.3	36.8	30.3	16.2	6.5	20.6
HP5837c	MDC32c	1100	27.4	1.23	2.63	53.1	14.4	16.3	38.8	36.8	30.9	16.1	5.9	20.6
HP5838a	MDC33a	1630	20.4	1.32	2.64	49.9	16.3	18.3	33.6	31.6	26.6	15.6	5.0	16.0
HP5838b	MDC33b	1243	20.9	1.34	2.65	49.3	14.7	16.6	34.6	32.7	26.7	16.7	6.0	16.0
HP5838c	MDC33c	1056	20.2	1.33	2.63	49.4	15.8	17.7	33.7	31.7	27.5	16.1	4.2	15.6
HP5839a	MDC35a	1229	47.8	1.10	2.55	57.0	5.5	7.6	51.5	49.4	41.3	14.0	8.1	35.4
HP5839b	MDC35b	1388	37.1	1.27	2.59	51.0	4.3	5.9	46.7	45.1	37.3	13.2	7.8	31.9
HP5839c	MDC35c	1238	48.9	1.03	2.57	59.9	10.3	13.1	49.6	46.8	37.3	13.6	9.6	33.2
HP5840a	MDC36a/1	1301	30.4	1.37	2.60	47.4	5.3	6.6	42.1	40.8	35.2	15.3	5.6	25.5
HP5840b	MDC36b/1	1591	26.2	1.43	2.60	45.1	5.0	6.3	40.1	38.8	32.5	16.0	6.2	22.8
HP5840c	MDC36c/1	1702	34.0	1.31	2.58	49.2	2.8	4.5	46.4	44.7	36.4	16.3	8.3	28.4
HP5841a	MDC36a/2	1613	32.9	1.24	2.58	52.0	11.2	12.8	40.7	39.2	32.9	15.9	6.3	23.3
HP5841b	MDC36b/2	1520	33.7	1.28	2.59	50.6	6.7	8.0	43.9	42.6	36.1	17.0	6.5	25.6
HP5841c	MDC36c/2	1217	41.8	1.13	2.52	55.0	7.0	9.4	48.0	45.6	35.3	14.2	10.4	31.5
HP5842a	MDC36a/3	1166	31.4	1.28	2.60	50.9	9.3	11.1	41.6	39.8	33.2	16.5	6.7	23.4
HP5842b	MDC36b/3	1713	31.5	1.32	2.59	48.9	5.7	6.6	43.3	42.3	37.5	18.4	4.9	24.0
HP5842c	MDC36c/3	1191	39.7	1.16	2.54	54.4	7.3	9.1	47.2	45.3	38.6	16.0	6.7	29.3
HP5843a	MDC37a/1	1547	29.6	1.15	2.59	55.8	18.0	19.9	37.8	35.9	30.7	18.9	5.2	17.0
HP5843b	MDC37b/1	1209	27.4	1.24	2.60	52.4	14.0	15.6	38.3	36.8	32.1	17.8	4.7	19.0
HP5843c	MDC37c/1	1514	21.2	1.23	2.58	52.5	19.0	20.8	33.5	31.7	26.7	17.3	5.0	14.5
HP5844a	MDC37a/2	1326	32.8	1.16	2.59	55.4	15.7	17.6	39.6	37.8	32.6	18.6	5.2	19.2
HP5844b	MDC37b/2	1028	28.3	1.18	2.58	54.3	16.6	17.6	37.8	36.7	31.7	17.7	5.1	19.0
HP5844c	MDC37c/2	1601	30.8	1.04	2.58	59.7	24.6	26.8	35.0	32.9	27.1	16.3	5.8	16.5
HP5845a	MDC37a/3	1084	31.2	1.21	2.61	53.5	14.4	16.2	39.1	37.3	32.0	17.6	5.3	19.7
HP5845b	MDC37b/3	1302	22.6	1.33	2.61	49.1	13.6	14.6	35.5	34.5	29.9	18.2	4.6	16.3
HP5845c	MDC37c/3	1336	24.4	1.27	2.58	50.9	14.0	15.2	37.0	35.7	30.7	17.2	5.0	18.5
HP5846a	MDC39a	1205	30.7	1.34	2.58	47.9	1.3	2.9	46.6	45.0	38.3	16.5	6.7	28.5
HP5846b	MDC39b	1640	30.3	1.21	2.61	53.8	6.7	9.5	47.1	44.3	34.6	14.8	9.7	29.5
HP5846c	MDC39c	1392	26.2	1.22	2.58	52.8	7.1	10.2	45.8	42.6	32.9	15.0	9.7	27.6
HP5847a	MDC40a	1636	36.7	1.21	2.56	52.9	5.9	7.4	47.0	45.5	40.2	22.6	5.3	22.9
HP5847b	MDC40b	1290	38.1	1.21	2.58	53.3	3.6	5.2	49.7	48.1	41.3	21.6	6.8	26.5
HP5847c	MDC40c	1177	43.2	1.11	2.58	57.1	6.8	8.6	50.3	48.5	42.0	22.0	6.5	26.5
HP5848a	MDC41a	1604	61.2	0.93	2.49	62.8	3.0	5.2	59.8	57.6	48.9	28.1	8.7	29.5
HP5848b	MDC41b	1700	61.6	0.90	2.49	63.7	5.3	7.2	58.5	56.5	47.5	27.8	9.0	28.7
HP5848c	MDC41c	1259	57.2	0.94	2.51	62.5	6.6	8.9	55.9	53.6	44.9	25.5	8.7	28.1
HP5849a	MDC43a	1370	45.3	0.98	2.52	61.2	13.8	16.4	47.4	44.8	36.5	28.6	8.3	16.1
HP5849b	MDC43b	1032	62.4	0.80	2.45	67.3	13.7	16.8	53.6	50.5	40.7	25.1	9.7	25.4
HP5849c	MDC43c	1598	61.4	0.83	2.47	66.3	13.2	16.1	53.1	50.2	42.0	25.7	8.1	24.5
HP5850a	MDC44a	1158	57.0	1.01	2.63	61.6	1.7	4.2	59.9	57.4	48.1	17.0	9.3	40.4
HP5850b	MDC44b	1087	47.6	1.13	2.65	57.3	1.1	3.1	56.2	54.2	45.0	21.0	9.2	33.2
HP5850c	MDC44c	1701	53.4	1.05	2.66	60.7	2.5	4.7	58.2	56.0	46.3	16.3	9.7	39.7

Note: Macro-porosity cited here is determined between total porosity and tension of -5 kPa, for consistency with the National Soils Database of New Zealand (NSD).
Air Filled-porosity cited here is determined between total porosity and tension of -10 kPa. This can be referred to as Macro-porosity. It is important to be aware what tension has been used, paticularly with historical or NSD data.

Sample MDC 44a (HP5850a) the liner was mis-recorded in the field as 1558 but was in fact 1158.

A visual inspection of the sub-sampled cores yielded the following:

MDC26a/1 (HP5825a), MDC26a/2 (HP5826a), MDC26a/3 (HP5827a): confirmed porosity variation by breaking the core apart for visual inspection. This showed pore architecture that matched data.
MDC 29c(HP5832c): sub-sampled core was partially repacked after a large stone was removed from the core.
MDC 39a (HP5846a): appeared compacted relative to its replicates.
MDC 36c/2 (HP5841c), MDC 36c/3 (HP5842c): contained areas of fibrous roots in the sub-sampled core.
MDC 37c/2 (HP5844c): sample was received in a disturbed state. The sub-sampled core was also partially repacked after removal of a large stone.

Checked by: John Claydon
Laboratory manager

Analyst: DT

Soil chemical data 2013 – Hills Laboratory

R J Hill Laboratories Ltd																							

Laboratory Job Number:	1183374																						
		pH	Olsen P	ASC_%	AMN	C/N Ratio	Total C	Total N	Total' Zn	Total' Cu	Total' Cr	Total' As	Total' Pb	Total' Ni	Total' Hg	Total' Cd	Potassium	Calcium	Magnesium	Sodium	CEC	Base Satu	olume Weight
		pH	OP_mg/L	ASC_%	AMN	CN	tC_%	tN_%	tZn_mg/kg	Cu_mg/kg	tCr_mg/kg	tAs_mg/kg	tPb_mg/kg	tNi_mg/kg	Hg_mg/kg	Cd_mg/kg	K_me/100g	Ca_me/100g	Mg_me/100g	Na_me/100g	CEC	tBS	VW_g/mL
		pH Units	mg/L	%	µg/g		%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	me/100g	me/100g	me/100g	me/100g	me/100g	%	g/mL
	Sample Name																						
	MDC26a	6.8	22	31	57	10.7	3.7	0.35	78	15	29	3.2	10.3	21	0.03	0.18	0.5	12.1	1.74	0.13	17	83	0.87
	MDC26b	6.8	21	29	80	10.9	3.6	0.33	73	15	28	3.3	10.3	21	0.03	0.17	0.77	11.8	1.84	0.07	17	86	0.87
	MDC26c	6.6	24	29	84	11	4	0.36	78	16	29	3.3	10.3	21	0.03	0.2	0.77	12.2	1.91	0.06	18	84	0.85
	MDC28	7	24	17	198	9.9	5.5	0.56	66	16	26	3.6	17.3	25	0.06	0.21	0.97	9.1	8.67	2.34	25	85	0.68
	MDC29	6.1	57	27	51	9.4	2.6	0.28	71	8	20	2.6	10	14.5	0.03	0.32	0.43	9.2	0.79	0.07	14	73	1.02
	MDC30a	6.4	25	29	62	9.3	2.4	0.26	66	11	30	3	10.3	18.9	0.03	0.18	0.39	9.6	1.13	0.11	15	76	0.99
	MDC30b	6	22	28	59	10.3	2.7	0.26	62	10	24	2.8	10.1	16.4	0.04	0.17	0.26	11.1	1.1	0.13	16	78	1.12
	MDC30c	6.3	23	28	92	10.2	3.3	0.32	65	11	28	2.9	10.2	18.4	0.03	0.18	0.37	10.8	1.29	0.14	17	74	0.91
	MDC31	6.4	35	30	59	9.7	2.7	0.28	62	10	27	2.8	10.2	17.1	0.04	0.17	0.3	10	1.29	0.14	15	77	0.98
	MDC32	6.4	35	29	64	9.6	3.1	0.32	73	12	28	2.9	10.1	21	0.03	0.21	0.48	10.9	1.16	0.11	16	77	0.92
	MDC33	6.1	47	32	63	12.4	3.8	0.31	70	6	25	2.9	9.4	13.7	0.02	0.15	1.17	8.7	1.62	0.07	18	66	1
	MDC34	6.2	14	28	104	9.7	3.6	0.38	68	8	28	2.5	9.6	18.1	0.03	0.19	0.67	10.4	1.07	0.1	16	76	0.89
	MDC36a	6.7	8	26	62	9.6	3.2	0.33	50	9	22	2.5	8.5	11.7	0.03	0.1	0.44	9.6	1.18	0.11	14	79	0.83
	MDC36b	6.6	12	29	86	9.7	3.4	0.35	38	9	17.5	2.5	8.3	10	0.03	0.11	0.47	9.4	1.15	0.1	14	80	0.91
	MDC36c	6.7	6	27	123	10.1	3.8	0.37	37	8	16.1	2.2	8.1	10	0.03	0.1	0.29	11.2	1.16	0.08	16	80	0.79
	MDC37a	6.6	41	27	90	9.3	3.6	0.38	72	11	25	3.7	11.2	15.6	0.02	0.21	1.08	11.6	2.07	0.07	19	78	0.83
	MDC37b	6.5	52	29	96	9.4	3.5	0.37	64	10	22	2.5	10.8	13.7	0.02	0.21	1.16	9.9	1.58	< 0.05	16	78	0.95
	MDC37c	6.3	37	29	118	9.4	3.8	0.4	65	10	19	2.5	11.2	14.4	0.02	0.21	0.74	11.6	1.47	0.05	19	74	0.83
	MDC39	6.1	6	27	120	10.7	3.9	0.36	54	7	27	3	9	14.1	0.02	0.09	1.12	6.5	2.29	0.11	15	66	0.97
	MDC40	6	43	30	267	9.9	5.4	0.54	56	15	22	2.8	10.1	11	0.03	0.48	1.63	10.2	1.38	0.09	22	60	0.73
	MDC35	6.6	10	35	154	11.1	4.1	0.37	37	5	19.8	2.1	8.2	10.9	0.04	0.14	0.17	12.3	0.72	0.09	15	91	0.8
	MDC44	5.8	14	30	176	8.9	3.8	0.42	58	16	21	3.7	10.3	14.2	0.04	0.34	0.33	8.6	0.75	0.09	17	57	0.75
	MDC27a	6.5	19	23	97	10.2	3.7	0.36	77	18	29	4.2	19	30	0.06	0.18	0.62	12.2	3.63	0.21	20	82	0.8
	MDC27b	6.6	31	21	122	9.7	4.2	0.43	69	18	29	4.2	18.3	29	0.06	0.16	0.91	13.5	4.32	0.19	22	85	0.76
	MDC27c	6.7	12	23	131	9.4	3.9	0.42	64	17	27	3.9	18	28	0.06	0.17	0.45	13.7	3.99	0.21	21	87	0.76
	MDC43	5.3	7	66	172	9.4	5.5	0.59	68	22	30	4.1	11.7	11.4	0.08	0.27	0.28	6.2	1.04	0.1	27	29	0.68
	MDC41	6.2	23	62	185	10.4	5.8	0.56	63	23	62	4.8	12.3	24	0.13	0.64	0.6	11.5	1.39	0.11	24	57	0.75