Annual soil quality monitoring report for the Wellington region, 2010/11

Quality for Life

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Te Pane Matua Taiao

Annual soil quality monitoring report for the Wellington region, 2010/11

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Main cover photo: Wairarapa vineyard.

Contents

1. Introduction

Soils in the Wellington region support a wide range of land uses, including horticulture, viticulture, vegetable growing, cropping, dairy farming, drystock farming and forestry. Greater Wellington Regional Council (Greater Wellington) monitors a variety of indicators to assess soil quality in the region. A reduction in soil quality can result in reduced agricultural yields, and less resilient soil and land ecosystems. Changes in soil quality can also be associated with changes in environmental risks, including potential effects on waterways, animal health and greenhouse gas emission. Monitoring soil quality is beneficial to improve knowledge of the soil resource, demonstrate changes in soil properties over time, and modify management practices if needed (Sparling & Schipper 2004; Houlbrooke et al. 2010).

This report summarises the results of soil quality monitoring undertaken during the period 1 July 2010 to 30 June 2011 at six horticulture sites, five vineyard sites, seven exotic forestry sites and two grazing sites.

2. Overview of the soil monitoring programme

2.1 Background

Greater Wellington became involved in a national soil quality programme known as "The 500 Soils Project" in 2000 (Sparling & Schipper 2004). After completion of the 500 soils project, 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 soil properties, were identified to assess soil quality, particularly for state of the environment and regional council reporting (Land Monitoring Forum 2009). A value or range of values for each of the properties was 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 soil quality indicators 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 the effects of primary land uses on long-term soil productivity and the environment;
- 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 information required to determine the effectiveness of regional policies and plans.

2.3 Monitoring sites and methods

Greater Wellington's current soil quality monitoring programme includes over 100 monitoring sites on 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. Soil quality data are evaluated periodically for 'State of the Environment' reporting (eg, Sorensen 2012).

2.3.1 Sites, soils and land uses sampled in 2010/11

Twenty sites were sampled during 7–15 April 2011 (Figure 2.1). Horticulture land uses sampled included six sites, being mainly apple, pear, pip fruit, stone

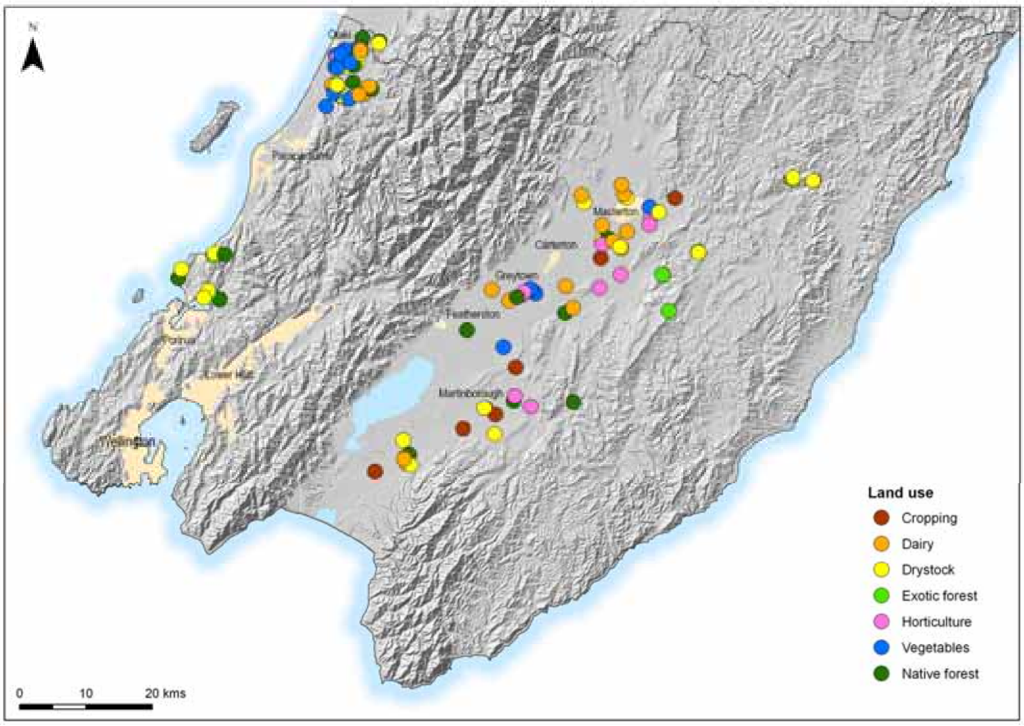

Figure 2.1: Greater Wellington's soil quality monitoring sites. The exotic forest and horticulture sites were sampled in April 2011

fruit and berry orchards. Many of the horticulture farms had been planted for 10–20 years. Five sites sampled were vineyards. Seven forestry sites sampled were exotic plantations of *Pinus radiata*, planted for 9–20 years. There were two sites that were mainly used for grazing.

A range of soil orders were sampled. Details of the soil order, group, subgroup, soil type and land use sampled are presented in Table 2.1. The soil classification used is the New Zealand Soil Classification. Soil classification was determined from sampling by Landcare Research staff during previous soil monitoring of the region. Further information and soil descriptions can be obtained from earlier reports such as Sparling (2005).

Five soil orders were sampled including Brown, Pallic, Recent, Gley and Melanic soils. Briefly, Brown Soils are characterised by brown colours due to iron oxide and are the most extensive soil order; Pallic Soils generally have high erosion potential and high subsoil density; Recent Soils have minimal soil profile development; Gley Soils are poorly or very poorly drained; and Melanic Soils are dark coloured and well structured (Hewitt 2010; McLaren & Cameron 1996).

2.3.2 Soil sampling methods

At each site a 50 m transect was laid out. Soil cores 2.5 cm in diameter to a depth of 10 cm were taken every 2 m along the transect. The 25 individual cores were bulked and mixed in preparation for chemical and biological analyses.

Table 2.1: Soil order, group, subgroup, soil type and land use sampled during 2010/11 (see Appendix 1 for site photos)

Site No.	Soil Order	Soil Group	Subgroup	Soil type	Land use
GW001	Brown	Orthic Brown	Typic Orthic Brown	Ashurst stony silt loam	Horticulture
GW025	Recent	Fluvial Recent	Mottled Fluvial Recent	Ahikouka silt loam	Vineyard
GW028	Recent	Fluvial Recent	Acidic-weathered Fluvial Recent	Manawatu shallow silt loam	Grazing
GW035	Pallic	Immature Pallic	Typic Immature Pallic	Martinborough silt loam	Vineyard
GW041	Pallic	Immature Pallic	Typic Immature Pallic	Tauherenikau gravelly sandy loam	Vineyard
GW047	Gley	Orthic Gley	Acid Orthic Gley	Rahui silt loam	Horticulture
GW053	Brown	Orthic Brown	Typic Orthic Brown	Makara steepland soils	Forestry
GW055	Brown	Firm Brown	Typic Firm Brown	Korokoro hill soils	Forestry
GW062	Brown	Firm Brown	Typic Firm Brown	Tinui hill soils	Forestry
GW064	Melanic	Rendzic Melanic	Weathered Rendzic Melanic	Kourarau hill soils	Forestry
GW065	Pallic	Argillic Pallic	Mottled Argillic Pallic	Wharekaka hill soils	Forestry
GW067	Recent	Orthic Recent	Typic Orthic Recent	Wharoama steepland soils	Forestry
GW069	Recent	Orthic Recent	Typic Orthic Recent	Taihape steepland soils	Forestry
GW073	Recent	Fluvial Recent	Weathered Fluvial Recent	Greytown silt loam	Horticulture
GW074	Recent	Fluvial Recent	Mottled-Weathered Fluvial Recent	Ahikouka silt loam	Grazing
GW077	Pallic	Argillic Pallic	Mottled Argillic Pallic	Kokotau silt loam	Vineyard
GW081	Recent	Fluvial Recent	Weathered Fluvial Recent	Greytown silt loam	Horticulture
GW083	Brown	Orthic Brown	Pallic Orthic Brown	Martinborough stony silt loam	Vineyard
GW089	Brown	Orthic Brown	Typic Orthic Brown	Ashurst stony silt loam	Horticulture
GW091	Gley	Orthic Gley	Typic Orthic Gley	Kairanga silt loam	Horticulture

Three undisturbed (intact) soil samples were also obtained from each site. The intact soil cores were collected 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, while taking care to preserve the soil structure. These intact soil cores were used to determine the physical properties of the soil such as bulk density, porosity, macroporosity and selected water holding contents. Further details on field methods are presented in Land Monitoring Forum (2009).

2.3.3 Soil analytical methods

The soil analytical methods are presented in Appendix 2. Further details on laboratory methods are presented in Land Monitoring Forum (2009).

2.4 Soil quality indicators and guideline values

Soil properties are measured and used as indicators of soil quality. Soil quality indicators include bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen, pH, and Olsen P, as well as heavy metal trace elements. The soil properties can be grouped into four specific areas of soil quality – physical condition, organic resources, fertility and trace elements (Table 2.2 and Appendix 3) – which together help provide an overall assessment of soil health.

Values of soil quality indicators can be interpreted to help evaluate how suitable a soil is for its particular land use. Similarly, soil quality indicators can be interpreted to help evaluate how management practices are affecting the soil for plant growth or for potential risks to the environment.

To help improve interpretation of soil quality indicators, an expert panel in several workshops developed guidelines for the soil quality indicators now commonly used by regional councils (Hill & Sparling 2009). The panel determined target ranges for the assessment of soil quality (eg, very low, optimal, very high etc.) for the predominant soil orders under different land uses (Hill & Sparling 2009). The interpretative ranges from Hill and Sparling (2009) are presented in Appendix 4.

For this report, the suggested target range for each indicator is the reporting ‘by exception’ as recommended by Hill and Sparling (2009). These guidelines are currently used by other regional councils in reporting soil quality monitoring, so are used in this report for consistency. Note that target values in Hill and Sparling (2009) were classified into target categories. For example, pH target ranges for ‘by exception’ reporting included the categories ‘slightly acid’, ‘optimal’ and sub-optimal’. Olsen P target ranges for by exception’ reporting were ‘low’, adequate’ and ‘ample’. However, some interpretive target ranges are still under development, particularly when examining environmental rather than production criteria (Hill & Sparling 2009). Therefore some consideration to other guidelines or research information is also discussed in this report.

The trace element results in this report have been compared to the soil targets presented in the New Zealand Water and Wastes Association (NZWWA 2003) ‘Guidelines for the Safe Application of Biosolids to Land in New Zealand’.

Table 2.2: 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 a measure of soil density. A high bulk density indicates a compacted or dense soil. Movement of water and air through soil pores is reduced in compacted soils. High soil bulk density can restrict root growth and adversely affect plant growth. There is also potential for increased run-off and nutrient loss to surface waters in compacted soils.
	Macroporosity	Soil compaction and degree of aeration	Macropores are important for soil air movement and drainage. Large soil pores are the most susceptible to collapse when soil is compacted. Low macroporosity adversely affects plant growth due to poor root environment, restricted air movement and N-fixation by clover roots. It also infers poor drainage and infiltration.
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 present 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.
	Anaerobic mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms.	Not all nitrogen can be used by plants; soil organisms change nitrogen to forms that plants can use. Mineralisable N gives a measure of how much organic nitrogen is available to plants, and the potential for nitrogen leaching at times of low plant demand. Mineralisable nitrogen is also used as a surrogate measure of the microbial biomass.
Acidity	Soil pH	Soil acidity	Most plants have an optimal pH range for growth. The pH of a soil influences the availability of many nutrients to plants and the solubility of some trace elements. Soil pH is influenced by the application of lime and some fertilisers.
Fertility	Olsen P	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Olsen P is a measure of the amount of phosphorus that is available to plants. Levels of P greater than agronomic requirements can increase P losses to waterways, and therefore contribute to eutrophication (nutrient enrichment).
Trace elements	Concentrations of total recoverable trace elements	Accumulation of trace elements	Some trace elements are essential micro-nutrients for plants and animals. 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 practices.

While guidelines containing soil contaminant values have been written for a specific activity (eg, biosolids application), the values are generally transferable to other activities that share similar hazardous substances (MAF 2008). For example, the NZWWA biosolids guidelines have been used by some regional councils to assess cadmium levels in soils as a result of fertiliser application (MAF 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. The biosolids guideline values for the selected trace elements relevant to this study are presented in Appendix 3.

Cadmium results can also be compared against the Tiered Fertiliser Management System (TFMS) from the recent New Zealand Cadmium Management Strategy (MAF 2011). This strategy, developed in response to concerns about the accumulation of cadmium in soils from phosphate fertiliser usage, recommends different management actions at certain trigger values. However, some caution is needed when interpreting values because the soil samples in this report were taken at a depth of 0–10 cm based on the methods in Hill and Sparling (2009), compared to a depth of 0–7.5 cm for uncultivated land which the TFMS is based on.

3. Soil quality results

This section summarises the results of the soil quality monitoring for 2010/11. Results are presented as means and summarised for comparison with the suggested 'by exception' target ranges reported in Hill and Sparling (2009).

For all the physical, chemical and trace element soil quality indicators, six out of 20 sites sampled (30%) had all soil indicators within the target range suggested in Hill and Sparling (2009). A further 11 sites sampled (55%) had one indicator that did not meet the target range, and three sites (15%) had two indicators that did not meet the target range.

Physical and chemical soil quality indicator means for the predominant land uses and for soil orders for the monitoring sites sampled are presented in Table 3.1 and Table 3.2, respectively. Results for individual soil quality monitoring sites are presented in Table 3.3. Values are compared with the suggested target range for the site's soil order and land use as reported in Hill and Sparling (2009).

3.1 Soil physical properties

Mean soil bulk density was greater for horticulture/vineyard land use than for forestry land use (Table 3.1). Mean bulk density was greatest on Gley Soils than the other soils (Table 3.2). All sites had bulk density within the guideline range (Table 3.3) suggested by Hill and Sparling (2009).

Mean soil macroporosity was less for the horticulture/vineyard land use than for forestry land use (Table 3.1). Mean macroporosity was much less on Gley soils than for the other soils. Six of the 20 sites had macroporosity values outside the guideline range suggested by Hill and Sparling (2009) and eight sites had macroporosity values <10% (Table 3.3).

3.2 Soil chemical properties

Mean soil pH was 6.3 for horticulture/vineyard land use and 5.3 for forestry land use (Table 3.1). All sites had soil pH within the guideline range suggested by Hill and Sparling (2009).

Mean soil carbon was less for horticulture/vineyard land use than for forestry land use (Table 3.1). Mean soil carbon was less for Gley and Recent Soils than for Brown and Pallic Soils (Table 3.2). All sites (Table 3.3) had total carbon levels within the guideline range suggested by Hill and Sparling (2009).

Two of the nine sites did not meet the total nitrogen guideline range suggested by Hill and Sparling (2009). Note that there was no guideline for horticulture/vineyard land use so those sites were excluded. Mean total nitrogen, carbon and anaerobic mineralisable nitrogen levels tended to be less on Gley and Recent Soils (Table 3.2).

Mean soil Olsen P was 79 mg/kg for horticulture/vineyard land use and 52 mg/kg for forestry land use (Table 3.1). Gley Soils had the greatest mean Olsen P (119 mg/kg), but there were only two sites on Gley Soils. Two Olsen P concentrations were very high at 156 and 186 mg/kg. Ten sites recorded Olsen P concentrations greater than 40 mg/kg, five of which recorded Olsen P above the upper guideline suggested by Hill and Sparling (2009).

3.3 Soil trace elements

With the exception of copper, trace element (total recoverable) concentrations in samples from soil monitoring sites were below the NZWWA (2003) guidelines (Table 3.4). Two of the 20 sites had copper concentrations that exceeded the NZWWA (2003) guidelines.

The majority of the samples recorded cadmium concentrations below the MAF (2011) proposed tier 1 trigger value of 0.6 mg/kg. Two sites had cadmium concentrations above this proposed trigger value. No samples exceeded the proposed tier 2 trigger value of 1 mg/kg.

Mean trace element concentrations by land use and soil order for sites sampled are presented in Table 3.5. The mean arsenic, cadmium, chromium, nickel, lead and zinc concentrations for horticulture/vineyards were greater than the mean for forestry sites. The mean copper concentration for horticulture/vineyards was approximately five times greater than the mean for forestry sites. While there was some variation between soil orders, this may be due to land use more likely to be present on some soils.

Table 3.1: Physical and chemical soil quality indicators by land use for monitoring sites sampled in April 2011. Means and standard deviations (sd) are presented

Land use	No. of samples	pH		Organic carbon (%)		Total N (%)		Anaerobic mineralisable-N (mg/kg)		Olsen P (mg/kg)		Bulk density (Mg/m^3)		Macroporosity (-10kPa % v/v)	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Horticulture/ vineyard	11	6.3	0.39	5.5	2.0	0.49	0.17	132	51	79	51	1.13	0.15	12.3	6.9
Forestry	7	5.3	1.02	6.9	2.9	0.49	0.22	79	32	52	48	1.03	0.19	16.3	8.8

Table 3.2: Physical and chemical soil quality indicators by soil order for monitoring sites sampled in April 2011. Means and standard deviations (sd) are presented

Soil Order	No. of samples	pH		Organic carbon (%)		Total N (%)		Anaerobic mineralisable-N (mg/kg)		Olsen P (mg/kg)		Bulk density (Mg/m^3)		Macroporosity (-10kPa % v/v)	
		Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Brown	6	6.0	1.07	7.4	2.8	0.55	0.20	117	55	71	62	1.01	0.20	17.9	7.8
Gley	2	6.1	0.01	4.0	1.0	0.35	0.08	85	34	119	38	1.22	0.07	4.0	2.0
Pallic	4	6.0	1.03	6.7	2.7	0.59	0.23	120	62	65	33	1.15	0.15	14.6	5.1
Recent	8	5.8	0.51	4.4	1.3	0.37	0.11	97	36	49	42	1.16	0.16	12.6	7.0

Table 3.3: Physical and chemical results for each soil quality monitoring site sampled in April 2011. Values in bold are outside the suggested target range for the site's soil order and land use as reported in Hill and Sparling (2009)

Site No.	Land use	Soil order	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)
GW001	Horticulture	Brown	6.0	8.3	0.76	**203**	79	0.88	14.0
GW025	Vineyard	Recent	5.7	4.8	0.45	127	13	1.15	6.4
GW028	Grazing	Recent	5.9	3.9	0.37	103	37	1.30	7.1
GW035	Vineyard	Pallic	6.2	3.8	0.33	73	45	1.33	12.6
GW041	Vineyard	Pallic	6.4	9.0	0.78	**227**	65	0.95	22.9
GW047	Horticulture	Gley	6.1	3.0	0.27	50	**156**	1.29	**2.0**
GW053	Forestry	Brown	4.8	9.8	0.54	87	5	0.85	**33.0**
GW055	Forestry	Brown	4.4	10.5	0.70	76	32	0.86	17.8
GW062	Forestry	Brown	7.4	2.5	0.16	41	20	1.40	**6.8**
GW064	Forestry	Melanic	5.9	6.1	0.49	149	33	1.11	**7.1**
GW065	Forestry	Pallic	4.3	9.7	**0.86**	78	**118**	1.08	13.9
GW067	Forestry	Recent	4.6	6.1	0.42	65	**136**	0.84	24.0
GW069	Forestry	Recent	5.7	3.7	0.26	58	23	1.10	11.4
GW073	Horticulture	Recent	6.3	3.2	0.28	95	25	1.29	**4.8**
GW074	Grazing	Recent	6.1	2.8	**0.24**	68	25	1.34	13.1
GW077	Vineyard	Pallic	7.1	4.1	0.38	104	31	1.23	9.1
GW081	Horticulture	Recent	6.0	6.4	0.57	164	87	1.08	21.6
GW083	Vineyard	Brown	7.0	5.3	0.44	128	**106**	1.13	18.1
GW089	Horticulture	Brown	6.2	8.0	0.68	165	**186**	0.95	18.1
GW091	Horticulture	Gley	6.1	5.0	0.43	119	81	1.14	**5.9**
Target range	Horticulture		5–7.6		excl	20–200	20–100		6–30
Target range	Pasture		5–6.6		0.25–0.7	50–250	15–100		6–30
Target range	Forestry		3.5–7.6		0.1–0.7	20–175	5–100		8–30
Target range	Recent soil			2–>12				0.4–1.4	
Target range	Other soils			2–>12				0.4–1.4	
Number of sites not meeting target			0/20	0/20	2/9[1]	2/20	5/20	0/20	6/20

[1] Target range not available for some land uses.

Table 3.4: Trace element concentrations (total recoverable) in soil samples from monitoring sites sampled over 2010/11. Samples highlighted in bold were greater than the NZWWA (2003) guideline

Site No.	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW001	4	0.5	11	**101**	10.3	5	56
GW025	7	0.16	11	20	12.5	9	69
GW028	6	0.27	16	28	21	14	83
GW035	5	0.19	13	25	13.4	9	72
GW041	<2	0.36	14	31	10.3	10	65
GW047	3	0.29	14	16	10.2	9	73
GW053	3	<0.10	12	8	11.5	7	30
GW055	2	0.14	7	6	9.2	3	25
GW062	3	0.12	18	8	13.2	16	55
GW064	6	0.73	14	8	16	8	45
GW065	4	0.34	10	12	9.7	7	61
GW067	3	0.12	7	7	8.8	5	48
GW069	3	<0.1	8	6	7.4	6	36
GW073	3	0.16	17	15	14.6	15	69
GW074	3	0.16	18	13	12.6	15	64
GW077	<2	0.16	11	18	10.1	9	57
GW081	5	0.36	18	**138**	61	17	194
GW083	3	0.16	11	9	13.8	7	61
GW089	5	0.64	12	86	11.7	5	82
GW091	6	0.32	19	20	30	13	92

Table 3.5: Mean trace element concentrations (total recoverable) by land use and soil order for sites sampled in April 2011

	No. of sites	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
Land use								
Horticulture/ vineyard	11	3.9	0.30	13.7	43.5	18.0	9.8	81
Forestry	7	3.4	0.22	10.9	7.9	10.8	7.4	42.9
Soil order								
Brown	6	3.3	0.27	11.8	36.3	11.6	7.2	51.5
Gley	2	4.5	0.31	16.5	18.0	20.1	11.0	82.5
Pallic	4	2.8	0.26	12.0	21.5	10.9	8.8	63.8
Recent	8	4.3	0.18	13.6	32.4	19.7	11.6	80.4

4. Discussion

All sites had soil pH, total carbon and bulk density within the guideline ranges suggested by Hill and Sparling (2009). Many of the sites surveyed on horticultural and exotic forestry land use generally had good soil quality.

Some soil quality indicators at some sites were outside the recommended range. Low macroporosity is an indicator that the volume of large pores in the soil, commonly responsible for soil drainage and aeration, is low. A common indicator guideline reported in the literature is that macroporosity values (measured at -10 kPa) should be greater than 10% v/v (Drewry et al. 2008). Mean macroporosity values were considered adequate for the horticulture/vineyard and exotic forestry land uses, and for the Brown, Pallic and Recent Soils. Six of the 20 sites had macroporosity values outside the guideline range suggested by Hill and Sparling (2009). The impact of soil compaction can be minimised where practicable by minimising the use of machinery and tyres in wet soil conditions on orchards.

The soil quality indicator Olsen P showed that phosphorus concentrations at some sites were higher than currently recommended levels. Ten sites had an Olsen P value greater than 40 mg/kg, of which five sites had values greater than the Hill and Sparling (2009) upper guideline of 100 mg/kg.

The Olsen P guidelines values suggested by Hill and Sparling (2009) are being reviewed, as the 100 mg/kg upper guideline value (eg, for pasture, forestry and horticulture land uses) is greater than some other guidelines (eg, Roberts & Morton 2009). Recommendations vary with horticultural crop, soils and management. For example, a recommended MAF soil test level for P (ie, measured as Olsen P) for grapes is 30+ (Anon 1995a; Clarke et al. 1986). For pip fruit, including apples, no P fertiliser is recommended above a MAF soil test P level of 70 (Anon 1995b; Clarke et al. 1986). Monitoring in this region has shown that five of the eight horticultural land use sites sampled had Olsen P levels greater than 70 mg/kg. While appropriate guidelines for horticultural crops may be greater than for pasture (eg, Anon 1995a, b; Clarke et al. 1986), further research is needed to determine guidelines for a variety of horticultural crops and management of potential environmental impacts. In terms of environmental impacts, there has been extensive research in New Zealand and internationally to show that as soil P levels increase, the risk to waterways via eutrophication also increases (McDowell et al. 2003; McDowell et al. 2004).

Two sites had cadmium concentrations above the tier 1 trigger value (0.6 mg/kg) proposed in the New Zealand Cadmium Management Strategy (MAF 2011). The two sites had contrasting land uses. One site was on forestry and was associated with adequate Olsen P levels. However, the other site was on horticultural land and was associated with the greatest Olsen P level in the 2011 monitoring round. It is possible that both indicators are elevated as a result of fertiliser usage. The Cadmium Management Strategy recommends different management actions at certain trigger values to ensure that soil cadmium is within recommended levels. Once levels reach tier 2 (ie, tier 1 is exceeded), it is recommended that fertiliser application is restricted to a set of products and rates that minimise cadmium accumulation (MAF 2011).

Two horticultural sites had copper concentrations above the NZWWA (2003) guidelines. The soil quality monitoring results also show that many of the other trace element concentrations were greater on horticulture/vineyard land uses than exotic forestry land use. Pesticide sprays can be a source of copper, lead and arsenic in horticulture and vineyard land uses (Gray 2011). Treated timber posts in vineyards can be a source of copper, chromium and arsenic to soil and water (Clothier et al. 2006). It is likely that some past or current management practices on horticulture blocks and vineyards could be a source of these trace elements at some monitoring sites. Soil quality monitoring in the Marlborough region (Gray 2011) showed that copper concentrations did not vary greatly between different land uses (including vineyards), and upper values of soil copper concentration were lower than for some of the monitoring sites in the Wellington region. In contrast, soil quality monitoring in the Waikato region has found soil copper concentrations were greater under horticulture than other land uses (Taylor et al. 2010), with median and upper values of soil copper concentrations greater than for the monitoring sites in this region. Management practices on sites that are close to or exceed the copper guideline should be evaluated and modified where possible so that copper levels do not increase in the long term.

5. Summary

Sampling of soils at six horticulture sites, five vineyard sites, seven exotic forestry (plantation) sites and two grazing sites in 2010/11 found that all sites had soil pH, total carbon levels and bulk density within their respective recommended target range. However, 11 of the 20 sites sampled (55%) sites had one soil quality indicator that outside of the target range and three sites (15%) were outside the target range for two indicators. Overall, the horticultural sites were generally in the poorest condition. Low macroporosity and elevated Olsen P values were recorded at some of these sites. In terms of trace elements, two sites – both horticultural – recorded soil copper concentrations above the NZWWA (2003) guidelines. Soil cadmium concentrations also exceeded the tier 1 trigger value in the national Cadmium Management Strategy at two sites (one horticultural site and one exotic forestry site).

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Appendix 1: Soil quality monitoring sites sampled in 2010/11

Sites were sampled over 7–15 April 2011.


Site GW001


Site GW025


Site GW028


Site GW035


Site GW041

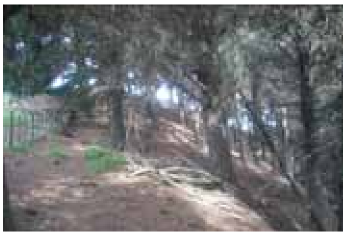

Site GW047


Site GW053


Site GW055


Site GW062


Site GW064


Site GW065


Site GW067


Site GW069


Site GW073


Site GW074


Site GW077


Site GW081


Site GW083


Site GW089


Site GW091

Appendix 2: Analytical methods

Analyses of the soil chemistry and soil physics were completed at the Landcare Research laboratory (Table A2.1). Trace element analyses 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: Soil quality indicators

Soil physical properties

The physical condition of the soil can affect transmission of water and air through soil and can subsequently affect plant yield. Soil physical conditions can also have implications on soil hydrology such as runoff and leaching and also the production of some greenhouse gases.

Bulk density and macroporosity are indicators of soil physical condition, and therefore indicators of soil compaction. Bulk density is the mass of soil per unit volume (McLaren and Cameron 1996). Macroporosity is an indicator of the volume of large pores in the soil, commonly responsible for soil drainage and aeration. Macroporosity describes the volume percentage of pores >30 micron diameter (McLaren & Cameron 1996; Drewry et al. 2008; 2004). Macropores are primarily responsible for adequate soil aeration and rapid drainage of water and solutes (McLaren & Cameron 1996). Note that macroporosity has also been defined with different pore diameters. For the purposes of this report macroporosity is measured at -10 kPa matric potential.

Macroporosity has been shown to be a good indicator of soil physical condition. It is commonly a more responsive indicator of soil compaction than bulk density. Macroporosity values of less than 10–12% have often used to indicate limiting conditions for plant health and soil aeration (Drewry et al. 2008). Optimum soil macroporosity, for example, for maximum pasture and crop yield ranges from 6–17% v/v (Drewry et al. 2008).

Soil compaction is commonly caused by either animal treading and the impact of machinery and tyres in wet soil conditions on horticulture orchards and cultivated land (Drewry et al. 2008; Vogeler et al. 2006). Soil compaction can also occur as a result of some forest harvesting management practices. Factors such as the loss of organic matter may also contribute to reduced soil physical quality.

Soil chemical properties

Soil organic matter helps retain moisture, nutrients and good soil structure for water and air movement. Soil carbon is used as an indicator of the soil organic matter content. Soil organic matter levels are particularly susceptible when land is used for market gardening and cropping. Intensive cultivation can lead to a reduction in soil organic matter through increasing the rate of organic matter decomposition, reducing inputs of organic residues to the soil and increasing aeration oxidation of the soil (McLaren & Cameron 1996).

Nitrogen (N) is an essential nutrient for plants and animals. Most nitrogen in soil is found in organic matter. Total nitrogen is used as an indicator. 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 lead to leaching of nitrate to groundwater and waterways (SINDI 2010).

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 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 2010).

Soil pH is a measure of the degree of acidity or alkalinity of the soil (McLaren & Cameron 1996). Most plants and soil organisms have an optimum soil pH range for optimum growth. Soil pH can affect many chemical reactions in the soil such as availability and retention of nutrients. Commonly, lime is added to many New Zealand to change pH to the optimum range for plant growth.

Many New Zealand soils are inherently deficient in phosphorus, sulphur, to a lesser extent potassium and in some cases, trace elements (Roberts & Morton 2009). Inputs of fertiliser or other soil amendments (eg, effluent) are used to improve soil fertility. Olsen P is an indicator of the plant available fraction of phosphorus in the soil. Olsen P is a widely used soil test indicator in New Zealand and has been extensively used for calibration of pasture and plant yield responses (Roberts & Morton 2009) and crop responses (Nicolls et al. 2009). While soil Olsen P is a well recognised indicator of soil fertility, it is increasingly being used as a soil quality indicator of risk to waterways (McDowell et al. 2004). Phosphorus is commonly strongly bound to soils. Soil erosion causing sediment to reach waterways often carries sediment bound phosphorus, which may result in contamination of water and enhanced algal growth.

Soil trace elements

Trace elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) can accumulate in soils as a result of common agricultural and horticultural land use activities such as the use of pesticides and the application of some types of effluent and phosphate fertilisers. While trace elements occur naturally, and the natural concentrations of most trace elements can vary greatly depending on geologic parent material, trace elements can become toxic at higher concentrations (Kim & Taylor 2009).

Appendix 4: Soil quality guidelines

Soil quality indicator target ranges from Hill and Sparling (2009) are presented below. Soil quality indicator values in bold are the suggested 'by exception' target ranges from Hill and Sparling (2009). Guideline values for trace element concentrations in soil are adapted from NZWWA (2003).

Bulk density target ranges (t/m^3 or Mg/m^3)

	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 (% v/v at -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					

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

Olsen P target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	
Pasture on Sedimentary and Allophanic soils	0	15	20	50	100	200
Pasture on Pumice and Organic soils	0	15	35	60	100	200
Cropping and horticulture on Sedimentary and Allophanic soils	0	20	50	100	100	200
Cropping and horticulture on Pumice and Organic soils	0	25	60	100	100	200
Forestry on all Soil Orders	0	5	10	100	100	200

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

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