Soil Quality In The Marlborough Region In 2011

Technical publication No 12-004

MARLBOROUGH DISTRICT COUNCIL

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MDC Technical Report No: 12-004

ISSN 1179-8181 (Print)
ISSN 1179-819X (Online)

ISBN 978-1-927159-14-9 (Print)
ISBN 978-1-927159-15-6 (Online)

File Reference/Record No: E355-001-001-06/1275749

March 2012

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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 nine new monitoring sites that included eight dairy sites and one under native lowland forest. These sites represented 3 different soil types from 2 soil orders.

Results indicate that in general the soils are in fairly good condition. For example indicators of soil acidity, organic reserves and soil fertility were all within currently acceptable soil quality target ranges. The only concern was one site showing signs of soil compaction i.e. low macroporosity and several other sites showing early signs. These results put these soils at risk of poor aeration and impeded drainage which may potentially affect pasture production and predispose the soil to surface runoff, nutrient loss, erosion and flooding. While soil compaction isn’t permanent, it clearly should be avoided and remediated where necessary. A range of beneficial management options to prevent and remediate soil compaction are outlined in the report.

Trace elements were also well within suggested upper limits for concentrations in soils. However for cadmium, average concentrations were about double those of typical background concentrations for soils. It is suggested there should be continued monitoring for cadmium in soils on intensively grazed pasture to determine how widely and to what concentrations cadmium has accumulated, especially at sites which have cadmium concentration approaching new MAF trigger thresholds.

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 becoming increasingly important as land use activities such as dairying are intensifying across New Zealand and putting pressure on our soils. Furthermore the way soils respond to different land activities can affect other parts of the environment including water quality as soils act as buffers to capture and store nutrients such as N, P and microbes.

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.

While a network of soil quality monitoring sites have been established over the last 3 years in Marlborough, it is recognised that we still have no soil information under some landuses in some parts of the region. This report presents the results for 9 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 9 sites that included 8 dairy sites and one site under native lowland forest. These sites represented 3 different soil types from 2 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
MDC76	Rai	Brown	Dairy; grazed
MDC77	Rai	Brown	Dairy; grazed
MDC78	Rai	Brown	Lowland forest
MDC79	Ronga	Recent	Dairy; grazed
MDC80	Ronga	Recent	Dairy; grazed
MDC84	Ronga	Recent	Dairy; grazed
MDC85	Rai	Brown	Dairy; grazed
MDC86	Pelorus	Brown	Dairy; grazed
MDC87	Ronga	Recent	Dairy; grazed

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.

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 °C for 7 days
Physical properties		
Dry bulk density	Compaction, volumetric conversions	Soil cores
Particle density	Used to calculate porosity and available water	Specific gravity
Total porosity, air capacity and macroporosity	Soil compaction, aeration, drainage	Pressure plates

2.4. Soil 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, mercury, nickel and zinc were determined by digesting soils in nitric/hydrochloric acid and analysing trace elements in the digest by inductively coupled plasma mass spectrometry (US EPA 200.2).

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

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

2.4.4. 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.

2.4.5. 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.

2.5. Results and Discussion

2.5.1. Comparison of Target Ranges

Figure 1 shows the number of sites not meeting their target for a specific soil quality indicator. AMN (2 sites) and macroporosity (1 sites) were the indicators not meeting their soil quality target. In contrast, soil pH, total C, total N, Olsen P and soil bulk density targets were met at all sites.

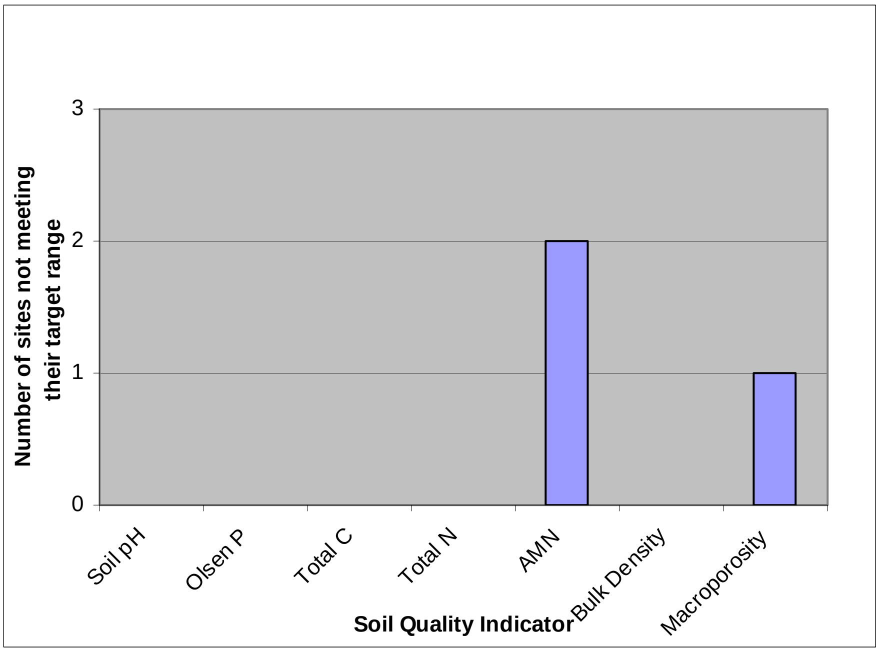

Figure 1 The number of sites not meeting their target range for a specific soil quality indicator

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.

2.5.2. 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. Although 2 sites were at the lower end of the optimal range for pasture soils of pH between 5.8 – 6.2 (Roberts and Morton, 2009) and would benefit from an application of a liming product to increase soil pH.

2.5.3. 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). It is fairly normal for soils under long-term, high producing pastures to accumulate carbon. Interestingly there was consistently more carbon in the Rai soil than the Ronga soil.

2.5.4. 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).

2.5.5. 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).

Table 3 Chemical and biological characteristic of soils sampled in the Marlborough Region 2011

Site Code	Land use	Soil Type	Soil pH	Olsen P ($\mu g\ g^{-1}$)	Total C ($mg\ cm^{-3}$)	Total N ($mg\ cm^{-3}$)	C:N ratio	AMN ($\mu g\ g^{-1}$)
MDC76	Dairy	Rai	5.9	51	65.9	5.5	12.1	**283**
MDC77	Dairy	Rai	5.8	60	66.7	5.7	11.7	**281**
MDC78	Native forest	Rai	5.4	11	72.0	5.4	13.4	162
MDC79	Dairy	Ronga	5.7	43	45.9	4.2	10.6	160
MDC80	Dairy	Ronga	6.2	28	43.0	4.9	8.8	161
MDC84	Dairy	Ronga	5.8	47	50.8	5.6	8.9	172
MDC85	Dairy	Rai	5.6	30	63.0	6.1	10.2	202
MDC86	Dairy	Pelorus	6.1	35	63.4	5.7	11.2	241
MDC87	Dairy	Ronga	6.0	23	37.0	4.5	8.2	163

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

2.5.6. 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 can potentially have a negative impact on water quality.

Olsen P concentrations varied about 6-fold between sites with the lowest value found at the native forest sites i.e. MDC78 and highest value at one of the dairy sites i.e. MDC77 (Table 3). As indicated in Figure 1, all sites had Olsen P values within the desirable target range for pasture soils of <100 $\mu g\ g^{-1}$. However it should be noted that the upper target range is currently under review. This is partly based on the recognition that for pasture soils there is little, if any, increase in relative pasture production above an Olsen P of 50 $\mu g\ g^{-1}$ (Edmeades et al. 2006). Based on this proposed upper limit two sites have Olsen P values higher than the agronomic level required for maximum pasture production.

2.5.7. 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 soil organic matter quality in terms of its ability to store nitrogen. However, the amount of AMN has also been found to correspond with the amount of soil microbial biomass – hence it is also a useful indicator of microbial activity in soils (Myrold, 1987).

Anaerobically Mineralisable Nitrogen concentrations varied about 2-fold between sites with the lowest value found on the native forest site and the highest values found on one of the dairy pasture sites (Table 3). All but two sites had values which were within their target range.

It has been suggested that AMN is useful as an indicator of potential N leaching (i.e. NO_3^--N) from soils. This is because it can provide an indication of N loading in soil as organic matter and plant residues are mineralised this will increase the amount of NO_3^--N in soil solution. However NO_3^--N losses are also controlled by other factors such as soil texture and soil structure which affect the rate of water movement (drainage) in the soil and therefore the rate of NO_3^--N loss. In addition because soils are only sampled to the 10 cm depth, it isn't necessarily going to accurately reflect what happens to the NO_3^--N further down the soil profile e.g. denitrification.

2.5.8. 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.

All sites were within the target range for bulk density (Table 4). However the four Ronga soils had consistently higher bulk density values than the Rai or Pelorus soils. This may reflect the significantly higher soil organic matter (soil carbon) in the these soils which is known to help develop and maintain good structure in soil.

2.5.9. 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.

Only one of the nine sites did not meet their target for macroporosity (Figure 1) with a value below the target value of 6%, although three others are in the low range i.e. <8% (Table 4). This is likely a result of animal treading on pastures that are too wet which has effectively reduced the large pore fraction in these soils.

Low macroporosity on dairy pasture soils has been noted previously in dairy pasture soils in Marlborough (Gray, 2011a) and has been observed in other regions of New Zealand. For example in the Auckland region, values for 21 dairy farm sites ranged between 0.6 – 8.6 % with a median value of 3.2% (Stevenson, 2010) and only one site had an 'adequate' macroporosity value. In the Northland region, values for 7 dairy sites ranged between 3.1 to 10.7% with a median value of 6.2% (Northland Regional Council, 2007) and like the Auckland study only one site had an 'adequate' macroporosity value.

There are a range of potential soil, plant and environmental effects of soil compaction/pugging from animal treading. One of the most important effects is what it can do to 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). In contrast 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 as a result of compaction/pugging can also lead to reduced infiltration of water which increases the potential for surface runoff of water. If this runoff contains nutrients i.e. nitrogen (N), phosphorous (P) or contaminants i.e. bacteria, this may negatively impact on stream and lake water quality (Ngyen et a., 1998; McDowell et al., 2003).

While several sites show evidence of soil compaction/pugging, the effects aren't necessarily permanent and there are several remediation options available. These can include:

- Natural soil amelioration processes i.e. wetting and drying cycles, freeze and thaw cycles, plant root growth and decay and soil fauna and flora activity.
- Mechanical loosening of soil (also called subsoling or aeration).
- Cultivation possibly involving growing a commercial fodder crop prior to re-sowing a new pasture is also shown to be effective.

Furthermore there are a number of potential mitigation methods that can be employed to prevent or minimise the affects of soil compaction/pugging in the future. Practices could include on/off grazing of animals, grazing wetter paddocks before the wet part of the season, maintaining good pasture cover which gives better protection against pugging, installing drainage in some areas, use of feeding platforms, standoff areas and decreasing winter stock numbers by moving stock onto well drained soil types.

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Table 4 Physical characteristic of soils sampled in the Marlborough Region 2011

Site Code	Land use	Soil Type	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Total porosity (% v/v)	Porosity -5kPa (%v/v)	Macro-porosity -10kPa (%v/v)
MDC76	Dairy	Rai	0.8	2.49	67.4	11.6	13.4
MDC77	Dairy	Rai	0.9	2.57	65.4	10.8	13.3
MDC78	Native forest	Rai	0.7	2.57	71.4	17.5	19.9
MDC79	Dairy	Ronga	1.2	2.69	57.4	6.2	8.6
MDC80	Dairy	Ronga	1.2	2.69	56.8	4.6	6.5
MDC84	Dairy	Ronga	1.3	2.70	50.6	6.6	8.5
MDC85	Dairy	Rai	0.9	2.55	63.7	5.0	6.8
MDC86	Dairy	Pelorus	0.9	2.54	63.9	5.3	7.6
MDC87	Dairy	Ronga	1.2	2.65	54.9	1.0	**1.2**

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

2.5.10. 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 4.6 mg kg^{-1} for arsenic, 0.39 mg kg^{-1} for cadmium, 88 mg kg^{-1} for chromium, 17 mg kg^{-1} for copper, 12 mg kg^{-1} for lead, 50 mg kg^{-1} for nickel, 0.10 mg kg^{-1} for mercury and 65 mg kg^{-1} for zinc. These concentrations are within the suggested upper limits for trace elements in soils as suggested by the New Zealand Water and Waste Association.1 Concentrations are also fairly similar to those that have been found in soils in other parts of New Zealand (Auckland Regional Council, 1999; Greater Wellington Regional Council, 2005; Canterbury Regional Council, 2006; Bay of Plenty, 2011) and what has previously found in Marlborough (Gray, 2011b) with the exception of nickel and chromium which were on average higher.

For both chromium and nickel, concentrations were about four and three times higher respectively than the concentrations previously reported at soil quality monitoring sites. The elevated concentrations were largely influenced by very high values in one soil type - the Ronga soil at two sites located in the central Rai valley. Elevated concentrations of these heavy metals has been found in these soils in other investigations of trace element concentrations in soils (Gray, et al., 2011) and is most likely related to the soil parent, possibly serpentine minerals which are known to contain elevated concentrations of both these trace elements.

For cadmium, average concentrations were approximately double typical background concentrations found in soils (Roberts and Longhurst, 2004) but similar to those that have found in the past for dairy pasture soils in Marlborough and what has been found elsewhere in New Zealand (Taylor et al., 2010). The source of cadmium is most likely phosphate fertiliser which has been shown to contain cadmium as an incidental impurity. However no sites had cadmium concentrations above the suggested 0.6 mg kg^{-1} trigger value outlined in the national strategy for managing risks caused by cadmium in agricultural soils (MAF, 2010). Although three sites i.e. MDC84, 85 and 86 have concentrations approaching this limit.

The new guidelines suggest that sites with soil cadmium concentration above the lowest trigger value of 0.6 mg kg^{-1} should be monitored for cadmium in soil every 5 years and farmers provided with a range of management options as a means of reducing cadmium accumulation. This will be a cost-benefit equation for each farmer based on factors such as proximity to the 1 mg kg^{-1} threshold, the price of purer forms of phosphate (i.e. lower cadmium concentration) and equity value of land that is relatively clean compared with land that has more cadmium.

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[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 2011

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})	Hg (mg kg^{-1})	Zn (mg kg^{-1})
MDC76	Dairy	Rai	4.9	0.39	79	15	13	34	0.13	55
MDC77	Dairy	Rai	4.6	0.39	101	13	10	43	0.11	50
MDC78	Lowland forest	Rai	3.5	0.07	85	18	12	46	0.22	105
MDC79	Dairy	Ronga	3.8	0.24	168	20	10	110	0.12	58
MDC80	Dairy	Ronga	4.7	0.36	191	25	11	141	0.07	67
MDC84	Dairy	Ronga	4.6	0.50	43	16	14	25	0.04	63
MDC85	Dairy;	Rai	5.9	0.57	55	16	13	21	0.09	65
MDC86	Dairy	Pelorus	5.5	0.53	28	17	13	12	0.1	62
MDC87	Dairy	Ronga	4.0	0.43	41	15	13	22	0.05	62

Bold – exceeds recommended guideline value (NZWWA, 2003)

3. Summary

Results for nine new soil quality monitoring sites indicate in general these soils are in fairly good condition. For example indicators of soil acidity, organic reserves and soil fertility were all within current soil quality target ranges. The only concern was one site showing signs of soil compaction i.e. low macroporosity, and several other sites showing early signs. These results put these soils at risk of poor aeration and impeded drainage which may potentially affect pasture production and predispose the soil to surface runoff, nutrient loss, erosion and flooding. While soil compaction isn't permanent, it clearly should be avoided and remediated where necessary. Management options to prevent and remediate soil compaction are outlined in the report.

Trace elements were also well within suggested upper limits for concentrations in soils. However for cadmium average concentrations were about double those of typical background concentrations for soils. It is suggested there should be continued monitoring for cadmium on intensive grazed pasture to determine how widely and to what concentrations cadmium has accumulated.

It is also recommended that repeat monitoring of these sites be conducted in the medium-term (≈ 3-5 years) to determine the rate of change over time in particular for soil compaction and cadmium accumulation.

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Appendix A: *Soil profile descriptions and site conditions*

Sample name: MDC76
Soil Name: Rai
Location: approximately 700m East of Pelorus Bridge on the North side of the Pelorus river
Land use: Dairy
Topography: Terrace
Elevation: 44m
Slope: 0°
Soil material: loamy/stony old terrace alluvium from greywacke, argillite
Soil drainage: Well
Date sampled: 3/11/2011

Horizon	Depth	Description
A	0-17cm	dark yellowish brown (10YR 4/4) silt loam; 5% medium to coarse partly stones; strongly developed fine polyhedral structure; weak soil strength; very friable; many fine roots
Bw1	17-35cm	yellowish brown (10YR 5/8) silt loam; 5% medium to coarse unweathered and partly weathered stones; strongly developed fine polyhedral structure; weak soil strength; very friable; many fine roots
Bw2	35-65cm	yellowish brown (10YR 5/8) sandy silt loam; 15% medium to very coarse unweathered and partly weathered stones; moderately developed fine polyhedral and weak blocky structure; weak soil strength; friable; few fine roots
BC	65-80cm+	yellowish brown to brownish yellow (10YR 5/8-6/8) sandy loam; 30% medium to very coarse unweathered and partly weathered stones; earthy; slightly firm; few fine roots

Sample name: MDC77
Soil Name: Rai
Location: approximately 700m East of Pelorus Bridge on the North side of the Pelorus river
Land use: Dairy
Topography: Terrace
Elevation: 40m
Slope: 0°
Soil material: loamy/stony old terrace alluvium from greywacke, argillite
Soil drainage: Well
Date sampled: 3/11/2011

Horizon	Depth	Description
A	0-17cm	dark yellowish brown (10YR 4/4) silt loam; 2% medium to coarse stones; moderately to strongly developed fine polyhedral structure; weak soil strength; friable; many fine roots
Bw1	17-35cm	yellowish brown (10YR 5/8) sandy silt loam; 5% medium to coarse stones; moderately developed fine polyhedral structure; weak soil strength; very friable; common fine roots
Bw2	35-65cm	yellowish brown (10YR 5/8) sandy silt loam; 10% fine to coarse stones; moderately developed fine polyhedral structure; weak soil strength; very friable; few roots
BC	65-80+ cm	yellowish brown (10YR 5/6) sandy loam; 15% fine to very coarse stones; weakly developed fine polyhedral structure; very weak soil strength; very friable; few roots

Sample name: MDC78
Soil Name: Rai
Location: approximately 600m E of Pelorus Bridge
Land use: Conservation reserve
Topography: Terrace
Elevation: 50m
Slope: 0º
Soil material: loamy/stony old terrace alluvium from greywacke, argillite
Soil drainage: Well
Date sampled: 4/11/2011

Horizon	Depth	Description
O	2-0cm	dark reddish brown (5YR 3/2) peaty loam; apedal; structureless; very friable
A	0-20cm	dark yellowish brown (10YR 4/6) silt loam; 2% fine and medium stones; moderately developed fine polyhedral structure; very weak soil strength; very friable abundant fine and coarse roots
Bw1	20-45cm	yellowish brown (10YR 5/8) silt loam; 5% fine to coarse stones; moderately developed fine polyhedral structure; very weak soil strength; many fine and coarse roots
Bw2	45-70cm+	yellowish brown (10YR 5/6) silt loam; 5% fine to coarse stones; weakly developed fine polyhedral structure; weak soil strength; very friable; few fine roots

Sample name: MDC79
Soil Name: Ronga
Location: approximately 900m ESE of Pelorus Bridge
Land use: Dairy
Topography: Terrace
Elevation: 25m
Slope: 0º
Soil material: fine textured recent alluvium from greywacke, argillite etc
Soil drainage: Well
Date sampled: 4/11/2011

Horizon	Depth	Description
A	0-11cm	brown to dark brown (10YR 4/3) silt loam; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots
(B)	11-45cm	light olive brown (2.5Y 5/6) silt loam; weakly developed fine polyhedral structure; weak soil strength; very friable; many fine roots
C1	45-60cm	light olive brown (2.5Y 5/6) silt loam; apedal; earthy; very weak soil strength; very friable; few fine roots
C2	60-90cm	light olive brown (2.5Y 5/6) fine sandy loam; apedal; earthy; very weak soil strength; very friable; very few fine roots

Sample name: MDC80
Soil Name: Ronga
Location: approximately 2km SW of Dalton Bridge, on the north side of SH6
Land use: Dairy
Topography: Terrace
Elevation: 5m
Slope: 0º
Soil material: fine textured recent alluvium from greywacke, argillite etc
Soil drainage: well
Date sampled: 4/11/2011

Horizon	Depth	Description
A	0-2cm	dark yellowish brown (10YR 4/4) silt loam; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots
A	2-20cm	dark yellowish brown (10YR 4/4) silt loam; moderately developed fine polyhedral structure; weak soil strength; friable; many fine roots
(B)	20-42cm	dark yellowish brown to light olive brown (10YR 4/6-2.5Y 5/6) silt loam; moderately developed fine polyhedral structure; weak soil strength; friable; common fine roots
b (B)	42-90cm	dark yellowish brown (10YR 4/6) clay loam;1% fine strong brown (7.5YR 5/8) and light yellowish brown (2.5Y 6/4) fine distinct mottles; moderately to strongly developed fine and medium polyhedral structure; weak soil strength;brittle; very few fine roots

Sample name: MDC84
Soil Name: Ronga
Location: 6.7 km eNE of Rai Valley on the nN side of Opouri River
Land use: Dairy
Topography: Terrace
Elevation: 64m
Slope: 0º
Soil material: recent alluvium
Soil drainage: well
Date sampled: 8/11/2011

Horizon	Depth	Description
A	0-10cm	dark yellowish brown (10YR 4/6) silt loam; weakly developed fine polyhedral structure; 2% medium stones; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots
AB	10-20cm	dark yellowish brown and light olive brown (10YR 4/6 + 2.5Y 5/6) silt loam; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots
(B)	20-52cm	light olive brown (2.5Y 6/2) silt loam; 5% medium to coarse stones; weakly developed fine blocky and polyhedral structure; weak soil strength; brittle; common fine roots
C1	52-68cm	light olive brown (2.5Y 5/6) sandy loam; 10% medium to coarse stones; apedal; earthy; very weak soil strength; very friable; few fine roots
C2	68-75cm+	light olive brown (2.5Y 5/6) sand; 20% medium to very coarse stones; apedal; single grain; loose; very few roots

Sample name: MDC85
Soil Name: Rai
Location: 5.9 km ENE of Rai Valley, N side of Opuri River on an upper terrace remnant
Land use: Dairy
Topography: Terrace
Elevation: 73m
Slope: 2°
Soil material: partly weathered older alluvium
Soil drainage: Well
Date sampled: 8/11/2011

Horizon	Depth	Description
A	0-5cm	dark yellowish brown (10YR 4/4) clay loam; 2% reddish brown (2.5YR 4/4) fine distinct mottles; weakly developed medium blocky structure; slightly firm soil strength; brittle; many fine roots
A	5-28cm	dark yellowish brown (10YR 4/4) clay loam; 2% medium stones; moderately developed fine polyhedral structure; weak soil strength; friable; many fine roots
Bw1	28-57cm	dark yellowish brown (10YR 5/8) silt loam; 10% fine to medium stones; strongly developed fine polyhedral structure; very weak soil strength; very friable; many fine roots
Bw2	57-80cm	dark yellowish brown (10YR 4/4) silt loam; 15% fine to coarse stones; strongly developed fine polyhedral structure; weak soil strength; very friable; few fine roots
Bw3	80-110cm+	dark yellowish brown (10YR 4/4) silt loam; 15% fine to medium stones; weakly develop[ed medium blocky structure; slightly firm; friable; few fine roots

Sample name: MDC86
Soil Name: Pelorus
Location: approximately 6 km ENE of Rai Valley, N side of Opouri River on a upper terrace remnant
Land use: Dairy
Topography: Hill
Elevation: 105m
Slope: 14°
Soil material: weathered slope detritus
Soil drainage: Well
Date sampled: 8/11/2011

Horizon	Depth	Description
A	0-14cm	dark yellowish brown (10YR 4/6) heavy silt loam; 2% medium to coarse stones; moderately developed medium polyhedral structure; weak soil strength; friable; many fine roots
AB	14-19cm	dark yellowish brown and yellowish brown (10YR 4/6 +10YR 5/8) heavy silt loam; 5% medium to coarse stones; strongly developed fine polyhedral structure; very weak soil strength; very friable; many fine roots
Bw1	19-38cm	yellowish brown (10YR 5/8) heavy silt loam; 5% medium to coarse stones; strongly developed fine polyhedral structure; very weak soil strength; very friable; common fine roots
Bw2	38-58cm	yellowish brown (10YR 5/8) heavy silt loam; 10% medium to very coarse stones; moderately developed fine polyhedral structure; very weak soil strength; friable; few fine roots
Bw3	58-100cm	yellowish brown (10YR 5/6) clay loam; 15% medium to very coarse stones; 5% light olive brown (2.5Y 6/4) and 5% red (2.5YR 4/8) medium distinct mottles associated with weathering clasts; moderately developed medium polyhedral and blocky structure; slightly firm soil strength; friable; very few roots

Sample name: MDC87
Soil Name: Ronga
Location: approximately 5.6 km ENE of Rai Valley, N side of Opouri River on a upper terrace remnant
Land use: Dairy
Topography: Hill
Elevation: 61m
Slope: 0º
Soil material: recent alluvium
Soil drainage: well
Date sampled: 8/11/2011

Horizon	Depth	Description
A	0-4cm	yellowish brown (10YR 5/4) heavy silt loam;1% fine to medium stones; weakly developed fine polyhedral structure; weak soil strength; friable; many fine roots;
AB	4-12cm	yellowish brown (10YR 5/4) silt loam; weakly developed fine polyhedral structure; very weak soil soil strength; very friable; common fine roots
(B)	12-30cm	light olive brown (2.5Y 5/6) silt loam; weakly developed fine polyhedral structure; very weak soil strength; very friable; very few fine roots
C1	30-55cm	light olive brown (2.5Y 5/6) fine sandy loam; apedal; earthy; very weak soil strength; few fine roots
C2	55-65cm	light olive brown (2.5Y 5/6) sand; 20% fine stones; apedal; single grain; loose
C3	65-100cm	light olive brown (2.5Y 5/6) loamy sand; apedal; earthy; loose