Soil Quality for Dairy and Converted Dairy Sites in the Auckland Region in 2014 and Changes after 18 years

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Soil Quality for Dairy and Converted Dairy Sites in the Auckland Region in 2014 and Changes after 18 years

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Executive summary

The land and soil in the Auckland region are important, valuable and non-renewable resources. Soil supports the growing population by providing food, a place to live and work, and recreational and tourism opportunities. Some soil and landform combinations also have cultural and historical significance to different groups of people. Auckland Council is required by the Resource Management Act 1991 section 35 to report on the state of the environment in part, or in whole, no longer than every five years. Monitoring of soil samples collected at a variety of land use sites is conducted every five years by the Auckland Council which concentrates on sampling one land use per year. Auckland Council monitors soil quality to determine any changes in the ability of the soil to sustain biological production, maintain environmental quality or promote plant and animal health.

Dairy sites were the focus of 2014 soil sampling. Land use in rural Auckland is undergoing rapid change, with much rural land being converted to residential and lifestyle living. While the number of dairy farms in Auckland has been decreasing over the last 14 years in Auckland, dairy farming has become more intensive with growing herd sizes.

Twenty dairy soil sites were first identified and sampled between 1996 and 2000 (i.e. <2000) and subsequently repeated in 2009. These 20 dairy and ‘converted-dairy’ sites were sampled again in 2014, adding to an increasingly valuable dataset for determining changes in soil quality. The ‘converted dairy’ sites included those farms that converted to drystock, rural lifestyle living and horse farming activities in rural Auckland. The 2014 sampling period also included sampling at an additional 5 new dairy sites across the region contributing to a total 25 dairy and ‘converted dairy’ sites as part of the annual soil quality monitoring programme.

Twenty-percent of all sites (n=5) sampled in 2014 failed to meet one soil quality indicator with 40% (n=10), 32% (n=8) and 8% (n=2) failing to meet two, three and four indicators, respectively. The soil quality indicator of most concern was soil macroporosity (-10 kPa) with 23 sites falling below the recommended macroporosity guidelines. Macroporosity measures the large pore space in soil and is an indicator of soil compaction. Compact soils are more prone to pollutant loss to surface waters via surface runoff and it can also affect pasture yields.

Concentrations of Olsen P and total nitrogen were also of concern with 60% and 40% of sites exceeding the upper recommended limits, respectively. When in excess of crop requirements, both phosphorous and nitrogen can be lost from soil to water via surface runoff and cause increased risk of eutrophic conditions.

There were significant differences between mean concentrations of Olsen P, macroporosity (-5kPa) and bulk density when the three sampling periods were compared. Of these changes, continuous low soil macroporosity was the indicator of most concern. With increasing land use change it is important to continue to monitor the quality of long term soil sites and to investigate potential changes over time.

Contents

1.0 Introduction

Much of New Zealand's economy is based on farming activities, with about half of the total land used for primary production (Statistics New Zealand, 2008) . Different land uses have varying impacts on soil quality. For example, soil compaction and high fertilisation rates are issues associated with pastoral land in Auckland, while depleted carbon levels, excessive fertiliser rates and the risk of sediment loss is an issue for cultivated crop land (Curran-Cournane, 2015). The latter is also true for harvesting activity associated with plantation forestry.

Nationally the percentage of land used for drystock (e.g. sheep, beef, cattle and deer) farming declined over the last 10 years while the amount of pastoral land used for dairy farming has increased. In Auckland dairy farming contributes to 10% of the total farming land use (Statistics New Zealand, 2014). While there has been a decline in dairy farm numbers and effective dairy farming area in Auckland, the average herd size has increased (Table 1). The effective dairy farm area decreased by 20%, between 2001/02 and 2013/14, yet the average dairy herd size increased 32% from 199 to 262 dairy stock, respectively (Table 1). Furthermore, there has been a continual decline in livestock numbers used for pastoral farming activities with the number of beef cattle, dairy cattle and sheep in the Auckland region declining by 33%, 27% and 43%, respectively, between 2001/02 and 2013/14) (Statistics New Zealand, 2014). Rapid changes in land use across the Auckland region and the differing impacts on soil quality highlight the need for long term continued monitoring because such changes can impact the quality of the receiving environment.

Table 1: Dairy farming area, herd size and number of dairy farms within the Auckland region, 2002-2014.

Period	**Effective farming area (ha)[1]**	**Average herd size[1]**	**Number of dairy farms[2]**
2001/02	61,393	199	564
2006/07	48,358	233	366
2011/12	46,282	249	360
2012/13	48,655	260	330
2013/14	48,826	262	
%change 2001/02-2013/14	**-20%**	**32%**	**-41%**

Data sourced from Livestock Improvement Corporation[1] and Statistics New Zealand[2]

Under the Resource management act (1991) Section 35, Auckland council is required to carry out monitoring and report on part, or in whole, the state of the environment. The aim of reporting is to: "assess the life supporting capacity of soils" and "ensure that current practices will meet the foreseeable need of future generations".

Soil quality monitoring in Auckland started in 1995 as part of the national 500 soils project (Hill *et al*., 2003) and concluded in 2000 after which time no monitoring on soils was conducted again until 2008. Five land uses were originally identified including horticulture, dairy, drystock, plantation forest and indigenous forest. Soils are sampled on an annual rotational basis, thus each land use is sampled every five years. Since 2008 the following land uses have been sampled and reported on: horticulture (Sparling, 2009b, Curran-

Cournane *et al*., 2014), dairy (Stevenson, 2010), drystock (Fraser and Stevenson, 2011) plantation and indigenous forest (Curran-Cournane, 2013).

In 2014 soil samples were collected across 20 sites originally identified as dairy sites pre-2000 (i.e. <2000), and five newly selected dairy sites, here-after collectively referred to as 'dairy and converted-dairy sites' unless otherwise stated. Apart from the newly selected sites, soil quality sampling in 2014 represents the third sampling period for dairy and converted-dairy sites, contributing to an ever increasingly valuable dataset. The soil quality of dairy farming pastures has been an ongoing concern in the Auckland region. Sparling (2009a) reported that only 19% of dairy soils in Auckland met guidelines for satisfactory soils for samples collected from 1996- 2000.

Soils can take thousands of years to develop, and for all practical purposes, it is a non-renewable resource that must be well managed. Production is directly affected by soil health, land management practices, and the biological, physical and chemical composition of soils. The objectives of this study are to:

- Repeat sampling for the dairy sites originally identified <2000 and select new sampling sites to further increase the broad geographic coverage of representative soil types and dairy land use in the Auckland region
- Identify which of the seven key soil quality indicators [soil pH, organic carbon (OC), total nitrogen (TN), anaerobic mineralisable nitrogen (AMN), Olsen P, bulk density (BD), and macroporosity] are of most concern and calculate the proportion of sites meeting soil quality guidelines
- Determine concentrations of trace element for all sites
- Report soil quality monitoring findings for 2014 sampled sites and determine changes in soil quality for dairy and converted-dairy sites across the three sampling periods (<2000, 2009 and 2014)
- Provide results to landowners, for educational and feedback purposes, and to better build and cement relationships between landowners and the Auckland Council.

2.0 Materials and Methods

2.1 Sample sites and soil sampling

Twenty-five dairy and converted dairy sites were sampled across the Auckland region between 02-23 September 2014 (Table 2, Figure 1). Twenty dairy sites were originally sampled <2000 and repeated in 2009 with only eight sites currently remaining as 'true' dairy farms. In 2014 five new dairy sites were added to ensure a better representation of dairy sites across the region and to cover previously unmonitored soils in the north of the Auckland region. Collectively these 25 sites cover much of rural Auckland (Figure 1), spanning a range of landscapes, soil orders (n=6) and soil series (n=22) (Hewitt 1998) (Table 2).

The soil samples collected from each site were analysed for a suite of seven key soil chemical, biological and physical indicators, including pH, organic carbon (OC), total nitrogen (TN), anerobic mineralisable nitrogen (AMN), Olsen P, bulk density (BD) and macroporosity (MP) at -10kPa (pore sizes >30 µm) (Table 3). Macroporosity -5kPa (pore size >60 µm) was used in previous (<2000) soil sampling to establish soil physical quality and therefore was continued to be measured for this study for trend analysis purposes. The ratio of carbon to nitrogen (C:N), although not one of the seven key soil quality indicators, was also calculated. A low C:N would suggest increased risk of N leaching whereas a high C:N ratio implies reduced soil fertility and poor ecosystem health. A C:N ratio of 7-30 is considered optimal (Sparling *et al* 2003).

A suite of 38 trace elements were also analysed (Appendix 1). Analytes reported in this study includes arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc. Nitrate, ammonium, initial water content, soil temperature, particle density and total porosity were also analysed and are presented in appendices (7.2).

To determine whether soil quality indicators 'met or failed' recommended guideline ranges, all chemical results will be discussed on a gravimetric basis (Table 3) according to the guidelines presented in Sparling *et al*. (2003) and Mackay *et al*. (2013). Target ranges for OC, TN, AMN, Olsen P and BD are based on values reported by Sparling *et al.* (2003) and Mackay *et al.* (2013). Target range for macroporosity (MP) (-10kPa) is based on values reported by Mackay *et al*. (2006). Guidelines for OC and BD are determined for soil orders while the remaining guidelines are specified for land use (Sparling *et al.* 2003)

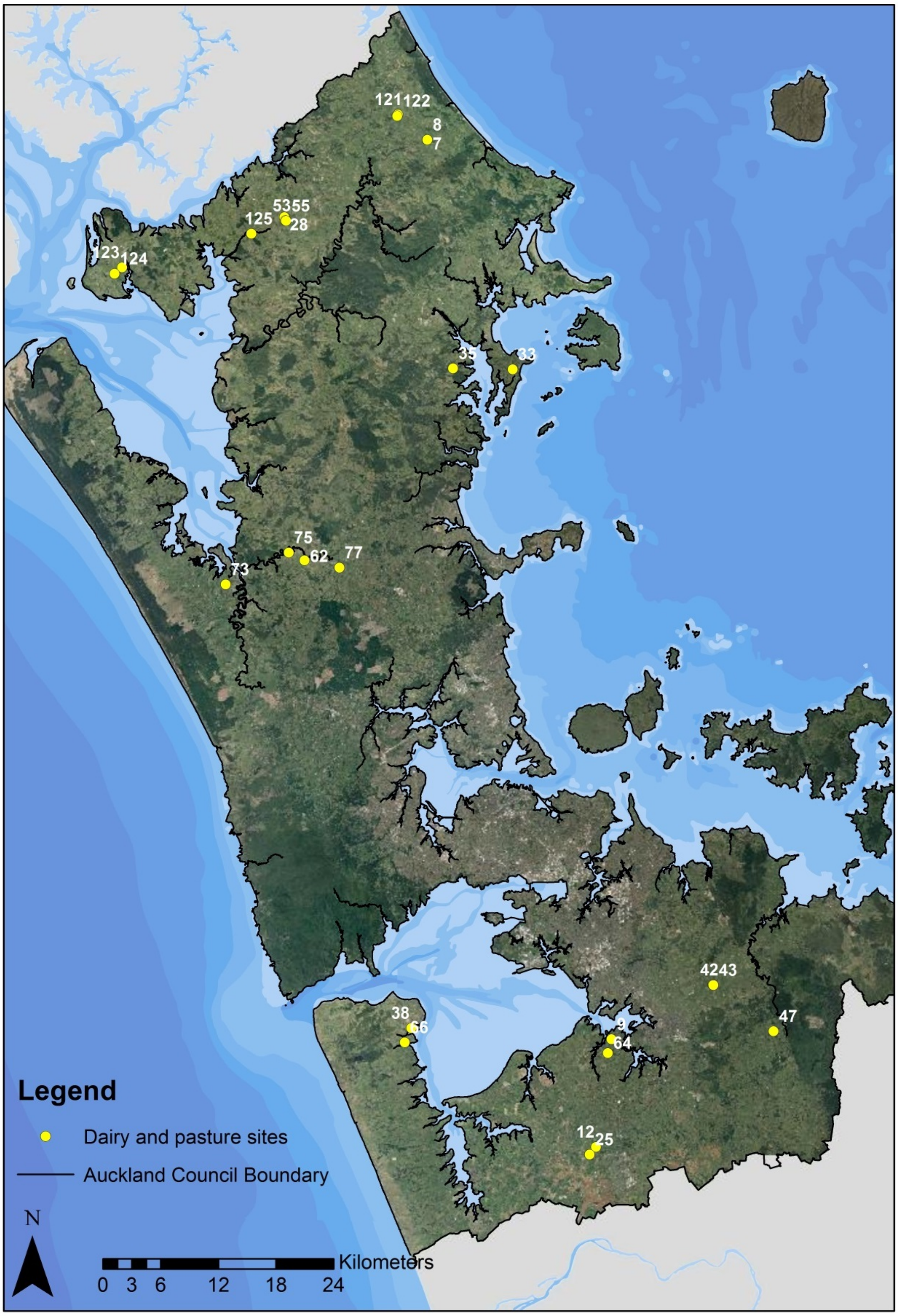

Figure 1: Location and site numbers of the 25 dairy and converted-dairy sites sampled within Auckland in 2014

Table 2: Land use, soil classification and soil series for 25 dairy and converted-dairy sites sampled for soil quality across the Auckland region in 2014

ARC code	Site number	Current land use	Year established	NZSC subgroup	Soil series
ARC96_05	2014-07-03	Dairy	1996	Organic soil	Ruakaka loamy peat
ARC96_06	2014-08-03	Dairy	1996	Organic soil	Ruakaka loamy peat
ARC97_01	2014-09-03	Dairy goat	1997	Typic Orthic Allophanic	Karaka silt loam
ARC97_04	2014-12-03	Lifestyle block	1997	Typic Oxidic Granular	Patumahoe clay loam
ARC98_13	2014-25-03	Drystock	1998	Typic Sandy Brown	Red Hill sand
ARC98_16	2014-28-03	Dairy	1998	Perch-gley Albic Ultic	Waikare clay
ARC98_21	2014-33-03	Drystock	1998	Typic Yellow Ultic	Warkworth clay loam
ARC98_23	2014-35-03	Drystock	1998	Typic Yellow Ultic	Whangaripo clay loam
ARC99_01	2014-38-03	Dairy	1999	Typic Orthic Allophanic	Matekawau clay loam
ARC99_05	2014-42-03	Horse stud	1999	Mellow Humic Organic	Ardmore peaty loam
ARC99_06	2014-43-03	Horse stud	1999	Mellow Humic Organic	Ardmore loamy peat
ARC99_10	2014-47-03	Drystock	1999	Typic Orthic Granular	Ararimu clay loam
ARC99_16	2014-53-03	Drystock	1999	Mottled Yellow Ultic	Aponga clay
ARC99_18	2014-55-03	Drystock	1999	Mottled Yellow Ultic	Aponga clay
ARC99_25	2014-62-03	Drystock	1999	Typic Orthic Allophanic	Otao silt loam
ARC00_02	2014-64-03	Dairy	2000	Typic Orthic Allophanic	Karaka silt loam
ARC00_04	2014-66-03	Lifestyle block	2000	Typic Orthic Allophanic	Matakawau sandy loam
ARC00_11	2014-73-03	Dairy	2000	Typic Orthic Gley	Kaipara clay
ARC00_13	2014-75-03	Dairy	2000	Typic Orthic Granular	Waitemata complex
ARC00_15	2014-77-03	Lifestyle block	2000	Typic Orthic Gley	Waitemata complex
ARC14_01	2014-121-01	Dairy	2014	Acidic Orthic Gley[1]	Kara Sandy Clay
ARC14_02	2014-122-01	Dairy	2014	Acidic Orthic Gley[1]	Kara Sandy Loam
ARC14_03	2014-123-01	Dairy	2014	Typic Sandy Ultic	Tangitiki Sandy Clay
ARC14_04	2014-124-01	Dairy	2014	Typc Orthic Gley	Tawharanui Sandy Clay
ARC14_05	2014-125-01	Dairy	2014	Typic Yellow Ultic	Whareora clay loam and Waipuna clay

[1] or Typic Perch-gley Podzol

Table 3: Provisional target ranges for soil quality under pastoral farming

Soil order	pH[1]	OC[1] %	TN[1] %	Olsen P[2] mg/kg	AMN[1] mg/kg	Bulk[1] density g/cm^{-3}	MP[3] -10 kPa	C:N[1]
Allophanic	5.5-6.5	4+	0.35-0.7	20-50	60+	0.6 –1.2	10-30	7-30
Brown	5.5 - 6.5	3.5+	0.35-0.7	20-50	60+	0.6 - 1.3	10-30	7-30
Gley	5.5 - 6.5	3.5+	0.35-0.7	20-50	60+	0.6 - 1.3	10-30	7-30
Granular	5.5 - 6.5	3.5+	0.35-0.7	20-50	60+	0.6 - 1.3	10-30	7-30
Organic	5 - 6.5	n/a	0.35-0.7	35-60	60+	0.3 - 0.7	10-30	7-30
Ultic	5.5 - 6.5	3.5+	0.35-0.7	20-50	60+	0.6 - 1.3	10-30	7-30

[1] Adapted from Sparling *et al*. (2003); [2] Mackay *et al* .(2013): [3] Beare *et al*. (2007) and Mackay *et al*. (2006)

The soil sampling methodology was comparable to previous years (Curran-Cournane, 2013, Curran-Cournane, 2015). Soil samples were collected using a 2.5 cm diameter and 10 cm long corer, every 2 m along a 50 m transect. The 25 individual samples were bulked in the field. This process was repeated twice, for soil chemical and trace element analysis. Three stainless steel (10 cm in diameter and 7.5 cm deep) rings were pressed into the soil at the 15 m intervals along the 50 m transect to obtain three intact soil cores for bulk density and MP analysis.

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 (<2 mm) for Olsen P analyses (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 incubation method from field moist conditions (Keeney and Bremner, 1966). All the above analyses were carried out at Landcare Research, Palmerston North.

For the soil physical analysis, the field collected soil cores were subsampled using a smaller steel ring (5.5 cm diameter and 3 cm depth). The subsampling of the larger ring is to correct for any sampling error or bias between field staff and to ensure the measurements of a fully intact soil core. The smaller cores were saturated and equilibrated at both -5 and -10 kPa on a ceramic tension plate to determine macroporosities. Dry bulk densities and total porosities were calculated from oven (105 ^{o}C) dry weights. All the above were carried out at Landcare Research, Hamilton.

Concentrations of trace element were measured at Watercare Laboratory using air dried (60^{o}C) and milled soil samples. 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).

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 Analysis of Variance (ANOVA) to determine changes in soil quality attributes for resampled sites. Blocking was used when comparing between the three sampling periods (<2000, 2009 and 2014) and the site number was used as the blocking factor.

Organic carbon, TN AMN and Olsen P are expressed on a gravimetric basis as well as volumetrically where specified using bulk density data. All statistical analyses were carried our using the statistical package Genstat 14 (Genstat, 2014) and graphics using Sigmaplot (SigmaPlot, 2014).

3.0 Results and Discussion

3.1 Soil quality 2014

Twenty-five sites across the Auckland region, spanning six soil orders (Allophanic, Brown, Gley, Granular, Organic and Ultic) as per the New Zealand Soil Classification (Hewitt, 1998), were sampled in 2014.
The sites were divided into the following land use categories

- Dairy n=13 (cattle =12, goat =1; 8 original and 5 new)
- Dairy - Drystock conversion n=7
- Dairy - Lifestyle conversion n=3
- Dairy - Horse stud conversion n=2

Of the 25 sites sampled, zero sites met all the recommended indicator guidelines indicators for soil quality with 20%, 40%, 32% and 8% failing to meet one, two, three and four indicators, respectively (Figure 2A). Of the 13 'true' dairy sites, six failed to meet two indicators, two sites failed to meet three indicators and one site failed on four indicators. Across the entire 25 sites sampled, macroporosity had the largest number of indicator failures, with 92% of sites falling well below the recommended macroporosity guideline (Figure 2B). Olsen P was the indicator of second most concern. The majority of sites contained concentrations of Olsen P above recommended levels (Table 4). In colour print copies, soil parameter values in red indicate where levels exceeded upper limits and blue values indicate where levels fell below recommended guidelines. Organic carbon, AMN, bulk density and pH were the indicators of least concern, with all sites meeting OC and AMN targets, and 23 sites meeting both BD and pH (Table 4 and Fig 2b).

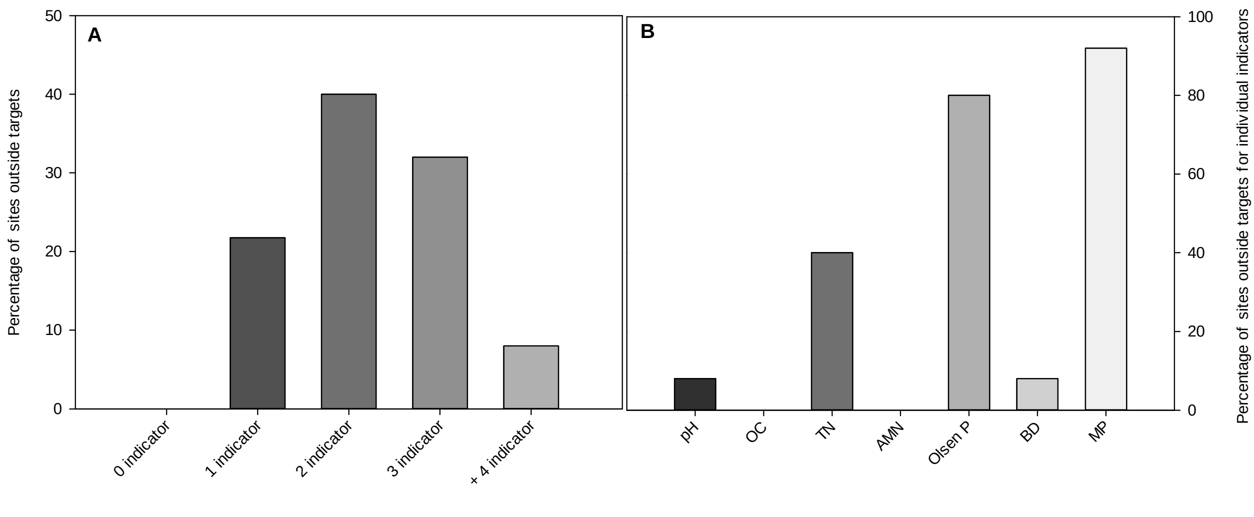

Figure 2 (A) Percentage of sites outside target ranges and **(B)** percentage of sites outside targets ranges for specific key soil indicators.

Table 4: Soil chemical, physical and biological characteristics for 2014 dairy and converted-dairy sites sampled within the Auckland region. Results for macroposity (-5 kPa) and C:N ratio are presented in the shaded section but excluded from the determination of meeting the soil quality guideline procedure. The red and blue bold numbers are values that are above recommended and below recommended guidelines, respectively.

Site no	NZSC	pH	OC %	TN %	AMN mg/kg	Olsen P mg/kg	Bulk density g/cm³	Macro -10 kPa	Macro - 5 kPa	C:N
7	Organic	**6.53**	13.7	**1.12**	244	**98**	0.64	**3.5**	1.8	12
8	Organic	6.19	12.2	**0.91**	265	**76**	0.66	**7.8**	4.5	13
9	Allophanic	6.39	4.6	0.37	71	**9**	0.99	**8.7**	6.6	12
12	Granular	5.84	5.9	0.54	128	31	1.15	**1.0**	7.3	11
25	Brown	6.37	7.2	0.69	155	**79**	1.00	**1.9**	1.9	10
28	Ultic	5.88	6.7	0.64	215	**63**	0.86	10.0	5.5	11
33	Ultic	5.83	6.7	0.63	156	**50**	1.03	**4.3**	4.2	11
35	Ultic	5.55	5.4	0.45	139	**69**	0.79	**6.7**	2.3	12
38	Allophanic	5.78	4.7	0.35	86	39	0.92	**7.2**	<1	13
42	Organic	6.2	11.8	**1.02**	187	44	0.69	**6.3**	1.5	12
43	Organic	5.85	7.5	0.59	193	**80**	0.77	**7.5**	7.7	13
47	Granular	6.63	8.4	**0.82**	326	**56**	0.90	**6.4**	5.8	10
53	Ultic	6.35	6.7	0.62	138	**61**	1.12	**8.3**	3.2	11
55	Ultic	**5.45**	4.0	0.43	160	**55**	1.07	**5.1**	3.5	9
62	Allophanic	6.25	5.8	0.57	198	**79**	0.74	**7.6**	3.6	10
64	Allophanic	6	6.7	0.53	139	37	1.04	**3.1**	<1	13
66	Allophanic	5.79	7.8	**0.72**	212	**58**	0.98	**8.5**	8.2	11
73	Gley	6.46	10.7	**0.94**	344	**55**	**0.53**	**6.6**	8.0	11
75	Granular	6.45	10.3	**0.93**	362	30	**0.58**	**5.7**	2.3	11
77	Gley	5.97	5.3	0.45	111	39	1.08	**6.2**	4.2	12
121	Gley	5.65	23.8	**1.84**	309	**77**	0.59	**3.3**	2.8	13
122	Gley	5.72	18.4	**1.57**	301	**72**	0.58	**9.7**	3.7	12
123	Ultic	5.9	7.3	0.61	189	**11**	0.99	**9.7**	2.4	12
124	Ultic	5.96	8.4	**0.78**	210	**10**	0.91	11.7	2.0	11
125	Brown	5.84	5.5	0.49	163	**12**	0.93	**8.7**	3.9	11

Macroporosity values (-10 kPa equivalent to pore sizes >30 µm) for pastoral soil is recommended to be between 10% - 30% v/v to ensure both environmental health and pastoral production (Beare *et al.* 2007 and Mackay *et al*. 2006). Mean macroporosity for sites sampled in 2014 was 6.6%, with only two sites meeting the target of 10% v/v. Macroporosity is a measure of large pore spaces and therefore is a useful indicator of soil compaction. Soil compaction is a recurring concern across rural Auckland particularly for grazed pasture systems (Curran Cournane *et al.*, 2013). Compacted soils are likely to have reduced pasture density (Drewry and Paton, 2000) and contribute to the exposure of bare soil. This increases the risk of surface and contaminant runoff, in turn leading to the potential sedimentation and eutrophication of waterways (McDowell et al., 2004, Curran-Cournane et al., 2011).

Macroporosity and **bulk density** are both considered to be measures of soil compaction (Sparling *et al*., 2008). However 92% of the sites sampled had bulk densities within the recommended guidelines, thus to look solely at bulk density, compaction would be assumed negligible. Bulk density is generally considered a less sensitive indicator of soil compaction (Cattle and Southorn, 2010) and its value is greatly affected by intrinsic soil mineralogy and carbon content.

Soil physical quality (i.e. macroporosity and bulk density) is generally better in summer than in winter, with pastoral soils displaying a strong annual cycle of compaction and recovery (Curran-Cournane et al., 2011, Drewry, 2006). Soil samples were collected in September and are likely to represent the worst case scenario for soil physical quality as soil moisture has reached or is likely close to field capacity. The hoof action of dairy cows and machinery on soils at field or close to field capacity is known to cause soil compaction or pugging damage (Curran-Cournane et al., 2011)

Olsen P was the indicator of second most concern with 60% of sites exceeding the 50 mg/kg upper limit. Seven sites exceeded the upper limit by more than 40%. The sites exceeding concentrations of Olsen P were a mix of dairy, dairy-drystock conversion and horse stud sites. Olsen P is both a sensitive and useful indicator of soil nutrient status, with phosphorus (P) being an essential nutrient for plants and animals. Many soils in New Zealand have low plant available P, and P in the form of fertiliser needs to be added for agronomic purposes. However, excessive levels can increase the risk of loss to waterways, contributing to eutrophication (McDowell, 2006, Curran-Cournane et al., 2011).

Forty-percent of all soil sites sampled had concentrations of **total nitrogen** in excess of recommended levels, of which 7 were 'true' dairy sites. The maximum recommended level of nitrogen (N) in the soil is 0.7%, with two sites exceeding the maximum recommended levels by 50%. Ninety percent of the N in top soil is in organic form (Mclaren and Cameron, 1996) and must be cycled to inorganic forms of nitrate and ammonia before it can be taken up by plants. Nitrogen is an important major nutrient for plants and animals and organic soil N is an important indicator of soil fertility. Very high nitrogen levels in soil are a concern for the environment because of the potential to leach and cause eutrophication (de Klein and Ledgard, 2005). Additionally the increased nitrate level can lead to increased gaseous N loss from soils with imperfect drainage or saturation conditions, contributing to atmospheric greenhouse gases.

Creation of nitrate in the soil is dependent on microbial activity and the ratio of C:N (total carbon content of the soil divided by the content of total nitrogen). Concentrations of AMN (an indicator of microbial biomass) at all sites were high, and the C:N ratio of soils were low (below 13), indicating that organic matter has the potential to be easily mineralised releasing plant available nitrogen, nitrate and ammonia. With the majority of soils at field capacity (as indicated by volumetric water content-10 kPa Appendix 2), there is potential for N leaching at all sampled sites.

3.2 Concentrations of trace elements

Mean concentrations of all the trace elements analysed across the 25 sampled sites are presented in Appendix 1. Specifically mean concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn are illustrated in Figure 3. Trace elements are generally negligible chemical constituents of soil, however some are essential as micronutrients for plants (McLaren and Cameron, 1996). Trace elements are mainly derived from soil parent materials, however deficiencies have been a longstanding issue in New Zealand agriculture with deficiencies being remediated through widespread farm and animal management practices, including top dressing and nutrient supplements. Additionally the use of fertilisers is known to contribute to heavy metal contamination of some trace elements in New Zealand soils. Longhurst *et al.* (2004) reported increased Cd and Cu levels in New Zealand soil which was attributed to phosphorous and copper sulphate fertilisers.

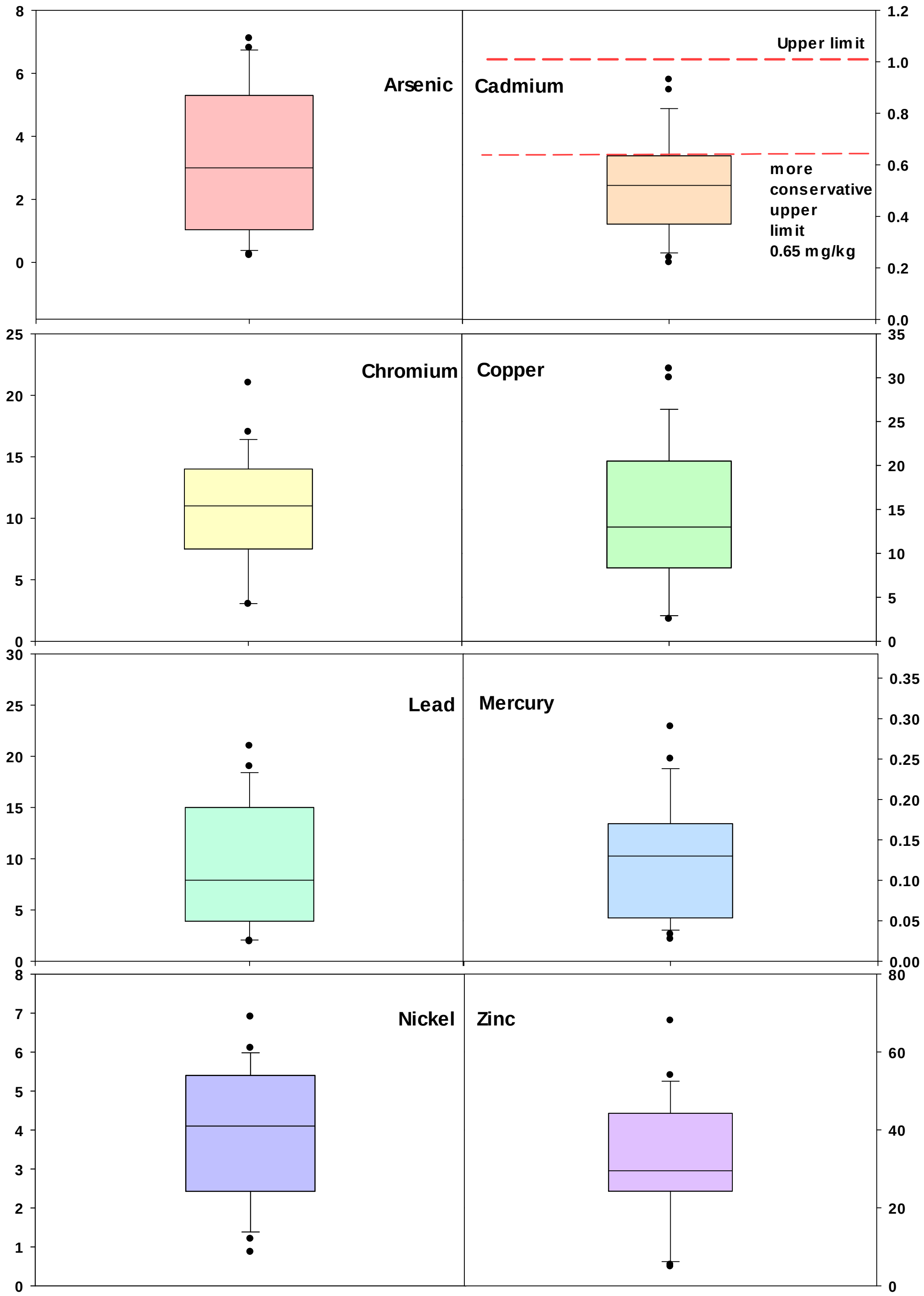

Figure 3: Concentrations (mg/kg on the y-axis) of selected trace elements for 25 dairy and converted-dairy soil quality monitoring sites. The boxes represent the inter-quartile range (5th and 95th percentile) and the whiskers show the range of values that fall within the inner fences. Outliers are illustrated 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 guideline ranges.

Two soil samples returned concentrations of **Cd** that approached the upper limit of Tier 1 (i.e. >0.6-1.0 mg/kg) in the Tiered Fertiliser Management System (TFMS) that is reported in the National Cadmium Management Strategy (MAF, 2011). However, the two sites were located on organic soils with bulk densities of 0.59 g/cm^3 and 0.58 g/cm^3. Therefore, when converted to a volumetric basis, levels of cadmium would be of a lower risk, highlighting the importance of considering the inherent physical characteristics of soil types. However, upper limits of trace elements have not been established on a volumetric basis. Four additional sites exceeded the conservative Cd values of 0.65 mg/kg (ARC, 2001).

Accumulation of cadmium in New Zealand agricultural soils is a known long-term management issue (Cavanagh, 2014). The data for assessing trends in cadmium on dairy and converted dairy soils is not presently available because not all sites sampled pre 2000 were measured for the analyte and not all soil samples were physically archived for repeat analyses. However, mean concentrations of cadmium across a variety of rural land uses in Auckland were not reported to be significantly different pre (0.38mg/kg) and post (0.40mg/kg) 2000 sampling periods (Curran-Cournane, 2015). As repeat soil sampling continues into the future these trends in concentrations of trace elements can be carried out for specific rural land uses.

3.3 Changes in soil quality over time

Soil chemical, physical and biological quality across the 20 repeat sites (i.e. those sites the originally identified as dairy sites <2000) were compared over time across the three sampling periods (<2000, 2009, and 2014). While macroporosity of -10 kPa is recognised as the measurement for soil quality (Sparling *et al*,2009), prior to year 2000 -10 kPa measurements were not made, thus -5 kPa is used for trend analysis purposes. Significant differences were observed for macroporosity (-5 kPa), bulk density and Olsen P for sampling period (Figure 4). Significant differences were also observed for all variables on a volumetric basis (TN vol, OC vol, Olsen P vol, AMN vol), a product of significantly different bulk density (Table 5A).

Macroporosity values declined between <2000 and 2009 with little change between 2009 and 2014 (Figure 4). Mean concentrations of **Olsen P** increased significantly in 2009 with 2014 concentrations falling just below the upper limit. Significant differences in **bulk density** were also observed for sampling period but mean values were all within recommended guideline range.

Many of the original 20 sites sampled <2000 have undergone a degree of land use change. The ANOVA was therefore repeated excluding the 12 converted-dairy sites (Table 5B) to determine the changes for the 'true' repeat dairy sites (n=8). Significant differences were observed for BD, MP (-5 kPa) and for all variables on a volumetric basis except for AMN. Significant differences in Olsen P were no longer indicating that variations in Olsen P were potentially affected by changes in land use. Land use change from dairy to rural lifestyle living or drystock farming activity are generally considered less intensive, as stocking rates tend to be lower and application of fertilisers including phosphorous are reduced. However, mean macroporosity has shown little improvement for sampling periods 2009 and 2014 highlighting the continual issue of soil compaction during wetter months, regardless of pastoral land use activity.

Continued monitoring of all identified dairy and converted-dairy sites will provide a better picture of changes in soil quality over time. It will also allow us to determine if soil quality improves across the converted, and generally less intensive, land use sites and whether the 'true' dairy pastures show signs of degradation or improving quality.

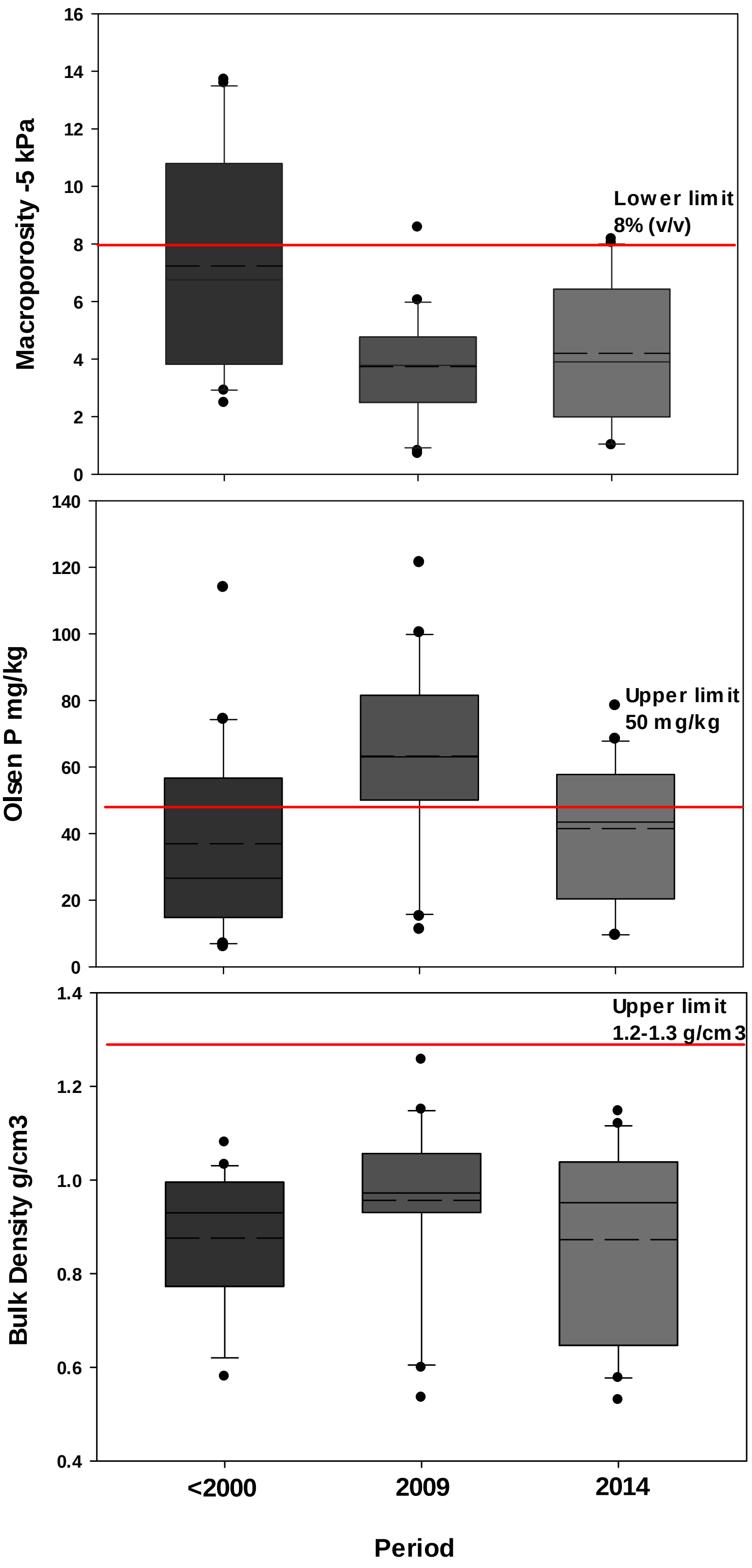

Figure 4: Significant differences in mean macroporosity (-5kPa), Olsen P and bulk density for sampling periods <2000, 2009 and 2014 for the 20 repeat soil sites. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within the 10th and 90th percentile. Outliers are illustrated with black circles. The mean lines are shown by the solid line through the boxes.

Table 5: Changes in soil quality values for the three sampling periods for **A)** all 2014 repeat sampled sites and **B)** only sites located on 'true' dairy soils in 2014. NS denotes not significant.

Period	OC%	TC vol[1]	TN%	TN vol[1]	Olsen P	Olsen P vol[2]	pH	AMN	AMN vol[2]	BD[3]	MP -5kPa[4]
A) All repeat sites (n=20)											
<2000	9.42	76	0.76	6.3	42	37	6.08	195	165	0.88	7
2009	8.77	77	0.76	6.8	68	63	6.09	217	192	0.96	4
2014	8.88	70	0.77	6.2	50	42	6.04	203	163	0.87	4
P-value	ns	*0.022*	ns	*0.008*	*0.002*	*<.001*	ns	ns	*0.007*	*0.014*	*<.001*
SED	0.41	2.6	0.035	0.2	7	6.1	0.083	17.5	9.7	0.031	0.8
LSD	0.829	5.2	0.071	0.4	14.1	12.4	0.168	35.4	19.6	0.062	1.6
B) 'True' dairy pasture sites only (n=8)											
<2000	8.57	73	0.72	6.2	48	43	6.18	202	177	0.89	7
2009	7.86	80	0.68	7	72	73	6.17	178	182	1.03	3
2014	7.96	69	0.69	6.1	59	51	6.17	171	150	0.93	4
P-value	ns	*0.011*	ns	*0.026*	ns	*0.003*	ns	ns	ns	*0.038*	*0.032*
SED	0.555	3.1	0.055	0.31	9.1	7.2	0.126	17.3	13.1	0.5	1.4
LSD	1.191	6.6	0.118	0.66	19.5	15.5	0.27	37	28.1	0.107	2.9

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

4.0 Conclusion

Twenty-five dairy and converted-dairy sites were sampled across the Auckland region in September 2014, to determine physical, chemical and biological soil quality. Twenty dairy sites were originally sampled <2000 and repeated in 2009, making 2014 sampling part of an increasingly valuable dataset for trend analysis. Only eight of the originally described 20 dairy sites have remained in dairying operations. Five new dairy sites were added in 2014 allowing sites to be broken down into the following categories: dairy (n=13), dairy to drystock farming conversion (n=7), dairy to rural lifestyle living conversion (n=3), dairy to horse stud conversion (n=2).

No sites met the guideline ranges for all indicators with 20% (n=5), 40% (n=10), 32% (n=8) and 8% (n=2) failing to meet one, two, three and four indicators, respectively. The indicator of most concern was macroporosity (-10 kPa) with 23 sites falling below the recommended guidelines for macroporosity. Macroporosity (-10kPa) is a measure of large pore spaces in the soil and is thus an indicator of soil compaction.

Olsen P and total nitrogen levels were also of concern with 60% and 40% of sites exceeding the upper limit, respectively. Excessive levels of nitrogen and phosphorous in soil can be lost to waterways through leaching or surface runoff contributing to eutrophication. Compact soils exacerbate the risk of pollutant loss to surface runoff.

Trace element analysis revealed Cd was the only element of concern. Cadmium levels at two sites neared exceedance for environmental soil health levels, however both soils were organic with very low bulk densities, and when adjusted for bulk density, Cd was of lesser concern.

Comparisons of soil quality between <2000, 2009 and 2014 sampling periods for the 20 repeat sites revealed significant differences for macroporosity (-5 kPa), BD and Olsen P. Of most concern was continuing issues of soil compaction regardless of pastoral land use activity.

Continuous land use change across the Auckland region from rural to urban and traditional farming to rural lifestyle living means on-going changes to our soil ecosystem. It is therefore recommended that soil quality monitoring is undertaken on dairy and converted-dairy sites every five years to establish a longer spanning record of soil quality data for these sites to unearth long term trends in soil quality.

5.0 Acknowledgments

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7.0 Appendix 1: Trace elements for 2014 dairy soils

Site#	Element													
	Aluminium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Boron	Cadmium	Calcium	Cesium	Chromium	Cobalt	Potassium	Rubidium
7	17000	<0.05	0.97	71	0.24	0.071	2.6	0.51	11000	1.7	16	1.9	870	8
8	16000	<0.05	1.1	89	0.34	0.072	1.9	0.72	9100	1.8	17	2.5	460	8
9	37000	0.07	4.9	110	<0.87	0.23	<43	0.52	4200	2.9	14	3.1	870	10
12	45000	0.071	5.4	120	<0.92	0.29	<46	0.35	2900	3	16	4.3	340	5.9
25	17000	<0.05	5.4	31	0.27	0.06	2.2	0.42	2900	0.8	14	5.8	920	8
28	5300	<0.05	0.46	27	0.05	0.035	1.5	0.24	4300	0.59	3	0.39	190	4.2
33	9900	<0.05	2.4	96	<0.91	0.074	<45	0.52	7100	0.2	13	8.8	1200	11
35	8800	<0.05	2	26	<0.88	0.073	<44	0.38	5900	0.2	12	2.4	610	9.7
38	45000	0.15	6.7	82	0.22	0.26	2.2	0.5	3500	2	21	2.9	460	4
42	28000	0.073	2.6	47	<0.88	0.11	<44	0.89	6700	1.5	11	0.89	730	6
43	35000	0.076	3	51	<0.91	0.14	<46	0.93	6300	1.9	13	1	460	5.9
47	27000	0.051	3.1	47	0.1	0.21	2	0.77	3500	1.7	8	1.3	250	3.3
53	9200	<0.05	2.6	67	0.089	0.12	3.9	0.56	12000	0.18	7.5	1.6	1000	7.7
55	10000	<0.05	2.5	50	0.096	0.13	3.9	0.59	11000	0.41	7.7	1.3	480	6
62	31000	<0.05	4.4	51	<0.92	0.17	<46	0.36	2600	1.5	7.5	0.85	490	3.7
64	43000	0.075	5.1	120	<0.91	0.24	<46	0.59	6700	2.5	12	2.6	740	6.9
66	44000	0.073	5.7	53	0.21	0.23	2	0.58	2400	1.3	14	2.7	300	2.1
73	14000	<0.05	7.1	47	<0.91	0.059	<45	0.36	5800	0.62	10	3.4	800	16
75	37000	<0.05	5.2	52	<0.92	0.25	<46	0.57	3400	2.1	14	1.3	290	4.2
77	6000	<0.05	0.74	18	<0.91	0.054	<46	0.22	2900	1	3	0.93	180	2.7
121	3100	<0.05	0.26	17	<0.89	0.023	<45	0.38	2000	0.47	3.1	0.39	140	0.94
122	2500	<0.05	0.22	21	<0.88	0.022	<44	0.27	2200	0.36	4.1	0.51	180	0.86
123	17000	<0.05	<1.8	51	<0.91	0.046	<45	0.57	8000	<0.91	6.5	0.99	<1800	4
124	6300	<0.05	6.8	47	<0.92	0.019	<46	0.7	7400	<0.92	11	4.5	<1800	4.3

125	34000	<0.05	3.5	82	<0.88	0.13	<44	0.68	7900	1.1	8.2	3.5	<1800	8.1

Site #	Element										
	Selenium	**Silicon (as Silica)**	**Silver**	**Sodium**	**Strontium**	**Thallium**	**Tin**	**Tungsten**	**Uranium**	**Vanadium**	**Zinc**	**Zirconium**
7	1.1	1900	<0.05	130	46	<0.2	0.29	0.017	1.3	28	45	<4.5
8	1.2	1500	0.056	160	41	<0.2	0.29	0.014	1.6	34	54	<4.5
9	1.1	2200	<0.05	<1700	17	0.2	1.2	0.13	2	74	44	4.6
12	1.5	1600	<0.05	<1800	16	<0.2	1.5	0.12	1.8	85	27	7.5
25	0.42	2900	<0.05	170	21	<0.2	0.48	0.09	1.1	71	43	<4.5
28	0.31	2500	<0.05	45	17	<0.2	0.13	0.012	0.53	6.6	4.9	0.38
33	0.59	1700	<0.05	<1800	35	<0.2	0.31	0.012	0.9	55	68	0.43
35	0.55	1700	<0.05	<1800	26	<0.2	0.36	0.021	0.7	51	26	0.52
38	1.9	2400	<0.05	100	16	<0.2	1.5	0.088	1.9	130	38	6.3
42	2.6	3600	0.069	<1800	27	<0.2	0.65	0.072	2.5	24	49	<4.4
43	2.9	6700	0.095	<1800	24	<0.2	0.81	0.066	2.9	26	48	4.9
47	1	2000	0.062	80	14	<0.2	1.3	0.06	1.6	36	28	<4.4
53	0.95	1900	<0.05	78	46	<0.2	0.32	0.037	0.89	22	28	0.63
55	1.1	1900	<0.05	80	47	<0.2	0.34	0.022	0.93	23	19	0.56
62	1.1	1700	<0.05	<1800	10	<0.2	1	0.086	1.4	54	26	1.4
64	1.7	2100	<0.05	<1800	23	<0.2	1.4	0.16	2	62	43	<4.6
66	1.6	3100	<0.05	120	14	<0.2	1.4	0.17	1.5	81	44	5.3
73	0.45	1300	<0.05	<1800	36	<0.2	0.35	0.014	1.2	27	31	<4.5
75	1.5	2000	<0.05	<1800	12	<0.2	1.5	0.21	2	72	26	2.6
77	0.45	1800	<0.05	<1800	12	<0.2	0.33	0.027	0.51	14	11	0.55
121	0.19	1400	<0.05	<1800	7.5	<0.2	0.11	0.012	0.79	6.8	5.4	0.48
122	0.25	1500	<0.05	<1800	7.6	<0.2	0.13	0.01	0.79	6.2	8.2	0.39
123	<1.8	3300	<4.5	<1800	37	<0.2	<6.8	0.035	1.8	9.7	<68	<4.5
124	<1.8	2900	<4.6	<1800	39	<0.2	<6.9	0.031	1.3	26	<69	<4.6
125	<1.8	4900	<4.4	<1800	41	<0.2	<6.6	0.18	1.9	24	<66	<4.4

8.0 Appendix 2: Soil physics data for 2014 dairy soil samples

Lab number	Site number	Transect	Initial Water Content (%, w/w)	Dry Bulk Density (t/m3)	Particle Density (t/m3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)
HP6168a	7	15 m	129.9	0.58	2.19	73.6	<1	3.2	74.0	70.4
HP6168b	7	30 m	100.6	0.68	2.22	69.2	<1	2.7	68.6	66.5
HP6168c	7	45 m	101.0	0.67	2.19	69.2	1.8	4.5	67.4	64.7
HP6169a	8	15 m	150.5	0.52	2.16	76.0	4.5	10.4	71.5	65.6
HP6169b	8	30 m	132.7	0.57	2.19	74.0	<1	5.1	73.6	68.9
HP6169c	8	45 m	73.9	0.88	2.28	61.2	<1	<1	63.4	60.9
HP6180a	9	15 m	39.4	1.11	2.48	55.3	9.0	10.8	46.3	44.5
HP6180b	9	30 m	38.6	1.19	2.49	52.3	4.0	5.6	48.3	46.7
HP6180c	9	45 m	44.6	1.06	2.46	57.1	6.9	8.5	50.2	48.6
HP6181a	12	15 m	48.8	0.95	2.48	61.9	8.2	10.8	53.7	51.1
HP6181b	12	30 m	41.8	1.02	2.50	59.4	8.7	10.7	50.7	48.6
HP6181c	12	45 m	47.2	1.01	2.47	59.2	5.1	7.5	54.1	51.8
HP6176a	25	15 m	48.6	1.06	2.44	56.6	<1	4.0	57.1	52.7
HP6176b	25	30 m	49.4	1.07	2.51	57.4	<1	2.3	58.4	55.1
HP6176c	25	45 m	40.8	1.07	2.48	56.8	1.9	9.0	55.0	47.8
HP6172a	28	15 m	55.4	0.97	2.50	61.0	6.1	9.1	55.0	51.9
HP6172b	28	30 m	51.8	1.01	2.50	59.8	7.4	10.9	52.4	48.9
HP6172c	28	45 m	56.9	1.00	2.50	60.1	2.9	6.0	57.2	54.1
HP6193a	33	15 m	65.8	0.90	2.47	63.7	4.7	7.7	58.9	56.0
HP6193b	33	30 m	120.1	0.64	2.50	74.3	1.1	5.7	73.1	68.5

HP6193c	33	45 m	93.9	0.67	2.54	73.6	6.7	9.4	66.9	64.2
HP6194a	35	15 m	53.7	1.03	2.50	58.9	2.3	4.5	56.6	54.4
HP6194b	35	30 m	47.0	1.11	2.51	55.7	2.2	4.0	53.5	51.7
HP6194c	35	45 m	60.9	0.98	2.44	59.7	<1	0.9	60.6	58.9
HP6177a	38	15 m	41.4	1.20	2.42	50.4	<1	<1	51.4	50.4
HP6177b	38	30 m	49.5	1.10	2.44	54.9	<1	<1	56.2	54.6
HP6177c	38	45 m	43.7	1.14	2.40	52.5	<1	<1	53.9	51.5
HP6179a	39	15 m	35.3	1.03	2.62	60.5	20.0	23.0	40.5	37.5
HP6179b	39	30 m	39.6	1.01	2.63	61.5	18.7	21.7	42.9	39.8
HP6179c	39	45 m	29.6	1.13	2.63	57.0	21.5	24.9	35.5	32.1
HP6184a	42	15 m	104.5	0.61	1.94	68.3	1.4	4.2	66.9	64.1
HP6184b	42	30 m	120.9	0.58	1.92	70.0	<1	1.2	71.5	68.8
HP6184c	42	45 m	118.9	0.57	1.93	70.6	1.5	4.6	69.1	66.0
HP6185a	43	15 m	100.6	0.58	2.10	72.2	9.1	11.0	63.0	61.2
HP6185b	43	30 m	102.2	0.57	2.06	72.1	6.1	7.2	66.0	65.0
HP6185c	43	45 m	96.4	0.60	2.06	70.9	7.9	10.9	63.0	59.9
HP6173a	47	15 m	55.2	0.96	2.38	59.7	2.5	5.5	57.2	54.2
HP6173b	47	30 m	48.1	0.99	2.42	59.2	9.3	11.4	49.9	47.8
HP6173c	47	45 m	51.9	0.98	2.41	59.5	5.7	8.5	53.8	51.0
HP6171a	53	15 m	165.8	0.47	2.25	79.0	3.1	7.6	76.0	71.4
HP6171b	53	30 m	131.1	0.58	2.31	74.8	<1	3.5	74.8	71.2
HP6171c	53	45 m	142.1	0.54	2.32	76.9	3.2	8.8	73.7	68.1
HP6170a	55	15 m	174.1	0.47	2.32	79.8	<1	5.4	79.1	74.4
HP6170b	55	30 m	124.0	0.58	2.36	75.3	3.7	6.4	71.5	68.9
HP6170c	55	45 m	99.8	0.68	2.40	71.6	3.2	5.3	68.3	66.2
HP6190a	56	15 m	65.1	0.85	2.51	66.0	9.5	11.7	56.5	54.4
HP6190b	56	30 m	77.2	0.83	2.52	67.0	2.4	4.2	64.7	62.8
HP6190c	56	45 m	64.7	0.86	2.57	66.4	9.7	11.5	56.8	55.0

HP6187a	62	15 m	53.9	1.06	2.53	58.1	2.4	5.5	55.7	52.6
HP6187b	62	30 m	42.8	1.17	2.53	53.8	4.3	6.6	49.5	47.2
HP6187c	62	45 m	54.4	1.01	2.47	58.9	4.2	6.5	54.8	52.4
HP6182a	64	15 m	67.3	0.95	2.47	61.5	<1	<1	64.4	62.6
HP6182b	64	30 m	60.5	0.99	2.50	60.4	<1	1.9	60.2	58.6
HP6182c	64	45 m	55.0	1.05	2.50	57.9	<1	<1	58.2	57.4
HP6178a	66	15 m	54.2	0.87	2.46	64.6	9.0	12.7	55.5	51.9
HP6178b	66	30 m	53.4	0.92	2.50	63.3	7.4	10.9	56.0	52.4
HP6178c	66	45 m	49.8	0.93	2.47	62.2	8.1	11.4	54.1	50.8
HP6191a	73	15 m	68.2	0.80	2.45	67.4	9.7	11.9	57.6	55.5
HP6191b	73	30 m	57.0	0.94	2.47	62.1	6.4	7.7	55.7	54.5
HP6191c	73	45 m	71.6	0.84	2.49	66.3	8.0	10.3	58.3	56.0
HP6188a	75	15 m	54.1	1.02	2.46	58.6	<1	2.6	58.7	56.1
HP6188b	75	30 m	51.6	1.05	2.47	57.6	2.4	5.1	55.2	52.5
HP6188c	75	45 m	52.3	1.03	2.51	58.9	2.2	5.2	56.8	53.8
HP6189a	77	15 m	63.5	0.93	2.49	62.5	7.5	11.5	55.0	50.9
HP6189b	77	30 m	59.9	1.01	2.50	59.7	1.2	4.8	58.5	55.0
HP6189c	77	45 m	80.5	0.84	2.47	65.9	4.0	9.9	61.8	55.9
HP6201a	121	15 m	84.5	0.79	2.44	67.5	4.2	8.3	63.2	59.1
HP6201b	121	30 m	69.5	0.90	2.46	63.5	1.8	4.6	61.7	58.9
HP6201c	121	45 m	105.4	0.69	2.41	71.3	2.3	7.3	69.0	64.0
HP6202a	122	15 m	53.3	1.07	2.50	57.3	2.1	5.4	55.1	51.9
HP6202b	122	30 m	82.0	0.80	2.38	66.4	5.4	8.6	61.0	57.8
HP6202c	122	45 m	70.9	0.88	2.41	63.5	3.5	7.5	60.0	56.0
HP6203a	123	15 m	132.4	0.58	2.26	74.5	2.7	7.5	71.8	67.0
HP6203b	123	30 m	86.8	0.77	2.38	67.8	1.9	5.3	65.9	62.4
HP6203c	123	45 m	93.8	0.72	2.20	67.2	2.6	6.2	64.7	61.0
HP6204a	124	15 m	87.4	0.77	2.34	67.1	1.1	7.0	66.0	60.1

HP6204b	124	30 m	89.6	0.77	2.37	67.6	<1	5.6	66.7	62.0
HP6204c	124	45 m	89.8	0.77	2.41	68.2	2.9	9.8	65.3	58.4
HP6205a	125	15 m	56.8	0.95	2.46	61.2	5.5	7.6	55.7	53.7
HP6205b	125	30 m	61.7	0.91	2.43	62.5	3.7	6.4	58.8	56.0
HP6205c	125	45 m	70.6	0.84	2.32	63.9	2.5	5.2	61.3	58.7

9.0 Appendix 3: Archived soil chemical physical and biological data for periods <2000 and 2009

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
<2000 sampling period													
1996-07-01	5.93	86.78	11.57	6.53	0.87	13.30	20.00	15.00	206.00	155.00	0.75	3.10	
1996-08-01	6.07	82.09	13.24	6.76	1.09	12.15	33.00	20.46	245.00	152.00	0.62	2.90	
1997-09-01	6.19	67.55	7.11	6.08	0.64	11.11	45.60	43.32	162.11	154.00	0.95	13.58	
1997-12-01	6.91	66.43	6.92	6.24	0.65	10.65	57.80	55.49	266.67	256.00	0.96	8.08	
1998-25-01	5.46	70.62	7.06	6.51	0.65	10.85	15.40	15.40	106.00	106.00	1.00	6.87	
1998-28-01	6.13	71.68	7.63	6.11	0.65	11.73	20.64	19.40	185.11	174.00	0.94	11.83	
1998-31-01	5.85	49.24	5.41	4.65	0.51	10.59	23.19	21.10	153.85	140.00	0.91	12.20	
1998-33-01	6.73	64.54	6.39	5.87	0.58	10.99	112.77	113.90	136.63	138.00	1.01	6.90	
1998-35-01	6.07	50.21	5.29	4.79	0.50	10.48	60.11	57.10	133.68	127.00	0.95	13.70	
1999-38-01	6.33	67.68	7.36	6.12	0.67	11.06	31.96	29.40	134.78	124.00	0.92	3.27	
1999-42-01	5.75	154.44	24.13	10.06	1.57	15.35	66.41	42.50	196.88	126.00	0.64	5.83	
1999-43-01	5.91	138.25	23.84	9.85	1.70	14.04	59.66	34.60	244.83	142.00	0.58	4.33	
1999-47-01	6.12	64.17	6.98	5.43	0.59	11.82	15.98	14.70	165.22	152.00	0.92	6.33	
1999-53-01	6.02	72.85	8.67	5.75	0.68	12.67	16.67	14.00	203.57	171.00	0.84	12.73	
1999-55-01	5.55	66.00	10.65	5.47	0.88	12.07	11.77	7.30	350.00	217.00	0.62	5.60	
1999-62-01	5.68	65.89	6.10	5.80	0.54	11.36	22.04	23.80	56.48	61.00	1.08	2.47	
2000-64-01	6.85	67.80	7.92	6.18	0.72	10.98	86.00	73.62	246.37	210.89	0.86	11.70	
2000-66-01	6.00	69.35	8.09	6.09	0.71	11.39	7.00	6.00	203.38	174.37	0.86	7.63	
2000-73-01	5.90	68.42	6.74	5.52	0.54	12.41	71.00	72.11	239.96	243.71	1.02	3.65	
2000-75-01	6.03	72.06	6.98	5.98	0.58	12.04	72.00	74.30	193.68	199.88	1.03	6.63	
2000-77-01	6.02	56.75	5.77	4.66	0.47	12.18	7.00	6.88	226.31	222.39	0.98	7.47	

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
2009 sampling period													
2009-07-02	6.06	95.98	10.19	7.63	0.81	12.58	61.82	58.21	179.59	169.12	0.94	3.35	3.00
2009-08-02	5.72	100.15	9.80	7.79	0.76	12.85	75.40	77.03	176.14	179.96	1.02	0.70	1.50
2009-09-02	6.54	80.05	7.28	7.14	0.65	11.21	91.22	100.31	185.05	203.49	1.10	5.33	6.90
2009-12-02	6.33	67.50	7.23	6.14	0.66	10.99	129.93	121.36	255.86	238.98	0.93	6.03	8.63
2009-25-02	5.71	52.04	4.53	5.18	0.45	10.04	72.17	83.00	113.44	130.46	1.15	4.37	9.23
2009-28-02	6.28	74.57	7.14	6.48	0.62	11.51	39.61	41.36	153.17	159.96	1.04	3.70	5.83
2009-31-02	6.32	65.51	5.92	5.63	0.51	11.63	110.94	122.85	159.98	177.16	1.11	1.65	2.97
2009-33-02	5.89	60.13	6.30	5.54	0.58	10.85	65.60	62.61	218.68	208.70	0.95	4.90	7.37
2009-35-02	6.16	63.99	6.52	5.91	0.60	10.82	52.15	51.14	180.28	176.79	0.98	3.87	6.37
2009-38-02	6.37	69.89	6.17	6.10	0.54	11.45	44.19	50.02	134.99	152.81	1.13	2.15	3.83
2009-42-02	6	137.68	23.00	10.81	1.81	12.73	86.74	51.93	381.24	228.24	0.60	2.77	6.77
2009-43-02	5.91	119.19	18.08	10.32	1.57	11.55	76.11	50.18	312.67	206.15	0.66	2.00	4.80
2009-47-02	5.85	60.84	5.98	5.65	0.56	10.76	75.16	76.41	204.51	207.92	1.02	0.80	2.80
2009-53-02	6.35	74.32	13.90	6.48	1.21	11.46	118.70	63.47	528.70	282.68	0.53	8.57	10.70
2009-55-02	6.28	73.90	8.17	6.38	0.71	11.57	23.58	21.32	226.09	204.46	0.90	2.80	4.73
2009-62-02	6.14	56.40	4.49	4.91	0.39	11.49	57.94	72.82	106.62	133.99	1.26	2.40	1.97
2009-64-02	6.28	76.03	7.89	7.19	0.75	10.57	95.65	92.21	200.41	193.20	0.96	3.23	5.67
2009-66-02	5.95	79.40	8.54	7.19	0.77	11.05	12.07	11.22	218.33	202.98	0.93	4.35	6.80
2009-73-02	6.25	67.78	7.13	6.27	0.66	10.81	74.53	70.85	195.45	185.81	0.95	4.17	5.80
2009-75-02	5.83	77.08	7.27	7.03	0.66	10.97	89.87	95.32	200.01	212.14	1.06	3.87	6.37
2009-77-02	5.85	58.50	5.87	5.33	0.53	10.98	15.18	15.12	172.46	171.82	1.00	5.47	8.47

10.0 Appendix 4: Site and soil type details for all 25 sites sampled

Site	7
Date	2/09/2014
Land use	Dairy
NZSC	Organic soil
Soil Type	Ruakaka loamy peat
Parent material	Strongly decomposed peat on humic alluvium
Comments: First sampled in 1996. Rye grass clover pasture. Soil was wet. Cows have not grazed prior to the week of sampling.	

Site	8
Date	2/09/2014
Land use	Dairy
NZSC	Organic soil
Soil Type	Ruakaka loamy peat
Parent material	Strongly decomposed peat on humic alluvium
Comments: First sampled in 1996**.** Surface ponding in area of transect. Indication of soil pugging along transect area	

Site	9
Date	12/09/2014
Land use	Dairy Goat
NZSC	Allophanic soil
Soil Type	Karaka silt loam
Parent material	Redeposited volcanic ash
Comments: First sampled in 1997. Very long Rye grass. Farm converted to dairy goats 2013. First year of milking occurred in 2014.	

Site	12
Date	12/09/2014
Land use	Lifestyle block
NZSC	Brown
Soil Type	Patumahoe clay loam
Parent material	Hamilton Ash
Comments: First sampled in 1997. Very short grass. Horses grazing at time of sampling.	

Site	25
Date	11/09/2014
Land use	Drystock
NZSC	Brown
Soil Type	Red Hill sand
Parent material	Sandstone
Comments: First sampled in 1998. Grass was mostly kikuyu with some rye	

Site	28
Date	23/09/2014
Land use	Dairy
NZSC	Ultic
Soil Type	Waikare clay
Parent material	Strongly weathered cretaceous claystone
Comments: First sampled in 1998. Hasn't been grazed in 4 weeks.	

Site	33	
Date	17/09/2014	
Land use	Drystock	
NZSC	Ultic	
Soil Type	Warkworth clay loam	
Parent material	Strongly weathered sandstone	
Comments: First sampled in 1998.		

Site	35	
Date	17/09/2014	
Land use	Drystock	
NZSC	Ultic	
Soil Type	Whangaripo clay loam	
Parent material	Strongly weathered sandstone	
Comments: First sampled in 1998. Site was grazed over the last 24 hours.		

Site	38
Date	11/09/2014
Land use	Dairy
NZSC	Allophanic
Soil Type	Matekawau clay loam
Parent material	Tephra
Comments: First sampled in 1999. Site grazed within the last 48 hours of sampling.	

Site	42
Date	9/09/2014
Land use	Horse Grazing
NZSC	Organic
Soil Type	Ardmore peaty loam
Parent material	Peat
Comments: First sampled in 1999. Paddock grazed at time of sampling. Short pasture with exposure of bare soil.	

Site	43
Date	9/09/2014
Land use	Horse Grazing
NZSC	Organic
Soil Type	Ardmore loamy Peat
Parent material	Peat
Comments: First sampled in 1999. Grass very long >0.3 m	

Site	47
Date	4/09/2014
Land use	Drystock
NZSC	Granular
Soil Type	Ararimu clay loam
Parent material	Sandstone
Comments: First sampled in 1999. Site leased for grazing. Grass very short.	

Site	53
Date	23/09/2014
Land use	Drystock
NZSC	Ultic
Soil Type	Aponga clay
Parent material	Claystone

Comments: First sampled in 1999. End of transect was very wet. Cattle grazing paddock.

Site	55
Date	23/09/2014
Land use	Drystock
NZSC	Allophanic
Soil Type	Otao silt loam
Parent material	Tephra

Comments: First sampled in 1999. Kikuyu grass abundant. Sections of transect were very wet.

Site	62
Date	16/09/2014
Land use	Drystock
NZSC	Ultic
Soil Type	Aponga clay
Parent material	Claystone
Comments: First sampled in 1999. Parts of the paddock were very wet. Recently grazed by calves.	

Site	64
Date	12/09/2014
Land use	Dairy
NZSC	Allophanic
Soil Type	Karaka silt loam
Parent material	Tephra
Comments: First sampled in 2000 Recently re-sown pasture. Recently grazed with signs of pugging. Wet sampling conditions.	

Site	66
Date	11/09/2014
Land use	Lifestyle block
NZSC	Allophanic
Soil Type	Matakawau sandy loam
Parent material	Sandstone/tephra
Comments: First sampled in 2000. Site is predominantly used to graze horses. Patchy grass growth.	

Site	73
Date	19/09/2014
Land use	Dairy
NZSC	Gley
Soil Type	Kaipara clay
Parent material	Alluvium
Comments: First sampled in 2000. Grass long >0.4 m	

Site	75
Date	16/09/2014
Land use	Dairy
NZSC	Granular
Soil Type	Waitemata complex (alluvial member)
Parent material	Old alluvium
Comments: First sampled in 2000. Rye grass and clover mix. Rain on the day of sampling and soil was saturated.	

Site	77
Date	02/09/2014
Land use	Lifestyle block
NZSC	Granular
Soil Type	Waitemata complex
Parent material	Old alluvium
Comments: First sampled in 2000. The soil surface was wet and pugged in some places. Horses have grazed the paddock recently.	

Site	121
Date	2/09/2014
land use	Dairy
NZSC	Gley
Soil Type	Kara Sandy Clay
Parent material	TBC
Comments: This site is new and was selected in 2014 to increase the number of true dairy farm sites. Rye grass clover.	

Site	122
Date	3/09/2014
Land use	Dairy
NZSC	Gley
Soil Type	Kara Sandy loam
Parent material	TBC
Comments: This site is new and was selected in 2014 to increase the number of true dairy farm sites. Rye grass clover. At the time of sampling the soil was saturated with surface ponding.	

Site	123
Date	3/09/2014
Land use	Dairy
NZSC	Ultic
Soil Type	Tangitiki Sandy Clay
Parent material	TBC
Comments: This site is new and was selected in 2014 to increase the number of true dairy farm sites. Rye grass clover. Transect ranged from dry to wet with puddles	

Site	124
Date	3/09/2014
Land use	Dairy
NZSC	Ultic
Soil Type	Tawharanui Sandy Clay
Parent material	TBC
Comments: This site is new and was selected in 2014 to increase the number of true dairy farm sites. Rye grass clover.	

<table>
<tr><td>Site</td><td>125</td><td rowspan="7"></td></tr>
<tr><td>Date</td><td>16/09/2014</td></tr>
<tr><td>Land use</td><td>Dairy</td></tr>
<tr><td>NZSC</td><td>Brown</td></tr>
<tr><td>Soil Type</td><td>Whareora clay loam and Waipuna clay</td></tr>
<tr><td>Parent material</td><td>TBC</td></tr>
<tr><td colspan="2">Comments: This site is new and was selected in 2014 to increase the number of true dairy farm sites. Rye grass clover.</td></tr>
</table>