Soil Quality for Horticultural Sites in the Auckland Region 2013 and Changes after 18 Years

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Soil Quality for Horticultural Sites in the Auckland Region 2013 and Changes after 18 Years

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Executive summary

Auckland has a unique and diverse natural environment that supports a varied and valuable terrestrial, freshwater and marine biodiversity. However, as a result of human settlement and an increasing population, Auckland’s land cover and land use has been severely modified from its once predominantly evergreen forest. Changes include the clearing or conversion of native forest to provide suitable sites for a place to live, crop rotation, pasture, along with the draining of wetlands to create more agricultural land.

To monitor the effects of change to the natural environment the Resource Management Act 1991 (RMA, 1991) Section 35 requires councils to carry out state of the environment reporting for marine, freshwater, groundwater, terrestrial, air and soil science disciplines.

Soil quality monitoring in Auckland started in 1995 as part of the national 500 Soils Project, this involves soil sampling across representative soil types and land uses. Horticultural sites were the focus of repeat soil sampling in 2013. Twenty-six horticultural sites were sampled to determine the physical, chemical and biological quality of these soil sites. Eighteen of the sites were originally sampled between 1995 and 2000 and repeated in 2008, therefore 2013 soil sampling contributes to an increasingly valuable dataset for soil quality trend analysis purposes.

Specific horticultural land uses included market gardening (n=7), orchards (n=6), viticulture (n=5), nursery (n=1) and horticulture-pastoral converted land use (n=7).

Forty-two per cent of sites (n=11) failed to meet one of the soil quality indicators, followed by 31 per cent of sites (n=8) failing to meet four or more soil quality indicators. The main indicator of concern was Olsen P (plant available phosphorus) with 20 sites outside the guideline range, 16 of which exceeded the upper limit. Olsen P is both a sensitive and useful indicator of soil nutrient status. Elevated concentrations of soil P influences stream P concentrations which can contribute to freshwater nutrient enrichment.

The next major indicators of concern were organic carbon (OC) content and soil aggregate stability (which indicates the resistance of soil aggregates to stress imposed by rapid wetting and mechanical abrasion). Half of the sites that failed to meet aggregate stability guidelines were market gardening sites. All of the latter sites that failed to meet these guidelines also had very low OC contents. This was not surprising because a strong, positive linear correlation exists between aggregate stability and OC. The latter poses an increased risk of soil erosion. Therefore, the use and incorporation of cover or green manure crop residues (e.g. ryegrass and oats) on fallow market gardening land is recommended. This will act as a protective cover against rainfall as well as subsequent sediment and pollutant runoff when land is fallow. Furthermore this will facilitate an increase in microbiological activity and subsequently enhance the organic carbon content of the soil ecosystem.

When soil quality was compared across the three sampling periods (before 2000, 2008 and 2013) for the 18 repeat sites, significant differences were only observed for macroporosity (-5kPa), an indicator of soil compaction. While macroporosity declined in 2008, values in 2013 tended to almost revert back to pre-2000 original values. When the 7 converted horticulture to pastoral land use sites were excluded from the analyses, in order to determine changes in soil quality for 'true' horticultural sites, significant differences were observed for OC content and AMN (anaerobic mineralisable nitrogen i.e. plant available nitrogen). However, no consistent soil quality improvement or degradation was observed across the sampling periods for these indicators. Soil OC levels were least in the 2013 sampling event signalling a cause for concern. A decrease in soil OC can reduce the water holding capacity of the soil as well as decreasing soil aggregate stability, rendering it more prone to soil erosion. It can also reduce the soils capacity to sequester carbon. Continuous future soil quality monitoring will be important to determine if these trends continue.

It is recommended that soil sampling for horticultural sites is repeated every five years to continue to determine changes in soil quality by building a longer spanning soil quality record for these sites.

Table of Contents

1.0 Introduction

Auckland has a unique and diverse natural environment that supports a varied and valuable terrestrial, freshwater and marine biodiversity. However, as a result of human settlement and an increasing population, Auckland’s land cover and land use has been severely modified from a once predominantly evergreen forest. Changes include the clearing or conversion of native forest to provide suitable sites for a place to live, crop rotation, pasture, along with the draining of wetlands to create more agricultural land.

To monitor the effects of change to the natural environment the Resource Management Act 1991 (RMA, 1991) Section 35 requires councils to carry out state of the environment reporting for marine, freshwater, groundwater, terrestrial, air and soil science disciplines.

Soil quality monitoring in Auckland started in 1995 as part of the national 500 Soils Project (Hill et al., 2003) and continued until 2000 after which time it was not again established until 2008. Annual soil sampling events contribute to state of the environment reporting. Land uses sampled in recent years include horticulture, dairy, drystock, plantation forestry and native bush sites sampled in 2008 (Sparling, 2009b), 2009 (Stevenson, 2010), 2010 (Fraser and Stevenson, 2011), 2011 (Curran-Cournane, 2012) and 2012 (Curran-Cournane, 2013), respectively.

Horticultural sites were the focus of repeat soil sampling in 2013 and this will be the third time that these sites have been sampled, making it an increasingly valuable and important dataset.

Key soil quality properties of interest include soil acidity (pH), organic carbon (OC), total nitrogen (TN), Olsen P (plant available phosphorus), anaerobic mineralisable nitrogen (AMN-plant available nitrogen), bulk density, macroporosity (at -10kPa) and aggregate stability. The following trace element concentrations were also of interest in the current report; arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. However, the majority of the report will focus on the key soil quality parameters listed above.

Study objectives included:

- Repeat soil sampling for those sites originally referred to as horticultural sites, which were first sampled between 1995-2000 and 2008
- Determine changes in soil quality for horticultural sites across the three sampling periods (i.e. those sampled in 1995-2000, 2008 and 2013, the latter using data from the current study)
- Selecting new sampling sites that further increase the broad geographic coverage of representative soil types and horticultural land uses in the Auckland region
- Identifying whether any key soil quality indicators are of concern regarding horticultural land useage
- Determining trace element concentrations for all sites
- Reporting findings from the study and comparing them with findings for the previous sampling periods
- Providing results to landowners, for not only educational and feedback purposes, but to establish better relationships between Auckland Council and landowners to ensure ongoing access to sites.

2.0 Materials and methods

2.1 Sample sites and soil sampling

Twenty six horticultural sites were sampled across the Auckland region during 02-26 September 2013 (Figure 1). Eighteen horticultural sites were originally sampled during sampling period 1995-2000 (Sparling, 2009a), and repeated in 2008 (Sparling, 2009b). Eight new sites were selected in 2013 to ensure better representation of market gardening and viticulture land use activities across the wider region, including Waiheke Island, which had remained unsampled until now. Collectively these sites represent a broad geographic coverage (Figure 1), encompassing eight soil series and seven soil orders (Hewitt, 1998) (Table 1).

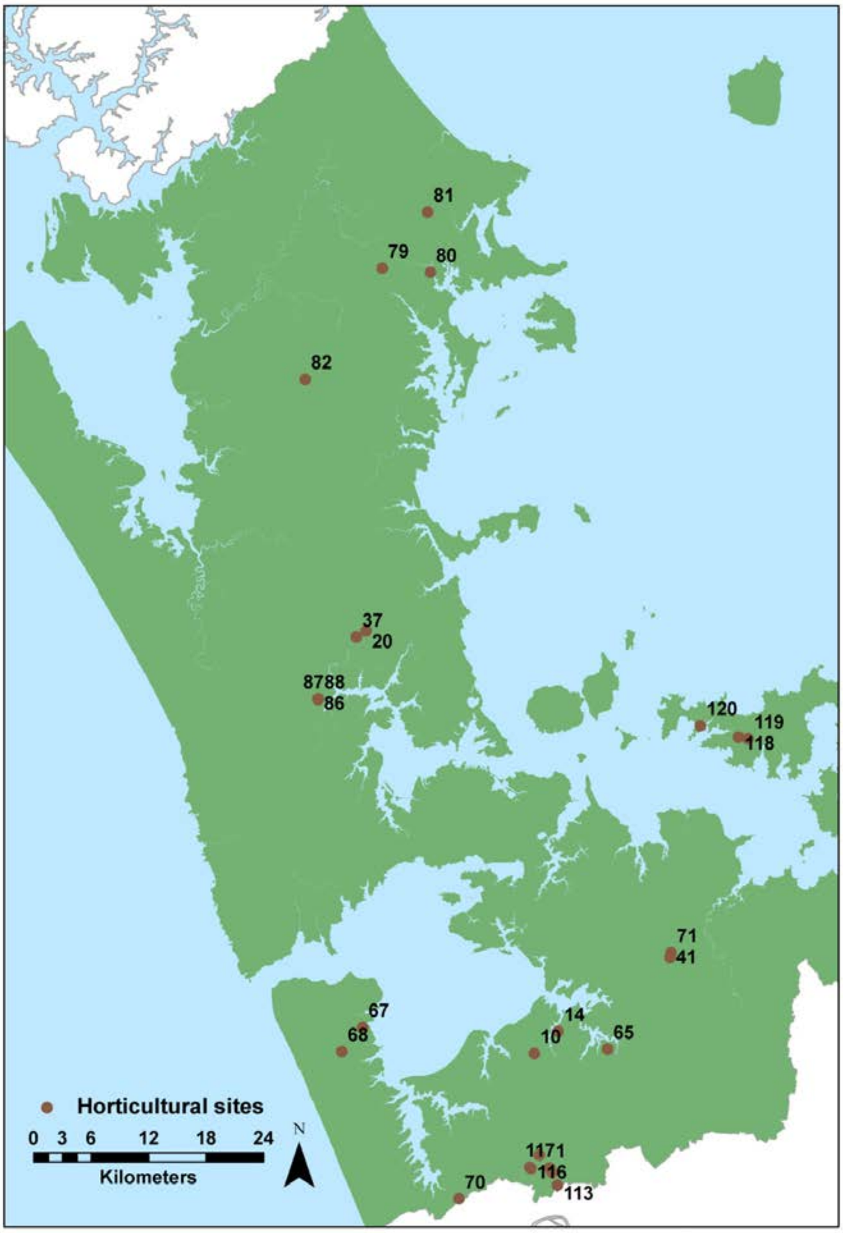

Figure 1 Location and site number of the 26 horticultural sites sampled within Auckland in 2013.

The soil samples collected at each site were analysed for a suite of eight key soil chemical, biological and physical indicators which included soil pH, organic carbon[1] (OC), total nitrogen (TN), anaerobic mineralisable nitrogen (AMN), Olsen P, bulk density, macroporosity at -10kPa (which includes pore sizes >30 microns) and aggregate stability. Aggregate stability has been identified as a key soil physical quality indicator for horticultural land use and was therefore sampled at each site. It has been reported that the proportion of soil aggregates less than 0.85mm is more at risk of being eroded (Mackay et al., 2013). However, laboratory analysis only conducts the sieving of aggregates using 0.5, 1 and 2mm sieves, therefore only the percentage of aggregates >1mm and mean weight diameter (mm) are reported. Macroporosity at -5kPa, corresponding to pore sizes >60microns, was also measured. This was because only macroporosity at -5kPa was analysed in the early establishment of the program and was used to determine soil quality changes over time. Although not regarded as a key soil quality indicator, the C/N ratio was calculated for each site. A low C/N ratio would suggest increased risk of N mineralisation and N leaching, whereas a high C/N ratio implies N limitations in soil and poor ecosystem health.

A suite of 38 trace element were also analysed (Appendix 6.4) and specific analytes presented in this report include arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. Nitrate, ammonium, initial water content, soil temperature, particle density and total porosity were also analysed some of which are presented in Appendix 6.1.

[1] Organic C is used instead of total C, because where pH >7, carbonate carbon is insignificant

Table 1 Land use, soil classification and soil series for 26 horticultural sites sampled in the Auckland region in 2013 for soil quality attributes.

ARC code	Site number	Land use	Year established	NZSC subgroup	Soil series
ARC95_01	2013-**01**-03	Market garden	1995	Typic Orthic Granular	Patumahoe clay loam
ARC97_02	2013-**10**-03	Hort-drystock conversion	1997	Typic Orthic Allophanic	Karaka silt loam
ARC98_02	2013-**14**-03	Hort-lifestyle block conversion	1998	Typic Orthic Allophanic	Karaka silt loam
ARC98_08	2013-**20**-03	Orchard-lifestyle conversion	1998	Weathered Fluvial Recent	Waitemata silt loam
ARC98_25	2013-**37**-03	Hort-lifestyle block conversion	1998	Weathered Fluvial Recent	Waitemata silt loam
ARC99_04	2013-**41**-03	Orchard	1999	Mellow Humic Organic	Ardmore peaty loam
ARC00_03	2013-**65**-03	Orchard	2000	Typic Orthic Allophanic	Karaka silt loam
ARC00_05	2013-**67**-03	Orchard	2000	Typic Orthic Allophanic	Matakawau sandy clay loam
ARC00_06	2013-**68**-03	Hort-drystock /lifestyle block conversion	2000	Typic Orthic Allophanic	Matakawau sandy loam
ARC00_08	2013-**70**-03	Market garden	2000	Typic Orthic Granular	Patumahoe silt loam
ARC00_09	2013-**71**-03	Nursery	2000	Mellow Humic Organic	Ardmore humic loam
ARC00_17	2013-**79**-03	Hort-lifestyle block conversion	2000	Typic Yellow Ultic	Warkworth clay loam
ARC00_18	2013-**80**-03	Orchard	2000	Typic Yellow Ultic	Warkworth clay loam
ARC00_19	2013-**81**-03	Orchard-lifestyle conversion	2000	Typic Yellow Ultic	Warkworth clay loam
ARC00_20	2013-**82**-03	Orchard	2000	Mottled Orthic Brown	Warkworth clay loam
ARC00_24	2013-**86**-03	Viticulture	2000	Typic Orthic Gley	Waitemata complex
ARC00_25	2013-**87**-03	Orchard	2000	Typic Orthic Gley	Waitemata complex
ARC00_26	2013-**88**-03	Orchard	2000	Typic Orthic Gley	Waitemata complex
New	2013-**113**-01	Market garden	2013	Typic Orthic Granular	Patumahoe clay loam
New	2013-**114**-01	Market garden	2013	Typic Orthic Granular	Patumahoe clay loam
New	2013-**115**-01	Market garden	2013	Typic Orthic Granular	Patumahoe clay loam
New	2013-**116**-01	Market garden	2013	Typic Orthic Granular	Patumahoe clay loam
New	2013-**117**-01	Market garden	2013	Typic Orthic Granular	Patumahoe clay loam
New	2013-**118**-01	Viticulture	2013	[1] Mottled Albic Ultic	[1] Rangiora
New	2013-**119**-01	Viticulture	2013	[1] Mottled Albic Ultic	[1] Rangiora
New	2013-**120**-01	Viticulture	2013	[1] Yellow Albic Ultic	[1] Mahurangi

[1] Soil classification subject to comprehensive pedological assessment. Currently taken from the Fundamental Soil Layer (NZLRI, 2010)

For key soil quality indicators, all chemical results are discussed on a gravimetric basis according to the guidelines presented in Sparling *et al.* (2003) and Mackay *et al.* (2013) (Table 2). Guidelines for OC and bulk density are determined for soil orders while the remaining are specified for land use (Sparling et al., 2003).

Table 2 Provisional target ranges for soil quality under horticultural land cover.

Soil order	pH[1]	OC[1] mg/kg	TN[1] mg/kg	Olsen P[2] mg/kg	AMN[2] mg/kg	Bulk[1] density g/cm[3]	Macro[3] - 10kPa	Agg stab (MWD) mm[1]	C/N[4]
Allophanic	5.5-7.2	4+	n/a	20-50	40+	>0.6-1.2	10-30	>1.5	7-30
Brown	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30
Gley	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30
Granular	5.5-7.2	3.5+	n/a	20-50	40+	>0.6-1.3	10-30	>1.5	7-30
Organic	5.0-7.0	n/a	n/a	20-40	40+	0.3-0.7	10-30	>1.5	7-30
Recent	5.5-7.2	3+	n/a	20-40	40+	>0.75-1.3	10-30	>1.5	7-30
Ultic	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30

[1] Adapted from Sparling *et al.* 2003, [2] Mackay *et al.* (2013), [3] Mackay *et al.* (2006).
[4] C/N ratio is not considered a key soil quality indicator but a guideline range for Soil Orders is provided.

The soil sampling methodology was comparable to that of previous years whereby samples were collected, with the aid of a 2.5cm diameter corer, every 2m along a 50m transect at a 0-10cm soil depth, for chemical analyses. The 25 individual samples were bulked. This process was repeated twice, for both chemical and trace element analysis. For soil physical analysis, three stainless steel rings (10cm in diameter and 7.5cm in depth) were pressed into the soil to excavate intact soil cores. The intact soil cores were collected at the 15, 30 and 45m intervals along the 50m transect (Figure 2). Aggregate stability samples were collected by cutting an approximately 15cm x 15cm spade width into the soil to a depth of 10cm and carefully extracting the intact sample.

Figure 2 An intact soil core used to establish soil physical quality.

2.2 Laboratory analysis

The methods used for the determination of all soil physical, chemical and biological analyses are outlined in Hill and Sparling (2009). Briefly, the composite samples were well mixed, air-dried and sieved (<2mm) for Olsen P (Olsen et al., 1954). High temperature combustion methods were used for OC and TN analyses (Blakemore et al., 1987). Soil pH was measured in deionised water at a 2.5:1 water to soil ratio (Blakemore et al., 1987) and AMN was determined under the anaerobic (waterlogged) incubation method from field moist conditions (Keeney and Bremner, 1966). All the above were carried out at Landcare Research, Palmerston North.

For the physical analysis, smaller stainless steel rings (5.5cm width and 3cm depth) were pressed into the larger core using a bench mounted drill press in order to sub-sample the larger rings. The sub-sampling of the larger rings is to correct for any sampling error or bias between field staff and to ensure the measurement of a fully intact soil core. The smaller cores were saturated and equilibrated at both -5 and -10kPa on ceramic tension plates to determine macroporosities. Dry bulk densities and total porosities were calculated from oven (105°C) dry weights. All the above were carried out at Landcare Research, Hamilton.

Aggregate stability (Agg Stab) was performed using the wet sieving methodology performed by Plant and Food, Christchurch.

Soil samples for trace element concentrations were mixed, dried at 60 degree Celsius and milled before chemical analysis. Total acid recoverable trace elements were determined by digestion of soil in nitric/hydrochloric acid and were analysed in digest by inductively coupled plasma mass spectrometry (ICPMS) (USEPA 200.8). Concentrations arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) are presented both at the trace level in the report and both at the trace and screen level in Appendix 6.4. For the remaining 30 trace elements listed in Appendix 6.4, concentrations are presented at the screen level. Analysis was carried out by Watercare Laboratory Services, Auckland.

2.3 Statistical analysis

Soil physical properties, OC, TN, AMN and Olsen P were tested for normality and transformed if necessary, before being subjected to an ANOVA test to determine changes in soil quality attributes for resampled sites corresponding to years 1995-2000 (hereafter referred to as period <2000), 2008 and 2013. Blocking was used when comparing between the three sampling periods (<2000, 2008 and 2013) and the site number was used as the blocking factor. Organic C, TN, AMN and Olsen P are expressed on a gravimetric basis and volumetric where specified using bulk density data. All statistical analyses were carried out using the statistical package Genstat 14 (GenStat, 2011) and graphics using SigmaPlot 11 (SigmaPlot, 2008). Summary data for trace element concentrations for eight analytes are presented as Box and Whisker plots. The boxes represent the inter-quartile range (25^{th} to 75^{th} percentile) and the whiskers show the range of values that fall within 10^{th} and 90^{th} percentile. Outliers are illustrated with black circles. The median is shown as a line in each box.

3.0 Results and discussion

Soil quality and trace elements results for horticultural sites sampled in 2013

Twenty-six sites representing a broad geographic coverage of the Auckland region and covering seven Soil Orders (Allophanic, Brown, Gley, Granular, Organic, Recent and Ultic) as per the New Zealand soil classification (Hewitt, 1998), corresponding to eight soil series, were sampled in 2013 (Tables 2 and 3). Eighteen sites were originally sampled prior to 2000 and repeated in 2008.

The 26 sites represented 5 horticultural categories (Appendix 7.5):

- Market gardening n=7
- Orchards n=6
- Viticulture n=5
- Nursery n=1
- Horticulture – drystock/lifestyle block conversions n= 7

Twelve per cent of sites met all the guideline targets. Forty-two per cent of sites (n=11) did not meet target criteria for one indicator followed by 12%, 4% and 31% failing to meet two, three and +four indicators, respectively (Figure 3A). The indicator failing to meet guidelines on most occurrences (77% of sites) was Olsen P with the majority of sites exceeding the recommended guideline range (Figures 3B and Tables 2 and 3). Items highlighted in bold represent values outside the recommended guideline target range. In colour print copies, the bold numbers in red are values below the recommended target range and bold numbers in blue exceed the recommended target range.

Eight sites where concentrations of **Olsen P** excessively exceeded guideline targets (i.e. >100 mg/kg) were a mix of market garden (n=6), orchard (n=1) and lifestyle block converted (n=1) sites. Olsen P is both a sensitive and useful indicator of the soil nutrient status. Elevated concentrations of soil P influences stream P concentrations which can contribute to freshwater pollution and eutrophication (McDowell et al., 2001, Curran Cournane et al., 2010). However, to determine the fraction of dissolved reactive P (DRP- the most bioavailable form of P), soil P retention would need to be determined, which when used as the denominator in a quotient with Olsen P can be a predictor of DRP in surface runoff (McDowell and Condron, 2004). However, soil P retention has not been identified as a key soil quality indicator and the conservative approach suggests limiting Olsen P concentrations to a maximum upper limit of 50 mg/kg for volcanic soils (Allophanic and Granular), for both agronomic and environment purposes, which would need to decrease to 20 mg/kg on hill country, to be within recommended guideline limits (Mackay et al., 2013).

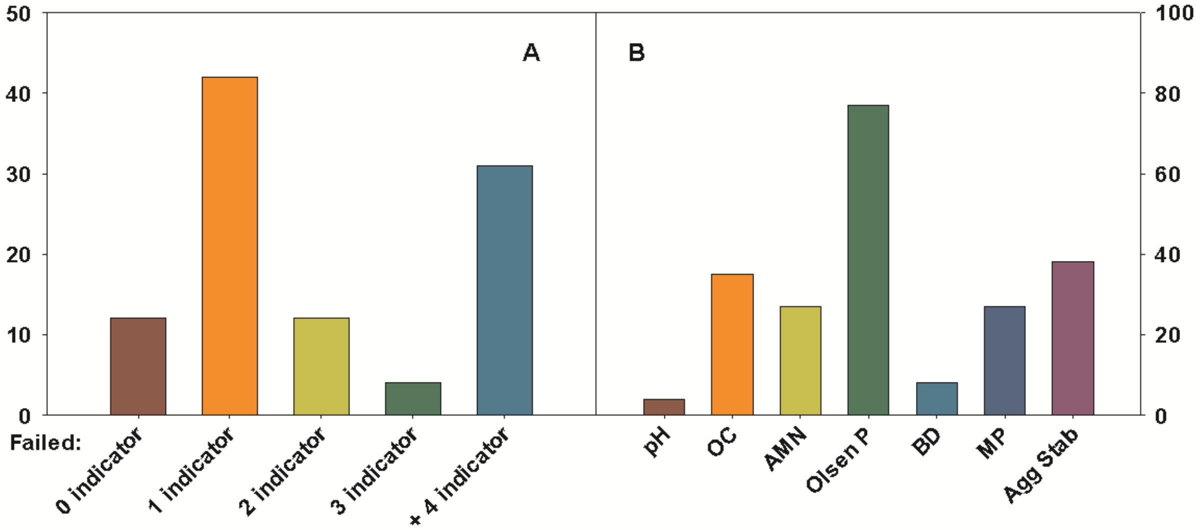

Figure 3 Percentage of horticultural sites outside targets for (A) a number of key soil quality indicators and for (B) key soil quality parameters.

Table 3 Soil chemical (pH, OC, TN, C/N, Olsen P), physical (bulk density, macroporosity, aggregate stability) and biological (AMN) characteristics for 2013 horticulture sampled sites within the Auckland region. Results for % aggregates >1mm, macroporosity (-5kPa) and C/N ratio are presented in the shaded column but excluded from the determination of meeting the soil quality guideline procedure.

Site no.	NZSC	pH	OC%	TN%	AMN mg/kg	Olsen P mg/kg	Bulk density g/cm^3	Macro - 10kPa	Agg stab (MWD) mm	% aggregates >1mm	Macro - 5kPa	C/N
1	Granular	6.02	2.17	0.22	13	276	1.04	24	0.69	20	23	10
10	Allophanic	6.41	3.56	0.30	51	70	1.09	12	0.95	33	9	12
14	Allophanic	6.09	5.97	0.52	92	161	1.08	11	2.39	88	9	11
20	Recent	6.20	12.59	0.79	140	64	0.76	12	2.63	99	11	16
37	Recent	6.22	5.05	0.37	93	32	1.21	3	2.50	92	2	13
41	Organic	6.79	15.26	1.29	165	122	0.54	11	2.30	96	9	12
65	Allophanic	6.53	5.31	0.43	50	84	0.97	23	2.32	88	21	12
67	Allophanic	5.45	4.85	0.42	95	13	0.92	22	2.65	94	20	12
68	Allophanic	5.95	7.14	0.66	127	53	0.93	8	2.25	88	5	11
70	Granular	7.20	4.06	0.38	48	48	0.98	22	1.56	60	21	11
71	Organic	6.20	14.46	0.68	165	27	0.65	18	2.26	93	14	21
79	Ultic	6.34	3.50	0.30	73	40	1.08	7	1.53	55	6	12
80	Ultic	5.64	4.36	0.38	79	19	1.02	11	2.32	86	10	11
81	Ultic	5.99	4.76	0.40	98	23	0.89	12	2.39	86	9	12
82	Brown	6.05	5.71	0.53	126	55	0.94	10	2.31	86	8	11
86	Gley	5.97	4.05	0.34	86	133	0.95	18	1.38	51	16	12
87	Gley	6.05	3.07	0.21	30	56	1.41	1	0.80	23	1	15
88	Gley	6.36	3.04	0.21	22	73	1.35	3	0.52	9	2	14
113	Granular	6.43	1.81	0.19	7	348	1.06	22	0.48	6	20	10
114	Granular	6.13	2.47	0.22	9	148	1.16	16	0.45	8	15	11
115	Granular	6.22	4.28	0.42	45	73	1.00	17	1.51	59	16	10
116	Granular	7.07	1.98	0.16	7	187	0.98	29	0.32	2	27	13
117	Granular	6.89	2.36	0.21	18	361	1.06	23	0.75	23	22	11
118	Ultic	6.62	4.21	0.34	78	11	1.04	14	2.49	89	12	12
119	Ultic	6.24	3.39	0.24	70	16	1.17	9	1.14	40	7	14
120	Ultic	6.28	4.00	0.32	96	28	1.15	6	1.57	58	4	12

Aggregate stability which indicates the resistance of soil aggregates to stress imposed by rapid wetting and mechanical abrasion was the indicator of second most concern (Figure 3 and Table 3). Thirty eight per cent of sites (n=10) in the current report failed to meet the >1.5 MWD mm minimum limit (Sparling et al., 2003), increasing the risk of soil erosion at these sites. Half of the sites that failed to meet this guideline were market gardens (n=5), followed by viticulture (n=2), orchards (n=2) and lifestyle block converted (n=1) sites. The percentage of aggregates >1mm for these ten sites ranged from 2-40% (Table 3). Furthermore, >40-90% of aggregates were <0.5mm for these same ten sites (Appendix 6.2) suggesting that these sites are very vulnerable to soil erosion and in particular sheet erosion (Lynn et al., 2009). In contrast, Basher *et al.* (1997) reported that aggregate stability for market garden sites in Pukekohe in 1997 were all within the 1-2.5mm range. These authors reported that only a very small proportion of samples had aggregates <1mm versus several market gardening sites in the current report having up to 80-98% of the sample with aggregates <1mm.

Basher *et al.* (1997) attributed the inter-particle bonding at the microstructural scale to the high degree of water stable aggregates. Furthermore, high levels of Fe and Al, particularly in the form of dithionite-citrate extractable Fe and dithionite-citrate extractable Al, further contributed to strong aggregate stability reported by these authors. However, this study took place over 15 years ago and therefore subsequent extended periods of market gardening activity could have resulted in the development of less stable aggregates over time. For example, one particular market garden site in the current study (site 115, Table 3) did not display the same level of poor aggregate stability because the site had only recently (1-3 years) been converted from pasture to market gardening land use activity. Therefore, the use and incorporation of green manure crop residues (e.g. ryegrass and oats) on fallow market gardening land is recommended. This will act as a protective cover against rainfall as well as subsequent sediment and pollutant runoff when land is fallow. Furthermore this will facilitate an increase in microbiological activity an subsequently enhance the organic carbon content to the soil environment (Haynes and Tregurtha, 1999).

Differences in aggregate stability between the current study and that reported by Basher *et al.* (1997) could also be the obvious result of different sampling sites, sampling time and rotation phase.

The dispersion of aggregates into smaller aggregates, and in some cases to primary soil particles, could potentially contribute to the delivery of suspended sediment and associated pollutants into receiving fresh water bodies. For **organic carbon** (OC), 35% of sites failed to meet the recommended guideline range. (Table 3). All but one of the sites that failed to meet the aggregate stability guideline also failed to meet the OC guideline range. This is not surprising because Haynes and Tregurtha (1999) reported a strong, positive linear correlation between aggregate stability and OC (i.e. an increase in OC results in an increase in aggregate stability). A similar relationship was also observed in the current study when three sites (those sites that had OC% contents >12%) were excluded (Figure 4).

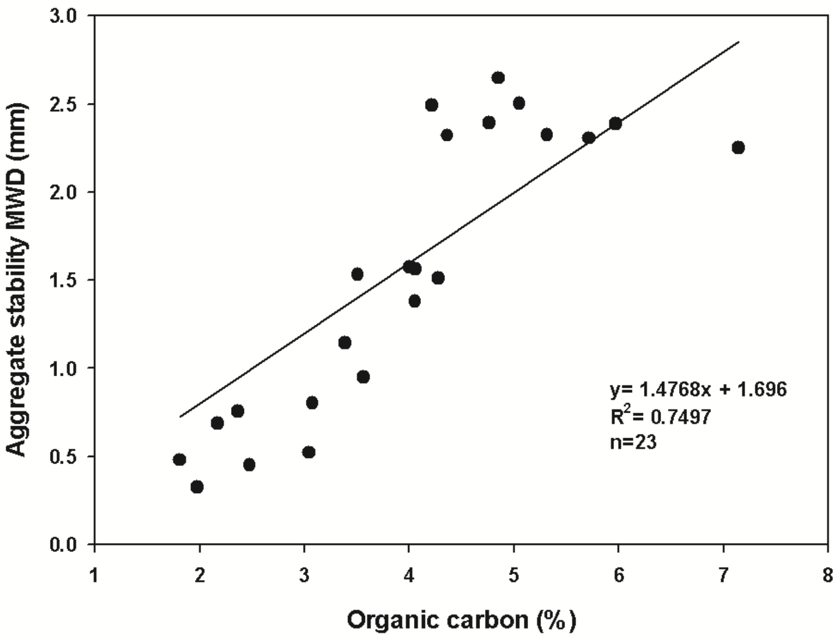

Figure 4 Relationship between organic carbon content and aggregate stability for horticultural sites.

Concentrations of **anaerobic mineralisable nitrogen** (AMN) (an indicator of microbial biomass) were low for seven sites indicating low levels of microbial activity and therefore low levels of plant available nitrogen (Table 3 and Figure 3). Five of the sites with very low concentrations of AMN (i.e. <20mg/kg) were market gardening sites.

Seven sites in the current study fell below the recommended guideline range for **macroporosity**, an indicator of soil compaction. In contrast, soil macroporosity is the indicator of most concern for pastoral sites in rural Auckland (Curran-Cournane et al., 2013). **Soil bulk density**, another indicator of soil compaction, was high for two orchard sites which had correspondingly very low macroporosities (Table 3). Both sites were located on the same property and on the same soil order, Gley, renown for being poor draining with relatively high bulk densities (Hewitt, 1998).

Concentrations of **total nitrogen** (TN) were within the recommended guideline range for all sites (Table 3) and the same can be said for **soil pH** with only one site being slightly on the low side.

The concentrations of the **trace elements** analysed are listed in Appendix 6.4. Specifically, concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn are illustrated in boxplots in Figure 5. Concentrations of Cd and Cu exceeded the suggested upper limits provided by the New Zealand Water and Wastes Association (2003) for one and two sites, respectively. The site that exceeded the upper limit for Cd was a commercial orchard. However, this site was located on an organic soil with a bulk density of 0.54 g/cm^3. Therefore, when converted to a volumetric basis, levels of cadmium equated to 1.08 g/cm^3, highlighting the importance of considering the inherent physical characteristics of the soil types. That said, upper limits of trace elements have not been established on a volumetric basis. Three other sites exceeded the conservative Cd value of 0.65 mg/kg (ARC, 2001) and all three sites were located on soils of volcanic origin. One site was located on a granular soil, a soil order reported to have enriched concentrations of Cd under minimally disturbed conditions (McDowell et al., 2013).

The two different sites that exceeded the upper limits for Cu were an orchard-lifestyle block converted site and a viticulture site (Figure 5). Conservative concentrations have also been established for Cu for both volcanically derived (20-90 mg/kg) and non-volcanically (1-45 mg/kg) derived soils (ARC, 2001), therefore one additional site exceeded these conservative guidelines which was located on an orchard. It is not uncommon to find high concentrations of Cu in orchards. For example Gaw et al.(2006) reported that concentrations of Cu were greatest for orchards followed by vineyards and market gardens and that mean concentrations in orchards were 224 mg/kg (range 21-490 mg/kg). These authors attributed high concentrations of Cu to the long term spraying of copper-based fungicide, agrichemicals and fertilisers.

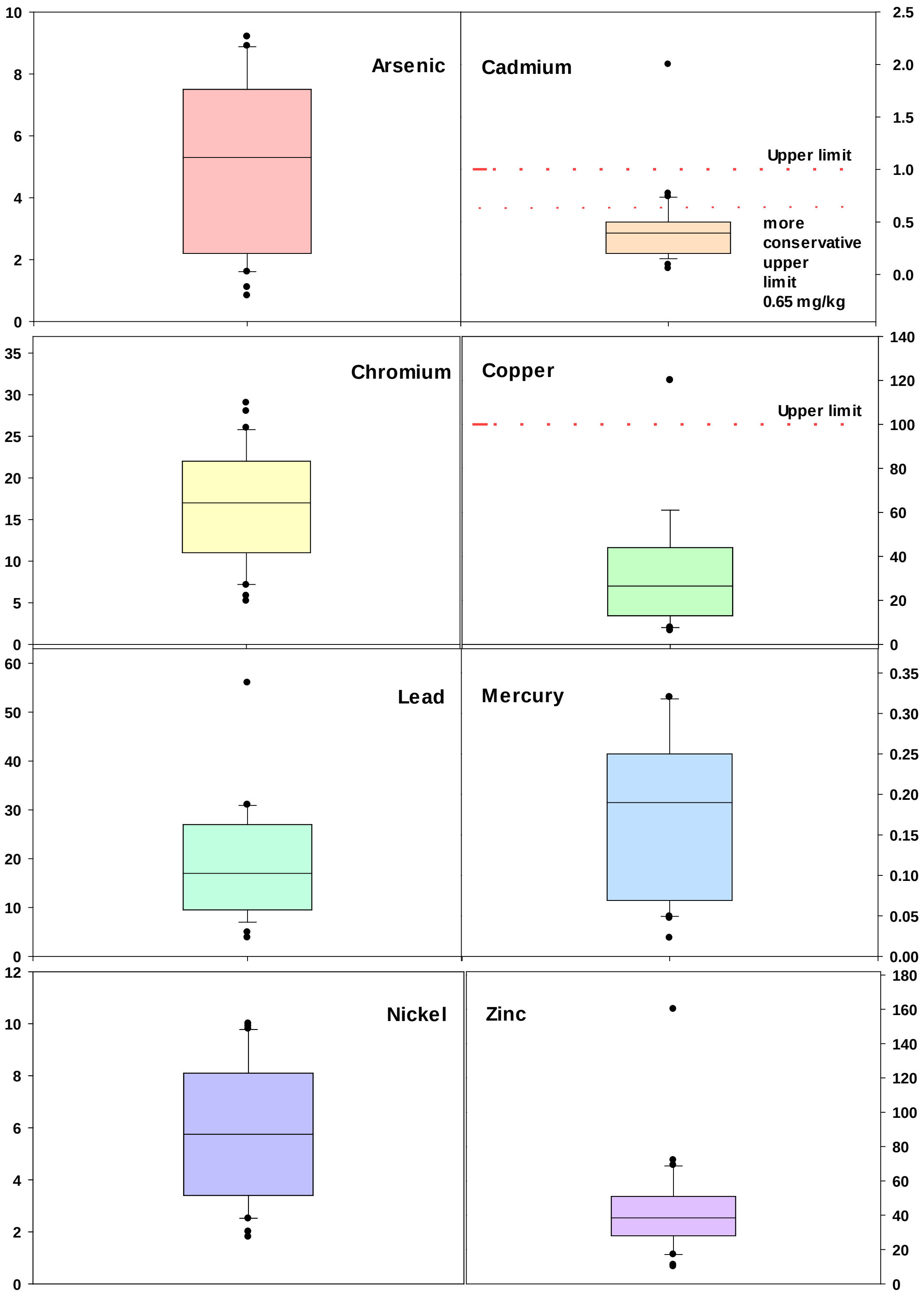

Figure 4 Concentrations (mg/kg on the y-axis) of selected trace elements for 26 horticultural soil quality monitoring sites. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within 10th and 90th percentile. Outliers are illustrated with black circles. The median is shown as a line in each box.

Note. Upper limits are illustrated for selected trace element where concentrations have either approached or exceeded.

Changes in soil quality over time

When soil chemical, physical and biological quality at the 18 repeat sites was compared across the three sampling periods (<2000, 2008 and 2013) significant differences were only observed for macroporosity (-5kPa: -10kPa data was not available for all sites <2000) (Table 4a and Figure 6). Significant differences were not observed for any other soil parameter for these three sampling periods. While macroporosity declined in 2008, values in 2013 tended to almost revert back to <2000 original values. Furthermore, 2013 macroporosities were above the recommended guideline range of 8% v/v for -5kPa (i.e. pore sizes >60 microns) (Table 4a and Figure 6) (Mackay et al., 2006).

Given that seven sites had been converted to pastoral land use (either drystock or lifestyle block conversions), the ANOVA was repeated excluding these seven sites to determine changes in soil quality for 'true' horticultural sites (Table 4b). Significant differences were observed for both OC and AMN contents on a volumetric basis and significant differences were no longer observed for macroporosity. Organic C contents were significantly less in 2013 than those values observed <2000 and 2008. In contrast, AMN values were least in 2008 and greatest <2000. Therefore, no obvious consistent trends of soil ecosystem improvement or degradation were observed. That said, decreasing soil OC levels is a cause for concern which will reduce the soils capacity to sequester carbon. A decrease in soil OC will also reduce the water holding capacity of the soil as well as decreasing soil aggregate stability (Figure 4) rendering it more prone to soil erosion (Glaser et al., 2002). Continuous future soil quality monitoring will be important to determine if these trends continue.

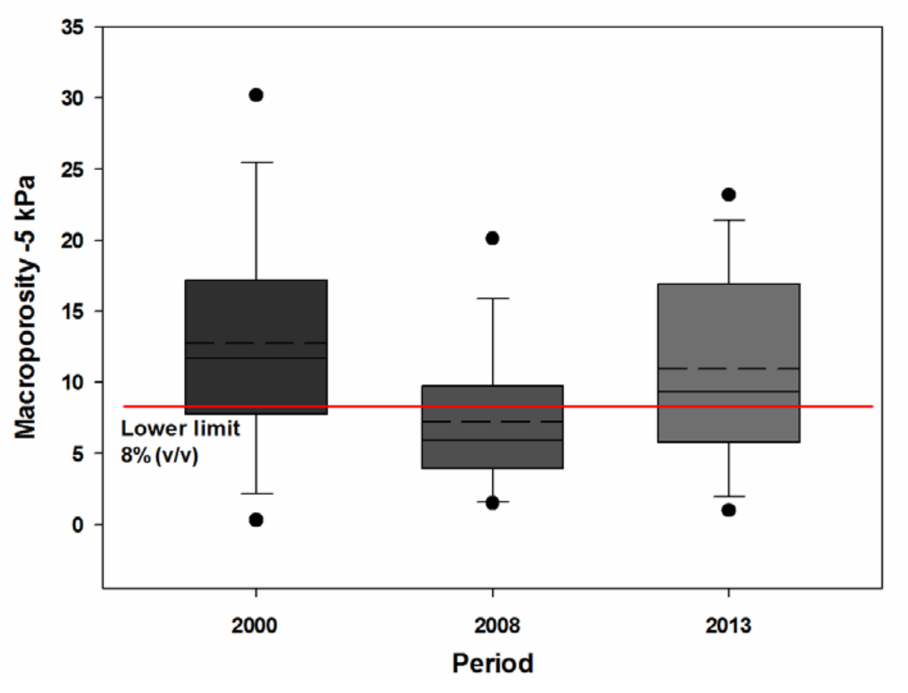

Figure 6. Significant differences in mean macroporosity for sampling periods <2008, 2008 and 2013. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within 10th and 90th percentile. Outliers are illustrated with black circles. The median and mean lines are shown as the straight and dashed lines, respectively, in each box.

Table 4 Changes in soil quality values for three sampling periods. *P*-value is based on log-transformed analyses. NS denotes not significant.

Period	OC%	OC vol[1]	TN%	TN vol[1]	pH	Olsen P	Olsen P vol[2]	AMN	AMN vol[2]	BD[3]	MP - 5kPa[4]
(A) Including all 18 sites											
<2000	6.26	55.9	0.45	4.05	6.20	68	72	111	108	1.00	13
2008	6.25	58.7	0.45	4.34	6.36	60	65	88	89	1.04	7
2013	6.05	53.6	0.47	4.21	6.19	75	74	88	99	0.99	11
P-value	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	P<0.01**
(B) Excluding 7 converted lifestyle block sites											
<2000	6.81	57.8	0.47	3.97	6.59	76	81	119	116	1.01	14
2008	6.84	60.5	0.48	4.40	6.34	63	70	82	82	1.04	8
2013	6.03	50.6	0.46	3.94	6.21	82	80	82	99	0.98	13
P-value	ns	P<0.01**	ns	ns	ns	ns	ns	ns	P<0.05*	ns	ns

units: **1**; mg/cm^3; **2**; µg/cm^3, **3** g/cm^3; **4** % v/v

4.0 Conclusion

Twenty-six horticultural sites were sampled in 2013 in rural Auckland to determine the physical, chemical and biological quality of these soil sites. Eighteen of the sites were originally sampled between 1995 and 2000 and repeated in 2008, therefore 2013 soil sampling contributes to an increasingly valuable dataset for soil quality trend analysis purposes.

Specific horticultural land uses included market gardening (n=7), orchards (n=6), viticulture (n=5), nursery (n=1) and horticulture-pastoral converted land use (n=7).

Forty-two per cent of sites (n=11) failed to meet one of the selected soil quality indicators, followed by 31% of sites (n=8) failing to meet four or more indicators. The main indicator of concern was Olsen P. Twenty sites failed to meet the Olsen P guideline, 16 of which exceeded the upper limit. Olsen P is both a sensitive and useful indicator of soil nutrient status. Elevated concentrations of soil P influences stream P concentrations which can contribute to freshwater pollution and eutrophication.

Organic carbon contents and soil aggregate stability were indicators of second most concern. Of the sites that failed to meet aggregate stability guidelines, half were market gardening sites. All of the latter sites that failed to meet these guidelines also had very low OC contents. This is not surprising because a strong, positive linear correlation exists between aggregate stability and OC (i.e. an increase in OC results in an increase in aggregate stability - Figure 4).

In terms of trace elements, concentrations of Cu tended to exceed the suggested upper limits on more occurrences than any other analyte. These sites corresponded to orchard (n=2) and viticulture (n=1) land uses.

When soil quality was compared across the three sampling periods (<2000, 2008 and 2013) for the 18 repeat sites, significant differences were only observed for macroporosity (-5kPa), an indicator of soil compaction. While macroporosity declined in 2008, values in 2013 tended to almost revert back to <2000 original values. When the 7 horticulture to pastoral conversion sites were excluded from the analyses, significant differences were observed for OC contents and AMN. However, no consistent soil quality improvement or degradation were observed across the sampling periods for these indicators. Soil OC levels were least in the 2013 sampling event signalling a cause for concern. A decrease in soil OC can reduce the water holding capacity of the soil as well as decreasing soil aggregate stability, rendering it more prone to soil erosion. Continuous future soil quality monitoring will be important to determine if these trends continue.

It is therefore recommended that soil sampling for horticultural sites should be repeated every five years in order to continuously monitor variations in soil quality by establishing a longer spanning record of soil quality data relating to these sites.

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7.0 Appendices

7.1 2013 soil physics data

Lab number	Site number	Transect	Initial water content (% w/w)	Dry Bulk Density (t/m3)	Particle density (t/m3)	Total porosity (%/v/v)	Macro -5kPa (% v/v)	Macro (-10kPa) (% v/v)	Vol. WC 5kPa (% v/v)	Vol. WC 10kPa (% v/v)
HP5784a	1	15m	34.2	1.07	2.63	59.1	20.2	21.4	38.9	37.8
HP5784b	1	30m	32.8	1.02	2.63	61.3	25.3	26.5	36.0	34.8
HP5784c	1	45m	34.9	1.02	2.62	61.0	24.0	25.2	37.0	35.8
HP5810a	10	15m	47.0	0.98	2.55	61.4	11.2	15.2	50.2	46.2
HP5810b	10	30m	35.6	1.16	2.55	54.4	11.6	13.1	42.8	41.3
HP5810c	10	45m	45.1	1.13	2.55	55.6	5.4	7.3	50.3	48.4
HP5798a	14	15m	36.7	1.19	2.52	52.9	8.0	10.0	44.9	42.9
HP5798b	14	30m	49.0	1.04	2.54	59.1	6.8	9.0	52.3	50.1
HP5798c	14	45m	45.1	1.02	2.51	59.3	11.8	14.0	47.5	45.2
HP5806a	20	15m	82.8	0.63	2.21	71.4	17.1	18.7	54.2	52.7
HP5806b	20	30m	62.8	0.84	2.32	63.9	7.8	9.9	56.1	54.0
HP5806c	20	45m	69.4	0.82	2.34	64.8	6.9	8.8	57.9	56.1
HP5807a	37	15m	41.4	1.21	2.56	52.6	1.7	3.6	50.9	49.0
HP5807b	37	30m	41.9	1.23	2.55	51.7	<1	1.0	52.2	50.7
HP5807c	37	45m	38.3	1.20	2.54	52.8	3.5	5.1	49.3	47.7
HP5800a	41	15m	118.8	0.54	2.17	75.3	9.9	11.8	65.4	63.5
HP5800b	41	30m	127.5	0.56	2.31	75.9	3.7	6.1	72.1	69.8
HP5800c	41	45m	114.7	0.53	2.25	76.4	14.2	16.5	62.2	59.9
HP5796a	65	15m	42.3	0.94	2.55	63.1	23.6	25.2	39.5	37.9

HP5796b	65	30m	39.1	1.00	2.55	60.7	21.0	22.5	39.7	38.2
HP5796c	65	45m	42.7	0.97	2.53	61.8	19.1	20.5	42.8	41.3
HP5804a	67	15m	37.9	0.95	2.52	62.4	24.3	25.9	38.1	36.4
HP5804b	67	30m	50.1	0.95	2.54	62.4	12.8	15.5	49.6	46.9
HP5804c	67	45m	47.2	0.87	2.50	65.3	23.4	25.3	41.9	40.0
HP5809a	68	15m	60.0	0.92	2.52	63.5	5.4	8.6	58.1	55.0
HP5809b	68	30m	54.6	0.92	2.53	63.8	9.3	12.1	54.5	51.7
HP5809c	68	45m	59.4	0.94	2.50	62.4	1.2	4.2	61.2	58.2
HP5805a	70	15m	40.1	0.94	2.56	63.1	23.6	25.1	39.5	38.0
HP5805b	70	30m	41.1	1.00	2.55	60.8	18.9	20.6	41.9	40.1
HP5805c	70	45m	42.7	0.99	2.59	61.8	19.7	21.4	42.0	40.3
HP5799a	71	15m	94.4	0.58	2.10	72.6	16.5	20.8	56.1	51.8
HP5799b	71	30m	75.3	0.61	2.15	71.5	21.7	26.3	49.8	45.2
HP5799c	71	45m	81.4	0.77	2.28	66.0	3.4	5.6	62.6	60.5
HP5793a	79	15m	61.1	1.00	2.59	61.3	5.8	7.1	55.5	54.3
HP5793b	79	30m	50.9	1.03	2.60	60.3	10.3	12.0	50.0	48.3
HP5793c	79	45m	44.1	1.21	2.64	54.1	1.8	2.9	52.3	51.2
HP5792a	80	15m	43.1	0.99	2.58	61.5	18.1	20.1	43.4	41.5
HP5792b	80	30m	52.4	0.98	2.56	61.7	7.9	9.4	53.8	52.3
HP5792c	80	45m	48.2	1.10	2.53	56.6	2.9	3.7	53.7	52.9
HP5808a	81	15m	75.7	0.80	2.51	68.2	9.2	12.8	58.9	55.3
HP5808b	81	30m	54.1	0.99	2.50	60.4	7.9	10.7	52.6	49.7
HP5808c	81	45m	64.9	0.87	2.46	64.6	9.0	12.0	55.6	52.6
HP5794a	82	15m	56.8	0.92	2.51	63.2	7.3	9.1	56.0	54.2
HP5794b	82	30m	57.4	0.99	2.54	61.0	4.9	6.7	56.1	54.3
HP5794c	82	45m	55.1	0.92	2.54	63.8	13.2	15.2	50.6	48.6
HP5786a	86	15m	52.0	0.68	2.53	73.1	37.6	41.0	35.5	32.1
HP5786b	86	30m	42.4	1.21	2.52	51.9	2.7	4.5	49.2	47.4
HP5786c	86	45m	60.3	0.96	2.50	61.5	7.1	9.2	54.4	52.3
HP5797a	87	15m	33.2	1.37	2.55	46.5	<1	<1	45.6	44.3

HP5797b	87	30m	29.9	1.43	2.56	44.0	<1	2.0	43.4	42.0
HP5797c	87	45m	31.6	1.42	2.56	44.4	<1	<1	44.9	43.6
HP5787a	88	15m	30.0	1.39	2.57	45.9	2.4	3.7	43.5	42.2
HP5787b	88	30m	34.1	1.36	2.57	47.0	1.9	2.8	45.2	44.3
HP5787c	88	45m	36.3	1.30	2.57	49.5	3.0	3.8	46.5	45.7
HP5785a	113	15m	34.1	1.04	2.64	60.5	21.9	23.6	38.6	36.9
HP5785b	113	30m	35.8	1.13	2.63	57.0	14.1	15.7	43.0	41.3
HP5785c	113	45m	32.7	1.02	2.63	61.3	24.3	26.0	36.9	35.3
HP5788a	114	15m	36.2	1.01	2.61	61.3	23.6	25.8	37.7	35.5
HP5788b	114	30m	37.1	1.04	2.58	59.6	20.3	22.3	39.3	37.3
HP5788c	114	45m	31.1	1.44	2.58	44.0	<1	<1	49.6	49.0
HP5789a	115	15m	45.4	0.96	2.57	62.5	18.0	20.5	44.6	42.0
HP5789b	115	30m	43.6	0.85	2.57	66.9	28.9	30.7	38.0	36.2
HP5789c	115	45m	44.2	1.19	2.57	53.7	<1	<1	55.1	54.2
HP5790a	116	15m	34.3	0.92	2.62	64.9	30.4	32.0	34.5	32.9
HP5790b	116	30m	35.8	0.94	2.62	64.0	28.1	29.9	35.9	34.0
HP5790c	116	45m	31.4	1.07	2.63	59.4	22.4	23.8	36.9	35.5
HP5791a	117	15m	33.1	1.08	2.60	58.4	18.8	20.3	39.6	38.1
HP5791b	117	30m	30.1	1.02	2.60	60.6	25.8	26.9	34.8	33.7
HP5791c	117	45m	31.2	1.09	2.59	58.0	20.4	21.4	37.6	36.7
HP5822a	118	15m	45.9	1.02	2.53	59.6	13.5	15.9	46.0	43.7
HP5822b	118	30m	46.6	1.04	2.50	58.5	9.4	11.5	49.1	47.1
HP5822c	118	45m	42.2	1.06	2.50	57.8	12.3	13.9	45.4	43.9
HP5823a	119	15m	39.0	1.23	2.55	51.8	6.6	8.9	45.2	42.8
HP5823b	119	30m	40.8	1.24	2.55	51.4	4.7	7.8	46.7	43.6
HP5823c	119	45m	47.1	1.05	2.52	58.5	9.3	11.5	49.2	46.9
HP5824a	120	15m	48.4	1.10	2.50	56.1	3.9	6.1	52.2	50.0
HP5824b	120	30m	48.0	1.12	2.55	56.1	3.3	6.1	52.8	50.0
HP5824c	120	45m	39.7	1.23	2.58	52.3	3.5	5.5	48.8	46.8

7.2 Percentage of aggregates remaining on various sized sieves after wet sieving aggregate stability analysis

Site	% 2-4mm	% 1-2mm	% 0.5-1mm	% <0.5mm	MWD	% >1mm
1	1.5	18.7	32.6	**47.2**	0.7	20.2
10	15.2	17.8	11.7	**55.3**	0.9	33.0
14	67.3	21.1	4.3	7.3	2.4	88.4
20	76.3	22.5	0.1	1.1	2.6	98.8
37	72.9	18.8	2.8	5.5	2.5	91.7
41	56.6	39.6	0.4	3.4	2.3	96.2
65	63.2	24.6	5.5	6.8	2.3	87.8
67	81.3	12.2	1.9	4.6	2.6	93.5
68	58.3	30.2	4.1	7.5	2.3	88.5
70	32.4	27.5	15.6	24.5	1.6	59.9
71	55.9	37.2	1.7	5.1	2.3	93.2
79	35.1	19.7	13.6	31.6	1.5	54.8
80	65.5	20.3	3.3	10.9	2.3	85.8
81	69.2	17.3	4.6	9.0	2.4	86.4
82	64.9	20.6	2.9	11.6	2.3	85.5
86	30.4	20.4	7.5	**41.7**	1.4	50.8
87	11.5	11.5	18.3	**58.7**	0.8	23.0
88	3.7	5.2	20.9	**70.2**	0.5	8.9
113	0.5	5.7	29.2	**64.7**	0.5	6.1
114	2.7	5.3	12.2	**79.8**	0.5	8.0
115	31.0	28.4	11.1	29.5	1.5	59.4
116	0.5	1.6	7.9	**90.0**	0.3	2.1
117	2.7	19.9	36.2	**41.3**	0.8	22.6
118	74.4	14.2	3.4	7.9	2.5	88.7
119	24.3	15.4	6.3	**54.1**	1.1	39.7
120	35.7	22.0	13.2	29.1	1.6	57.7

Note. Figures highlighted in bold and in red indicate the sites that are more at risk of soil erosion with the majority of particles <0.5mm.

7.3 Archived soil chemical, physical and biological data for sampling periods < 2000 and 2008

Unique Site #	pH	TC vol	TC%	TN vol	TN%	C/N	Olsen P mg/kg	Olsen P vol	AMN mg/kg	AMN vol	BD t/m3	MP - 5kPa	MP - 10kPa	Agg Stab
<2000 sampling period														
1995-01-01	7.17	20	2.10	1.92	0.20	11	200	192	9	9	0.96	30.2		
1997-10-01	6.58	56	6.53	4.82	0.56	12	22	19	85	73	0.86	15.4	19.62	
1998-14-01	6.17	60	6.55	5.34	0.59	11	53	48	109	99	0.91	15.6		2.86
1998-20-01	6.38	63	6.15	4.36	0.42	15	97	100	65	67	1.03	8.3		2.66
1998-37-01	5.34	38	3.83	3.10	0.31	12	112	112	40	40	1	21.9		1.25
1999-41-01	6.82	73	16.11	6.03	1.34	12	78	35	171	77	0.45	7.6		2.29
2000-65-01	6.57	58	6.07	4.51	0.47	13	63	60	139	133	0.96	17.50	19.40	2.63
2000-67-01	6.24	56	4.80	4.45	0.38	13	14	16	162	188	1.16	13.90	15.73	2.62
2000-68-01	5.76	67	5.77	5.35	0.46	12	72	84	78	91	1.16	0.30	1.17	1.75
2000-70-01	6.36	47	5.60	3.82	0.46	12	18	15	145	120	0.83	24.90	26.47	2.48
2000-71-01	6.4	148	19.93	5.94	0.80	25	30	22	59	44	0.74	10.50	5.30	1.66
2000-79-01	6.33	39	3.91	2.79	0.28	14	17	17	153	151	0.99	2.40	4.20	1.96
2000-80-01	5.84	48	4.95	3.91	0.40	12	16	16	158	153	0.97	17.10	18.80	2.58
2000-81-01	5.77	48	5.11	3.45	0.37	14	17	16	155	144	0.93	10.40	12.36	2.58
2000-82-01	5.94	61	5.77	5.08	0.48	12	44	46	228	239	1.05	8.60	10.90	2.55
2000-86-01	5.8	49	3.47	3.36	0.24	14	144	202	91	127	1.40	7.80	7.83	1.81
2000-87-01	5.87	42	3.41	2.45	0.20	17	107	132	115	141	1.23	12.90	15.71	2.1
2000-88-01	6.18	36	2.70	2.15	0.16	17	119	161	34	46	1.35	4.20	6.43	2.62
2008 sampling period														
2008-01-02	6.41	24	2.03	2.23	0.19	11	181	209	13	15	1.16	11.9	12.83	
2008-10-02	6.88	39	4.39	3.14	0.35	13	44	39	26	23	0.9	20.1	24.4	
2008-14-02	6.31	59	5.73	5.12	0.49	12	150	155	108	111	1.03	5.7	7.97	
2008-20-02	5.97	57	4.74	3.75	0.31	15	86	104	82	99	1.21	1.5	3.87	

2008-37-02	7.2	63	5.22	4.32	0.36	15	44	53	72	86	1.21	1.6	3.83	
2008-41-02	6.51	96	15.4	7.53	1.21	13	52	32	139	86	0.62	5.5	3.47	
2008-65-02	6.81	62	5.79	5.04	0.47	12	61	65	72	77	1.07	6.9	8.7	
2008-67-02	6.68	52	4.84	4.41	0.41	12	42	46	115	123	1.07	15.4	18.2	
2008-68-02	6.09	74	7.55	6.38	0.65	12	29	28	135	132	0.98	4.3	7.97	
2008-70-02	7.02	53	5.05	4.77	0.45	11	21	23	91	96	1.06	12.6	14.67	
2008-71-02	6.41	127	20	5.15	0.82	25	27	17	63	39	0.63	6.7	8.17	
2008-79-02	6.2	47	4.63	3.2	0.32	15	15	16	102	103	1.02	2.8	5.23	
2008-80-02	5.57	57	5.33	4.87	0.45	12	19	21	105	112	1.07	7.3	7.13	
2008-81-02	6.11	50	4.98	3.9	0.39	13	15	15	150	151	1.01	5.2	8.06	
2008-82-02	5.89	55	5.45	4.87	0.48	11	37	38	126	128	1.01	6.1	9.3	
2008-86-02	6.19	55	4.34	4.17	0.33	13	115	147	81	104	1.28	2.5	4.76	
2008-87-02	6.29	48	3.85	3.28	0.26	15	79	99	72	90	1.25	4.8	7.1	
2008-88-02	5.97	37	3.12	2.06	0.18	18	57	67	25	29	1.18	9	11.43	

7.4 Trace element concentrations for 2013 horticultural sites

Element	Site number													
	1	**10**	**14**	**20**	**37**	**41**	**65**	**67**	**68**	**70**	**71**	**79**	**80**	**81**	**82**
Aluminium	41000	42000	26000	20000	43000	37000	60000	19000	46000	30000	48000	11000	6600	7000	8700
Antimony	<0.45	<2.3	<0.45	<2.3	<2.3	<2.3	<0.44	<0.46	<2.3	<0.44	<0.45	<0.44	<0.45	<0.45	<0.46
Arsenic	7.3	6.3	4.9	2.9	7.2	4.9	6.5	3.5	8.1	6.5	3.9	3.5	0.93	2	1.5
As 2014[1]	5.6	6.1	6.9	2.2	8.9	5	7	6.1	7.2	7.5	4.6	3.1	1.6	2.1	2.2
Barium	250	130	120	24	62	85	130	43	34	110	48	31	12	33	10
Beryllium	0.43	<0.45	0.3	<0.45	<0.45	0.78	0.54	0.28	<0.46	0.29	0.61	0.11	<0.091	<0.09	<0.091
Bismuth	0.38	<0.45	0.24	<0.45	<0.45	<0.45	0.33	0.17	<0.46	0.3	0.17	<0.089	<0.091	<0.09	<0.091
Boron	<4.5	<23	<4.5	<23	<23	<23	<4.4	<4.6	<23	<4.4	<4.5	<4.4	<4.5	<4.5	<4.6
Cadmium	0.62	<0.45	0.46	<0.45	0.47	1.8	0.58	0.3	0.74	0.52	0.3	0.15	0.38	<0.09	0.16
Cd 2014[1]	0.5	0.42	0.48	0.47	0.35	2	0.77	0.28	0.74	0.47	0.37	0.19	0.33	0.093	0.22
Calcium	3100	4400	5500	5600	3800	13000	4900	1500	3600	7600	3400	4300	3500	1900	2300
Cesium	1.8	2.5	2.4	1.8	2.1	2.6	2.5	1.8	0.85	1.7	2.5	0.61	0.44	0.29	0.73
Chromium	28	13	12	7.7	15	26	16	11	20	19	17	20	10	9.4	9
Cr 2014[1]	29	15	17	9.3	17	28	21	16	22	24	18	22	17	12	11
Cobalt	14	3.6	4	0.65	1.1	1.6	3.9	4.3	3.7	11	1.4	17	0.32	3.1	0.42
Copper	48	16	12	88	24	33	16	7.6	14	22	27	8.7	53	5.3	30
Cu 2014[1]	47	16	13	120	26	38	17	7.6	15	25	27	7.4	18	6.2	35
Gold	<0.45	<2.3	<0.45	<2.3	<2.3	<2.3	<0.44	<0.46	<2.3	<0.44	<0.45	<0.44	<0.45	<0.45	<0.46

Iron	50000	20000	24000	2500	23000	7800	36000	26000	33000	37000	12000	28000	13000	16000	15000
Lanthanum	8.4	38	5.8	5.1	4.6	15	28	3.7	12	5.9	14	1.5	0.94	0.86	0.97
Lead	34	20	26	13	17	17	23	17	12	29	14	11	2.8	5.6	5.1
Pb 2014[1]	29	19	27	14	21	16	20	18	12	27	14	9.5	3.8	9.1	7
Lithium	8.9	8.8	7.1	4.6	8.1	12	11	6.9	9.9	9.5	8.7	2.3	<0.68	2	1.2
Magnesium	540	480	500	500	570	1200	730	440	700	740	970	610	410	700	310
Manganese	3200	530	480	69	140	340	210	1300	420	2600	120	1200	150	500	120
Mercury	0.26	0.29	0.13	0.26	<0.23	<0.23	0.27	0.14	0.31	0.21	0.36	0.058	<0.045	0.045	0.064
Hg 2014	0.27	0.22	0.18	0.22	0.22	0.11	0.2	0.17	0.25	0.23	0.32	0.069	0.086	0.047	0.074
Molybdenum	2.5	<2.3	0.84	<2.3	<2.3	<2.3	1.3	0.71	<2.3	1.2	0.62	<0.44	<0.45	<0.45	<0.46
Nickel	6.6	5.7	3.2	2.3	3.8	5.9	5.1	2	4.1	6.1	3.5	2.9	1.1	1.7	0.82
Ni 2014[1]	10	8.1	7.3	3.7	6.5	9.5	8	4.9	6.9	9.6	5	4.1	1.8	3.2	2
Phosphorus	2700	1600	3700	1800	1300	5100	1200	370	2900	2000	1500	1400	770	450	650
Potassium	850	<900	950	<910	<910	<910	620	300	<910	630	430	<180	310	400	220
Rubidium	3.4	5.3	14	2.9	4.5	3	4.6	4.3	4.3	3.9	4	5	2.5	5	3.1
Selenium	1.8	1.4	0.82	2.2	1.4	2.2	2	0.83	2.5	1.8	2.3	0.76	0.27	0.49	0.53
Silicon (as Silica)	2200	3300	1800	2900	2700	3100	4600	3100	3900	2800	2200	1700	2300	2600	1500
Silver	<0.45	<2.3	<0.45	<2.3	<2.3	<2.3	<0.44	<0.46	<2.3	<0.44	<0.45	<0.44	<0.45	<0.45	<0.46
Sodium	<180	<900	<180	<910	<910	<910	<180	<180	<910	<180	<180	<180	<180	<180	<180
Strontium	24	34	19	28	20	71	15	9.2	17	30	17	21	16	11	11
Thallium	<1.8	<9.0	<1.8	<9.1	<9.1	<9.1	<1.8	<1.8	<9.1	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
Tin	2.1	<3.4	1.5	<3.4	<3.4	<3.4	1.8	0.78	<3.4	1.3	1.5	<0.67	<0.68	<0.67	<0.68

Tungsten	<0.091	<0.45	0.11	<0.45	<0.45	<0.45	0.13	<0.091	<0.46	<0.088	<0.09	<0.089	<0.091	<0.09	<0.091
Uranium	3.6	2.3	1.6	1.6	1.9	4.1	2.5	1.3	2.2	2.5	2.1	0.6	0.64	0.22	0.54
Vanadium	120	55	55	9.3	64	47	79	69	96	110	34	83	45	44	50
Zinc	71	34	80	50	<34	130	<13	32	56	<13	<14	13	<14	<13	<14
Zn 2014[1]	47	44	69	61	28	160	46	29	72	53	37	30	18	27	17
Zirconium	4	6.9	1.8	2.3	4.7	15	14	2.9	8.6	4.5	6.3	<0.44	<0.45	<0.45	<0.46

Element	**Site number**														
	86	**87**	**88**	**113**	**114**	**115**	**116**	**117**	**118**	**119**	**120**				
Aluminium	8300	3200	7200	56000	71000	37000	73000	50000	6700	6400	8500				
Antimony	<0.46	<0.45	<0.45	<0.45	<0.44	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45				
Arsenic	1.1	0.54	1.7	8	8.2	7.3	9.2	6.9	2.9	2.3	5.7				
As 2014[1]	1.1	0.83	1.9	9.2	8.4	8.7	9.2	7.6	3.3	1.7	4				
Barium	21	9.1	9.6	220	210	210	290	200	35	33	160				
Beryllium	<0.091	<0.091	<0.09	0.38	0.46	0.45	0.39	0.31	0.099	0.091	0.44				
Bismuth	<0.091	<0.091	<0.09	0.42	0.58	0.35	0.55	0.4	0.1	<0.09	0.19				
Boron	<4.6	<4.5	<4.5	4.7	<4.4	<4.5	5.6	<4.5	<4.5	<4.5	<4.5				
Cadmium	0.59	0.17	0.17	0.52	0.57	0.27	0.38	0.7	<0.091	<0.09	0.16				
Cd 2014[1]	0.43	0.2	0.19	0.58	0.56	0.36	0.47	0.7	0.15	0.055	0.15				
Calcium	6300	1700	1600	3800	2800	3000	5500	5400	2700	2200	3500				
Cesium	0.69	0.32	0.78	2	2	3.2	1.2	1.2	<0.091	1.1	0.18				
Chromium	6.2	2.3	4	22	25	26	29	23	5.3	4.7	13				

Cr 2014[1]	7.1	5.2	5.8	23	24	22	26	22	8.1	8.7	13				
Cobalt	0.7	0.28	0.36	11	7.5	17	5.2	8.7	1.1	0.52	12				
Copper	220	60	5.9	56	52	42	44	40	7.4	11	55				
Cu 2014[1]	120	61	8.9	61	49	43	43	40	12	7.8	44				
Gold	<0.46	<0.45	<0.45	<0.45	<0.44	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45				
Iron	3900	950	8700	50000	45000	46000	51000	45000	15000	8300	24000				
Lanthanum	2.3	1.2	1.8	12	10	14	5	6.4	2.2	2.2	7.2				
Lead	8.2	3.6	15	33	33	47	33	33	9.2	6.5	26				
Pb 2014[1]	8.3	4.9	14	30	31	56	31	30	13	7	18				
Lithium	1.6	<0.68	2	8.5	9.7	10	7.9	8	1.4	2.8	1.7				
Magnesium	430	220	250	610	600	390	820	760	520	270	1200				
Manganese	190	43	64	2800	1100	6900	240	1100	620	150	3200				
Mercury	0.052	0.055	0.069	0.25	0.3	0.28	0.26	0.3	0.058	0.059	0.064				
Hg 2014[1]	<0.045	0.063	0.076	0.25	0.32	0.3	0.28	0.32	0.052	0.049	0.063				
Molybdenum	<0.46	<0.45	<0.45	2.1	2	1.4	2.2	2.5	<0.45	<0.45	0.56				
Nickel	5.5	1.9	1.6	5.9	7	5	6.9	4.9	1.1	1.2	3.6				
Ni 2014[1]	4.6	2.8	2.7	8.7	9.8	7.2	9.9	7.1	2.5	3.4	3.8				
Phosphorus	2200	540	510	2900	2000	1400	2400	3200	290	340	550				
Potassium	410	<180	<180	810	490	670	810	910	490	240	1000				
Rubidium	2.7	0.93	1.9	4	4.3	6.9	2.5	3.2	6.9	6.1	17				
Selenium	0.34	<0.18	0.62	1.8	1.9	1.8	2.6	2	0.54	0.57	0.75				
Silicon (as Silica)	2200	1600	2100	2100	2100	3400	3100	2300	2400	2300	2900				

Silver	<0.46	<0.45	<0.45	<0.45	<0.44	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45				
Sodium	<180	<180	<180	<180	<180	<180	<180	<180	<180	<180	<180				
Strontium	32	8.1	8.1	23	16	14	35	28	14	7.2	26				
Thallium	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8				
Tin	<0.68	<0.68	0.91	2.3	2.9	1.6	2.9	2.5	<0.68	<0.68	<0.68				
Tungsten	<0.091	<0.091	<0.09	<0.09	0.12	<0.09	0.14	<0.09	<0.091	<0.09	<0.091				
Uranium	1	0.37	0.51	3.7	4.1	2.2	4.4	3.9	0.57	0.54	0.96				
Vanadium	12	4.9	21	120	110	130	110	110	39	21	55				
Zinc	90	<68	<68	<68	17	74	16	22	12	15	49				
Zn 2014[1]	31	10	46	48	40	66	36	51	18	11	33				
Zirconium	0.73	<0.45	1	5.1	15	5.6	20	5.7	1.1	1.2	0.99				

[1] Repeat analysis at the neat/trace level using the second composite soil sample taken at the exact same time at the exact same site

7.5 Site and soil type details for all 26 sites sampled

Site	1
Date sampled	02/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The site is located in Pukekohe and it was first sampled in 1995 and repeated in 2008. Potatoes were the crop that were growing when the site was sampled.

Site	10
Date sampled	20/09/2013
Landuse	Drystock converted site
NZSC	Typic Orthic Allophanic
Soil type	Karaka silt loam
Parent material	Redeposited volcanic ash

Sampling/field notes

The site is located in Karaka and it was first sampled in 1997 and repeated in 2008. The site is no longer being used for market gardening activity and has been converted to drystock farming.

Site	14
Date sampled	13/09/2013
Landuse	Lifestyle block converted site
NZSC	Typic Orthic Allophanic
Soil type	Karaka silt loam
Parent material	Tephra

Sampling/field notes

The site is located in Karaka and it was first sampled in 1998 and repeated in 2008. The site is no longer being used as a commercial feijoa orchard and has been converted to a lifestyle block.

Site	20
Date sampled	19/09/2013
Landuse	Lifestyle block converted site
NZSC	Weathered Fluvial Recent
Soil type	Waitemata silt loam
Parent material	Alluvium partly derived from Tephra

Sampling/field notes

The site was first sampled in 1998 and repeated in 2008. The site is no longer being used as a commercial orchard and the section itself is se to be subdivided in the imminent future.

Site	37
Date sampled	19/09/2013
Landuse	Lifestyle block converted site
NZSC	Weathered Fluvial Recent
Soil type	Waitemata silt loam
Parent material	Alluvium

Sampling/field notes

The site was first sampled in 1998 and repeated in 2008. The site is no longer being used as a market garden and is being used for pastoral grazing.

Site	41
Date sampled	23/09/2013
Landuse	Kiwifruit orchard
NZSC	Mellow Humic Organic
Soil type	Ardmore peaty loam
Parent material	Thin alluvium overlying peat

Sampling/field notes

The site was first sampled in 1999 and repeated in 2008 and is the only commercial kiwifruit orchard across all selected horticultural sites.

Site	65
Date sampled	13/09/2013
Landuse	Persimmon orchard
NZSC	Typic Orthic Allophanic
Soil type	Karaka silt loam
Parent material	Tephra (andesitic)

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008 and is the only commercial persimmon orchard across all selected horticultural sites.

Site	67
Date sampled	16/09/2013
Landuse	Citrus orchard
NZSC	Typic Orthic Allophanic
Soil type	Matakawau sandy clay loam
Parent material	Sandstone

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008 and is located in Waiuku. It is a commercial citrus orchard.

Site	68
Date sampled	20/09/2013
Landuse	Pastoral conversion
NZSC	Typic Orthic Allophanic
Soil type	Matakawau sandy clay loam
Parent material	Sandstone with a veneer of tephra

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008 and is located in Ahwitu. It is no longer used for market gardening but for pastoral grazing.

Site	70
Date sampled	16/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe silt loam
Parent material	Strongly weathered tephra

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008 and was growing kale when the site was sampled in 2013.

Site	71
Date sampled	13/09/2013
Landuse	Nursery
NZSC	Mellow Humic Organic
Soil type	Ardmore humic loam
Parent material	Sandstone with a veneer of tephra

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008 and is the only commercial nursery across all selected horticultural sites.

Site	79
Date sampled	09/09/2013
Landuse	Lifestyle block conversion
NZSC	Typic Yellow Ultic
Soil type	Warkworth clay loam
Parent material	Fine strongly weathered sandstone

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008. It is a site located in Warkworth that has converted from organic cropping to lifestyle block horticultural and pastoral farming.

Site	80
Date sampled	09/09/2013
Landuse	Viticulture
NZSC	Typic Yellow Ultic
Soil type	Warkworth clay loam
Parent material	Fine strongly weathered sandstone

Sampling/field notes

The site was first sampled in 2000 and repeated in 2008. It is a site located in Warkworth that is a commercial vineyard.

Site	81
Date sampled	17/09/2013
Landuse	Lifestyle block conversion
NZSC	Typic Yellow Ultic
Soil type	Warkworth clay loam
Parent material	Sandstone

Sampling/field notes

The site which is located in Warkworth was first sampled in 2000 and repeated in 2008. It was a mixed commercial orchard and now operates at a lifestyle block scale.

Site	82
Date sampled	10/09/2013
Landuse	Orchard
NZSC	Typic Yellow Ultic
Soil type	Waitemata complex
Parent material	Alluvium and colluvium

Sampling/field notes

The site which is located in Puhoi was first sampled in 2000 and repeated in 2008. It is a mixed orchard with both feijoa and grapefruit trees.

Site	86
Date sampled	04/09/2013
Landuse	Viticulture
NZSC	Typic Orthic Gley
Soil type	Waitemata complex
Parent material	Alluvium

Sampling/field notes

The site which is located in the Coatesville/Riverhead area was first sampled in 2000 and repeated in 2008. The site is used for commercial viticulture.

Site	87
Date sampled	04/09/2013
Landuse	Viticulture
NZSC	Typic Orthic Gley
Soil type	Waitemata complex
Parent material	Alluvium

Sampling/field notes

The site which is located in the Coatesville/Riverhead area was first sampled in 2000 and repeated in 2008. The site is used for commercial strawberry growing.

Site	88
Date sampled	04/09/2013
Landuse	Viticulture
NZSC	Typic Orthic Gley
Soil type	Waitemata complex
Parent material	Alluvium

Sampling/field notes

The site is located in the Coatesville/Riverhead area on the same property as site 87. It was first sampled in 2000 and repeated in 2008. The site is also used for commercial strawberry growing.

Site	113
Date sampled	02/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The is a new site that was selected in 2013 to increase the number of market garden soil sites in Pukekohe. The paddock was growing lettuces during soil sample collection.

Site	114
Date sampled	06/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The is a new site that was selected in 2013 to increase the number of market garden soil sites in Pukekohe. The paddock was growing carrots during soil sample collection.

Site	115
Date sampled	06/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The is a new site that was selected in 2013 to increase the number of market garden soil sites in Pukekohe. The paddock was growing carrots during soil sample collection.

Site	116
Date sampled	06/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The is a new site that was selected in 2013 to increase the number of market garden soil sites in Pukekohe. The paddock had been harvested for onions the previous March and was currently left fallow.

Site	117
Date sampled	06/09/2013
Landuse	Market garden
NZSC	Typic Orthic Granular
Soil type	Patumahoe clay loam
Parent material	Hamilton ash formation

Sampling/field notes

The is a new site that was selected in 2013 to increase the number of market garden soil sites in Pukekohe. The paddock had been harvested for onions the previous March and was currently left fallow.

Site	118
Date sampled	26/09/2013
Landuse	Viticulture
NZSC	Mottled Albic Ultic[1]
Soil type	Rangiora[1]
Parent material	[1]

Sampling/field notes

The is a new site that was selected in 2013 to ensure a selection of sites in Waiheke Island were added to dataset. The site was used for commercial viticulture.

[1] subject to a comprehensive pedological assessment

Site	119
Date sampled	26/09/2013
Landuse	Viticulture
NZSC	Mottled Albic Ultic[1]
Soil type	Rangiora[1]
Parent material	[1]

Sampling/field notes

The is a new site that was selected in 2013 to ensure a selection of sites in Waiheke Island were added to dataset. The site was used for commercial viticulture.

[1] subject to a comprehensive pedological assessment

Site	120
Date sampled	26/09/2013
Landuse	Viticulture
NZSC	Yellow Albic Ultic[1]
Soil type	Mahurangi[1]
Parent material	[1]

Sampling/field notes

The is a new site that was selected in 2013 to ensure a selection of sites in Waiheke Island were added to dataset. The site was used for commercial viticulture.

[1] subject to a comprehensive pedological assessment