Annual soil monitoring report for the Wellington region, 2008/09

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Annual soil quality monitoring report for the Wellington region, 2008/09

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Contents

1. Introduction

The soil ecosystem has multiple roles in the environment, including maintenance of productivity, providing habitat and acting as a buffer against pollution of adjacent water resources (Hill & Sparling 2009). Soil in the Wellington region is used to support a wide range of land uses including market gardens, horticulture, viticulture, dairy farming, drystock farming and forestry.

Inappropriate land use practices such as overstocking and over-cultivation can result in a long-term reduction in soil quality. Declining levels of organic matter, soil compaction and acidification have been apparent for some time in New Zealand under some land uses (Hill & Sparling 2009). Poor soil quality can produce lower agricultural yields, a less resilient soil and land ecosystem, and increase contamination of adjacent water bodies (Hill & Sparling 2009). Greater Wellington Regional Council (Greater Wellington) monitors the health of our region's high quality soils to ensure that the effects of land use on soil quality are no more than minor.

This report summarises the results of soil quality monitoring undertaken at 23 dairying sites over the period 1 July 2008 to 30 June 2009. A report containing a detailed analysis of long-term trends in soil quality is produced approximately every six years (see Croucher 2005).

2. Overview of the soil quality monitoring programme

2.1 Background

Greater Wellington became involved in a national soil quality programme known as "The 500 Soils Project" in 2000. After completion of the 500 soils project in 2001 Greater Wellington implemented a soil quality monitoring programme to continue monitoring the quality of soils in the Wellington region. As part of the 500 Soils Project a standard set of sampling methods, as well as physical, chemical and biological properties, were identified. A value or ranges of values for each of the properties were derived enabling the relationship between the quantitative measure of the soil attribute and its soil quality rating to be determined. The use of these standard methods and properties allows comparisons of similar soils and land uses both within the region and nationally. These sampling methods and properties were adopted for use in Greater Wellington's soil quality monitoring programme.

2.2 Monitoring objectives

The objectives of Greater Wellington's soil quality monitoring programme are to:

- Provide information on the physical, chemical and biological properties of soils;
- Provide an early-warning system to identify effects of primary land uses on long-term soil productivity;
- Track specific, identified issues relating to the effects of land use 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 policies and plans.

2.3 Monitoring sites and methods

The monitoring programme currently consists of 118 sites on the high quality soils across the region under different land uses (Figure 2.1). The frequency of sampling is dependent on the intensity of the land use; dairying, cropping and market garden sites are sampled every 3-4 years, drystock, horticulture and exotic forestry sites are sampled every 5-7 years, while native forest sites are sampled every 10 years. In 2008/09, 23 pastoral sites used for dairy farming were sampled (Figure 2.1, Appendix 1).

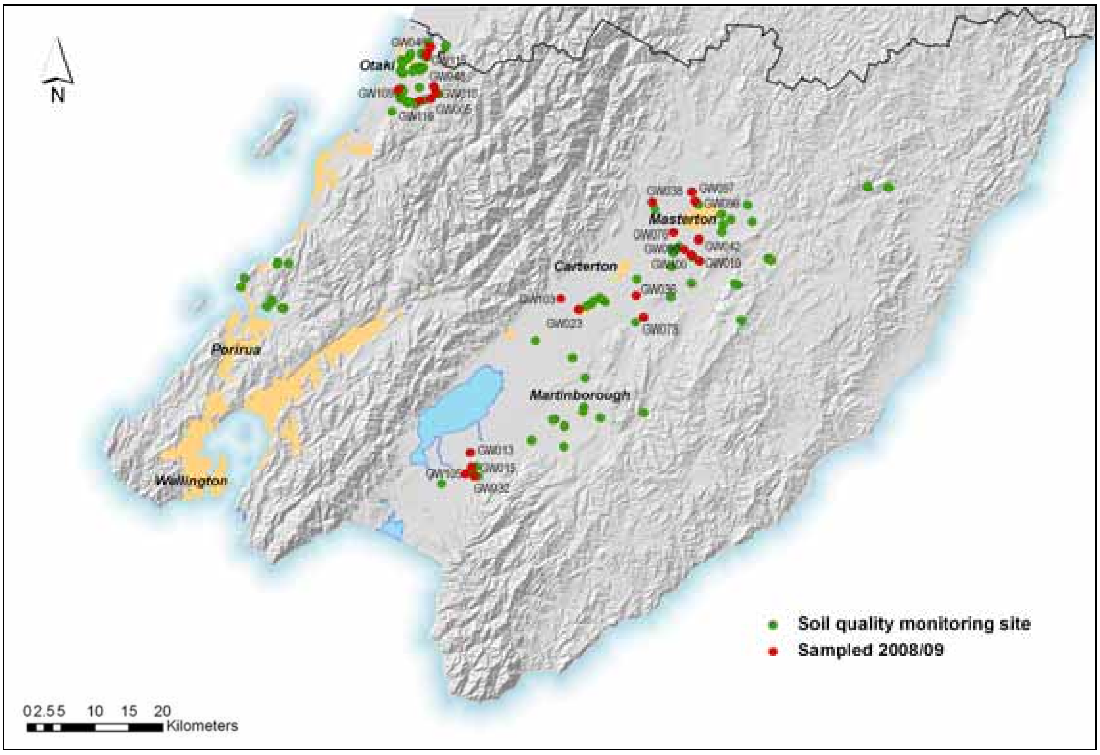

Figure 2.1: Greater Wellington's soil quality monitoring sites, including those sampled during 2008/09

At each monitoring site three core samples (such as in Figure 2.2a) are collected to establish the physical soil properties, while a composite of core samples is taken along a transect using a soil corer (see Figure 2.2b); the composite sample is used to determine the organic resources, acidity and fertility of the soil. A more detailed description of the sampling and laboratory methods used can be found in Appendix 2.

Figure 2.2: (a) One of three intact core samples taken at each site, to establish the physical properties of the soil. (b) Collecting a composite of core samples along a transect using a soil corer.

2.4 Monitoring variables

Seven primary soil properties as well as trace elements were measured and used as indicators of soil quality (Table 2.1). Soil physical condition was assessed from the dry bulk density and macroporosity measured at a pressure of -10 kPa. These soil physical measurements also provide measures of the total porosity and particle density. Chemical and biological characteristics (which give an indication of the organic resources, acidity and fertility of soils) were assessed by measuring the amount of carbon, nitrogen and available phosphorus (Olsen P) in the soil, how much nitrogen is potentially mineralisable by microorganisms and the soil pH. Total recoverable arsenic, cadmium, chromium, copper, lead, nickel and zinc were measured to assess the levels of trace elements in the soil.

The soil properties themselves do not measure soil quality, rather soil quality is a value judgement about how suitable a soil is for its particular land use. A group of New Zealand experts in soil science developed soil response curves for each of the soil properties, and established critical values or optimal ranges for the assessment of soil quality for the predominant Soil Orders under a number of different land uses. These critical values and optimal ranges are used to assess soil quality in this report.

Table 2.1: Indicators used for soil quality assessment (adapted from Hill & Sparling 2009)

Soil property	Indicator	Soil quality information	Why is this indicator important?
Physical condition	Bulk density	Soil compaction	Bulk density is the weight of a soil and is used for volumetric conversions. A high bulk density indicates a compacted or denser soil. Compacted soils will not allow water or air to penetrate, do not drain easily and restrict root growth adversely affecting plant growth. There is also potential for increased run-off and nutrient loss to surface waters.
	Macroporosity	Soil compaction and degree of aeration	Macropores are important for air penetration into soil and are the first pores to collapse when soil is compacted. Low macroporosity adversely affects plant growth due to poor root environment, restricted air access and N-fixation by clover roots. It also infers poor drainage and infiltration (see bulk density).
Organic resources	Total carbon (C) content	Organic matter carbon content	Used as an estimate of the amount of organic matter. Organic matter helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth. Used to address the issue of organic matter depletion and carbon loss from the soil.
	Total nitrogen (N) content	Organic matter nitrogen content	Most nitrogen in soil is within the organic matter fraction, and total nitrogen gives a measure of those reserves. It also provides an indication for the potential of nitrogen to leach into underlying groundwater.
	Mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms.	Not all of the total nitrogen can be used by plants; soil organisms change the nitrogen to forms that plants can use. Mineralisable N gives a measure of how much organic nitrogen is available to the plants, and the potential for nitrogen leaching at times of low plant demand. Also used as a surrogate measure of the microbial biomass.
Acidity	Soil pH	Soil acidity	Most plants and animals have an optimal pH range for growth. The pH of a soil also controls the availability of many nutrients to plants and the solubility of some trace elements. Soil pH is greatly influenced by the application of lime and fertilisers.
Fertility	Olsen P	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Plants get their P from phosphates in the soil. Olsen P is a measure of the amount of phosphorus that is available to plants. Excessive levels can increase loss to waterways, contributing to eutrophication (nutrient enrichment).
Trace elements	Concentrations of total recoverable trace elements (As, Cd, Cr, Cu, Ni, Pb and Zn)	Accumulation of trace elements	Some trace elements are essential micronutrients for plants and animals while others are not. Both essential and non-essential trace elements can become toxic at high concentrations. Trace elements can accumulate in the soil from various common agricultural and horticultural land use activities.

3. Soil quality results

The majority of the 23 pastoral soil sites under dairy farming were found to be in good condition, with five sites meeting all the soil quality criteria, and just six sites having more than one soil quality indicator outside the target (optimal) range (Figure 3.1). However, over half the sites were found to have low macroporosity values (indicating soil compaction), while high levels of total nitrogen and potentially mineralisable nitrogen were found at some other sites. The full results of the 2008/09 soil quality monitoring can be found in Appendix 3.

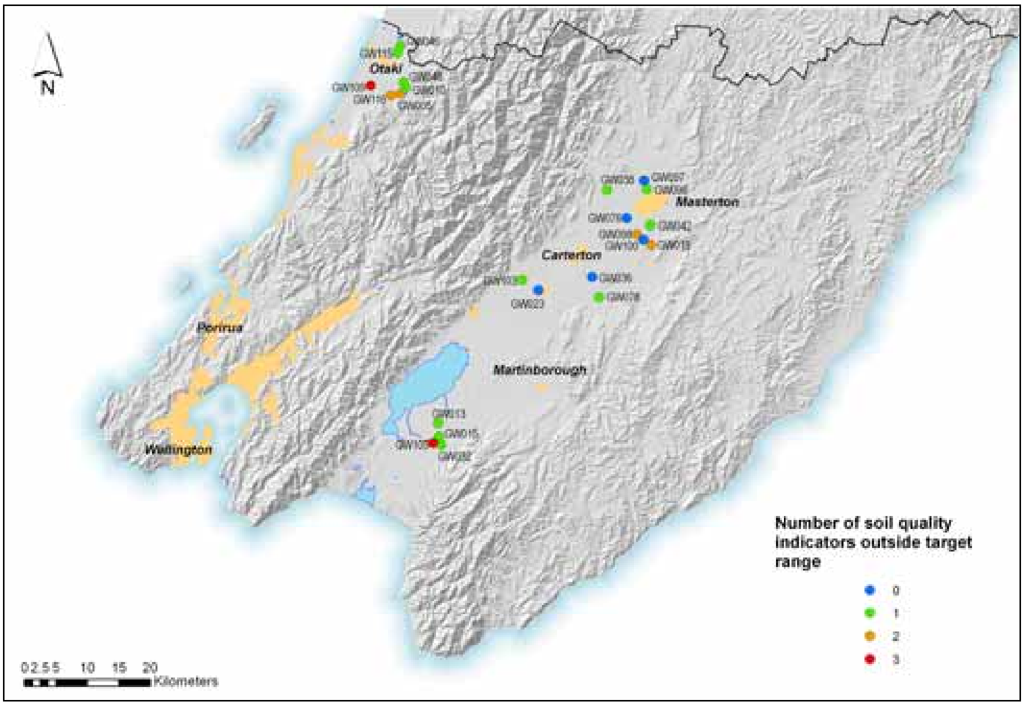

Figure 3.1: Number of soil quality indicators outside target ranges for each of the 23 monitoring sites sampled in 2008/09

3.1 Physical quality

The physical properties measured determine the weight, porosity and size of the soil and its particles. The properties measured were bulk density, particle density and water release characteristics, which provide information on total porosity, macroporosity, total available water and readily available water.

Bulk density and macroporosity are both measures of soil compaction. Bulk density is the weight of a standard volume of soil, while macroporosity[1] is a measure of the larger voids in the soil and indicates the ability of the soil to supply air and water to the roots (SINDI 2009). Compaction is caused by either animal treading, the impact of heavy machinery, cultivation, the loss of organic matter and subsequent desiccation, or a combination of some of these factors. Compaction on dairy farm sites is a particular concern. Compaction reduces the

1 For the purposes of this report macroporosity is measured at a pressure of -10 kPa. It is also commonly known as and reported in the results in Appendix 3 as “air filled porosity”.

number of pores available for water and gas movement, aeration, root growth and distribution, and nutrient uptake.

All but one (GW098) of the 23 sites sampled had optimal bulk density values (Figure 3.2). The bulk density of the soil at site GW098 was 1.48 t/m^3, marginally exceeding the upper limit of the optimal range of 1.4 t/m^3.

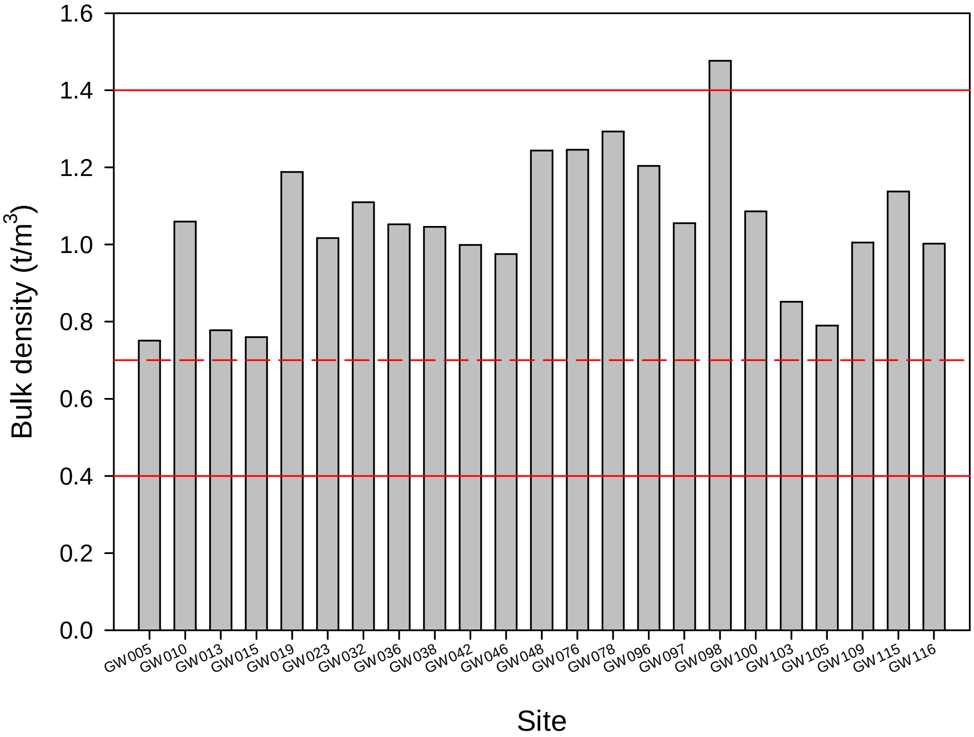

Figure 3.2: Bulk density at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range*.

* The lower threshold values for bulk density are 0.4 for pallic and recent soils, and 0.7 for all other soils.

The macroporosity levels were generally low across all of the 23 sites sampled, with 13 exceeding the lower limit for the optimal range (Figure 3.3). Macroporosity values ranged from 2.80 to 22.70. Site GW098, which exceeded the upper limit for the optimal range for bulk density consequently had the lowest macroporosity of just 2.80.

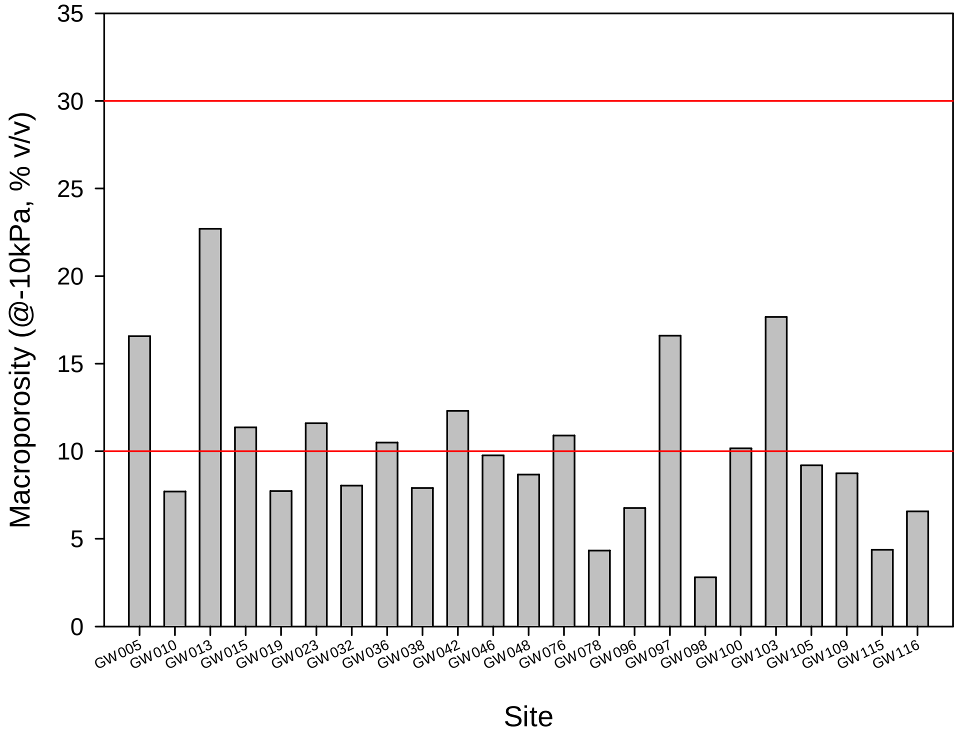

Figure 3.3: Macroporosity at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range.

3.2 Organic resources

Carbon is one of the basic building blocks of organic matter which helps soils retain moisture and nutrients, and gives good soil structure for water movement and growth. The total content of organic matter in the soil is not easily measured accurately, but soil carbon can be measured accurately (SINDI 2009). Consequently, total carbon is usually measured and used as an estimate of the soil organic matter content of the soil. Carbon content of soils can be reduced through the erosion of topsoil and excessive tillage, however, the total carbon contents of the 23 sites sampled were all found to be within the optimal range (Figure 3.4).

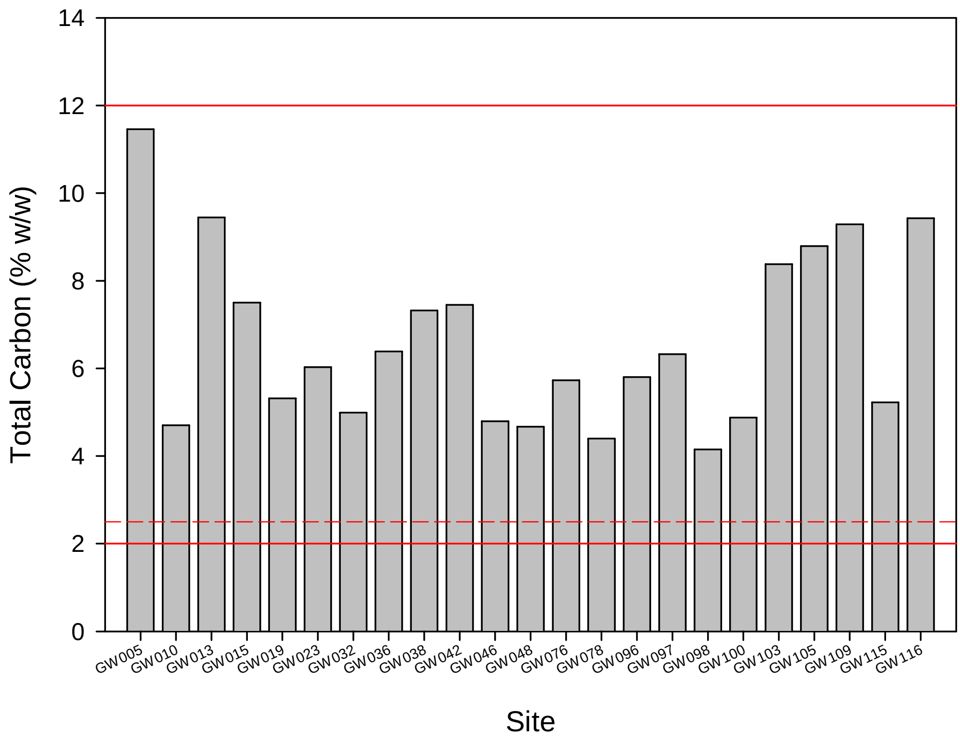

Figure 3.4: Total carbon content at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range*.

* Recent soils have a slightly higher low threshold value (red dashed line) than all other soil orders except organic.

Nitrogen is an essential nutrient for plants and animals. Most nitrogen in soil is found in organic matter and total nitrogen gives a measure of those reserves. Usually only a small fraction of the total N is immediately available for plant uptake (soluble inorganic nitrogen), while a variable proportion of the total nitrogen is potentially mineralisable to inorganic. In general, high total nitrogen indicates the soil is in good biological condition. However, very high total nitrogen contents increase the risk that nitrogen supply may be in excess of plant demand, and ultimately lead to leaching of nitrate to groundwater (SINDI 2009).

Total nitrogen concentrations ranged from 0.38 to 0.95 % v/v (Figure 3.5). Sixteen out of the 23 sites had total nitrogen contents within the optimal range, while seven of the sites were found to have high total N contents.

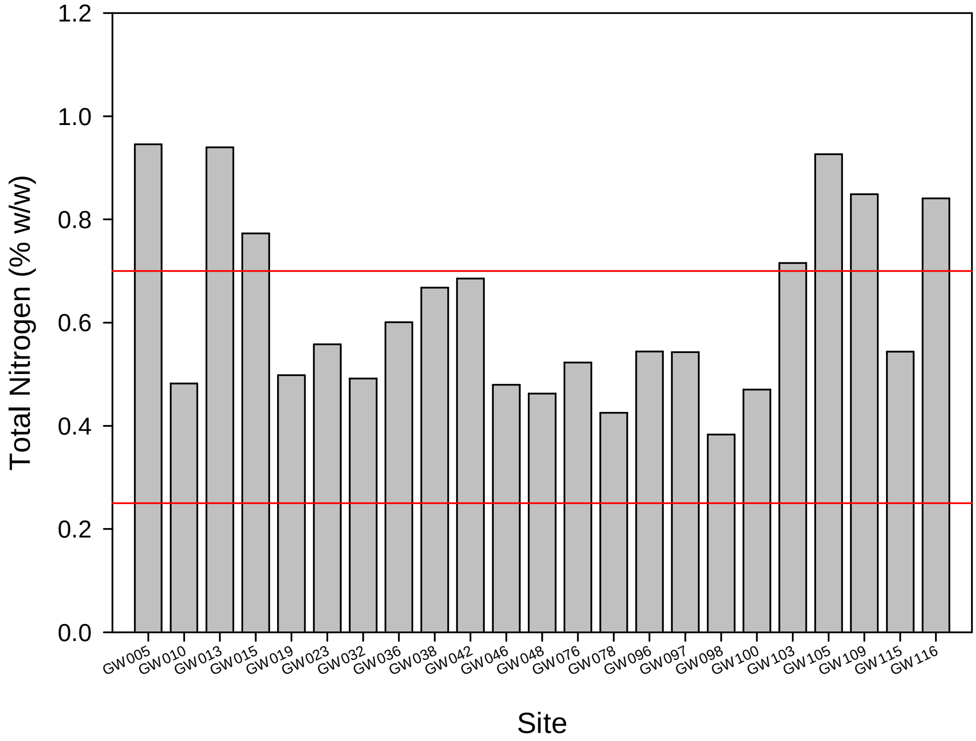

Figure 3.5: Total nitrogen content at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range.

Not all of the nitrogen in organic matter can be used by plants; soil organisms change the nitrogen to forms plants can use. Mineralisable nitrogen gives a measure of how much organic nitrogen is potentially available for plant uptake, and the activity of the soil organisms (Hill & Sparling 2009). While mineralisable nitrogen is not a direct measure of soil biology, it has been found to correlate reasonably well with microbial biomass carbon, so mineralisable nitrogen can act as a surrogate measure for microbial biomass (SINDI 2009).

Just three of the 23 sites sampled contained mineralisable nitrogen values outside the optimal range (Figure 3.6). Those sites (GW005, GW042 and GW109) had mineralisable nitrogen concentrations of 276, 287 and 288 mg/kg, respectively, exceeding the upper limit of the optimal range of 250 mg/kg.

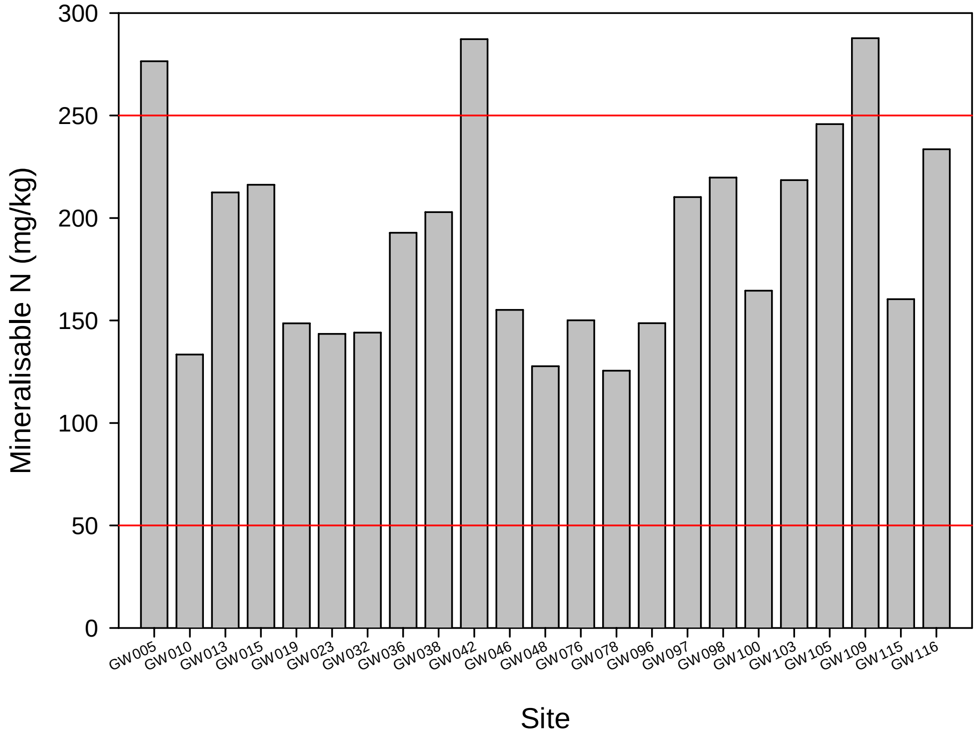

Figure 3.6: Mineralisable nitrogen content at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range.

3.3 Acidity

Most plants and soil organisms have an optimum soil pH range for growth. Soil pH is a measure of how acidic or alkaline a soil is. Most New Zealand soils have a pH within the range of 3 to 9, but many unmodified New Zealand soils have a pH between 4 and 5, which needs to be raised to grow crops and productive pasture (SINDI 2009). Indigenous species are generally tolerant of acidic conditions but introduced pasture and crop species require a more alkaline soil (Hill & Sparling 2009). A common farming practice to raise soil pH and reduce the acidity of the soil is to add limestone ($CaCO_3$). The application of fertilisers containing ammonium or urea has the opposite effect, speeding up the rate at which acidity develops. Soil pH also influences the solubility and availability of a wide range of compounds in soil.

The soil pH of all of the 23 sites sampled was within the optimal range, ranging from 5.45 to 6.55 (Figure 3.7).

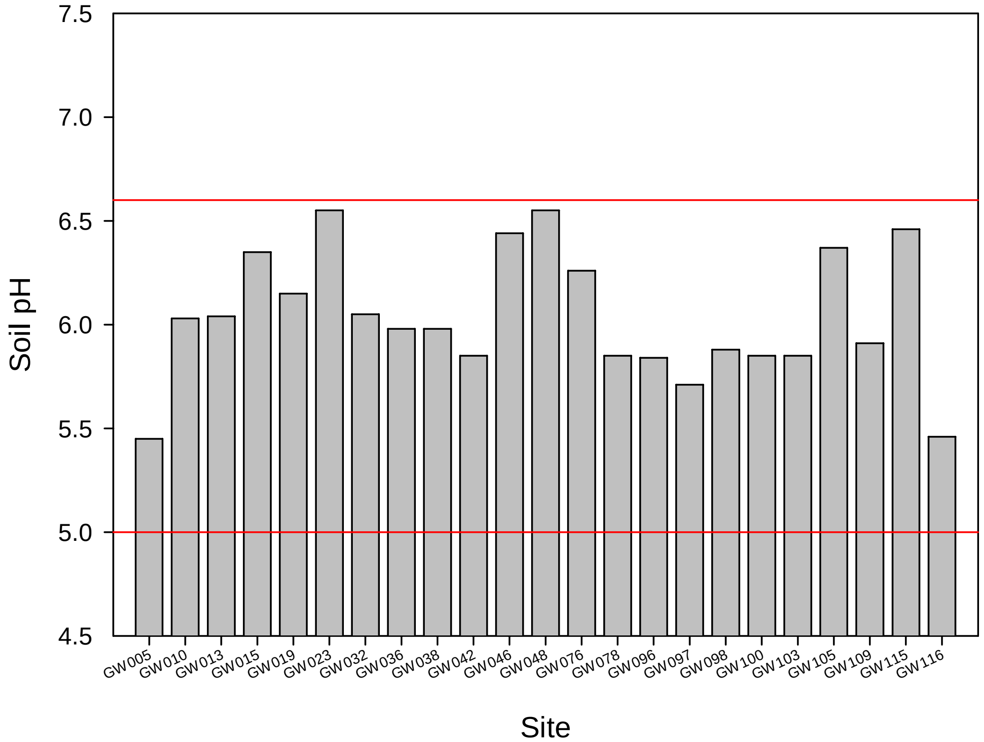

Figure 3.7: Soil pH at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range.

3.4 Fertility

Phosphorus (like nitrogen) is an essential nutrient for plants and animals. Plants get their phosphorus from phosphates in the soil, and the plant available phosphate is measured as Olsen P. Many soils in New Zealand have low available phosphorus and phosphorus needs to be added for agricultural use, usually in the form of soluble fertiliser sources such as super-phosphate or di-ammonium phosphate (Kim & Taylor 2009). Phosphate is normally strongly bound to soils, but high levels on shallow soils with low P retention have a risk of phosphorus leaching and contaminating waters. Phosphorus is often bound to surface soil particles, and surface erosion causing sediment to reach waters often carries phosphate as well. Again, this may result in contamination of water and enhanced algal growth (SINDI 2009).

Olsen P concentrations were variable ranging from 23 to 114 mg/kg (Figure 3.8). Of the 23 sites sampled, only two sites (GW019 and GW105) had concentrations of Olsen P which slightly exceeded the upper limit of the optimal range (100 mg/kg).

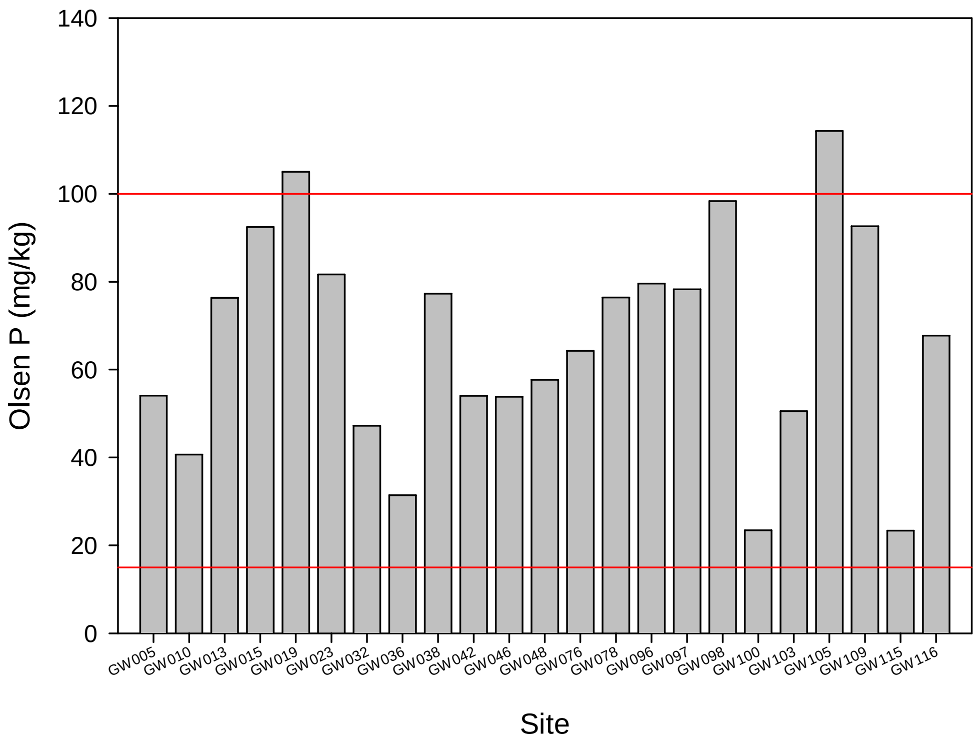

Figure 3.8: Olsen P values at each soil quality monitoring site sampled over 2008/09. The area between the red lines represents the optimal range.

3.5 Trace elements

Trace elements occur naturally, and the natural concentrations of most trace elements can vary greatly depending on geologic parent material (Stevenson 2008). Some trace elements are essential micronutrients for plants and animals while others are not. However, both essential and non-essential elements can become toxic at higher concentrations (Kim & Taylor 2009). A suite of the most common environment-impacting elements, including total recoverable arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) were measured. These trace elements can accumulate in soils as a result of common agricultural and horticultural land use activities (e.g., the use of pesticides, application of effluent and phosphate fertilisers), and are the elements most likely to have a negative effect on soil quality.

The trace element results in this report have been compared to the soil limits presented in the New Zealand Water and Wastes Association (NZWWA 2003) 'Guidelines for the Safe Application of Biosolids to Land in New Zealand' (referred to as the biosolids guidelines). While guidelines containing soil contaminant values like the biosolids guidelines have been written for a specific activity (biosolids application), the values are generally transferable to other activities that share similar hazardous substances (Cadmium Working Group 2008). For example, the NZWWA biosolids guidelines have been used by some regional councils to measure and assess cadmium present in soils as a result of phosphate fertiliser application, rather than the application of biosolids (Cadmium Working Group 2008). Other guidelines are available such as the Health and Environmental Guidelines for Selected Timber Treatment

Chemicals (MfE 1997) for assessing the concentrations of specific trace elements.

Concentrations of trace elements (total recoverable) at all the 23 sites are shown in Figure 3.9. Site GW096 exceeded the soil limit for arsenic with a concentration of 30 mg/kg. In comparison to the timber treatment guidelines, the concentration of 30 mg/kg is equal to the interim soil acceptance criteria for arsenic in an agricultural land use, and is still within background concentrations of arsenic in New Zealand soils, which typically range from 2 to 30 mg/kg (MfE 1997). It is important to note that concentrations of both copper and chromium are also elevated at the site in comparison to the other sites. Elevated concentrations of copper, chromium and arsenic suggest the source could be associated with a common timber treatment preservative known as CCA (copper chromium arsenate).

Cadmium concentrations were generally elevated throughout the sites ranging from 0.23 to 1.30 mg/kg, in comparison to background concentrations for the Wellington region which are typically between 0.05 to 0.20 mg/kg (Sulzberger & Whitty 2003). The soil limit of 1 mg/kg was exceeded at site GW013, with a concentration of 1.30 mg/kg.

The concentrations of the other trace elements were all well below their respective soil limits, and generally within the range of typical background concentrations for the Wellington region outlined in Sulzberger & Whitty (2003).

Table 3.1: 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

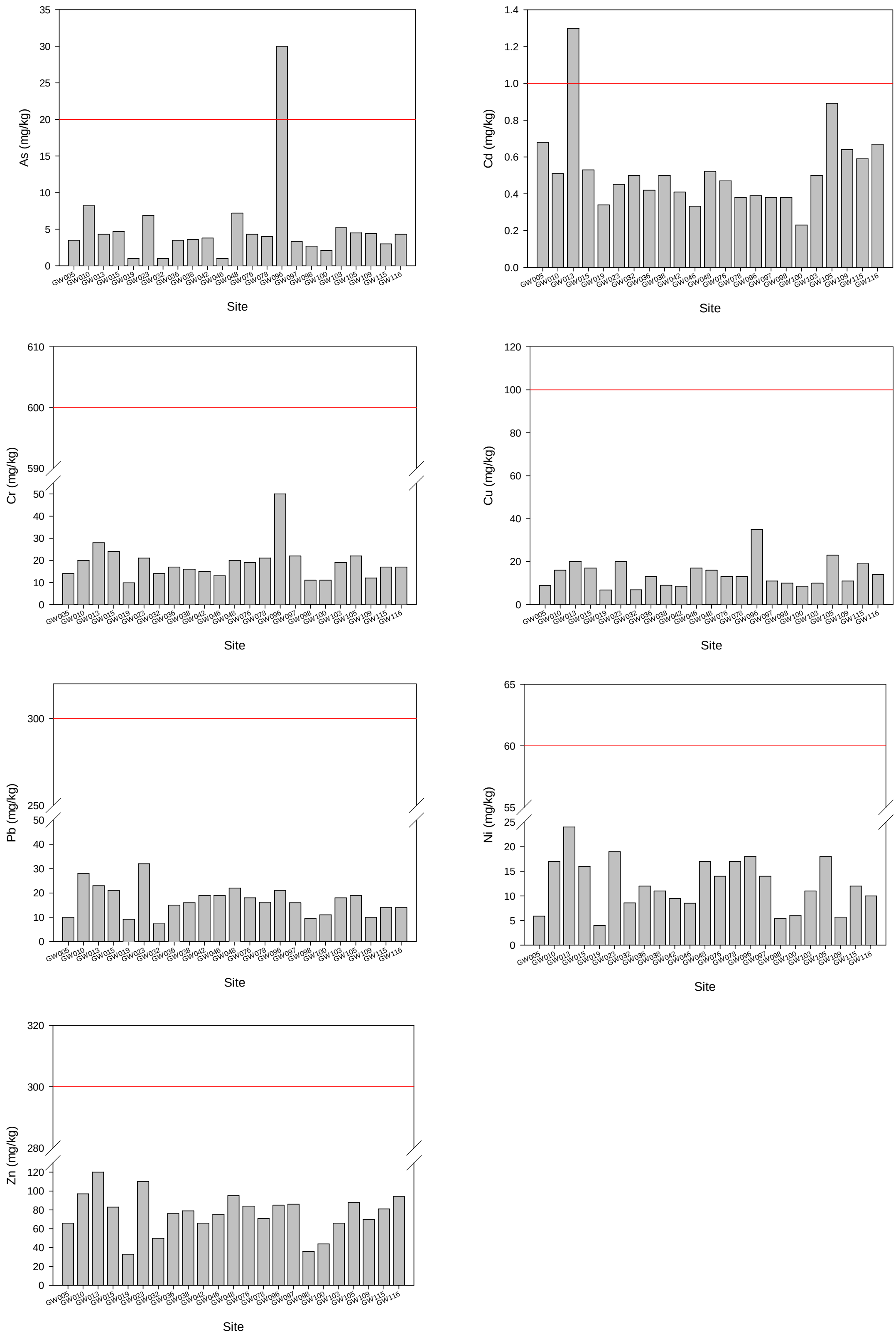

Figure 3.9: Total recoverable heavy metal concentrations at each soil quality monitoring site sampled over 2008/09. The red lines represent the (maximum) guideline values from NZWWA (2003). Note the y-axis breaks on some graphs.

4. Summary

The 2008/09 sampling results for 23 dairy farm sites across the Wellington region found the soils to generally be in good condition. The primary concern was compaction, with over half of the sites containing low macroporosity levels. Other soil quality indicators including total nitrogen, mineralisable nitrogen and Olsen P, were found at concentrations outside of the optimal range at a few sites.

While soil compaction by itself may affect farm productivity (by limiting grass growth), excess nitrogen or phosphorus combined with compacted soils can also increase the risk of excess nutrients leaching into groundwater or running off into surface water bodies. Only three sites (GW005, GW105 and GW109) were found to be compacted and contain excess nutrients. Concentrations of arsenic and cadmium were slightly elevated at one site each, but generally trace element concentrations were within typical background ranges for soils in the Wellington region.

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Acknowledgements

I would like to acknowledge and thank Tony Faulkner and Jake Brown from Greater Wellington for helping with the sampling, and the many farmers and landowners for their cooperation and for providing access to their land for sampling.

Appendix 1: Soil quality monitoring sites sampled in 2008/09

Site Number	General Location	Easting	Northing	Land use	Soil Group	Soil Order	Date Sampled
GW005	Otaki	2693665	6042327	Dairy	Acidic Allophanic Brown	Brown Soil	22/04/2009
GW010	Otaki	2694443	6043163	Dairy	Acidic-weathered Fluvial Recent	Recent Soil	21/04/2009
GW013	South Wairarapa	2699568	5989866	Dairy	Typic Recent Gley	Gley Soil	8/04/2009
GW015	South Wairarapa	2699789	5987188	Dairy	Typic Recent Gley	Gley Soil	8/04/2009
GW019	Masterton	2732430	6018882	Dairy	Argillic Perch-gley Pallic	Pallic Soil	7/04/2009
GW023	Carterton	2715507	6010988	Dairy	Acidic-weathered Fluvial Recent	Recent Soil	15/04/2009
GW032	South Wairarapa	2700125	5986340	Dairy	Typic Perch-gley Pallic	Pallic Soil	8/04/2009
GW036	Carterton	2724044	6013131	Dairy	Typic Perch-gley Pallic	Pallic Soil	15/04/2009
GW038	Masterton	2726394	6026937	Dairy	Typic Argillic Pallic	Pallic Soil	7/04/2009
GW042	Masterton	2733271	6021422	Dairy	Typic Immature Pallic	Pallic Soil	7/04/2009
GW046	Otaki	2693201	6049036	Dairy	Acid Orthic Gley	Gley Soil	21/04/2009
GW048	Otaki	2694436	6043359	Dairy	Acid Fluvial Recent	Recent Soil	21/04/2009
GW076	Masterton	2729522	6022418	Dairy	Mottled Immature Pallic	Pallic Soil	15/04/2009
GW078	Carterton	2725148	6009867	Dairy	Weathered Fluvial Recent	Recent Soil	8/04/2009
GW096	Masterton	2732782	6027086	Dairy	Weathered Fluvial Recent	Recent Soil	7/04/2009
GW097	Masterton	2732308	6028493	Dairy	Weathered Fluvial Recent	Recent Soil	7/04/2009
GW098	Masterton	2731173	6019970	Dairy	Typic Perch-gley Pallic	Pallic Soil	15/04/2009
GW100	Masterton	2732230	6019110	Dairy	Mottled Argillic Pallic	Pallic Soil	7/04/2009
GW103	Carterton	2712890	6012677	Dairy	Typic Immature Pallic	Pallic Soil	15/04/2009
GW105	South Wairarapa	2699659	5987007	Dairy	Mottled Argillic Pallic	Pallic Soil	8/04/2009
GW109	Otaki	2688865	6043591	Dairy	Typic Orthic Brown	Brown Soil	21/04/2009
GW115	Otaki	2693090	6048855	Dairy	Typic Orthic Brown	Brown Soil	21/04/2009
GW116	Otaki	2692834	6042086	Dairy	Typic Orthic Brown	Brown Soil	22/04/2009

Appendix 2: Sampling and analytical methods

At each site a 50 m transect is laid out. Soil cores 2.5 cm in diameter to a depth of 10 cm are taken every 2 m along the transect. The 25 individual cores are bulked and mixed in preparation for chemical and biological analyses. Three undisturbed soil samples used for physical analyses are also obtained from each site at 15, 30 and 45 m intervals along the transect by pressing steel liners 10 cm in width and 7.5 cm in depth into the top 10 cm of soil.

Soil analyses were completed at the Landcare Research soil chemistry and soil physics laboratories in Palmerston North (the exception being trace element analyses which were undertaken at R.J. Hills Laboratory in Hamilton). Where necessary, samples were stored at 4°C until analysis.

Table A2.1: Analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
Macroporosity	Determined by drainage on pressure plates at –10 kPa.
Total C content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Total N content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Mineralisable N	Waterlogged incubation method. Increase in NH_4^+ concentration was measured after incubation for 7 days at 40°C and extraction in 2M KCl.
Soil pH	Measured in water using glass electrodes and a 2.5:1 water-to-soil ratio.
Olsen P	Bicarbonate extraction method. Extracting <2 mm air dried soils for 30 mins with 0.5M $NaHCO_3$ at pH 8.5 and measuring the PO_4^{3-} concentration by the molybdenum blue method.
Trace elements	Total recoverable digestion. Nitric/hydrochloric acid digestion, USEPA 200.2.

Appendix 3: Analytical results

Table A3.1: Analytical results for soil quality monitoring sites sampled in 2008/09

Site Number	pH	Total C %	Total N %	C:N ratio	Olsen P mg/kg	NO_3-N mg/kg	NH_4-N mg/kg	Mineralisable N mg/kg	Bulk Density T/m^3	Particle Density T/m^3	Total Porosity %v/v	Macro Porosity (@-5kPa) % v/v	Air Filled Porosity (@-10kPa) % v/v
GW005	5.45	11.5	**0.95**	12.1	54	18.5	3.8	**276**	0.75	2.31	67.47	13.50	16.57
GW010	6.03	4.70	0.48	9.8	41	71.6	1.2	133	1.06	2.49	57.53	5.60	**7.70**
GW013	6.04	9.45	**0.94**	10.1	76	76.1	0.0	212	0.78	2.45	68.27	20.70	22.70
GW015	6.35	7.50	**0.77**	9.7	92	56.2	1.3	216	0.76	2.45	69.00	9.27	11.37
GW019	6.15	5.32	0.50	10.7	**105**	78.7	9.6	149	1.19	2.49	52.23	5.77	**7.73**
GW023	6.55	6.03	0.56	10.8	82	28.5	1.4	144	1.02	2.51	59.50	8.97	11.60
GW032	6.05	4.99	0.49	10.2	47	99.3	0.5	144	1.11	2.60	57.30	5.67	**8.03**
GW036	5.98	6.39	0.60	10.6	31	76.4	1.6	193	1.05	2.51	58.00	7.33	10.50
GW038	5.98	7.32	0.67	11.0	77	65.6	0.2	203	1.05	2.50	58.10	5.63	**7.90**
GW042	5.85	7.45	0.69	10.9	54	59.0	1.3	**287**	1.00	2.46	59.37	10.47	12.30
GW046	6.44	4.79	0.48	10.0	54	41.0	2.3	155	0.98	2.52	61.23	6.80	**9.77**
GW048	6.55	4.67	0.46	10.1	58	33.5	5.0	128	1.24	2.60	52.17	6.10	**8.67**
GW076	6.26	5.73	0.52	11.0	64	9.8	4.6	150	1.25	2.60	52.03	8.43	10.90
GW078	5.85	4.40	0.43	10.3	76	61.5	3.6	126	1.29	2.63	50.83	2.87	**4.33**
GW096	5.84	5.80	0.54	10.7	80	162	85.9	149	1.20	2.56	53.07	4.70	**6.77**
GW097	5.71	6.32	0.54	11.6	78	47.4	4.0	210	1.06	2.55	58.63	13.50	16.60
GW098	5.88	4.15	0.38	10.8	98	94.5	51.7	220	**1.48**	2.58	42.83	0.73	**2.80**
GW100	5.85	4.88	0.47	10.4	23	36.8	2.7	164	1.09	2.52	57.00	7.67	10.17
GW103	5.85	8.38	**0.72**	11.7	51	34.9	2.8	218	0.85	2.42	64.77	14.97	17.67
GW105	6.37	8.79	**0.93**	9.5	**114**	127	1.1	246	0.79	2.41	67.20	8.00	**9.20**
GW109	5.91	9.29	**0.85**	10.9	93	82.5	5.2	**288**	1.01	2.41	58.23	6.43	**8.73**
GW115	6.46	5.22	0.54	9.6	23	57.4	5.2	160	1.14	2.56	55.97	2.03	**4.37**
GW116	5.46	9.43	**0.84**	11.2	68	46.4	3.5	234	1.00	2.42	59.13	2.87	**6.57**

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

Table A3.2: Soil trace element concentrations (total recoverable) of soil quality monitoring sites sampled in 2008/09

Site Number	Arsenic (As) mg/kg	Cadmium (Cd) mg/kg	Chromium (Cr) mg/kg	Copper (Cu) mg/kg	Nickel (Ni) mg/kg	Lead (Pb) mg/kg	Zinc (Zn) mg/kg
GW005	3.5	0.68	14.0	8.9	5.9	10.0	66
GW010	8.2	0.51	20.0	16.0	17.0	28.0	97
GW013	4.3	**1.30**	28.0	20.0	24.0	23.0	120
GW015	4.7	0.53	24.0	17.0	16.0	21.0	83
GW019	< 2.0	0.34	9.8	6.8	4.0	9.2	33
GW023	6.9	0.45	21.0	20.0	19.0	32.0	110
GW032	< 2.0	0.50	14.0	6.9	8.6	7.3	50
GW036	3.5	0.42	17.0	13.0	12.0	15.0	76
GW038	3.6	0.50	16.0	9.0	11.0	16.0	79
GW042	3.8	0.41	15.0	8.6	9.5	19.0	66
GW046	< 2.0	0.33	13.0	17.0	8.5	19.0	75
GW048	7.2	0.52	20.0	16.0	17.0	22.0	95
GW076	4.3	0.47	19.0	13.0	14.0	18.0	84
GW078	4.0	0.38	21.0	13.0	17.0	16.0	71
GW096	**30**	0.39	50.0	35.0	18.0	21.0	85
GW097	3.3	0.38	22.0	11.0	14.0	16.0	86
GW098	2.7	0.38	11.0	10.0	5.4	9.5	36
GW100	2.1	0.23	11.0	8.3	6.0	11.0	44
GW103	5.2	0.50	19.0	10.0	11.0	18.0	66
GW105	4.5	0.89	22.0	23.0	18.0	19.0	88
GW109	4.4	0.64	12.0	11.0	5.7	10.0	70
GW115	3.0	0.59	17.0	19.0	12.0	14.0	81
GW116	4.3	0.67	17.0	14.0	10.0	14.0	94

Bold – exceeds recommended guideline value (NZWWA 2003).

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