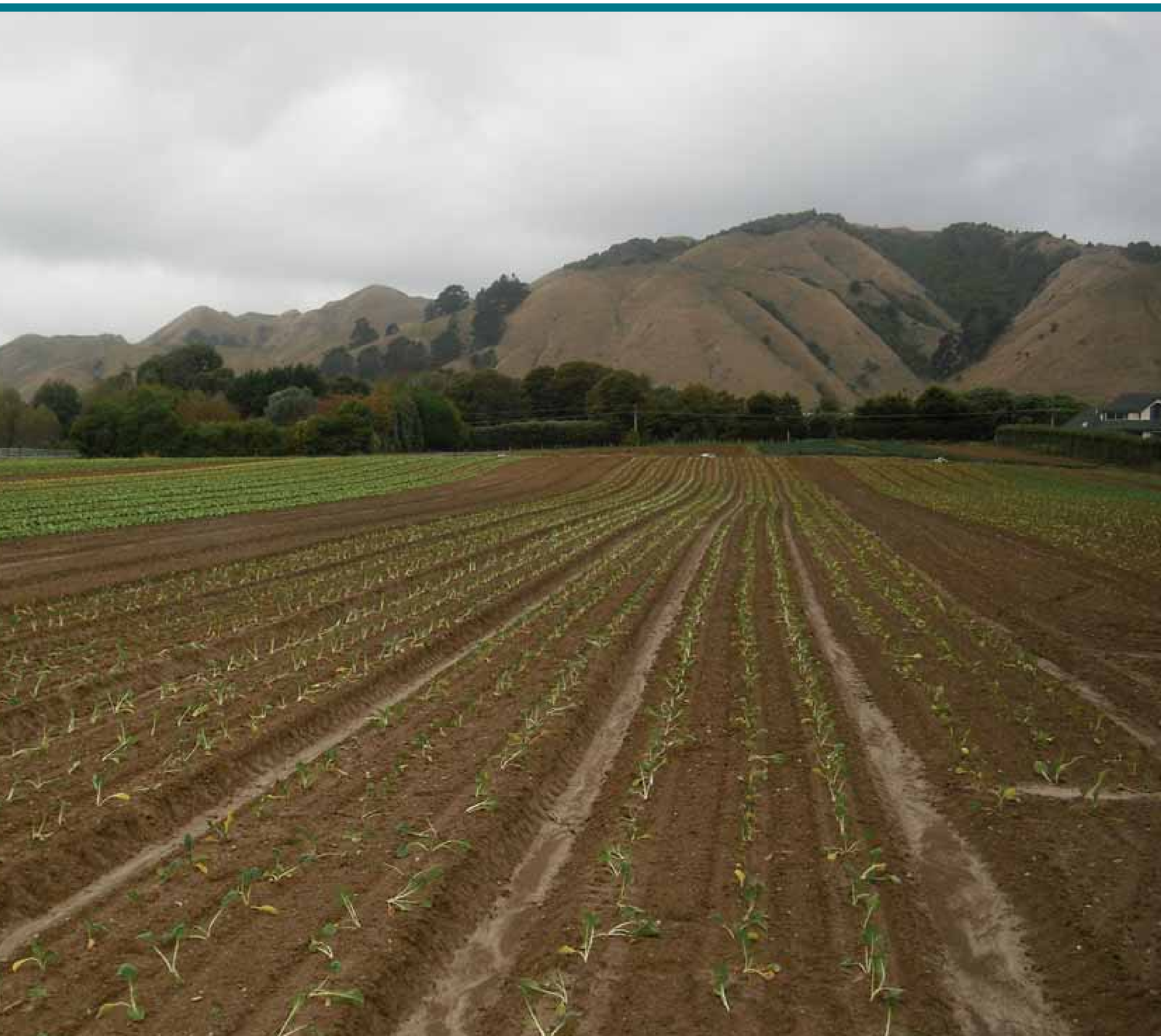
Annual soil quality monitoring report for the Wellington region, 2009/10

Quality for Life

greater WELLINGTON REGIONAL COUNCIL | Environment Management



Annual soil quality monitoring report for the Wellington region, 2009/10

Paul Sorensen

Environmental Monitoring and Investigations Department

For more information, contact Greater Wellington:

Wellington
PO Box 11646

T 04 384 5708
F 04 385 6960
www.gw.govt.nz

Masterton
PO Box 41

T 06 378 2484
F 06 378 2146
www.gw.govt.nz

GW/EMI-G-10/165

November 2010

www.gw.govt.nz
info@gw.govt.nz

The report may be cited as:

Sorensen, P. 2010. *Annual soil quality monitoring report for the Wellington region, 2009/10*. Greater Wellington Regional Council, Publication No. GW/EMI-G-10/165.

Contents

1. Introduction

Soil in the Wellington region is used to support a wide range of land uses including market gardens, horticulture, viticulture, cropping, dairy farming, drystock farming and forestry. Greater Wellington Regional Council (Greater Wellington) monitors our region's high quality soils to determine whether or not these land uses are having any effects on soil health. Inappropriate land use practices such as overstocking and over-cultivation can result in a long-term reduction in soil quality. Poor soil quality can also produce lower agricultural yields, a less resilient soil and land ecosystem, and increase the risks of contamination of adjacent water bodies.

This report summarises the results of soil quality monitoring undertaken at 14 market garden and 8 cropping sites over the period 1 July 2009 to 30 June 2010. A report containing a detailed analysis of long-term trends in soil quality is produced approximately every six years (e.g., 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 soil properties, were identified to assess soil quality. 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 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 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 a mechanism to determine the effectiveness of regional 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.

2.3.1 Sites sampled in 2009/10

In 2009/10, 14 market garden sites and 8 cropping sites were sampled (Figure 2.1). Four further sites were intended to be sampled, but for various reasons could not be:

- site GW084 was a double-up of site GW022 and so did not need to be sampled;

- site GW087 was overgrown in scrub, and sampling was not practical;
- site GW088 was found to be developed as part of a recent residential development; and
- the owners of site GW101 advised that this site is no longer used for market gardening.

While the sites were recorded as being market garden or cropping sites from when the sites were sampled previously, land use has since changed at some of the sites. Information was recorded on field sheets including the current land use of the site, and visual characteristics of the soil. This information is recorded in Appendix 1.

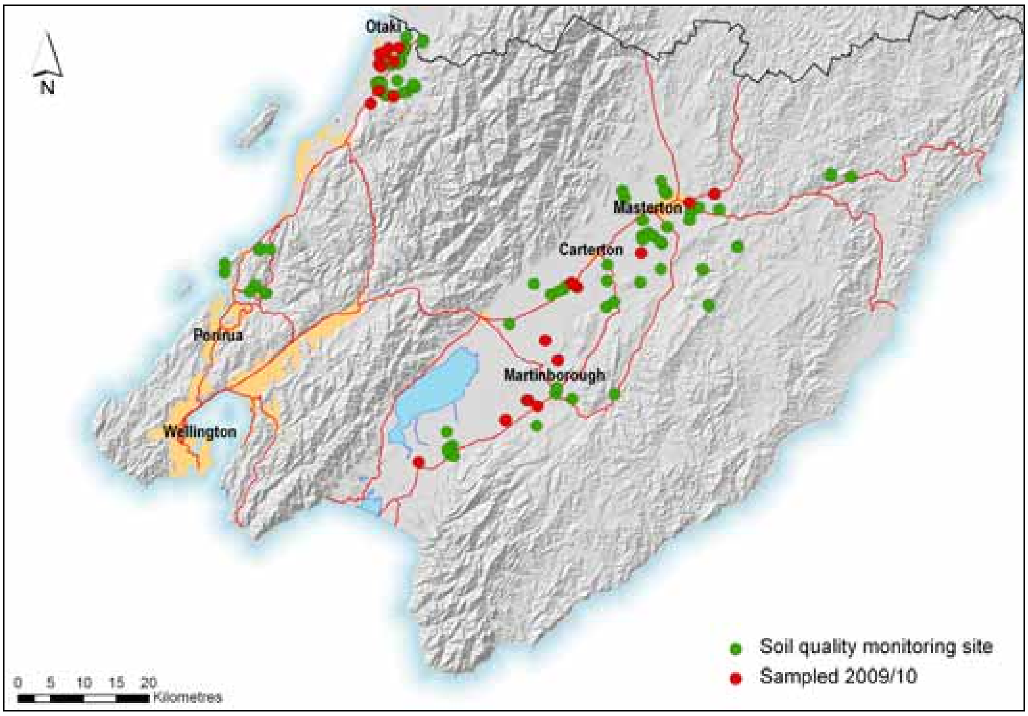


Figure 2.1: Greater Wellington's soil quality monitoring sites, including those sampled during 2009/10

2.3.2 Soil sampling 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 (Figure 2.2a). The 25 individual cores are bulked and mixed in preparation for chemical and biological analyses to determine the organic resources, acidity and fertility of the soil and concentrations of trace elements.

Three undisturbed (intact) soil samples are also obtained from each site (Figure 2.2b). The intact soil cores are 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. These intact soil cores are used to determine the physical properties of the soil as such density, porosity and water holding characteristics.

In 2009/10, an additional sample was also collected at the market garden sites to assess aggregate stability (see section 2.4). The sample was collected at the same interval as the intact cores by cutting a vertical block of soil with a spade approximately 10 cm square (10 cm high x 10 cm wide) and 10-12 cm thick from a fresh vertical soil face. Care was taken to ensure a sufficient volume of soil (approximately 3 kg) was collected to enable three replicate analyses on each sample. Samples were carefully handled to avoid crushing, smearing or altering the aggregates in any way. A detailed description of the laboratory methods used can be found in Appendix 2.

Figure 2.2: (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.

2.4 Soil quality indicators

Seven soil properties were measured and used as indicators of soil quality (Table 2.1): bulk density, macroporosity, total carbon, total nitrogen, mineralisable nitrogen, soil pH and Olsen P, as well as trace elements and in some cases aggregate stability[1]. The soil properties can be grouped into specific areas of soil quality; physical condition, organic resources, acidity, fertility and trace elements, which together provide an overall picture of the health of the soil.

The physical condition of the soil is determined from the bulk density, macroporosity and aggregate stability of the soil. Bulk density and macroporosity are both measures of soil compaction. Bulk density is the weight of a standard volume of soil, while macroporosity[2] 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 2010). Compaction is caused by either animal treading, the impact of heavy machinery, cultivation, the loss of organic matter and

1 Aggregate stability was only measured at seven of the sites which were observed to be used for market gardening as aggregate stability is known to be affected by cultivation.

2 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”.

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).
	Aggregate stability	Soil structure breakdown – how resistant soil crumbs are to breakage.	Aggregate stability is a measure of the stable crumbs in soil that are of a desirable size, and resist compaction, slaking, and capping of seedbeds. It is useful to measure at horticultural and cropping soils because aggregates are affected by cultivation. A stable "crumbly" texture lets water quickly soak into soil, doesn't dry out too rapidly, and allows roots to spread easily.
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.
	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 the 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 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	Accumulation of trace elements	Some trace elements are essential micro-nutrients 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.

subsequent desiccation, or a combination of some of these factors. Compaction reduces the number of pores available for water and gas movement, aeration, root growth and distribution, and nutrient uptake. Therefore, compaction of soils used for market gardening or cropping will reduce productivity, while also potentially impacting the environment by increasing the risk or surface run-off during rainfall events.

Aggregate stability is a measure of soil structure. Soil aggregates need to be of a size, shape and packing that maintains the necessary soil porosity for roots to easily access air, water and nutrients (Beare et al. 2005). Soils with high aggregate stability are better able to withstand the degradation that may result from cultivation, compaction and raindrop impact. Aggregates with low structural stability are more prone to dispersion by wind and water. Particles dispersed by water tend to fill the surrounding pores, restricting the movement of water and air into the soil profile. When this occurs at the soil surface, caps may form that can restrict seedling emergence, and impede drainage (Beare et al. 2005). Research has shown that soil with low aggregate stability also have lower crop yields (Beare et al. 2005).

The organic resources are established from the soil's total carbon, total nitrogen and mineralisable nitrogen. 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 2010). Consequently, total carbon is measured and used as an estimate of the soil organic matter content of the soil. Soil organic matter and carbon levels are particularly susceptible when land is used for market gardening and cropping. Intensive cultivation can lead to a considerable reduction in soil organic matter and carbon through increasing the rate of organic matter decomposition in soil, reducing inputs of organic residues to the soil each year 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 and total nitrogen gives a measure of those reserves. 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 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 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 2010).

Acidity is a measure of the soil's pH. Most plants and soil organisms have an optimum soil pH range for growth. 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 2010). 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.

Fertility is determined by the Olsen P concentration of the soil. Olsen P is the plant available fraction of phosphates in the soil. Phosphorus (like nitrogen) is an essential nutrient for plants and animals. 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 groundwater. 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 2010).

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 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 (Stevenson 2008), trace elements can become toxic at higher concentrations (Kim & Taylor 2009).

2.4.1 Soil quality guideline values

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. However, interpretive frameworks are still under development, particularly when examining environmental rather than production criteria (Hill & Sparling 2009). As a result, the critical values and optimal ranges used to assess soil quality in this report are often related to effects on production but effects on the environment can also be inferred. The critical values and optimal ranges taken from Hill & Sparling can be found in Appendix 3.

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 (MAF 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 (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.

3. Soil quality results

The majority of the 22 market garden and cropping sites were found to be in poor condition, with only four sites meeting all of the soil quality criteria, and 12 sites having more than two soil quality indicators outside the target (optimal) range (Table 3.1, Figure 3.1). Out of the 12 sites, five were outside the optimal range for three soil quality indicators, and four were outside the optimal range for four soil quality indicators. The most common soil quality issues were low levels of soil carbon, high concentrations of Olsen P, low macroporosity and very low aggregate stability.

This section summarises the results of the soil quality monitoring for 2009/10. The full monitoring results can be found in Appendix 4.

Table 3.1: Physical and chemical results for the 22 soil quality monitoring sites sampled in 2009/10. Values in bold are outside the optimal range for the site's specific soil order and land use.

Site No. (No. of targets exceeded)	Soil pH	Total C %	Total N %	C:N ratio	Mineral-isable N mg/kg	Olsen P mg/kg	Bulk Density t/m^3	Macro Porosity (@-10kPa) % v/v	Aggregate Stability* m.w.d
GW016 (1)	5.49	4.25	0.39	11.0	146	48	1.31	4.27	
GW017 (1)	5.59	3.00	0.27	11.1	85	40	1.38	2.20	
GW021 (1)	5.94	6.04	0.53	11.3	226	60	1.21	6.00	
GW022 (0)	6.03	2.82	0.28	10.1	144	82	1.37	6.40	
GW027 (3)	7.33	1.42	0.15	9.5	26	139	1.37	18.73	0.41
GW031 (0)	6.03	3.30	0.29	11.3	66	31	1.24	11.80	
GW044 (3)	5.82	1.98	0.17	11.6	69	14	1.34	5.67	
GW071 (3)	5.94	2.87	0.28	10.2	51	80	1.29	5.40	
GW075 (2)	5.73	1.70	0.15	11.3	33	58	1.36	20.60	0.40
GW079 (3)	7.27	1.84	0.17	10.8	39	77	1.46	1.97	
GW080 (1)	5.18	2.02	0.19	10.7	42	32	1.40	7.10	
GW082 (1)	6.76	4.27	0.36	11.9	100	113	1.15	21.23	
GW085 (0)	6.03	3.00	0.31	9.8	59	32	1.14	14.13	
GW086 (0)	6.12	3.15	0.32	9.9	66	30	1.24	6.23	
GW090 (1)	6.24	2.90	0.28	10.4	40	35	1.10	18.10	1.19
GW092 (2)	6.02	2.59	0.24	10.9	45	184	1.27	10.67	0.54
GW093 (4)	6.52	1.64	0.15	11.1	37	142	1.59	1.93	
GW094 (4)	5.76	1.46	0.14	10.3	16	241	1.34	17.43	0.31
GW107 (4)	6.37	1.23	0.12	10.0	13	154	1.37	21.00	0.27
GW108 (2)	5.57	4.66	0.33	14.3	29	151	1.06	20.53	0.47
GW111 (4)	6.90	1.69	0.16	10.5	43	198	1.65	2.30	
GW112 (3)	6.53	1.73	0.16	10.6	16	191	1.39	12.47	

* No target range is provided in Hill & Sparling (2009) for aggregate stability, but 1.5 m.w.d. is considered to be the desirable lower limit for good soil structure (Stevenson 2007).

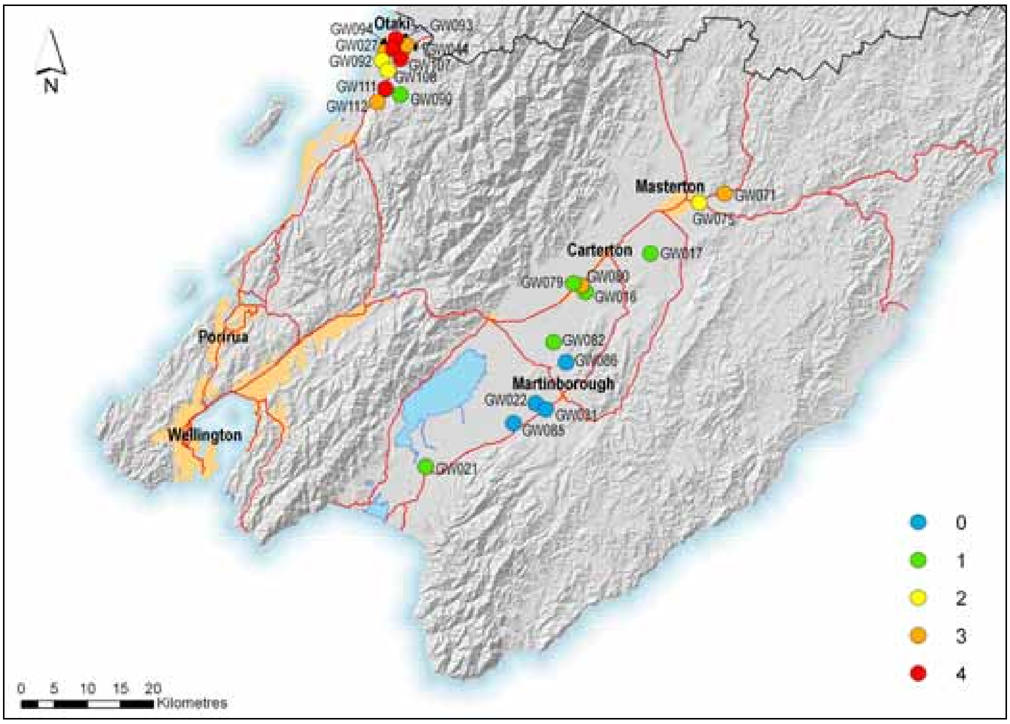


Figure 3.1: Number of soil quality indicators outside target ranges for each of the 22 monitoring sites sampled in 2009/10

3.1 Physical quality

Bulk density across all the 22 sites sampled was high (Figure 3.2). Samples from all sites recorded bulk density values in excess of 1.00 t/m^3, and four sites recorded values greater than 1.40 t/m^3, exceeding the upper limit of the optimal range. However, the optimal ranges for cropping and horticulture are poorly defined (Hill & Sparling 2009).

The four sites that recorded high bulk density values (GW079, GW080, GW093 and GW111) were all documented in previous sampling as being market garden sites. However, it was noted during the 2009/10 sampling that all these sites had been developed into pasture or lucerne, and the use of machinery in this process could have impacted on the bulk density of these soils.

Macroporosity levels varied across the 23 sites sampled, ranging from 1.93 to 21.23%, with seven sites below the lower limit (6) of the optimal range (Figure 3.3). However, as with bulk density, the optimal ranges for cropping and horticulture are poorly defined (Hill & Sparling 2009).

The sites with macroporosity values below 6 included three of the sites with the highest bulk density (GW079, GW093 and GW111) as well as sites GW016, GW017, GW044 and GW071. None of these sites were active market gardens at the time of sampling, and all appeared to have been exposed to machinery or stock recently which could have had an impact on soil macroporosity.

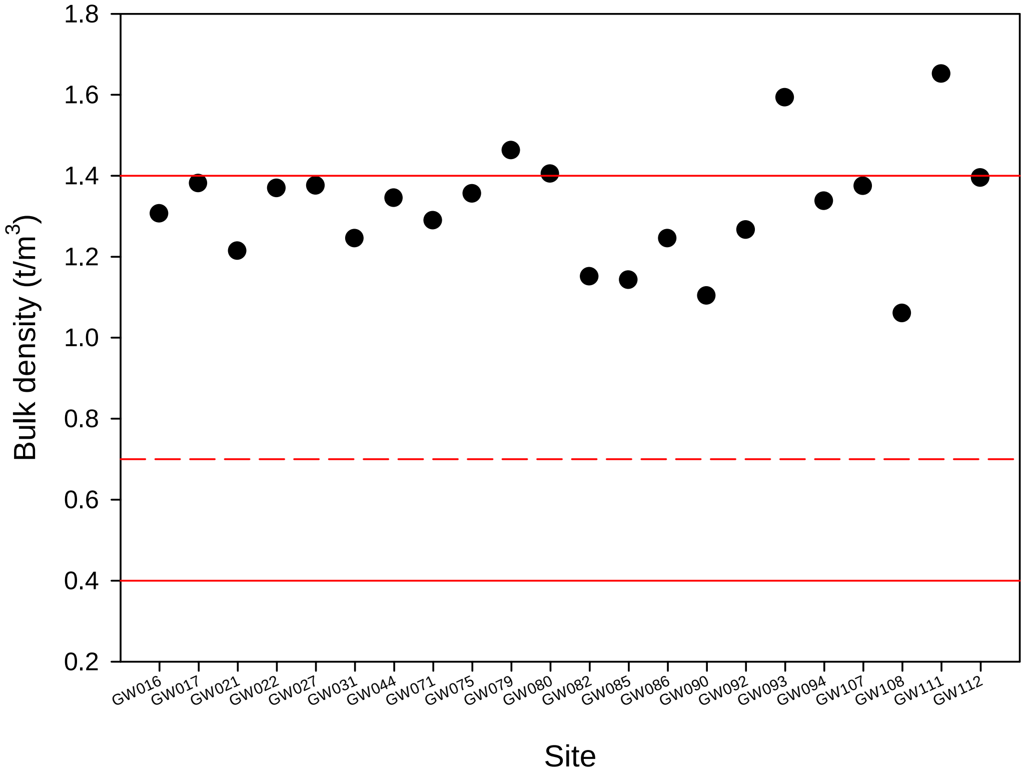


Figure 3.2: Bulk density at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range*.

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

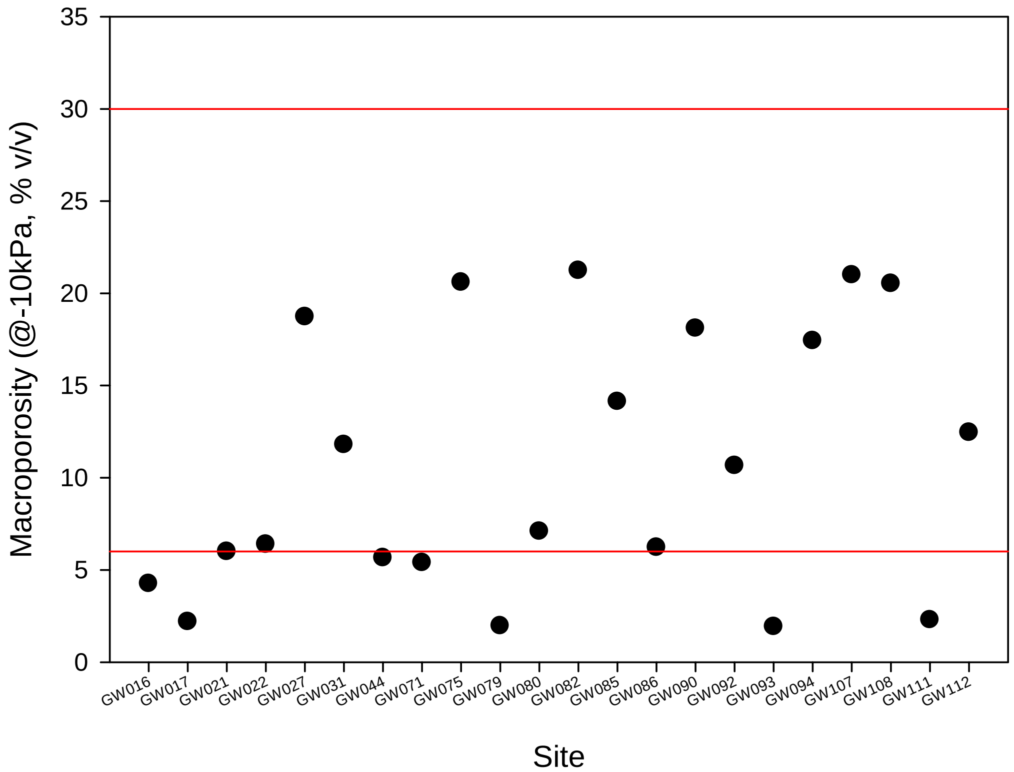


Figure 3.3: Macroporosity at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range.

Aggregate stability was low to very low across all the seven sites measured, ranging from 0.27 to 1.19 mean weighted diameter (m.w.d.) (Figure 3.4). All seven sites had an aggregate stability value of less than 1.5, which is considered the lower limit for a good soil structure and the level at which production begins to decrease (Taylor[3], pers. comm. 2010); five of these sites had values less than 0.5, indicating a poor soil structure and considerable structural degradation (Stevenson 2007).

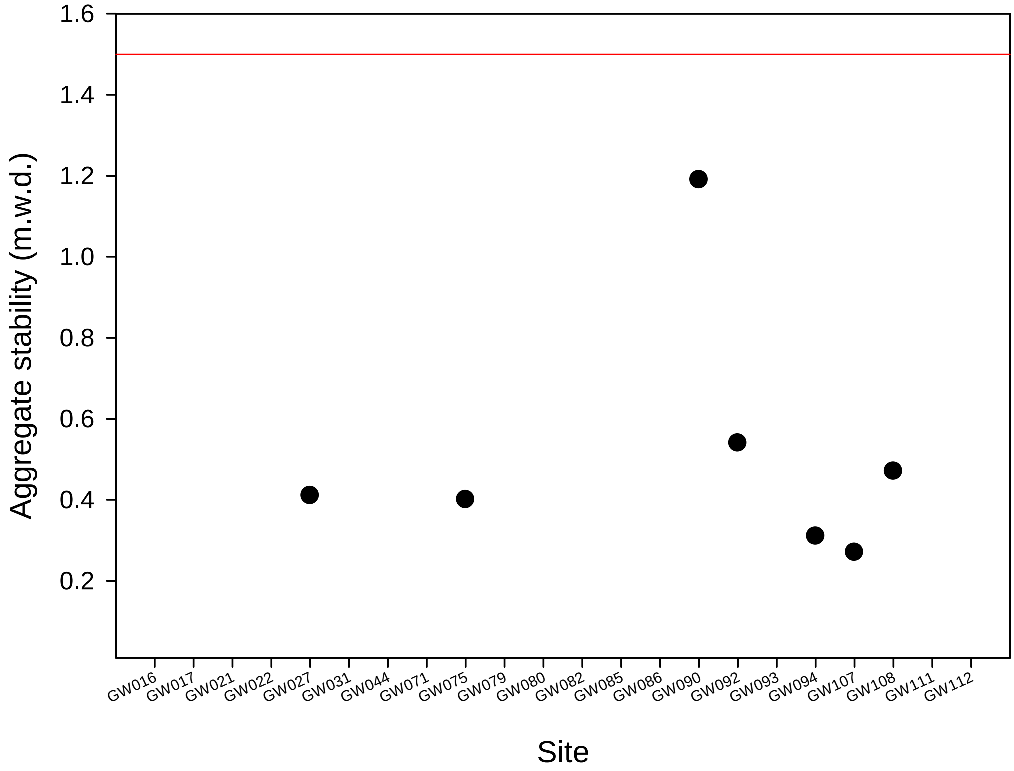


Figure 3.4: Aggregate stability at seven market garden soil quality monitoring sites sampled over 2009/10. The red line represents the lower limit for good soil structure, and the level at which production will begin to decrease.

3.2 Organic resources

Total carbon contents of all the 22 sites sampled were low ranging from 1.23 % w/w to 6.04 % w/w. Nine of the sites were below the lower limit of the optimal range (Figure 3.5). Hill and Sparling (2009) acknowledge that the optimal range for cropping and horticultural soils is poorly defined, but a soil with less than 2 % w/w of carbon should be considered depleted.

[3] Matthew Taylor, Soil Scientist, Environment Waikato.

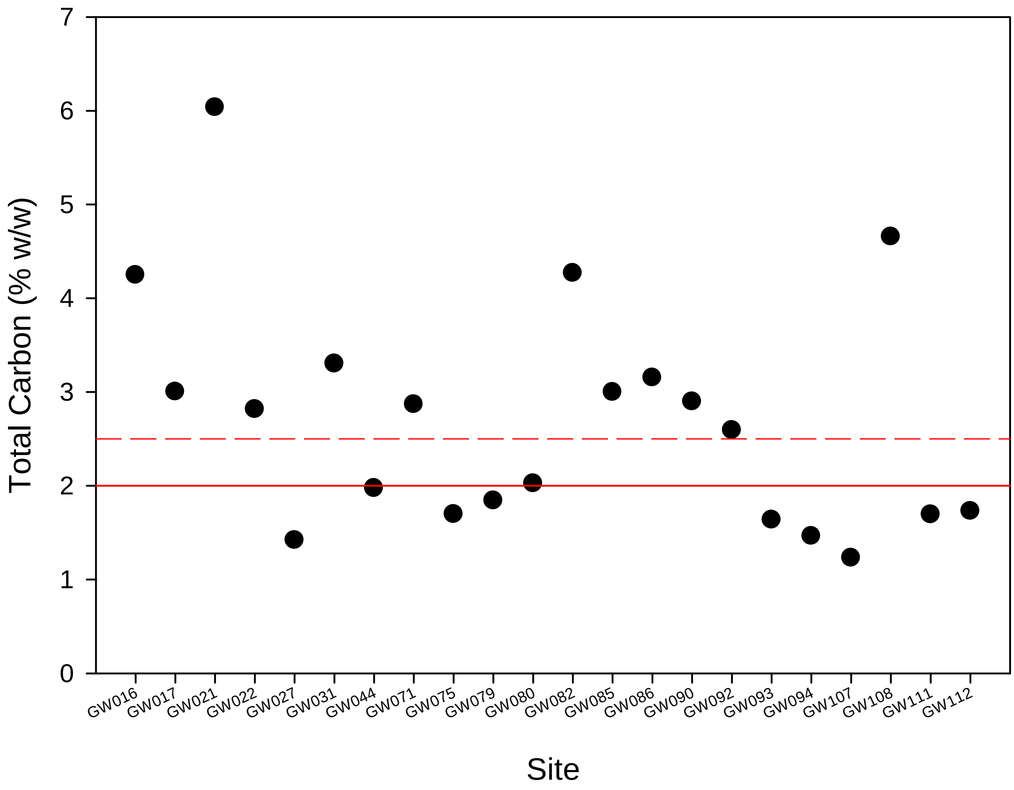


Figure 3.5: Total carbon content at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range*.

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

Of the nine sites with total carbon below the lower limit of the optimal range, five (GW027, GW075, GW094, GW107 and GW112) are active market gardens, while another three were market gardens but have been converted to pasture. This suggests that cultivation at the market garden sites is having a negative impact on the organic matter and carbon contents of the soils.

Total nitrogen concentrations were low across all 22 sites sampled, ranging from 0.12 to 0.53 % w/w (Figure 3.6). There is no target range for total nitrogen for horticultural and cropping as target values will depend on the specific crop grown (Hill & Sparling 2009). However, total nitrogen concentrations across all the 22 sites sampled can be considered low, which is not surprising given the low carbon contents of the sites.

Concentrations of mineralisable nitrogen were variable across the 22 sites sampled, ranging from 13 to 226 mg/kg (Figure 3.7). Soil from one site (GW021) recorded 226 mg/kg of mineralisable nitrogen, which exceeds the upper limit of the optimal range of 200 mg/kg. This site is in pasture and was observed at the time of sampling to be used for drystock farming. Soil samples from three sites (GW094, GW107 and GW112) used for intensive market gardening contained levels less than the lower limit of the optimal range. These sites also had the lowest concentrations of total carbon and total nitrogen.

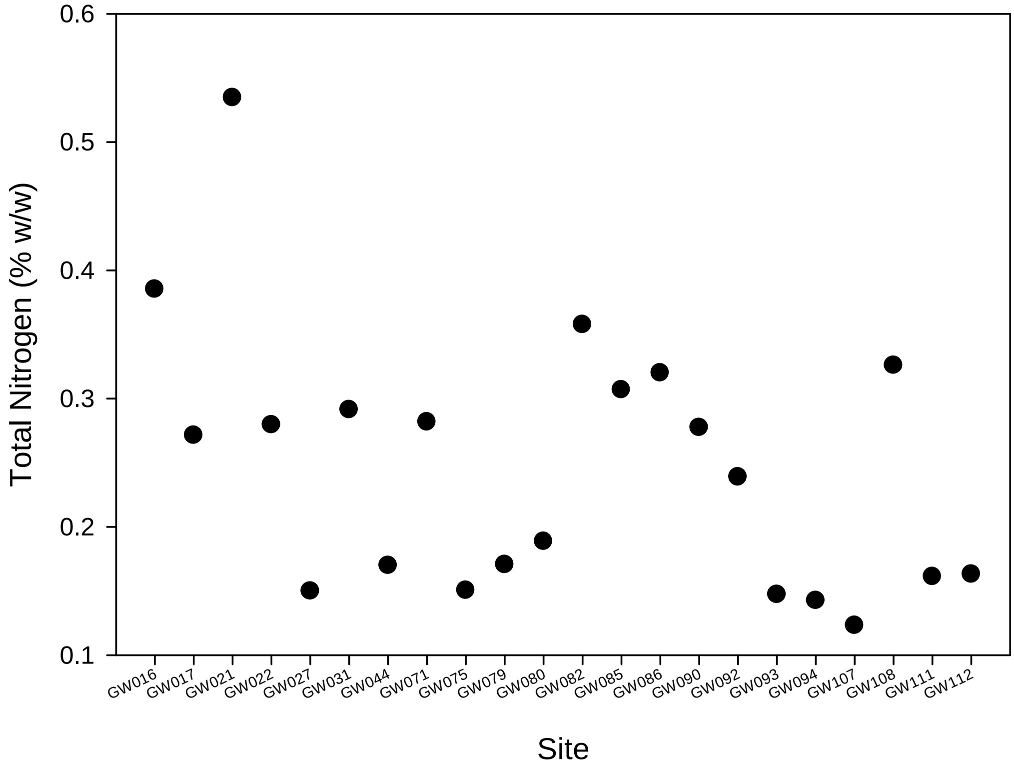


Figure 3.6: Total nitrogen content at each soil quality monitoring site sampled over 2009/10

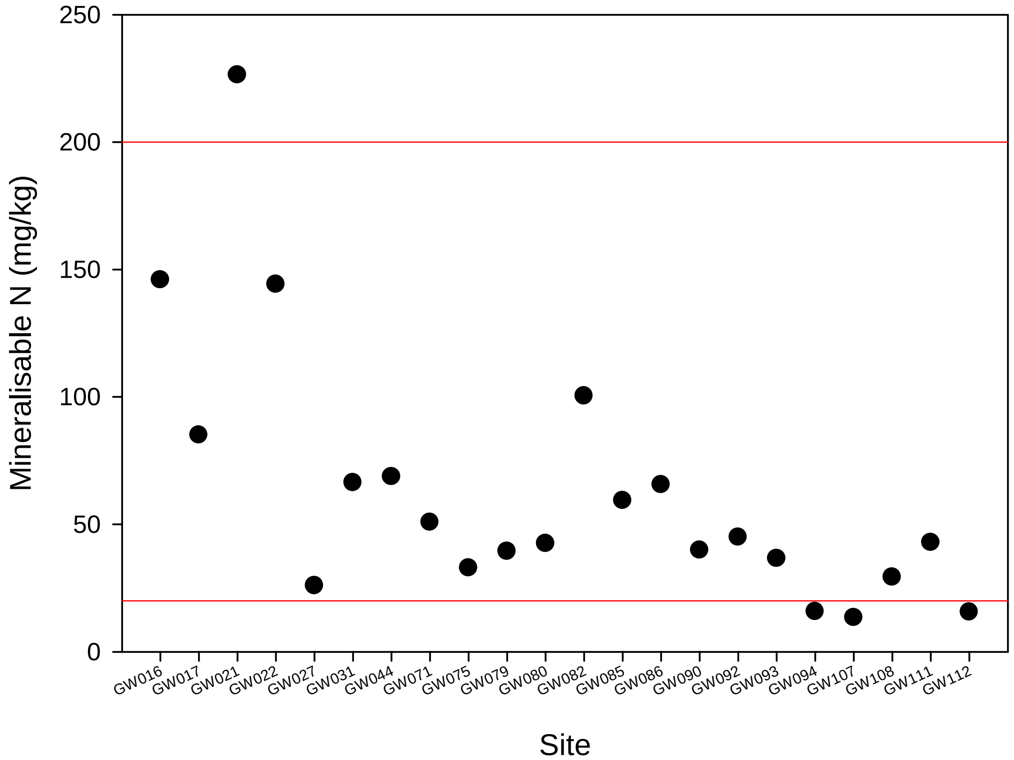


Figure 3.7: Mineralisable nitrogen content at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range.

3.3 Acidity

The soil pH of all of the 22 sites sampled was within the optimal range, ranging from 5.18 to 7.33 (Figure 3.8).

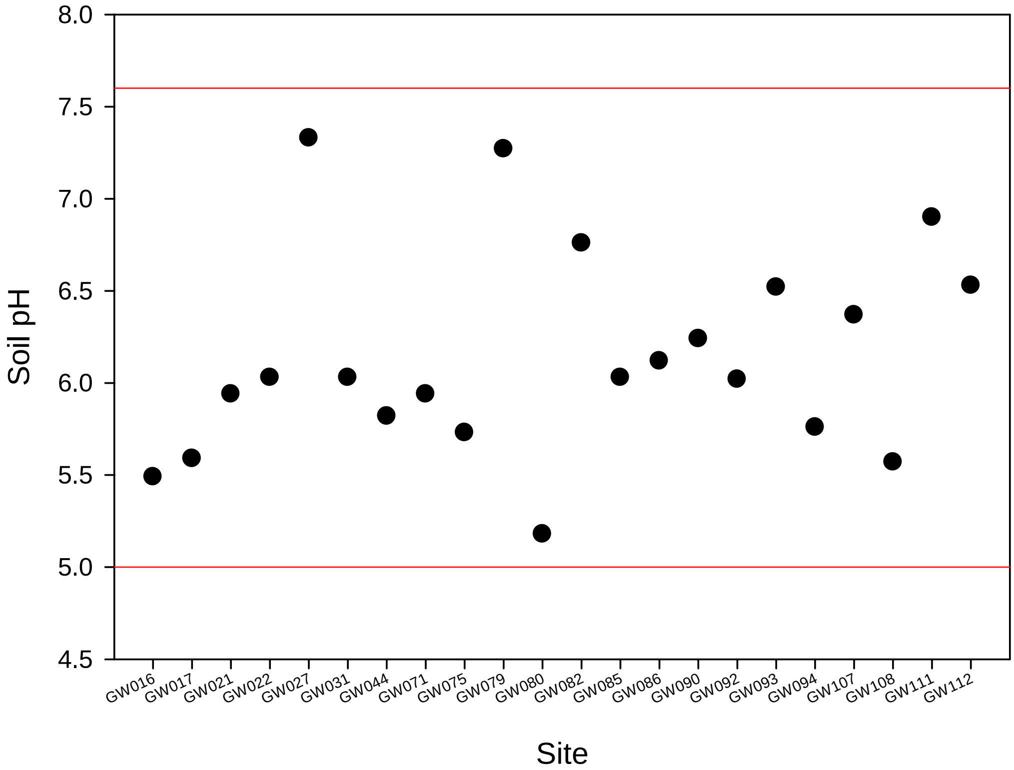


Figure 3.8: Soil pH at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range.

3.4 Fertility

Olsen P concentrations were variable across all the sites ranging from 14 mg/kg (low) to 241 mg/kg (extremely high) (Figure 3.9). Of the 22 sites sampled, nine recorded concentrations of Olsen P above the upper limit of the optimal range (100 mg/kg), and one site recorded an Olsen P concentration less than the lower limit of the optimal range.

Of the nine sites that exceeded the upper limit of the optimal range for Olsen P, six were market garden sites, two were cropping sites and one was a pasture site. The very high fertility (Olsen P) levels are most likely related to the application of large and probably excessive quantities of phosphate fertilisers. High concentrations of Olsen P are of particular concern when the soil structure is also poor as such soil is more susceptible to erosion, increasing the risk of nutrient and sediment-rich runoff into nearby streams.

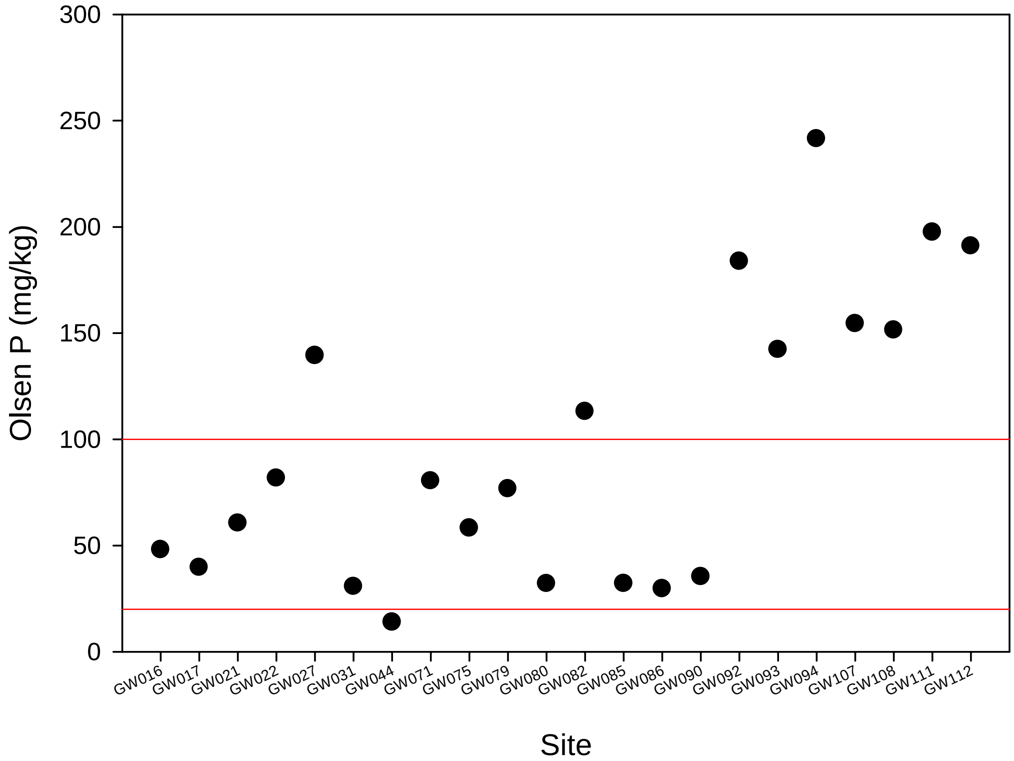


Figure 3.9: Olsen P values at each soil quality monitoring site sampled over 2009/10. The area between the red lines represents the optimal range.

3.5 Trace elements

Trace element (total recoverable) concentrations in samples from all 22 soil monitoring sites were well below the NZWWA (2003) guidelines (Table 3.2). The concentrations were also generally within the range of typical background concentrations for the Wellington region outlined in Sulzberger and Whitty (2003).

Table 3.2: Trace element concentrations (total recoverable) in soil samples from 22 monitoring sites sampled over 2009/10

Site No.	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
GW016	11	0.23	23	25	30	22	99
GW017	3	0.18	9	4	9	5	28
GW021	3	0.31	19	14	17	15	80
GW022	5	0.21	18	14	16	16	88
GW027	7	0.34	18	34	22	18	84
GW031	<2	0.21	10	4	8	7	39
GW044	4	<0.10	16	11	15	13	66
GW071	2	0.18	18	7	11	15	60
GW075	4	<0.10	18	14	22	15	75
GW079	7	0.27	20	18	25	19	85
GW080	7	<0.10	18	20	29	18	98
GW082	<2	0.18	5	4	6	2	15
GW085	5	0.18	20	17	20	19	84
GW086	4	0.18	18	10	15	16	86
GW090	3	0.20	18	13	18	13	82
GW092	8	0.36	22	25	33	18	107
GW093	8	0.27	17	47	31	16	89
GW094	8	0.33	19	100	33	17	100
GW107	10	0.30	17	52	30	16	89
GW108	3	0.22	17	35	26	12	82
GW111	3	0.28	18	18	16	12	74
GW112	3	0.19	15	28	15	8	64

4. Discussion

Many of the market garden sites sampled in 2010 are well established, and numerous years of using the land for market gardening including extensive tillage practices like ploughing and cultivation appears to be having an effect on both soil carbon levels and soil structure. It is well recognised that loss of soil carbon and a breakdown of aggregates can be attributed to reduced inputs of organic matter, increased decomposability of crop residues and tillage effects (Post & Kwon 2000).

Low levels of soil carbon have an effect on the environment and productivity. A loss of soil carbon (inferring a reduction in soil organic matter) reduces the soil's ability to store nutrients, particularly nitrogen which is critical for plant growth. This effect is highlighted in the results as the sites with the lowest total carbon levels also contained the lowest levels of total nitrogen and mineralisable nitrogen. Three market garden sites, as well as recording levels of soil carbon below the lower limit, also recorded concentrations of mineralisable nitrogen (plant available nitrogen) below the lower limit, which will have a negative impact on production.

Intensive tillage, in addition to reducing soil carbon and nutrient storage of the soil, also breaks up soil aggregates and so affects the soil structure. Soils with low aggregate stability are susceptible to erosion and are more prone to dispersion by wind and water. Soil particles dispersed by water tend to fill surrounding pores, impeding the infiltration of water and air into the soil profile, but can also be washed from the land into nearby streams. This is a particular concern when the soil contains elevated concentration of phosphorus (bound to soil particles), which was common throughout the market garden sites. Of the seven sites measured for aggregate stability, five contained high to very high concentrations of Olsen P (plant available phosphorus). Very high Olsen P levels in market gardens have been recorded previously in Sparling (2005), and were attributed to the application of large and excessive quantities of phosphorus fertilisers to the land. Given the poor soil structure and high concentrations of Olsen P, there is potential for any surface water courses in close proximity of these sites to be impacted.

In contrast with the market garden sites, the main issue identified with the cropping sites was high bulk density and low macroporosity, indicating compaction of the soil. The issue of soil compaction by itself is largely an on-farm issue which affects productivity by limiting crop growth, and is generally the result of over-stocking or use of heavy machinery. However, low macroporosity is also associated with decreased infiltration and an increased risk of overland flow (runoff) during high intensity rainfall (Sparling 2005). Overland flow is a great contributor to the eutrophication of surface waters, and loss of soil quality (Monaghan et al. 2002). Only two sites were found to be compacted and had excess nutrients (Olsen P).

All the adverse soil quality characteristics reported here can be modified (reversed) through suitable management such as greater return of crop residues, reduced tillage, nutrient budgeting and minimal use of machinery. However, in some cases, such as loss of soil organic matter, the restoration process could take many years (Sparling 2006).

Land use change was apparent from the sampling undertaken in 2009/10. While there is little record of sampling or field observations from previous monitoring rounds, 18 market garden sites and eight cropping sites were originally scheduled to be sampled in 2009/10. However, 10 of the 18 market gardening sites were not being used for this purpose at the time of sampling, and three of the eight cropping sites were observed to be in pasture. While some of the sites previously used for market gardening have been converted into pasture or cropping, three sites had been or are in the process of being converted into residential development, indicating the impact of urban development and the reduction of high quality, productive soils in our region.

5. Summary

Sampling of soil quality at 22 market garden and cropping sites across the Wellington region found the soils to generally be in poor condition. The market garden sites, which were predominantly located in Otaki, had the poorest soil quality. Seven out of the eight market garden sites were outside the optimal range for two or more soil quality indicators. The soil results of concern were low levels of total carbon, very low levels of aggregate stability, high concentrations of Olsen P and, to a lesser extent, low concentrations of mineralisable nitrogen. In comparison, the primary concern at the cropping sites was high bulk density and associated low macroporosity (indicating soil compaction). All the adverse soil quality characteristics reported here can be modified (reversed) through suitable management.

References

Beare, M.H.; Lawrence, E.J.; Tregurtha, C.S.; Harrison-Kirk, T.; Pearson, A.; Meenken, E.D. 2005. *Progress towards the development of the Land Management Index – 2004-05 project report.* Crop & Food Research Confidential Report No. 1408 (unpublished).

Croucher, B. 2005. *Soil quality monitoring technical report.* Greater Wellington Regional Council, Publication No. GW/RINV-T-05/85.

Hill, R.B.; Sparling, G.P. 2009. Soil quality monitoring. In *Land and soil monitoring: A guide for SoE and regional council reporting.* Land Monitoring Forum, New Zealand, pp. 27-86.

Kim, N.D.; Taylor, M.D. 2009. Trace element monitoring. In *Land and soil monitoring: A guide for SoE and regional council reporting.* Land Monitoring Forum, New Zealand, pp. 117-165.

McLaren, R.G.; Cameron, K.C. 1996. *Soil science: Sustainable production and environmental protection.* Second edition. Oxford University Press.

Ministry of Agriculture and Forestry. 2008. *Report one: Cadmium in New Zealand agriculture, report of the Cadmium Working Group.* MAF Information Services, Wellington.

Ministry for the Environment. 1997. *Health and environmental guidelines for selected timber treatment chemicals.* Ministry for the Environment, Wellington.

Monaghan, R.M.; Paton, R.J.; Drewry, J.J.; 2002. Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *New Zealand Journal of Agricultural Research,* 45: 197-205.

NZWWA. 2003. *Guidelines for the safe application of biosolids to land in New Zealand.* New Zealand Water and Wastes Association, Wellington.

Post, W.M.; Kwon, K.C. 2000. Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biology,* 6:317-328.

SINDI. 2010. *Soil quality indicators database.* Accessed online at: http://sindi.landcareresearch.co.nz

Sparling, G. 2005. *Implementing soil quality indicators for land: Wellington region 2004-2005.* Landcare Research Contract Report LC0405/070, prepared for the Greater Wellington Regional Council.

Sparling, G. 2006. *Soil quality in Greater Wellington region 2006: Comparison with previous samplings between 2000 and 2004.* Landcare Research Contract Report LC0506/124, prepared for the Greater Wellington Regional Council.

Stevenson, B. 2007. *Soil quality in Greater Wellington region 2007: Comparison with previous samplings in 2004.* Landcare Research Contract Report LC0708/023, prepared for the Greater Wellington Regional Council.

Stevenson, B. 2008. *Soil quality in Greater Wellington region 2007/08: Current status of selected drystock sites and comparison with previous sampling results.* Landcare Research Contract Report LC0809/002, prepared for the Greater Wellington Regional Council.

Sulzberger, C; Whitty, D. 2003. *Determination of common pollutant background soil concentrations for the Wellington region.* URS, Wellington.

Acknowledgements

I would like to thank Tony Faulkner and Sam Gundersen (Greater Wellington) for helping with the sampling. The information from the various farmers and landowners was also greatly appreciated, and particular thanks goes to the owners who provided access to their land for the sampling.

Appendix 1: Soil quality monitoring sites sampled in 2009/10

Site	GW016
Date Sampled	04/05/2010
Landuse	Horticulture
NZ Soil Classification	Typic Recent Gley
Soil Type	Ahikouka clay loam

Sampling/field notes
Appears to have been horticulture previously from old aerial photos. Some fruit trees at the end of the paddock. Currently drystock, small amount of sheep in the paddock.

Site	GW017
Date Sampled	04/05/2010
Landuse	Cropping
NZ Soil Classification	Argillic Perch-gley Pallic
Soil Type	Kokotau silt loam

Sampling/field notes
Paddock recently been sown with what looks like grass. Fertiliser recently been applied, granules still visible on surface.

Site	GW021
Date Sampled	05/05/2010
Landuse	Cropping
NZ Soil Classification	Typic Recent Gley
Soil Type	Ahikouka clay loam

Sampling/field notes
From old aerial photos it looks like it has been used for cropping in the past, but currently in pasture, probably for drystock. Good amount of grass.

Site	GW022
Date Sampled	05/05/2010
Landuse	Cropping
NZ Soil Classification	Acidic-weathered Fluvial Recent
Soil Type	Greytown silt loam

Sampling/field notes
Doesn't appear to have been cropped for a while, currently in pasture and sheep grazing. Some of the neighbouring paddocks have recently been ploughed though.

Site	GW027
Date Sampled	27/04/2010
Landuse	Cropping
NZ Soil Classification	Acidic-weathered Fluvial Recent
Soil Type	Manawatu v fine sandy loam

Sampling/field notes
Currently planted with courgettes. Few small weeds. Dark and flaky/crumbly soil. Spray residue on plants and also fertiliser visible around the base of the plants. Classified as cropping but permanent horticulture – vegetables.

Site	GW031
Date Sampled	05/05/2010
Landuse	Cropping
NZ Soil Classification	Mottled Immature Pallic Soil
Soil Type	Martinborough loam

Sampling/field notes
Sampling site in paddock next to Pirinoa vineyard. Doesn't look like it has been used for cropping for a while. Currently drystock – sheep. Very dry. Trees on the road edge have been chopped down.

Site	GW044
Date Sampled	27/04/2010
Landuse	Market Garden
NZ Soil Classification	Acid Orthic Gley Soil
Soil Type	Rahui silt loam

<u>Sampling/field notes</u>
Definitely not horticulture – market garden, now part of a larger dairy farm. Farmer recently got consent to apply dairy effluent to land. Front section of paddock been recently grazed, sampled just on the ungrazed side of the paddock. Good grass growth.

Site	GW071
Date Sampled	04/05/2010
Landuse	Cropping
NZ Soil Classification	Mottled-Weathered Fluvial Recent Soil
Soil Type	Ahikouka silt loam

<u>Sampling/field notes</u>
The paddock has just recently been harvested. Looks like either wheat or barley. The soil is pretty dry and hard.

Site	GW075
Date Sampled	04/05/2010
Landuse	Market Garden
NZ Soil Classification	Weathered Fluvial Recent Soil
Soil Type	Greytown silt loam

<u>Sampling/field notes</u>
A small scale market garden, sells vegetables in a shed out the front of the property. Looks like all work is done by hand, no machinery or evidence of machinery present.

Site	GW079
Date Sampled	04/05/2010
Landuse	Market Garden
NZ Soil Classification	Mottled-Weathered Fluvial Recent Soil
Soil Type	Ahikouka silt loam

<u>Sampling/field notes</u>
Sampling site is currently in clover, good cover and growth. Some of the surrounding area is used for market gardening at a small scale, but this part looks like it is retired. Possibly being subdivided and for sale?

Site	GW080
Date Sampled	04/05/2010
Landuse	Market Garden
NZ Soil Classification	Weathered Fluvial Recent Soil
Soil Type	Greytown silt loam

<u>Sampling/field notes</u>
Craft shop out the front of the property. Not currently used for market gardening or horticulture, recently been sown with what looks to be grass, possibly used for drystock grazing. Pine trees surround the site.

Site	GW082
Date Sampled	05/05/2010
Landuse	Market Garden
NZ Soil Classification	Typic Recent Gley Soil
Soil Type	Otukura stony z. l.

<u>Sampling/field notes</u>
Looks like the site has been harvested recently. Maybe for arable seed – chicory? It looks like the farmer sells seed and grain over the road from his shed. Lots of dead stalks, good growth coming back. Heavy soil.

Site	GW085
Date Sampled	05/05/2010
Landuse	Cropping
NZ Soil Classification	Mottled-Weathered Fluvial Recent Soil
Soil Type	Ahikouka silt loam

Sampling/field notes
Paddock is currently in peas. Quite patchy growth. Soil quite dry and hard. A few thistles around.

Site	GW086
Date Sampled	Cropping
Landuse	05/05/2010
NZ Soil Classification	Mottled-Weathered Fluvial Recent Soil
Soil Type	Ahikouka silt loam

Sampling/field notes
Paddock has been recently harvested – either wheat/barley/straw? Sheep now grazing the paddock. Pretty good soil moisture. Neighbouring paddock has been recently ploughed.

Site	GW090
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Typic Orthic Brown Soil
Soil Type	Te Horo silt loam

Sampling/field notes
Organically certified market garden. Soil quite crumbly, and slightly lighter than others. Looks like they use some kind of biochar as a compost/fertiliser around the plants?

Site	GW092
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Typic Orthic Gley Soil
Soil Type	Kairanga silt loam

Sampling/field notes
Site had just been freshly cultivated and sown with seedlings, so didn't want to disturb, sampled next door patch. Currently growing capsicums. Soil was pretty wet and crumbly.

No photo available

Site	GW093
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Weathered Fluvial Recent Soil
Soil Type	Manawatu silt loam

Sampling/field notes
Sign on fence showing the site has been subdivided into residential lots which are for sale. Old garden fresh vege shed still present. Looks like it is currently used for drystock grazing. Good grass growth, but soil seems quite hard and compact.

Site	GW094
Date Sampled	27/04/2010
Landuse	Market Garden
NZ Soil Classification	Weathered Fluvial Recent Soil
Soil Type	Manawatu silt loam

Sampling/field notes
Small in size but quite extensive and intensive market garden. Sampled the more established courgette rows. Soil very soft and silty, not many weeds. Very flaky, hard to collect intact cores.

Site	GW107
Date Sampled	27/04/2010
Landuse	Market Garden
NZ Soil Classification	Weathered Orthic Recent Soil
Soil Type	Manawatu silt loam

Sampling/field notes
Reasonably big, intensive market garden. Lots of different vegetables grown. Owners don't speak much English.

Site	GW108
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Typic Orthic Gley Soil
Soil Type	Kairanga silt loam

Sampling/field notes
Large intensive market garden. Soil a bit moist from last night's rain. Soil quite crumbly and sticky.

No photo available

Site	GW111
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Typic Orthic Brown Soil
Soil Type	Hautere clay loam

Sampling/field notes
Talked to owner who advised that the site used to be a market garden, but the last couple of years he has put it into pasture or lucerne. Bailage visible down the side fence. Currently in lucerne, soil a bit stony.

Site	GW112
Date Sampled	28/04/2010
Landuse	Market Garden
NZ Soil Classification	Typic Immature Pallic Soil
Soil Type	Shannon silt loam

<u>Sampling/field notes</u>
Large intensive market garden. Large area and a wide range of vegetables grown. Sampled some rows from where celery had recently been harvested (to the left of the photo). Soil damp and sticky from overnight rainfall.

Appendix 2: Sampling and analytical methods

Analyses of the soil chemistry and soil physics were completed at the Landcare Research laboratories in Palmerston North. Trace element analyses were undertaken at R.J. Hills Laboratory in Hamilton, and aggregate stability analyses were undertaken by Plant & Food Research laboratory in Lincoln. 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.
Aggregate stability	Calculated from the mean weight diameters of aggregates remaining on 2 mm, 1mm and 0.5 mm sieves after wet sieving. If stones are present a stone correction is undertaken.

Appendix 3: Soil quality guidelines

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

Bulk density target ranges (t/m³ or Mg/m³)

	Very loose	Loose	Adequate	Compact	Very compact	
Semi-arid, Pallic and Recent soils	0.3	0.4	0.9	1.25	1.4	1.6
Allophanic soils		0.3	0.6	0.9	1.3	
Organic soils		0.2	0.4	0.6	1.0	
All other soils	0.3	0.7	0.8	1.2	1.4	1.6

Macroporosity target ranges (% @ -10 kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	6	10[1]	30	40
Forestry	0	8	10	30	40

Total carbon target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	
Allophanic	0.5	3	4	9	12
Semi-arid, Pallic and Recent	0	2	3	5	12
Organic	exclusion				
All other Soil Orders	0.5	2.5	3.5	7	12

Total nitrogen target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	High	
Pasture	0	0.25	0.35	0.65	0.70	1.0
Forestry	0	0.10	0.20	0.60	0.70	
Cropping and horticulture	exclusion					

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

Appendix 4: Analytical results

Table A3.1: Analytical results for soil samples collected in 2009/10. Values in bold are outside the optimal range for the site's specific soil order and land use.

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	Aggregate Stability m.w.d.
GW016	5.49	4.25	0.39	11.0	48	30.9	1.2	146	1.31	2.66	50.9	2.97	**4.27**	
GW017	5.59	3.00	0.27	11.1	40	130	11.2	85	1.38	2.59	46.7	1.70	**2.20**	
GW021	5.94	6.04	0.53	11.3	60	30.1	2.8	**226**	1.21	2.58	53.0	5.00	6.00	
GW022	6.03	2.82	0.28	10.1	82	11.4	1.8	144	1.37	2.61	47.6	4.87	6.40	
GW027	7.33	**1.42**	0.15	9.5	**139**	11.0	<0.1	26	1.37	2.70	49.0	16.57	18.73	0.41
GW031	6.03	3.30	0.29	11.3	31	32.4	1.4	66	1.24	2.54	51.0	8.37	11.80	
GW044	5.82	**1.98**	0.17	11.6	**14**	28.9	<0.1	69	1.34	2.64	49.1	2.70	**5.67**	
GW071	5.94	2.87	0.28	10.2	80	93.0	<0.1	51	1.29	2.63	50.9	3.87	**5.40**	
GW075	5.73	**1.70**	0.15	11.3	58	12.9	<0.1	33	1.36	2.69	49.6	18.30	20.60	0.40
GW079	7.27	**1.84**	0.17	10.8	77	20.2	3.3	39	**1.46**	2.68	45.5	1.10	**1.97**	
GW080	5.18	2.02	0.19	10.7	32	40.8	3.2	42	**1.40**	2.67	47.5	4.50	7.10	
GW082	6.76	4.27	0.36	11.9	**113**	1.6	<0.1	100	1.15	2.51	54.2	17.73	21.23	
GW085	6.03	3.00	0.31	9.8	32	91.5	<0.1	59	1.14	2.64	56.7	12.43	14.13	
GW086	6.12	3.15	0.32	9.9	30	50.5	<0.1	66	1.24	2.60	52.1	4.30	6.23	
GW090	6.24	2.90	0.28	10.4	35	49.8	<0.1	40	1.10	2.58	57.2	16.27	18.10	1.19
GW092	6.02	2.59	0.24	10.9	**184**	21.8	<0.1	45	1.27	2.65	52.3	9.27	10.67	0.54
GW093	6.52	**1.64**	0.15	11.1	**142**	19.8	<0.1	37	**1.59**	2.67	40.5	0.37	**1.93**	
GW094	5.76	**1.46**	0.14	10.3	**241**	18.6	<0.1	**16**	1.34	2.70	50.4	16.20	17.43	0.31
GW107	6.37	**1.23**	0.12	10.0	**154**	89.0	<0.1	**13**	1.37	2.69	49.0	19.10	21.00	0.27
GW108	5.57	4.66	0.33	14.3	**151**	22.7	<0.1	29	1.06	2.56	58.6	19.17	20.53	0.47
GW111	6.90	**1.69**	0.16	10.5	**198**	16.7	<0.1	43	**1.65**	2.63	37.3	1.00	**2.30**	
GW112	6.53	**1.73**	0.16	10.6	**191**	22.3	<0.1	**16**	1.39	2.63	47.0	11.17	12.47	

Water, air, earth and energy – elements in Greater Wellington's logo that combine to create and sustain life. Greater Wellington promotes **Quality for Life** by ensuring our environment is protected while meeting the economic, cultural and social needs of the community

For more information, contact Greater Wellington:

Wellington office
PO Box 11646
Manners Street
Wellington 6142
T 04 384 5708
F 04 385 6960

Masterton office
PO Box 41
Masterton 5840
T 06 378 2484
F 06 378 2146

facebook.com/GreaterWellington

twitter.com/greaterwgtn

www.gw.govt.nz

Photo
A market garden near Otaki

Please recycle
Produced sustainably

GW/EMI-G-10/165
November 2010