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Summary

Introduction

Environment Waikato (EW) participated in two national soil quality monitoring projects from 1995–2001. The two projects co-funded from the Ministry for the Environment Sustainable Management Fund (SMF), identified methods and protocols for soil quality monitoring. The projects ceased in June 2001, but EW has continued to sample new sites and resample previously sampled sites each year to determine the extent and direction of changes in soil condition. Soil quality analysis using the same protocols has also been followed by several other Regional Councils.

The EW staff with responsibility for land resources selected 24 sites (nine new sites and 15 previously sampled sites) for sampling. Samples were supplied to Landcare Research for analyses using a standard set of soil chemical, physical and biochemical characteristics as defined under the 500 Soils Project protocols, and interpretation. Data from these samples were added to the EW soil quality database, which now consists of 137 sites. A brief summary of sites sampled this year and interpretation on the whole dataset is presented in this report.

Objectives

- Provide an assessment of the current soil quality status of all soils EW has sampled as related to soil class and land use.
- Provide interpretation of changes in soil characteristics in relation to previous samples from 1996 to 2002.

Methods

- EW land resource staff sampled sites and supplied soil samples to Landcare Research.
- A standard set of seven soil characteristics was used by Landcare Research to assess soil quality of the various soil and land-use combinations.
- Exceptional sites were identified by grouping soils under similar land uses and recording those sites that exceeded an expected range for that land use, and by comparison against expected characteristics for that soil and land use.

Results

- The 24 sites sampled in 2008/09 were tested for seven soil quality characteristics. Data from the new sites were added to the existing data set and data from resampled sites updated, giving a total dataset of 137 sites (126 managed land use sites plus 11 indigenous sites) that EW has sampled from 1996 onwards. Soil Quality, based on land use and soil type, was assessed on the 126 managed land use sites.
- The indicator most frequently outside the target ranges was macroporosity on 53 sites, largely associated with low values (indicating compaction) on approximately half of dairy and drystock sites. Macroporosity was often high (and bulk density low) on plantation forestry sites (10 sites) indicating increased erosion risk.

- Chemical indicators outside of target ranges were dominated by Olsen P on 32 sites and Total N on 20 sites. While the total N was most often above target ranges (primarily on dairy and drystock land uses), Olsen P was sometimes above target ranges (9 of the 31 sites, primarily cropping and horticulture or dairy sites), but was often below target ranges on drystock sites.
- On resampled sites, macroporosity on dairy and drystock sites and cropping and horticulture sites was significantly lower. Mineralisable nitrogen was also higher on dairy and drystock sites. Few other consistent changes (either positive or negative) occurred on dairy or horticultural and cropping sites compared to the previous sampling. It is expected that at least three sampling rounds will be needed before trends become apparent.

Conclusions

- Low macroporosity (air capacity) values on dairy and drystock sites continue to be a concern.
- High fertility (total N and Olsen P) on dairy and some drystock sites indicate increased risk of nutrient transfer to waterways
- Low Olsen P values on some drystock sites indicated potential productivity benefits from increased fertiliser application.
- Although few cropping and horticulture sites are currently below target values for total carbon, past reports have noted this as a major concern, and total C should continue to be monitored closely for this land use.
- Primary concerns are:
  (1) compaction of soils on dairy and drystock sites
  (2) high fertility on dairy sites, which could lead to eutrophication in receiving waters
  (3) Low bulk density/high macroporosity on plantation forestry soils
- Most cases of poor soil quality could be reversed by appropriate management.

Recommendations

- EW should continue to develop policies that protect the environment while allowing an economic return from the land
- EW should continue activities to educate land managers on strategies to protect the environment while achieving an economic return from the land.
- Long-term monitoring is needed to measure the effectiveness of education and policy implementation
- EW should continue with its programme of resampling existing sites to determine the extent and direction of any changes since original sampling. For comparison between sampling dates for a particular land use, a larger number of similar sites (>8) has been beneficial in statistically determining changes in direction of soil quality indicators.
- Resampling after 3–5 years is recommended for sites undergoing rapid change (e.g., recent land-use change). Resampling after 5–10 years is recommended for sites that are stable and under long-term consistent land use and management.
- Repeat sampling on 3–5 occasions will give confidence about change on individual sites. Where equivalent land uses on similar soils can be combined, 1 or 2 further samplings should be adequate to confirm changes under that particular land use.
- The greater the number of samples and the more detailed the information obtained (particularly in reference to land use history) for each site, the more robust the conclusions that can be drawn about soil quality in the region, particularly when differentiating between the effects of land management strategies on improvements in soil quality. When choosing

sites to resample, more statistical power is gained by restricting sampling to specific land uses, so increasing the number of sites for each land use. We have found that a minimum of 8 sites is helpful in discerning changes in most indicators between sampling dates.

1. Introduction

1.1. Background

Environment Waikato (EW) participated in two national soil quality monitoring projects from 1995–2001. The two projects, co-funded from the Ministry for the Environment Sustainable Management Fund (SMF), identified methods and protocols for soil quality monitoring. The projects ceased in June 2001, but EW has continued to sample new sites and resample previously sampled sites each year to determine the extent and direction of changes in soil condition. Soil quality analysis using the same protocols has also been followed by several other Regional Councils.

Soil quality was appraised using the set of seven soil chemical, physical, and biological properties that were initially measured and included the key properties and sampling protocols used by the 500 Soils Project (Sparling et al. 2001a; Hill et al. 2003). The various properties target dynamic aspects of soil health rather than land-use capability, contamination, or erosion. Soil quality assessment was based on the fitness of the soil for its particular use, which depended on the match between the soil capability (based on physical and chemical properties associated with soil type) and its actual use. Differences in soil characteristics since the earlier samplings are used to assess the extent and direction of change.

2. Objectives

- Provide an assessment of the current soil quality status of soils EW has sampled as related to soil class and land use.
- Provide interpretation of changes in soil characteristics in relation to previous samples from 1996 to 2002.

3. Methods

Methodologies have been described in earlier reports (Sparling et al. 1996, 2001a) and only brief details are given here.

3.1. Soil sampling

Soil samples were collected by EW staff and supplied to Landcare Research for analyses. Staff collected the soils using the protocols established in earlier sampling for the 500 Soils Project. The 24 individual samples for soil chemical and biological characteristics were analysed at the Landcare Research laboratory at Palmerston North. Soil physical analyses were completed at the Landcare Research laboratory in Hamilton. Where necessary, samples were stored at 5°C until analysis.

3.2. Soil quality measurements

Seven primary soil properties were measured to assess soil quality (Table 1). Chemical and biological characteristics were assessed by total C content, total N content, potentially mineralisable N, Olsen P, soil pH, and derived measurements such as C/N ratio. Soil physical condition was assessed from the dry bulk density and macroporosity (air capacity, measured at –10 kPa tension). These soil physical measurements also provided measures of the total porosity and particle density.

3.3. Analyses

Biochemical properties

Potentially mineralisable N was estimated by the anaerobic (waterlogged) incubation method; the increase in NH_4^+ concentration was measured after incubation for 7 days at 40°C and extraction in 2M KCl (Keeney & Bremner 1966).

Chemical properties

Total C and N were determined by dry combustion of air-dry, finely ground soils using a Leco 2000 CNS analyser. Olsen P was determined by extracting <2 mm air-dry soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen et al. 1954) and measuring the PO_4^{3-} concentration by the molybdenum blue method. Soil pH was measured in water using glass electrodes and a 1:2.5 soil-to-water ratio (Blakemore et al. 1987).

Physical properties

Macroporosity (air capacity) was determined by drainage on pressure plates at –10 kPa, dry bulk density was measured on a subsampled core dried at 105°C, and macroporosity and total porosity were calculated (Klute 1986). Volumetric water content at –5 kPa was also included as prior to 2003, macroporosity was calculated using water content at –5 kPa (Sparling et al. 2001). To retain consistency between measurements on sites previously sampled, direct comparison of current measurements to previous measurements used the –5 kPa measure of macroporosity. For calculation of percentage of sites meeting macroporosity target values for the entire data set, macroporosity data prior to 2003 was converted to an equivalent –10 kPa macroporosity value by using a regression equation between –5 kPa and –10 kPa macroporosity values from available 500 soils data (n = 110).

3.4. Data presentation

All data were expressed on a weight/volume or volume/volume basis to allow comparison among soils with differing bulk density. Where appropriate, data from the same land-use category or soil type were combined to allow statistical testing.

3.5. Target Ranges

Target ranges were based on Sparling et al (2003) and subsequent modifications by Sparling (e.g. Sparling & Rijske, 2003) with the exception of macroporosity, which was updated from an internal document from SLURI, "**Macroporosity"**, Mackay AD, Simcock R, Sparling GP, Vogeler I, and Francis G. 2005. 19p

Table 1 Analyses used for soil quality assessment

Analysis	Soil Quality Information	Method
Chemical properties		
Total C content	Organic matter status	Dry combustion, CHN Analyser
Total N content	Organic N reserves	Dry combustion, CHN Analyser
pH	Acidity or alkalinity	Glass electrode pH meter, 1:2.5 in water
Olsen P	Plant available phosphate	Bicarbonate extraction, molybdenum blue method
Biological properties		
Potentially mineralisable N	Readily mineralised N reserves	Waterlogged incubation at 40°C for 7 days
Physical properties		
Dry bulk density	Compaction, volumetric conversions	Soil cores
Particle density	Used to calculate porosity and available water	Specific gravity
Total and macroporosity (air capacity)	Soil compaction, root environment, aeration	Pressure plates

4. Results

4.1. Soils and sites

The 24 new sites were tested for seven soil quality characteristics. Summarized site and soil information for sites sampled in 2008/09 is given in Table 2 and chemical and physical data are shown in Tables 3 and 4 respectively. Full site and soil profile descriptions from new sites are provided in the Appendix. Changes in soil characteristics for previously sampled sites are shown in Tables 5–7 (volumetric values for each indicator from the current and previous samplings shown in Appendix). For compilation of the entire EW soil quality data set, current data from resampled sites replaced older data for those sites, and data from new sites added, giving a total dataset of 137 sites. Values for the seven soil quality indicators for the entire data set are shown in the appendix.

Table 2 Site codes, soil types, soil orders and land uses resampled in 2008

Current Site code	Previous Site Code	Soil sub-groups (NZSC[+])	Soil series	Land use
EW08 - 01	New	Typic Orthic Allophanic	Otorohanga	Dry Stock (being converted to dairy)
EW08 - 02	New	Mottled Orthic Brown	Puniu	Dry Stock (being converted to dairy)
EW08 - 03	New	Typic Orthic Allophanic	Te Kuiti	Forestry
EW08 - 04	New	Typic Orthic Allophanic	Te Kuiti	Drystock
EW08 - 05	New	Typic Orthic Allophanic	Tirau	Dairy
EW08 - 06	New	Typic Orthic Allophanic	Tirau	Maize
EW08 - 07	WAI96 - 1	Typic Orthic Allophanic Soil	Kereone series	Dairy
EW08 - 08	WAI96 - 2	Typic Orthic Allophanic Soil	Kereone series	Dairy
EW08 - 09	WAI98 - 16	Acid or Mellow Fibric Organic Soil	Rukahia peat	Indigenous
EW08 - 10	EW02 - 10	Typic Orthic Allophanic Soil	Horotiu	Horticulture (orchard)
EW08 - 11	EW01 - 21	Mottled Orthic Granular Soil	Patumahoe	Indigenous
EW08 - 12	EW01 - 15	Mottled Orthic Granular Soil	Patumahoe	Crop
EW08 - 13	EW01 - 11	Typic Recent Gley Soil	Mercer	Dairy
EW08 - 14	EW01 - 12	Typic Recent Gley Soil	Mercer	Dairy
EW08 - 15	EW01 - 10	Typic Orthic Granular Soil	Patumahoe	Crop
EW08 - 16	EW01 - 9	Typic Orthic Granular Soil	Patumahoe	Crop
EW08 - 17	New	Mottled Orthic Granular Soil	Patumahoe	Drystock
EW08 - 18	New	Typic Orthic Gley Soil	Mercer Silt loam	Indigenous
EW08 - 19	New	Mottled Orthic Brown Soil	Puniu	Drystock (being converted to dairy)
EW08 - 20	WAI00 - 15	Immature Orthic Pumice Soil	Taupo loamy sand	Indigenous
EW08 - 21	EW01 - 17	Typic Orthic Granular Soil	Patumahoe	Dry Stock
EW08 - 22	EW02 - 13	Typic Orthic Granular Soil	Patumahoe	Crop (potato/onions)
EW08 - 23	EW02 - 14	Mottled Orthic Granular Soil	Patumahoe	Crop (potato/onions)
EW08 - 24	EW01 - 18	Typic Orthic Gley Soil	Helvetia	Crop (Maize)

[+] New Zealand Soil Classification

Table 3 Soil chemical characteristics of sites sampled in 2008/09

Code	Land use and NZSC soil order	pH	Total C mg/cm^3	Total N mg/cm^3	C:N ratio	Olsen P µg/cm^3	Mineralisable N µg/cm^3
EW08 - 01	Dry Stock, Allophanic	5.88	76.2	**8.1**	9.4	23	157
EW08 - 02	Dry Stock, Brown	6.35	42.7	4.5	9.6	36	93
EW08 - 03	Forestry, Allophanic	5.59	71.9	6.0	12.0	7	62
EW08 - 04	Dry stock, Allophanic	5.62	88.3	**8.0**	11.0	**11**	134
EW08 - 05	Dairy, Allophanic	6.00	76.9	**7.9**	9.7	29	196
EW08 - 06	Cropping, Allophanic	6.66	57.2	5.8	9.9	51	98
EW08 - 07	Dairy, Allophanic	5.82	60.9	6.0	10.1	67	133
EW08 - 08	Dairy, Allophanic	6.20	71.3	**7.6**	9.4	47	210
EW08 - 09	Indigenous, Organic	4.38	**45.3**	1.1	39.9	**1**	27
EW08 - 10	Horticulture, Allophanic	6.37	60.2	5.6	10.8	25	129
EW08 - 11	Indigenous, Granular	5.66	65.7	4.8	13.8	6	135
EW08 - 12	Cropping, Granular	6.30	43.6	3.6	12.1	52	57
EW08 - 13	Dairy, Gley	5.54	88.4	6.8	12.9	26	140
EW08 - 14	Dairy, Gley	5.64	64.4	5.2	12.4	49	195
EW08 - 15	Cropping, Granular	6.53	**24.4**	2.1	11.4	**210**	**16**
EW08 - 16	Cropping, Granular	5.79	33.5	3.0	11.1	70	24
EW08 - 17	Dry Stock, Granular	5.99	83.1	**7.8**	10.6	42	167
EW08 - 18	Indigenous, Gley	**6.47**	54.6	3.9	14.0	8	93
EW08 - 19	Dry Stock, Brown	5.80	52.7	5.3	10.0	18	135
EW08 - 20	Indigenous, Pumice	5.32	47.1	3.5	13.4	6	96
EW08 - 21	Dry Stock, Granular	5.50	86.0	**7.8**	11.0	**122**	220
EW08 - 22	Cropping, Granular	6.91	37.5	3.1	12.0	98	42
EW08 - 23	Cropping, Granular	6.40	36.8	3.2	11.4	74	35
EW08 - 24	Cropping, Gley	6.23	79.3	6.5	12.2	35	63

* Bold indicates values outside target range (if in colour, blue represents values above target range and orange values below target range

Table 4 Soil physical characteristics of sites sampled in 2008/09

Code	Soil and land use	Bulk density Mg m^3	Particle density Mg/m^3	Total porosity %v/v	Macroporosity @–10 kPa (Air capacity) %v/v	Macroporosity @ –5 kPa %v/v	Moisture content at –10 kPa (%v/v)	Moisture content at –5 kPa (%v/v)
EW08 - 01	Dry Stock, Allophanic	0.72	2.25	68.5	**7.2**	5.8	61.4	64.7
EW08 - 02	Dry Stock, Brown	1.23	2.50	52.4	**2.0**	1.2	50.4	52.0
EW08 - 03	Forestry, Allophanic	0.52	2.22	76.7	28.8	24.3	47.8	52.4
EW08 - 04	Dry stock, Allophanic	0.57	2.18	73.9	14.4	9.9	59.5	63.9
EW08 - 05	Dairy, Allophanic	0.78	2.31	66.3	**6.6**	2.6	59.7	63.7
EW08 - 06	Cropping, Allophanic	0.80	2.36	65.9	12.7	8.3	53.2	57.6
EW08 - 07	Dairy, Allophanic	0.90	2.36	61.9	**8.2**	4.9	53.7	57.0
EW08 - 08	Dairy, Allophanic	0.71	2.28	68.9	10.9	6.2	58.0	62.7
EW08 - 09	Indigenous, Organic	**0.09**	1.50	94.1	**57.1**	50.4	37.0	43.7
EW08 - 10	Horticulture, Allophanic	0.84	2.45	65.5	13.2	9.5	52.2	55.9
EW08 - 11	Indigenous, Granular	0.91	2.56	64.3	15.9	13.2	48.4	51.0
EW08 - 12	Cropping, Granular	1.36	2.70	49.7	**7.5**	5.8	42.2	43.9
EW08 - 13	Dairy, Gley	0.62	2.16	71.6	13.2	10.1	58.4	61.4
EW08 - 14	Dairy, Gley	0.81	2.36	65.5	10.9	8.3	54.6	57.2
EW08 - 15	Cropping, Granular	1.12	2.63	57.3	19.0	17.0	38.3	40.2
EW08 - 16	Cropping, Granular	1.16	2.62	55.5	12.3	10.1	43.2	45.4
EW08 - 17	Dry Stock, Granular	0.98	2.45	60.0	**7.9**	5.3	52.2	54.7
EW08 - 18	Indigenous, Gley	0.96	2.59	63.0	**7.6**	5.9	55.5	57.1
EW08 - 19	Dry Stock, Brown	0.90	2.36	61.8	**8.9**	6.5	52.8	55.3
EW08 - 20	Indigenous, Pumice	**0.42**	2.28	81.7	**31.8**	25.4	49.9	56.3
EW08 - 21	Dry Stock, Granular	1.02	2.46	58.4	**5.3**	4.8	53.1	53.5
EW08 - 22	Cropping, Granular	1.03	2.61	60.6	22.9	22.0	37.7	38.6
EW08 - 23	Cropping, Granular	1.04	2.57	59.7	17.1	14.2	42.6	45.5
EW08 - 24	Cropping, Gley	0.81	2.26	64.1	**7.6**	6.4	56.4	57.7

* Bold indicates values outside target range (if in colour, blue represents values above target range and orange values below target range)

Table 5 Changes in soil quality attribute units of dairy([1])and drystock([2]) soils between 2008/09 and the previous sampling

Code	Year Previously Sampled	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	C/N ratio	Mineralisable N $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Dry bulk density $Mg\ m^3$	Particle density $Mg\ m^3$	Macroporosity (–5 kPa) %v/v
EW08 -7[1]	1996	Allophanic	0.19	15.5	–1.8	0.3	7	24	0.26	0.16	–6.4
EW08 - 08[1]	1996	Allophanic	–0.23	5.5	0.7	–0.1	35	25	0.04	0.01	–5.4
EW08 - 13[1]	2002	Gley	–0.19	23.3	1.7	0.3	33	0	0.04	-0.12	–13.0
EW08 - 14[1]	2002	Gley	–0.11	–5.0	–0.2	-0.4	63	–25	–0.12	0.02	0.3
EW08 - 21[2]	2002	Granular	–0.17	7.7	0.5	0.2	19	-8	0.02	–0.02	-6.6
	Sum		–0.51	15.9	0.9	0.4	158	16	0.25	0.06	–31.1
	SD		0.17	14.6	1.3	0.3	21	22	0.14	0.10	4.7
	Mean		–0.10	3.2	0.2	0.1	32*	3	0.05	0.01	–6.2*

*Indicates difference is significantly different from 0 ($P < 0.05$)
Bold indicates particularly large changes observed between sampling dates

Table 6 Changes in soil quality attribute units of cropping and horticultural soils between 2008/09 and the previous sampling

Code	Year Previously Sampled	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	C/N Ratio	Mineralisable N $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Dry bulk density $Mg\ m^3$	Particle density $Mg\ m^3$	Macroporosity (–5 kPa) %v/v
EW08 - 16	2002	Granular	–0.06	3.0	0.3	–0.1	–9	31	0.20	0.02	–16.4
EW08 - 15	2002	Granular	–0.01	0.6	0.1	–0.1	3	38	0.04	0.00	–5.5
EW08 - 12	2002	Granular	0.16	9.2	0.7	0.5	29	0	0.32	–0.01	–17.2
EW08 - 24	2002	Granular	0.74	10.9	0.6	0.6	–4	2	–0.03	–0.09	–15.0
EW08 - 10	2002	Allophanic	–0.20	–7.7	–0.3	–0.7	14	–18	–0.07	–0.03	–5.7
EW08 - 22	2002	Granular	0.55	–9.2	–0.7	–0.3	–7	-4	0.14	0.11	–1.2
EW08 - 23	2002	Granular	0.05	–3.1	–0.2	-0.3	8	–31	0.08	0.04	–8.5
	Sum		1.23	3.6	0.4	–0.4	33	19	0.68	0.03	–69.4
	SD		0.34	7.8	0.5	0.5	14	25	0.14	0.06	6.3
	Mean		0.18	0.5	0.1	–0.1	5	3	0.10	0.00	–9.9*

*Indicates difference is significantly different from 0 ($P < 0.05$)
Bold indicates particularly large changes observed between sampling dates

Table 7 Changes in soil quality attribute units of indigenous soils between 2008/09 and the previous sampling

Code	Year Previously Sampled	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	C/N Ratio	Mineralisable N µg/ cm^3	Olsen P µg/cm^3	Dry bulk density Mg m^3	Particle density Mg m^3	Macroporosity (Air capacity) %v/v
EW08 - 09	1998	Organic	0.43	–7.5	–0.1	–3.0	2	–2	–0.02	0.02	9.8
EW08 - 20	2000	Pumice	0.24	–5.1	0.2	–2.3	–3	–9	–0.09	0.11	1.2
EW08 - 11	2002	Granular	0.80	–11.5	0.3	–3.6	30	0	0.09	0.08	–10.3
	Sum		1.47	–24.1	0.4	–8.9	30	–11	–0.02	0.21	0.7
	SD		0.28	3.3	0.2	0.7	18	5	0.09	0.04	10.1
	Mean		0.49	–8.0*	0.1	–3.0*	10	–4	–0.01	0.07	0.2

*Indicates difference is significantly different from 0 ($P < 0.05$)

Bold indicates particularly large changes observed between sampling dates

5. Discussion

5.1. Soil quality of sites sampled in 2008/09

Twenty-four sites were sampled in 2008/09 – eight sites on cropping and horticulture soils, five sites on dairy soils, six sites on drystock soils, four sites on indigenous vegetation and one site on plantation forestry. Nine of the 24 sites met all soil quality targets, six sites had one soil quality indicator outside of target ranges, six sites had two indicators outside target ranges and three sites had three or more indicators outside target ranges.

Soil quality characteristics of sites sampled in 2008/09 followed many trends noted in previous reports and land use was the major driver of soil quality characteristics. Macroporosity was often below target values on dairy and drystock sites (EW08-01, EW08-5, EW08-7, EW08-17, EW08-19 and EW08-2 where it was particularly low). Total N was also often above target ranges on dairy and drystock sites (EW08-1, EW08-4, EW08-8, EW08-17, EW08-21). Olsen P values were above target values on two sites – one drystock site (EW08-21) and one cropping and horticulture site (EW08-15) where it was particularly high. Total C was below target ranges on one cropping and horticulture site (EW08-15).

5.2 Overall soil quality

Current data from resampled sites replaced older data for those sites, and data from new sites added, giving a total dataset of 137 sites. Eleven of the 137 sites were under native vegetation and were not included in statistical representations of target value comparisons as target values for native sites are not well defined. Of the 126 sites representing the major productive land uses in the Waikato region (dairy pasture, drystock pasture, cropping and horticulture, and plantation forestry), 38 % of sites met all indicator targets (Table 8).

Figure 1 displays the percentage of sites deemed satisfactory (meeting all soil quality targets) against the percentage of sites “of concern” (not meeting one or more soil quality targets) for each land use. Drystock sites had the lowest “satisfactory” rating (~13%) followed by dairy and plantation forestry sites (~43% satisfactory) and cropping and horticulture had the highest percent of “satisfactory” sites (~51%).

Table 8 Number (and percent) of productive land use sites meeting/failing to meet indicator targets

Land use	Percent of sites meeting target indicators	Percent of sites failing to meet 1 target indicators	Percent of sites failing to meet 2 target indicators	Percent of sites failing to meet 3 target indicators	Percent of sites failing to meet 4 target indicators	Total Number of sites
All productive land uses	48 (38 %)	45 (36 %)	25 (20 %)	8 (6 %)	0 (0 %)	126
Dairy	17 (43 %)	15 (38 %)	6 (15 %)	2 (5 %)	0 (0 %)	40
Drystock	4 (13 %)	15 (50 %)	10 (33 %)	1 (3 %)	0 (0 %)	30
Cropping + Horticulture	18 (51 %)	13 (37 %)	3 (9 %)	1 (3 %)	0 (0 %)	35
Forestry	9 (43 %)	2 (10 %)	6 (29 %)	4 (19 %)	0 (0 %)	21
(Indigenous)						(11)

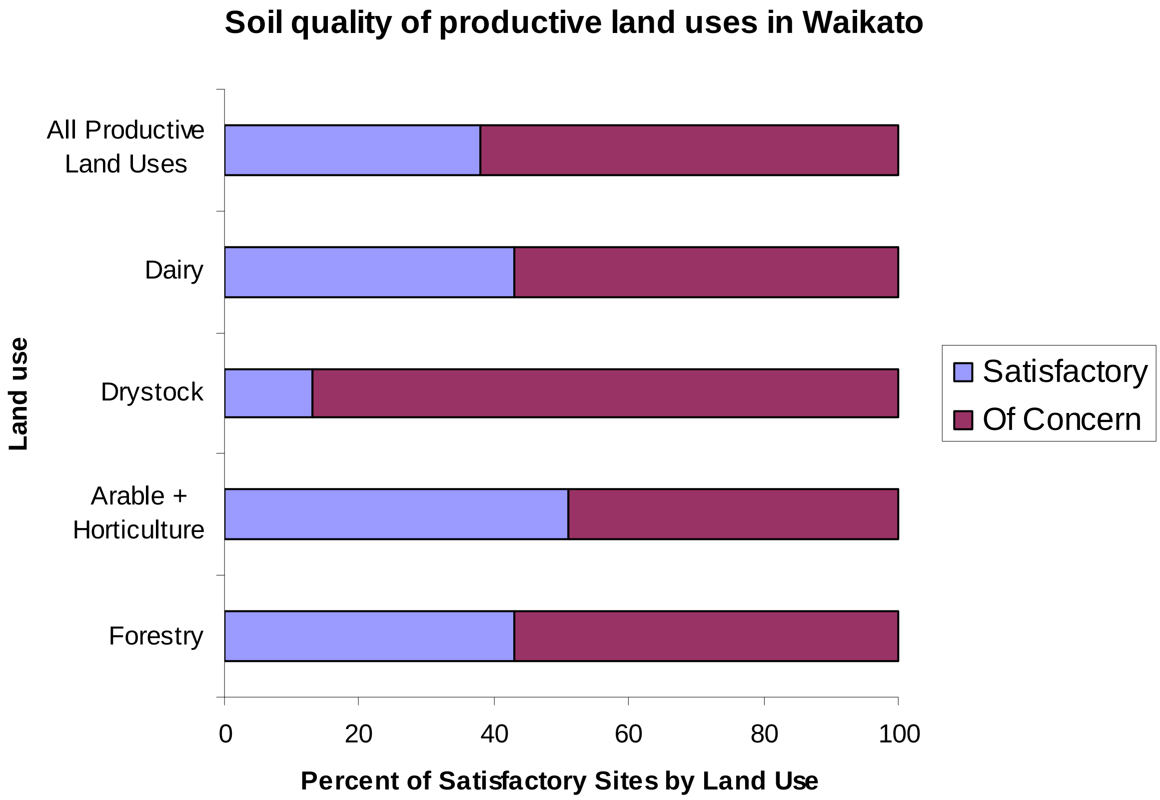

Figure 1. Percent of all productive land uses meeting/not meeting targets for soil quality indicators

In the Waikato, compaction on dairy and drystock sites remains a particular concern (Table 9). Compaction reduces the number of pores available for water and gas movement in soil, reduces aeration, root growth and distribution, and nutrient uptake and may decrease infiltration and increase runoff (Beare et al. 2007). The most sensitive indicator of compaction is macroporosity. Macroporosity below 10% may inhibit pasture growth (Drewery 1999; Singleton 2000), and as indicated in this and several previous reports, there is a continuing trend of decreasing macroporosity values for dairy and drystock sites between sampling periods (Table 5).

High fertility (both N and P) also remains a problem on dairy and some drystock sites. The international competitiveness of the New Zealand pastoral industries is built on a favourable temperate climate that enables stock to graze pastures for most of the year. Wise use of fertiliser in these systems can increase agricultural yields and maintain nutrient stores, but excess fertiliser use can lead to degradation of water and air quality, biodiversity, ecosystem services and human health (UNEP 2007). While New Zealand's pasture farming system is very efficient at generating produce, it has also been identified as a source of nutrients (N and P), which have contributed to water quality degradation in some rivers and lakes (Monaghan et al. 2008).

Drystock sites overall had the lowest satisfactory rating of any managed land use. Approximately half of drystock sites were outside target ranges for macroporosity (almost all below the target range). Additionally approximately one third of sites were outside target values for total N (generally above the target ranges) but another one third of sites were outside target values for Olsen P (generally below the target range). There appears to be a divergence in land-use management of drystock sites as the fertility measurements (total N and Olsen P) indicate some drystock sites are above target values (presumably intensively managed sites), whereas other sites (probably the more marginal sites) are below target values, particularly for Olsen P, indicating production could be improved by additions of P fertiliser.

Table 9 Number (and percent) of sites not meeting specific indicators

Indicator	pH	Total C	Total N	Mineralisable-N	Olsen P	Bulk Density	Macro-porosity
All productive land uses	0 (0 %)	2 (2 %)	20 (16 %)	1 (1 %)	32 (25 %)	11 (9 %)	53 (42 %)
Dairy	0 (0 %)	0 (0 %)	7 (18 %)	2 (5 %)	6 (15 %)	1 (3 %)	19 (48 %)
Drystock	0 (0 %)	0 (0 %)	11 (37 %)	0 (0 %)	10 (33 %)	1 (3 %)	16 (53 %)
Cropping + Horticulture	0 (0 %)	2 (6 %)	2 (6 %)	1 (3 %)	9 (26 %)	0 (0 %)	8 (23 %)
Forestry	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	7 (33 %)	9 (43 %)	10 (48 %)

High P levels remain an issue for cropping and horticulture sites (Table 9, Appendix). Currently only a few sites are below target values for soil C. Past reports have noted a larger percentage of sites with low carbon and suggested that loss of soil carbon may be a more pressing issue than high fertility (Sparling et al. 2003). Soil carbon levels should continue to be monitored closely as soil organic matter is a key attribute that affects many physical, chemical and biological properties that control soil productivity and resistance to degradation (Dick & Grergorich 2004).

Approximately 43 % of Plantation forestry sites failed to meet suggested target ranges. Indicators most often outside target ranges were high macroporosity, low bulk density, and, to a lesser extent, low Olsen P values. Many of the plantation forestry sites monitored in the Waikato were on pumice soils, where low bulk density and high macroporosity (particularly on topography with higher slopes) could make these soils susceptible to erosion. Plantation forestry can be a useful management option for erosion prone land as once trees are established, canopy cover can reduce the volume and peak flows of rain impacting the ground thereby reducing erosion risk; however, careful planning must be taken during forest reestablishment, road cutting, and tree harvest to avoid erosion. The low Olsen P in adult *Pinus radiata* forests is probably less serious than for other land uses (or for young *P. radiata* forests) because Olsen P is generally not highly correlated with *P. radiata* growth rates (e.g., Watt et al. 2008). Olsen P is also more often used to determine P availability in pasture, crops, and horticulture than in forestry. Whether a higher Olsen P would increase growth in adult *P. radiata* is debatable, but from an environmental aspect the low Olsen P should pose minimal risks. Some forestry sites that had been converted from pastoral land use had total N above target ranges. Nitrogen levels are expected to decline over time in these soils as fertiliser inputs cease.

5.3 Soil quality by land area

Enough samples from each major land use were taken to provide a statistically robust measure of that land use. That meant that some land uses were over or under represented when compared to actual amount of that land use in the Region. To more accurately assess soil quality by land area, the data set was converted to the actual area of the different land (Table 10). Drystock and dairy land uses are of greatest concern due to the large area in pastoral farming and the large proportion of land failing to meet target indicators (Fig. 2).

Table 10 Land area meeting/not meeting target indicators

	Land area (ha*1000)	Land area Satisfactory (ha*1000)	Land area of concern (ha*1000)
Dairy	623	267.9	355.1
Drystock	805	104.7	700.4
Crop/Hort	10	5.1	4.9
Forestry	330	141.9	188.1
Total Productive Land Area	1768		

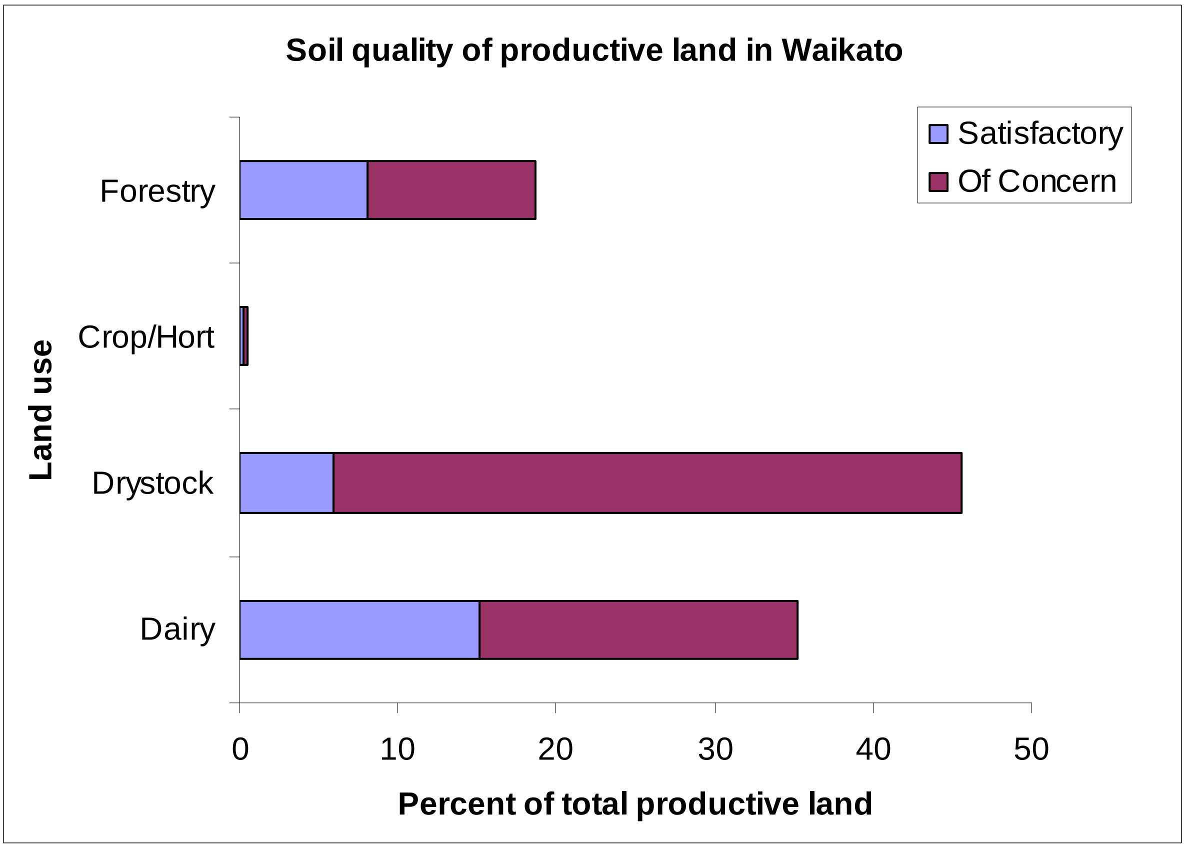

Figure 2. Percent of productive land meeting/not meeting target indicators

Some land uses are over or under represented in the data set in comparison to their proportional land area. The bias in number of sites sampled per land use against the percentage area of that land use in the Waikato region is shown in Table 11. A bias greater than 1.0 indicates that land use is under represented with respect to its land area whereas values less that 1.0 indicate that land use is over represented (Sparling, 2007). There are valid reasons for bias in the data set, cropping and horticulture sites, for instance, may use larger amounts of chemicals and fertilisers and thus be of greater concern. However, the bias should be considered in future soil quality sampling when selecting new sites.

Table 11. Areas of land under managed land uses in the Waikato Region, and representation (bias) in the soil quality data set

Regional land are under different uses (000 ha)			Proportion of different land uses in the data set			
Land use	Total area	Percentage	Land use	Number	Percentage	Bias
Dairy	623	35	Dairy	40	32	1.11
Drystock	805	46	Drystock	30	24	1.91
Crop	10	1	Crop/hort	35	28	0.02
Forestry	330	19	Forestry	21	17	1.12
Total	1768	100	Total	126	100	

5.4 Changes in soil quality since previous sampling

To determine the extent and direction of any change, current data were compared against those from the previous sampling (Sparling et al., 1996, 1999, 2001a; Sparling & Rijkse 2002, 2003). Volumetric data used for comparison between each sampling period are provided in the Appendix. For each indicator the difference between the current and previous sampling is shown for dairy and drystock sites (as only one drystock site was resampled, this site was grouped with the dairy sites), cropping and horticulture, and indigenous land used in Tables 5–7 respectively. Summary statistics in the Tables comprise the accumulated change across all the sites in that land use group (Sum), the standard deviation (SD) as a measure of variability, and the mean to show the average change (in units for that particular indicator) across all sites in the group. Average change for each indicator in managed land uses is shown in Figures 3–4. For dairy and drystock sites and indigenous sites, the date of previous sampling varied from 1996 to 2002. There was no difference in statistical significance of change when values were annualised (e.g., total change divide divided by the number of years since previous sampling) and for simplicity of presentation, the data is presented as total change similar to other land uses.

Data from several resampled sites showed several excessively large differences, particularly in total carbon, suggesting apparent changes (both positive and negative) should be interpreted cautiously until more data are obtained and consistent trends are recorded. The total above- and below-ground inputs into high production pasture and maize system are approximately 10 tonnes C per year (Sparling & Stevenson 2007; Parfitt et al. 2002). Large "one-off" changes in parameters should be viewed cautiously, as they may be caused by various factors including changes in land use or management, recent fertilisation, or significant variation in sampling location or procedure. Precise relocation of sampling sites and an increase in the number of similar land use sites sampled would reduce statistical variation inherent in soil sampling. Accurate site history data (e.g., how recently the site has been fertilised) are often difficult to obtain during field sampling but can be valuable for determining the cause of large changes in soil quality values, and for evaluating the effects of land use and or management changes on soil quality indicators.

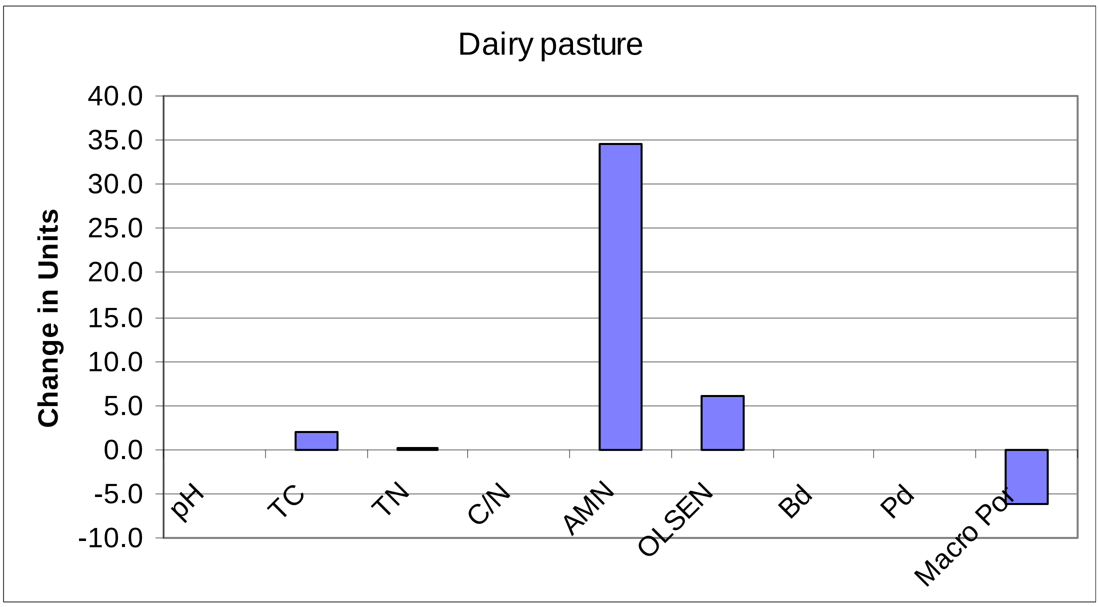

Figure 3. Average change in attribute units between current and previous samplings for dairy (+1 drystock) soils (n=5)

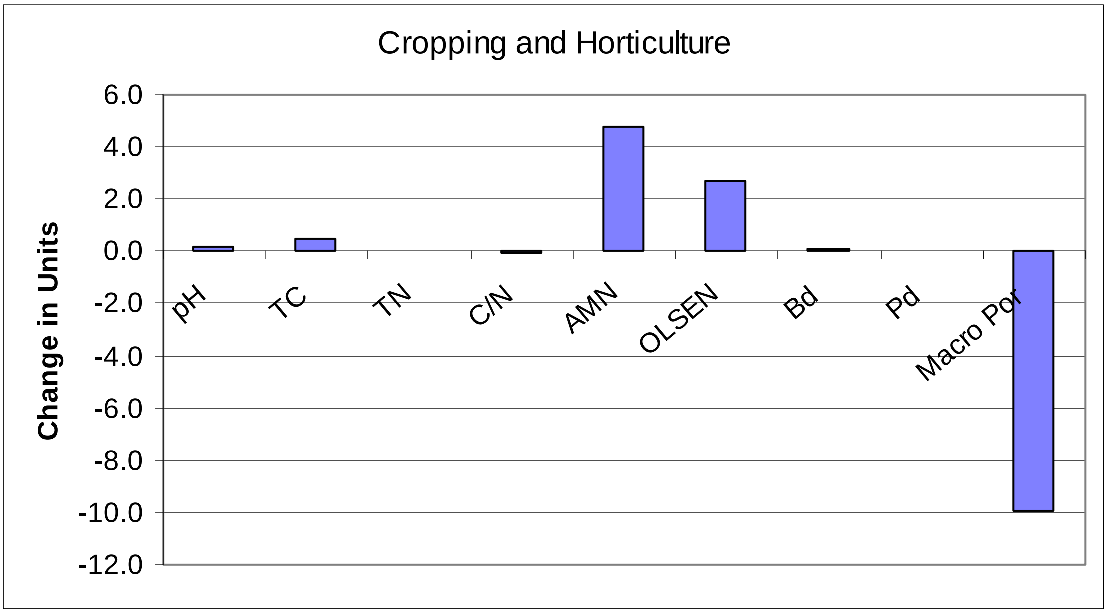

Figure 4. Average change in attribute units from between current and previous sampling for cropping and horticultural soils (n=7)

Dairy + Drystock Farms (Table 5, Fig. 3)
There was a significant decrease in macroporosity and a significant increase in mineralisable nitrogen in the four dairy plus one drystock sites resampled. Decreasing macroporosity on dairy and drystock sites has been noted in several previous reports and continues to be a concern. Although few dairy and drystock sites were outside target values for mineralisable nitrogen, the increase in this indicator is consistent with increased fertility on dairy and some drystock sites. EW08-7 had a large loss of C while EW08-13 had a large gain in carbon content.

Crop/Horticulture (Table 6, Fig. 4)

There was a significant decrease in macroporosity for cropping and horticultural sites. Cropping and horticultural sites, in particular, can be significantly affected by management changes that could substantially alter soil quality indicators. Detailed management history would be needed to determine the cause of these changes. There was little overall change in other soil quality indicators for cropping and horticulture sites.

Indigenous Sites (Table 7)
In the three indigenous sites sampled there was a significant decrease in total C and soil C/N ratio. The sample size is small and these changes probably resulted from slight variation in sampling location. Soil variability in indigenous systems tends to be greater than in pasture and care must be taken in ensuring that the sampling procedure and location between sampling periods are consistent (Giltrap & Hewitt 2004). However, if a large number of indigenous sites display this trend (of both decreased C and C/N ratio) it could indicate disturbance or change in species composition. Although indigenous sites were not included in statistical representation of target value statistics, it is recommended that EW continue to sample indigenous sites as they provide valuable base line data as to how indicators change on different soil type/ land use combinations.

5.5 Summary

The current national trend is for greater land intensification (Parliamentary Commission for the Environment 2004). As a result, state of the environment reporting is becoming increasingly important at both regional and national scales "to provide information and analysis on understanding the linkages between agriculture and the environment to help governments design and implement environmentally effective and economically efficient policies" (Agri-Environmental Indicators, April 2008). Earlier soil quality reports (e.g., Sparling et al. 2001b, 2004; Sparling & Schipper 2004) highlighted issues such as widespread compaction in dairy farms and suboptimal soil fertility. Examples of possible management options include:

- run-off pads on dairy farms
- active management of livestock during wet weather to minimise pugging
- on-farm nutrient budgeting
- disposal of effluents only onto suitable land and at rates that allow adequate treatment
- greater return of crop residues
- use of minimum and zero tillage in arable farming and pasture renewal for dairy and drystock

The continued intensification of dairy farming is consistent with the increases in nitrogen and phosphorus measured in Waikato rivers and streams (Vant 2008). These fertility issues, as well as the other soil quality characteristics reported, can be modified (reversed) by suitable management. Education of land owners and land managers, and soil and water monitoring is essential to achieving long-term practical land management.

6. Conclusions

- Low macroporosity (air capacity) values on dairy and drystock sites continue to be a concern.
- High fertility (total N and Olsen P) on dairy and some drystock sites indicate increased risk of nutrient transfer to waterways
- Low Olsen P values on some drystock sites indicated potential productivity benefits from increased fertiliser application.
- Although few cropping and horticulture sites are currently below target values for total carbon, past reports have noted this as a major concern, and total C should continue to be monitored closely for this land use.
- Primary concerns are:
  (1) compaction of soils on dairy and drystock sites
  (2) high fertility on dairy sites, which could lead to eutrophication in receiving waters
  (3) Low bulk density/high macroporosity on plantation forestry soils
- Most cases of poor soil quality could be reversed by appropriate management.

7. Recommendations

- EW should continue to develop policies that protect the environment while allowing an economic return from the land
- EW should continue activities to educate land managers on strategies to protect the environment while achieving an economic return from the land.
- Long-term monitoring is needed to measure the effectiveness of education and policy implementation
- EW should continue with its programme of resampling existing sites to determine the extent and direction of any changes since original sampling. For comparison between sampling dates for a particular land use, a larger number of similar sites (>8) has been beneficial in statistically determining changes in direction of soil quality indicators.
- Resampling after 3–5 years is recommended for sites undergoing rapid change (e.g., recent land-use change). Resampling after 5–10 years is recommended for sites that are stable and under long-term consistent land use and management.
- Repeat sampling on 3–5 occasions will give confidence about change on individual sites. Where equivalent land uses on similar soils can be combined, 1 or 2 further samplings should be adequate to confirm changes under that particular land use.
- The greater the number of samples and the more detailed the information obtained (particularly in reference to land-use history) for each site, the more robust the conclusions that can be drawn about soil quality in the region, particularly when differentiating between the effects of land management strategies on improvements in soil quality. When choosing sites to resample, more statistical power is gained by restricting sampling to specific land uses, so increasing the number of sites for each land use. We have found a minimum of 8 sites is helpful in discerning changes in most indicators between sampling dates.

8. Acknowledgements

Soil chemical analyses were completed at the Environmental Chemistry Laboratory, Landcare Research, Palmerston North. Soil physical analyses were completed by the Soil Physics Laboratory, Landcare Research, Hamilton.

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Appendices

Site and soil descriptions for new sites sampled in 2008/09

Current sampling soil chemical and physical analysis data tables

Comparison of soil quality indicators on resampled sites

All EW Soil Quality sites and values for the soil quality indicators

Site: EW08 - 01

Soil Series	Otorohanga
GPS coordinates	E2714335 N6345300
Location	Tokanui Farm, 25 Te Mawhai Rd. Paddock 70, Farm Rd
Transect length and direction °	50 m N–S (~13 m in from fenceline and 100 m W of office)
Local contact person	Alan Macmanus, Farms Coordinator, AgResearch
Classification	Typic Orthic Allophanic Soils
Land use	Drystock (to be converted to dairy)
Date sampled	14/11/08
Land use history	To be provided by owner
Present vegetation	Pasture grasses
Slope °	<1°
Landform	Upland plane
Annual rain (mm)	1283
Elevation (m)	39
Parent material	Tephra
Drainage	Well drained
Topsoil depth (cm)	15 (Ap)
Total rooting depth (cm)	100+
Limiting horizon	None
Sampled by	Bryan Stevenson and Matthew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
Ap	0–15	Very dark brown (10YR 2/2) silt loam; slightly sticky; slightly plastic; very weak soil strength; friable failure; earthy; abundant fine roots; distinct wavy boundary.
Bw1	15–40	Very dark greyish brown (10YR 4/3) silt loam; slightly sticky; non-plastic; very weak soil strength; friable failure; moderately pedal; common fine roots; distinct wavy boundary.
Bw2	40–75	Dark yellowish brown (10YR 5/6) silt loam; slightly sticky; non-plastic; weak soil strength; friable failure; moderately pedal; indistinct wavy boundary.
2C	75–100+	Light yellowish brown (10YR 6/4) clay loam; slightly-sticky; slightly plastic; semi-deformable failure; massive

Site: EW08 - 02

Soil Series	Puniu
GPS coordinates	E2716187 N6345516
Location	Tokanui Farm, Waikerea Rd. Paddock 147 between strips
Transect length and direction °	50 m 210° (N of water trough on along slight ridge)
Local contact person	Alan Macmanus, Farms Coordinator, AgResearch
Classification	Mottled Orthic Brown Soils
Land use	Drystock (in process of being converted to maize)
Date sampled	14/1/08
Land use history	To be provided by owner
Present vegetation	Pasture grasses
Slope °	<1°
Landform	Lowland plain
Annual rain (mm)	1257
Elevation (m)	39
Parent material	Old floodplain alluvium
Drainage	Imperfectly drained
Topsoil depth (cm)	15
Total rooting depth (cm)	100+
Limiting horizon	None
Sampled by	Bryan Stevenson and Matthew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
Ap	0–13	Very dark brown (10YR 3/2) fine sandy clay loam; slightly sticky; non-plastic; weak soil strength; friable failure; earthy; abundant fine roots; distinct smooth boundary.
Bw1	13–30	Very dark greyish brown (10YR 5/4) fine sandy clay loam; common fine and medium distinct strong brown (7.5YR 5/6) mottles; slightly sticky; non-plastic; very weak soil strength; friable failure; moderately pedal; common fine roots; distinct wavy boundary.
Bw2	30–70	Dark yellowish brown (10YR 6/4) fine sandy clay loam; common fine and medium distinct strong brown (7.5YR 5/6) mottles; slightly sticky; non-plastic; weak soil strength; friable failure; moderately pedal; indistinct wavy boundary.
Cg	70–100+	Light yellowish brown (10YR 7/3) fine sandy clay; many fine and medium distinct 7.5Y 5/6 mottles; sticky; plastic; deformable failure; massive

Site: EW08 - 03

Soil Series	Te Kuiti
GPS coordinates	E2706673 N6321399
Location	262 Ngapene Rd. Ototorohanga
Transect length and direction °	40 m 120°
Local contact person	Phil Coley
Classification	Typic Orthic Allophanic Soils
Land use	Exotic Forestry
Date sampled	12/11/08
Land use history	
Present vegetation	Pinus radiata
Slope °	15°
Landform	Slope
Annual rain (mm)	1439
Elevation (m)	173
Parent material	Mairoa Ash
Drainage	Excessively drained
Topsoil depth (cm)	10 (Ap)
Total rooting depth (cm)	100+
Limiting horizon	-
Sampled by	Bryan Stevenson and Matthew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
A	0–10	Black (10YR 2/1) fine sandy loam; non-sticky; non-plastic; very weak soil strength; friable failure; earthy; abundant fine roots; distinct wavy boundary.
Bw1	10–26	Dark yellowish brown (10YR 4/4) fine sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; weakly pedal; common fine roots; distinct wavy boundary.
Bw2	26–60	Yellowish brown (10YR 5/6) fine sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; weakly pedal; indistinct wavy boundary.
C	60–100+	Yellowish brown (10YR 5/6) fine sandy loam; slightly sticky; slightly plastic; firm soil strength; friable failure; massive,

Site: EW08 - 04

Soil Series	Te Kuiti
GPS coordinates	E2706663 N6321388
Location	262 Ngapene, Otorohanga
Transect length and direction °	40 m N-S, ~5 m in from fence diagonally down slope
Local contact person	Phil Coley
Classification	Typic Orthic Allophanic Soils
Land use	Drystock sheep & beef
Date sampled	12/11/08
Land use history	
Present vegetation	Pasture grasses
Slope °	12°
Landform	Slope
Annual rain (mm)	1439
Elevation (m)	173
Parent material	Mairoa Ash
Drainage	Excessively drained
Topsoil depth (cm)	17
Total rooting depth (cm)	100+
Limiting horizon	-
Sampled by	Bryan Stevenson and Matthew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
A	0–17	Black (10YR 2/1) fine sandy loam; non-sticky; non-plastic; very weak soil strength; friable failure; earthy; abundant fine roots; distinct wavy boundary.
Bw1	17–26	Dark yellowish brown (10YR 3/4) fine sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; weakly pedal; common fine roots; distinct wavy boundary.
Bw2	26–60	Yellowish brown (10YR 5/6) fine sandy loam; slightly sticky; non-plastic; weak soil strength; friable failure; weakly pedal; indistinct wavy boundary.
C	60–100+	Yellowish brown (10YR 5/6) fine sandy loam; slightly sticky; slightly plastic; firm soil strength; friable failure; massive.

Site: EW08 - 05

Soil Series	Tirau
GPS coordinates	E2745203 N6362237
Location	5740 SH 29 near Hinuera, left fork, past sheds, 3rd paddock past right angle bend
Transect length and direction °	50 m 140°
Local contact person	Grant Dixon
Classification	Typic Orthic Allophanic Soils
Land use	Dairy
Date sampled	14/11/08
Land use history	To be provided by owner
Present vegetation	Pasture grasses
Slope °	1–3°
Landform	Lowland plain
Annual rain (mm)	1346
Elevation (m)	165
Parent material	Hamilton Ash (probably Mairoa)
Drainage	Well drained
Topsoil depth (cm)	14
Total rooting depth (cm)	100+
Limiting horizon	-
Sampled by	Bryan Stevenson and Matthew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
Ap	0–14	Very dark greyish brown (10YR 3/2) fine sandy loam; non-sticky; non- plastic; very weak soil strength; friable failure; earthy; abundant fine roots; distinct wavy boundary.
Bw1	14–28	Dark yellowish brown (10YR 4/6) fine sandy loam; non-sticky; non-plastic; very weak soil strength; friable failure; common fine roots; weakly pedal; distinct wavy boundary.
Bw2	28–60	Dark yellowish brown (10YR 5/6) fine sandy loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; indistinct wavy boundary.
BC	60–100+	Dark yellowish brown (10YR 5/6) fine sandy loam to fine sandy clay loam; slightly sticky; slightly plastic; semi-deformable failure; massive

Site: EW08 - 06

Soil Series	Tirau
GPS coordinates	E2745184 N6362271
Location	5740 SH 29 near Hinuera, across race, continue transect line of site 133
Transect length and direction °	50 m 140°
Local contact person	Grant Dixon
Classification	Typic Orthic Allophanic Soils
Land use	Crop
Date sampled	
Land use history	To be provided by owner
Present vegetation	Maize
Slope °	1–3°
Landform	Lowland Plain
Annual rain (mm)	1346
Elevation (m)	165
Parent material	
Drainage	Well drained
Topsoil depth (cm)	14
Total rooting depth (cm)	100+
Limiting horizon	-
Sampled by	Matthew Taylor (EW)

Profile description same as EW08-5.

Site: EW08 - 17

Soil Series	Patumahoe
GPS coordinates	E2688739 N6427120 (37°20.424 175°00.842)
Location	234 Clark and Denize Rd, Pukekawa, RD1 Tuakau Follow track E past 2 ponds to native trees. Site behind S tree hedge
Transect length and direction °	50 m 250° (10 m in from hedge)
Local contact person	Ray & Win Shepherd 234 Clark & Denize Rd, Pukekawa, RD1 Tuakau
Classification	Mottled Orthic Granular Soil
Land use	Drystock
Date sampled	2 Feb 2009
Land use history	Never cropped, Longterm sheep/beef
Present vegetation	Pasture: Ryegrass clover, "heather"
Slope °	5°
Landform	Flat to easy rolling surface
Annual rain (mm)	1310
Elevation (m)	97
Parent material	Tephra
Drainage	Imperfectly drained
Topsoil depth (cm)	24
Total rooting depth (cm)	40
Limiting horizon	Bg (firm)
Sampled by	Mathew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
Ap	0–24	Very dark Grey (10YR 3/1) clay loam; sticky; plastic; weak soil strength; friable failure; earthy; common fine & very fine roots; distinct smooth boundary.
Bg1	24–40	Light olive brown (2.5Y 5/6) clay; with common medium distinct yellowish red (5YR 5/8) and yellowish brown (10YR 5/4) mottles; sticky; plastic; slightly firm; deformable; moderately pedal; few very fine roots; indistinct smooth boundary.
Bg2	40–60	Light olive brown (2.5Y 5/6) clay; with many medium distinct yellowish red (5YR 5/8) and yellowish brown (10YR 5/4) mottles; few distinct black (10YR 2/1) Mn concretions; sticky; plastic; firm; deformable; massive; no roots; indistinct smooth boundary.
Bg3	60+	Olive yellow (2.5Y 6/6) clay; with common medium distinct yellowish red (5YR 5/8) and yellowish brown (10YR 5/4) mottles; few distinct black (10YR 2/1) Mn concretions; sticky; plastic; firm; deformable; no roots; massive.

Site: EW08 - 18

Soil Series	Mercer silt loam
GPS coordinates	E2682507 N6433071
Location	Alexanda Redoubt Reserve, River Rd, on river flat, 200 m before Franklyn district recycling centre
Transect length and direction °	
Local contact person	Public land
Classification	Typic Recent Gley Soil
Land use	Indigenous
Date sampled	19 Feb 2009
Land use history	Reserve
Present vegetation	Native Bush-Tawa, Manuka/kanuka, Punga, ferns
Slope °	3
Landform	River Flat
Annual rain (mm)	1330
Elevation (m)	19
Parent material	Alluvium
Drainage	Poorly drained
Topsoil depth (cm)	5
Total rooting depth (cm)	30+
Limiting horizon	Bg2
Sampled by	Mathew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
A	0–5	Dark yellowish brown (10YR 4/4) silt loam; few distinct light gray (2.5Y 7/0) mottles; slightly sticky; slightly plastic; very weak soil strength; friable failure; earthy; common fine roots; indistinct smooth boundary.
Bg1	5–30	Light gray (5Y 7/1) silt loam; common distinct olive brown (2.5Y 4/4) mottles; common fine and medium distinct 7.5Y 5/6 mottles; slightly sticky; slightly plastic; weak soil strength; friable failure; common fine roots; indistinct smooth boundary.
Bg2	30–75	Light gray (5Y 7/1) silt loam; common distinct reddish brown (5YR 4/4) mottles; slightly sticky; slightly plastic; weak soil strength; friable failure; distinct smooth boundary.
Bg3	90+	Light gray (5Y 7/1) clay loam; many distinct reddish brown (5YR 4/4) mottles; sticky; plastic; friable failure; massive

Site: EW08 - 19

Soil Series	Puniu
GPS coordinates	E2714406 N6345449
Location	Tokanui Farm, 25 Te Mawhai Rd. Paddock 81, before office, West off farm Rd.
Transect length and direction °	
Local contact person	Alan Macmanus, Farms Co-ordinator, AgResearch
Classification	Mottled Orthic Recent Soil
Land use	Drystock (being converted to dairy)
Date sampled	11 February 2009
Land use history	
Present vegetation	pasture-ryegrass/clover
Slope °	0
Landform	Valley floor
Annual rain (mm)	1280
Elevation (m)	39
Parent material	Rhyolytic tephra
Drainage	Imperfectly drained
Topsoil depth (cm)	18
Total rooting depth (cm)	62
Limiting horizon	Bg
Sampled by	Mathew Taylor (EW)

Description:

Horizon	Depth (cm)	Description
Ap	0–18	Very dark brown (10YR 2/1) silt loam; slightly sticky; non-plastic; weak soil strength; friable failure; earthy; abundant fine roots; distinct wavy boundary.
Bw1	18–37	Very dark greyish brown (10YR 5/4) silty clay loam; slightly sticky; slightly plastic; slightly firm soil strength; friable failure; few fine roots; indistinct wavy boundary.
Bw2	37–62	Dark yellowish brown (10YR 5/6) silty clay; common fine to coarse distinct 7.5YR 4/4 mottles; sticky; plastic; firm; deformable failure; few fine roots; diffuse irregular boundary.
Bg	62–100+	Light yellowish brown (10YR 7/2) clay; common fine to coarse distinct brown and strong brown (7.5YR 4/4 and 7.5YR 5/8) mottles; very sticky; very plastic; firm; deformable failure; massive

Soil Analysis Results
Environmental Chemistry Laboratory

Landcare Research
Manaaki Whenua

Client: Bryan Stevenson, Landcare Research Ltd

Job No.: LJ08111

Date In: 2nd December 08

Date Out: 22nd December 08

Client ID	Sample No.	Water Content (method 104) (% dry wt)	pH (water) (method 106)	Total C (method 114) (%)	Total N (method 114) (%)	Anaerobic Mineralisable-N (method (120) (mg/kg)	Olsen P (method 124) (mg/kg)
EW08-01	M8/3887	68	5.88	10.7	1.14	220	32
EW08-02	M8/3888	38	6.35	3.48	0.36	76	29
EW08-03	M8/3889	87	5.59	13.9	1.16	121	14
EW08-04	M8/3890	84	5.62	15.5	1.41	236	19
EW08-05	M8/3891	56	6.00	9.89	1.02	252	37
EW08-07	M8/3892	35	5.82	6.76	0.67	148	74
EW08-08	M8/3893	57	6.20	10.0	1.06	296	66
EW08-09	M8/3894	395	4.38	51.5	1.29	307	10
EW08-10	M8/3895	47	6.37	7.13	0.66	152	29
EW08-11	M8/3896	51	5.66	7.19	0.52	148	7

Soil Analysis Results
Environmental Chemistry Laboratory

Landcare Resear
Manaaki When

Client: Bryan Stevenson, Landcare Research

Job No.: LJ08151

Date In: 5th March 2009

Date Out: 28th April 2009

Client ID	Sample No.	Water Content (method 104) (% dry wt)	pH (water) (method 106)	Total C (method 114) (%)	Total N (method 114) (%)	Anaerobic Mineralisable-N (method (120) (mg/kg)	Olsen P (method 124) (mg/kg)
EW08 - 06	M8/6690	40.5	6.66	7.11	0.72	122	64
EW08 - 12	M8/6691	23.2	6.30	3.22	0.27	42	39
EW08 - 13	M8/6692	47.9	5.54	14.4	1.11	228	42
EW08 - 14	M8/6693	25.8	5.64	7.90	0.64	240	60
EW08 - 15	M8/6694	22.3	6.53	2.17	0.19	15	187
EW08 - 16	M8/6695	21.2	5.79	2.88	0.26	20	60
EW08 - 17	M8/6696	28.7	5.99	8.50	0.80	171	43
EW08 - 18	M8/6697	42.2	6.47	5.70	0.41	97	8
EW08 - 19	M8/6698	41.6	5.80	5.86	0.58	150	20
EW08 - 20	M8/6699	78.1	5.32	11.3	0.84	230	14
EW08 - 21	M8/6700	28.1	5.50	8.39	0.76	215	119
EW08 - 22	M8/6701	24.9	6.91	3.66	0.31	41	95
EW08 - 23	M8/6702	27.7	6.40	3.56	0.31	34	71
EW08 - 24	M8/6703	52.6	6.23	9.78	0.80	77	44

Table showing full current (2007) soil physical data (3 replicates)

Environment Waikato Soil Quality
Moisture Release Results
Job Code: 682202-0039
January 2009

Lab Number	Client ID	Initial Water Content	Dry Bulk Density	Particle Density	Total Porosity	Macro Porosity	Air Filled Porosity	Vol. WC 5kPa	Vol. WC 10kPa
		(%, w/w)	(t/m3)	(t/m3)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)
HP3753a	EW08 - 01	73.8	0.70	2.27	69.1	7.9	11.0	61.2	58.1
HP3753b		80.0	0.72	2.23	69.0	<1	2.5	69.0	66.5
HP3753c		69.9	0.73	2.24	67.5	3.7	8.0	63.8	59.5
HP3754a	EW08 - 02	37.4	1.21	2.51	52.7	<1	2.0	52.7	50.7
HP3754b		39.1	1.21	2.50	51.8	1.2	2.9	50.6	48.9
HP3754c		36.7	1.26	2.49	52.7	<1	1.0	52.7	51.7
HP3755a	EW08 - 03	89.5	0.53	2.16	75.4	16.4	23.0	59.0	52.4
HP3755b		88.2	0.49	2.27	78.5	29.6	33.4	48.9	45.1
HP3755c		82.0	0.53	2.23	76.1	26.8	30.1	49.3	46.0
HP3756a	EW08 - 04	89.6	0.57	2.18	73.8	14.3	18.1	59.5	55.7
HP3756b		88.7	0.57	2.15	73.7	10.9	15.7	62.8	58.0
HP3756c		99.1	0.57	2.22	74.1	4.6	9.3	69.5	64.8
HP3765a	EW08 - 07	48.7	0.74	2.29	67.8	9.4	13.3	58.4	54.5
HP3765b		39.0	0.98	2.37	58.6	3.5	6.9	55.1	51.7
HP3765c		40.5	0.98	2.41	59.3	1.7	4.5	57.6	54.8
HP3766a	EW08 - 08	69.5	0.67	2.27	70.3	11.9	16.8	58.3	53.5
HP3766b		59.1	0.73	2.24	67.5	1.1	5.9	66.4	61.6
HP3766c		63.9	0.73	2.35	68.9	5.7	10.0	63.3	58.9
HP3767a	EW08 - 09	454.4	0.09	1.59	94.1	52.0	57.6	42.1	36.5
HP3767b		641.0	0.08	1.44	94.4	46.4	54.0	47.9	40.4
HP3767c		474.3	0.09	1.47	93.9	52.7	59.7	41.2	34.2
HP3768a	EW08 - 10	61.3	0.78	2.45	68.0	11.0	14.6	57.0	53.4
HP3768b		49.5	0.90	2.43	63.2	7.7	11.5	55.5	51.7
HP3768c		53.8	0.86	2.46	65.2	9.9	13.6	55.3	51.6
HP3769a	EW08 - 11	36.5	0.94	2.54	63.2	15.5	18.5	47.7	44.7
HP3769b		50.9	0.90	2.57	65.0	12.1	14.3	52.9	50.7
HP3769c		53.9	0.90	2.56	64.7	12.1	14.9	52.5	49.8
HP3770a	EW08 - 05	60.6	0.79	2.31	65.7	1.7	5.7	64.0	60.0
HP3770b		62.4	0.77	2.30	66.4	1.0	4.9	65.3	61.5
HP3770c		58.5	0.77	2.33	66.9	5.1	9.3	61.8	57.6

Notes: EW08 - 04 rep. 3 (HP3756c): appeared to be slightly compacted relative to its replicates.
EW08 - 07 rep. 1 (HP3765a) and EW08 - 08 rep. 1 (HP3766a): cores showed some disturbance and was loose in its liner.
EW08 - 09 (HP3767a-c): all replicates were almost entirely composed of organic litter.
EW08 - 11 rep. 1 (HP3769a): was of a different colour relative to its replicates.

Analyst: DT

Environment Waikato Soil Quality
Moisture Release Results
Job Code: 682202-0039
May 2009

Lab Number	Client ID	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)
HP3823a	EW08 - 06	38.6	0.78	2.36	66.9	8.9	13.9	58.0	53.0
HP3823b		41.4	0.85	2.38	64.2	7.9	11.5	56.3	52.7
HP3823c		38.9	0.78	2.34	66.7	8.2	12.7	58.5	54.0
HP3824a	EW08 - 12	27.1	1.29	2.70	52.1	8.8	11.0	43.3	41.1
HP3824b		22.8	1.39	2.69	48.2	3.3	4.7	44.9	43.5
HP3824c		26.2	1.38	2.70	48.8	5.3	6.7	43.5	42.1
HP3825a	EW08 - 13	66.6	0.63	2.12	70.3	12.0	15.0	58.2	55.3
HP3825b		48.1	0.69	2.33	70.6	11.2	14.4	59.4	56.2
HP3825c		82.7	0.53	2.03	73.9	7.2	10.2	66.7	63.7
HP3826a	EW08 - 14	40.7	0.77	2.39	67.8	9.8	12.3	57.9	55.5
HP3826b		35.4	0.85	2.34	63.8	6.7	9.2	57.1	54.6
HP3826c		33.8	0.82	2.35	64.9	8.4	11.2	56.5	53.7
HP3827a	EW08 - 15	32.9	1.12	2.63	57.3	16.3	18.6	40.9	38.7
HP3827b		33.8	1.14	2.63	56.8	16.1	17.7	40.7	39.1
HP3827c		31.3	1.11	2.64	57.7	18.7	20.7	39.0	37.0
HP3828a	EW08 - 16	41.1	1.14	2.61	56.4	11.9	13.9	44.6	42.5
HP3828b		34.8	1.23	2.62	53.0	7.9	9.8	45.1	43.2
HP3828c		45.9	1.12	2.62	57.1	10.6	13.3	46.6	43.8
HP3829a	EW08 - 17	29.9	1.00	2.45	59.0	5.4	7.9	53.7	51.1
HP3829b		32.3	1.00	2.45	59.0	2.8	5.8	56.2	53.2
HP3829c		33.7	0.93	2.45	62.1	7.8	9.9	54.3	52.2
HP3830a	EW08 - 18	45.2	0.97	2.59	62.6	7.0	9.0	55.6	53.6
HP3830b		62.1	0.92	2.56	64.2	2.6	4.0	61.6	60.2
HP3830c		44.4	0.99	2.61	62.3	8.2	9.7	54.1	52.6
HP3831a	EW08 - 19	47.2	0.95	2.18	56.7	0.4	3.1	56.3	53.6
HP3831b		57.5	0.85	2.41	64.7	5.9	8.2	58.8	56.5
HP3831c		47.0	0.90	2.49	63.9	13.2	15.5	50.7	48.4
HP3832a	EW08 - 20	98.4	0.42	2.45	82.9	20.8	24.0	62.1	58.9
HP3832b		97.0	0.30	2.13	85.7	31.9	41.1	53.8	44.6
HP3832c		61.6	0.53	2.26	76.5	23.4	30.2	53.1	46.3
HP3833a	EW08 - 21	27.8	1.05	2.48	57.6	6.9	7.1	50.7	50.5
HP3833b		33.0	1.00	2.45	59.0	0.0	0.8	58.9	58.2
HP3833c		27.4	1.02	2.46	58.6	7.6	8.0	51.0	50.6
HP3834a	EW08 - 22	33.3	1.02	2.63	61.1	22.4	23.5	38.7	37.6
HP3834b		36.5	1.01	2.61	61.3	22.5	23.5	38.8	37.8
HP3834c		28.4	1.05	2.59	59.4	21.1	21.7	38.3	37.7
HP3835a	EW08 - 23	46.2	1.04	2.56	59.3	13.4	16.0	45.9	43.3
HP3835b		50.3	1.04	2.57	59.7	15.6	18.7	44.1	41.0
HP3835c		51.1	1.03	2.58	60.1	13.6	16.7	46.6	43.4
HP3836a	EW08 - 24	44.5	0.77	2.27	66.0	9.6	11.5	56.4	54.5
HP3836b		55.6	0.84	2.25	62.7	4.4	5.6	58.3	57.1
HP3836c		60.9	0.82	2.25	63.5	5.1	5.8	58.4	57.7

Analyst: DT

Table showing all current and previous chemical, biochemical, and physical data on a volume basis for dairy + drystock and indigenous sites

Code	Soil Order	pH	TC mg/cm³	TN mg/cm³	C:N ratio	AMN µg/cm³	Olsen P µg/cm³	Bd Mg/m³	Pd Mg/m³	Macroporosity (–5 kPa) %v/v
Dairy[1] +Drystock[2]		Current (2008/09) Measurements— grouped by land use								
EW08 - 07[1]	Allophanic	5.82	60.9	6.0	10.1	133	67	0.90	2.36	4.9
EW08 - 08[1]	Allophanic	6.20	71.3	7.6	9.4	210	47	0.71	2.28	6.2
EW08 - 13[1]	Gley	5.54	88.4	6.8	12.9	140	26	0.62	2.16	10.1
EW08 - 14[1]	Gley	5.64	64.4	5.2	12.4	195	49	0.81	2.36	8.3
EW08 - 21[2]	Granular	5.50	86.0	7.8	11.0	220	122	1.02	2.46	4.8
		Previous Measurements								
WAI96 - 1[1]	Allophanic	5.63	76.4	7.8	9.8	126	43	0.64	2.20	11.3
WAI96 - 2[1]	Allophanic	6.43	65.8	6.9	9.6	175	22	0.67	2.27	11.7
EW01 - 11[1]	Gley	5.73	65.1	5.2	12.6	107	26	0.58	2.28	23.1
EW01 - 12[1]	Gley	5.75	69.4	5.4	12.8	132	74	0.93	2.34	8.0
EW01 - 17[2]	Granular	5.67	78.3	7.3	10.8	201	130	1.00	2.48	11.4
Indigenous					Current (2008/09) Measurements—grouped by land use					
EW08 - 09	Organic	4.38	45.3	1.1	39.9	27	1	0.09	1.50	50.4
EW08 - 20	Pumice	5.32	47.1	3.5	13.4	96	6	0.42	2.28	25.4
EW08 - 11	Granular	5.66	65.7	4.8	13.8	135	6	0.91	2.56	13.2
						Previous Measurements				
WAI98 - 16	Organic	3.95	52.8	1.2	42.9	25	3.2	0.11	1.48	40.5
WAI00 - 15	Pumice	5.08	52.2	3.3	15.7	99	15	0.51	2.17	24.2
EW01 - 21	Granular	4.86	77.2	4.5	17.4	105	6	0.82	2.48	23.5

Table showing all current and previous chemical, biochemical, and physical data on a volume basis for horticulture/cropping sites

Code	Soil Order	pH	TC mg/cm^3	TN mg/cm^3	C:N ratio	AMN µg/cm^3	Olsen P µg/cm^3	Bd Mg/m^3	Pd Mg/m^3	Macroporosity (–5 kPa) %v/v
Crop/Hort		Current (2008/09) Measurements— grouped by land use								
EW08 - 16	Granular	5.79	33.5	3.0	11.1	24	70	1.16	2.62	10.1
EW08 - 15	Granular	6.53	24.4	2.1	11.4	16	210	1.12	2.63	17.0
EW08 - 12	Granular	6.30	43.6	3.6	12.1	57	52	1.36	2.70	5.8
EW08 - 24	Gley	6.23	79.3	6.5	12.2	63	35	0.81	2.26	6.4
EW08 - 10	Allophanic	6.37	60.2	5.6	10.8	129	25	0.84	2.45	9.5
EW08 - 22	Granular	6.91	37.5	3.1	12.0	42	98	1.03	2.61	22.0
EW08 - 23	Granular	6.40	36.8	3.2	11.4	35	74	1.04	2.57	14.2
		Previous Measurements								
EW01 - 9	Granular	5.85	30.5	2.7	11.2	33	39	0.96	2.60	26.5
EW01 - 10	Granular	6.54	23.8	2.1	11.5	13	172	1.08	2.63	22.5
EW01 - 15	Granular	6.14	34.4	3.0	11.6	28	52	1.04	2.71	23.0
EW01 - 18	Gley	5.49	68.4	5.9	11.6	67	33	0.84	2.35	21.4
EW02 - 10	Allophanic	6.57	67.9	5.9	11.6	115.0	42.6	0.9	2.48	15.2
EW02 - 13	Granular	6.36	46.8	3.8	12.3	48.7	101.7	0.9	2.49	23.2
EW02 - 14	Granular	6.35	39.9	3.4	11.6	27.5	104.4	1.0	2.53	22.7

Table showing all EW Soil Quality sites and values for the seven soil quality indicators

Code	Soil	Land Use	pH	Total C T/ha	Total N T/ha	AMN μg/cm^3	Olsen P μg/cm^3	Bulk Density T/m^3	Macropores %v/v
EW01 - 13	Granular	Crop/Hort	6.46	41.2	3.6	45	**132**	1.35	**2.4**
EW01 - 14	Granular	Crop/Hort	6.14	41.1	3.7	87	**134**	1.31	**4.8**
EW01 - 16	Brown	Crop/Hort	6.07	65.7	5.8	74	39	0.96	12.1
EW01 - 19	Brown	Crop/Hort	5.94	78.2	**7.1**	83	44	0.86	11.6
EW01 - 6	Organic	Crop/Hort	5.31	132.8	**8.0**	127	33	0.54	13.0
EW02 - 11	Allophanic	Crop/Hort	6.67	51.3	5.1	79	46	0.78	21.8
EW02 - 15	Granular	Crop/Hort	7.52	39.7	3.1	73	88	1.16	17.2
EW03 - 10	Organic	Crop/Hort	5.99	123.0	6.0	67	37	0.28	**30.2**
EW04 - 13	Allophanic	Crop/Hort	6.17	38.9	3.8	33	60	0.68	26.4
EW04 - 16	Allophanic	Crop/Hort	6.39	46.6	4.5	42	38	0.73	20.4
EW04 - 7	Pumice	Crop/Hort	6.02	39.2	3.1	53	**20**	0.73	24.9
EW05 - 01	Allophanic	Crop/hort	5.52	49.4	3.6	35	21	0.61	**37.2**
EW05 - 02	Allophanic	Crop/hort	5.82	34.7	3.5	31	**18**	0.64	**34.2**
EW05 - 03	Allophanic	Crop/hort	6.35	33.6	3.2	29	22	0.62	**37.7**
EW05 - 05	Gley	Crop/hort	6.3	35.0	3.6	55	26	0.95	10.2
EW05 - 06	Gley	Crop/hort	6.33	26.4	2.5	34	50	1.01	15.2
EW05 - 15	Gley	Crop/hort	6.15	47.5	4.9	54	28	0.78	16.3
EW05 - 16	Brown	Crop/hort	6.57	37.3	3.2	62	50	1.12	12.3
EW06 - 15	Gley	Crop/Hort	5.89	42.2	3.9	149	**10**	0.62	12.0
EW06 - 16	Allophanic	Crop/Hort	6.38	60.1	5.9	143	**5**	0.63	13.6
EW06 - 3	Allophanic	Crop/Hort	6.29	42.0	4.1	37	32	0.64	24.1
EW06 - 9	Gley	Crop/Hort	6.14	38.6	3.8	112	**108**	1.09	8.2
EW07 - 15	Allophanic	Crop/Hort	6.51	57.0	5.3	140	32	0.78	21.6
EW07 - 16	Allophanic	Crop/Hort	6.34	39.8	3.5	26	27	0.81	22.5
EW07 - 17	Gley	Crop/Hort	6.1	**21.1**	2.0	40	63	0.96	19.2
EW07 - 19	Allophanic	Crop/Hort	6.54	63.4	6.3	151	33	0.75	11.7
EW07 - 20	Allophanic	Crop/Hort	6.28	50.0	5.2	86	**16**	0.76	16.1
EW08 - 06	Allophanic	Crop/Hort	6.66	57.2	5.8	98	51	0.80	12.7
EW08 - 12	Granular	Crop/Hort	6.3	43.6	3.6	57	52	1.36	**7.5**
EW08 - 15	Granular	Crop/Hort	6.53	**24.4**	2.1	**16**	**210**	1.12	19.0
EW08 - 16	Granular	Crop/Hort	5.79	33.5	3.0	24	70	1.16	12.3
EW08 - 22	Granular	Crop/Hort	6.91	37.5	3.1	42	98	1.03	22.9
EW08 - 23	Granular	Crop/Hort	6.4	36.8	3.2	35	74	1.04	17.1
EW08 - 24	Gley	Crop/Hort	6.23	79.3	6.5	63	35	0.81	**7.6**
EW08-10	Allophanic	Crop/Hort	6.37	60.2	5.6	129	25	0.84	13.2
EW06 - 10	Gley	Dairy	5.75	66.1	5.8	125	**129**	0.86	**5.6**
EW06 - 13	Granular	Dairy	5.73	69.7	6.0	169	76	0.90	**8.8**
EW01 - 7	Organic	Dairy	5.16	128.0	6.9	107	36	0.53	19.1
EW02 - 8	Pumice	Dairy	5.56	55.2	5.0	94	**132**	0.80	10.0
EW02 - 9	Pumice	Dairy	5.28	55.5	5.1	165	**180**	**0.51**	**34.6**
EW03 - 03	Allophanic	Dairy	6.13	68.9	6.6	177	30	0.80	**4.3**
EW03 - 06	Allophanic	Dairy	6.24	66.6	6.6	171	35	0.78	**5.0**
EW03 - 07	Pumice	Dairy	6.09	53.8	4.3	130	82	0.73	**8.4**
EW03 - 08	Pumice	Dairy	6.46	51.6	3.8	95	25	0.85	18.6
EW03 - 09	Organic	Dairy	6.28	139.9	5.9	68	24	0.29	13.7
EW03 - 11	Recent	Dairy	6.15	52.8	5.2	176	87	0.85	**6.0**
EW03 - 12	Recent	Dairy	6.22	49.1	4.8	178	48	0.71	10.7
EW03 - 13	Allophanic	Dairy	6.34	85.4	**8.5**	192	18	0.60	**8.7**
EW04 - 14	Allophanic	Dairy	5.77	72.6	**7.4**	137	56	0.76	**5.3**
EW04 - 3	Pumice	Dairy	5.73	56.6	5.0	174	49	0.63	10.7
EW05 - 04	Allophanic	Dairy	5.83	65.8	5.4	124	51	1.10	10.9
EW05 - 07	Brown	Dairy	5.45	48.6	4.4	162	36	0.82	12.0

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EW05 - 08	Brown	Dairy	5.61	35.0	3.5	78	33	1.04	10.7
EW05 - 09	Gley	Dairy	5.68	76.7	6.0	103	36	1.27	**5.5**
EW05 - 17	Brown	Dairy	5.79	59.4	5.4	138	98	0.76	15.8
EW05 - 18	Brown	Dairy	5.97	68.1	6.0	119	72	0.82	**8.5**
EW05 - 19	Gley	Dairy	5.56	49.4	4.6	174	41	0.89	11.4
EW07 - 01	Pumice	Dairy	5.54	54.8	4.7	113	70	0.77	12.3
EW07 - 04	Pumice	Dairy	5.76	61.3	5.0	123	49	0.72	12.2
EW07 - 05	Pumice	Dairy	5.45	60.3	5.5	175	**186**	0.74	15.0
EW07 - 07	Pumice	Dairy	6.11	52.8	4.3	98	56	0.80	**5.7**
EW07 - 11	Gley	Dairy	5.31	50.3	4.4	55	22	0.86	10.1
EW07 - 12	Gley	Dairy	5.29	77.9	6.4	86	21	0.85	**9.0**
EW07 - 13	Allophanic	Dairy	5.74	68.0	6.6	117	44	0.89	**6.7**
EW07 - 14	Organic	Dairy	5.31	159.5	**7.7**	86	33	0.57	**6.7**
EW07 - 21	Allophanic	Dairy	5.85	117.2	**9.9**	183	**13**	0.76	**4.9**
EW07 - 22	Recent	Dairy	6.02	51.0	4.8	148	21	0.85	14.4
EW07 - 23	Gley	Dairy	6.03	87.9	7.0	218	44	0.72	13.2
EW08 - 13	Gley	Dairy	5.54	88.4	6.8	140	26	0.62	13.2
EW08 - 14	Gley	Dairy	5.64	64.4	5.2	195	49	0.81	10.9
EW08 - 05	Allophanic	Dairy	6	76.9	**7.9**	196	29	0.78	**6.6**
EW08 - 07	Allophanic	Dairy	5.82	60.9	6.0	133	67	0.90	**8.2**
EW08 - 08	Allophanic	Dairy	6.2	71.3	**7.6**	210	47	0.71	10.9
WAI96 - 3	Organic	Dairy	5.93	122.6	**9.0**	100	28	0.53	10.0
WAI96 - 4	Organic	Dairy	6.11	141.5	6.6	102	**12**	0.39	**7.3**
EW06 - 12	Ultic	Drystock	5.77	68.4	6.2	209	29	1.04	**3.5**
EW06 - 14	Granular	Drystock	5.35	65.9	5.6	197	**9**	0.77	10.4
EW06 - 17	Brown	Drystock	5.4	49.2	4.3	181	17	0.98	**6.6**
EW06 - 18	Allophanic	Drystock	6.42	67.3	5.6	124	**6**	0.66	**8.8**
EW06 - 19	Allophanic	Drystock	5.6	58.6	4.7	184	**9**	0.68	16.2
EW06 - 2	Allophanic	Drystock	5.71	83.7	6.1	148	**3**	0.55	**4.1**
EW06 - 8	Recent	Drystock	5.19	48.9	3.9	189	19	1.04	**6.6**
EW01 - 20	Brown	Drystock	5.34	82.6	**7.5**	175	49	0.86	10.5
EW03 - 01	Brown	Drystock	5.65	103.3	**9.1**	165	24	0.81	**4.3**
EW03 - 05	Allophanic	Drystock	5.5	57.4	5.3	150	53	0.78	**9.8**
EW04 - 10	Podzol	Drystock	5.92	47.8	3.0	107	17	**0.46**	14.7
EW04 - 12	Allophanic	Drystock	5.46	107.5	**9.0**	144	**5**	0.52	18.8
EW04 - 15	Allophanic	Drystock	6.25	59.4	5.8	131	**3**	0.73	**5.7**
EW05 - 10	Granular	Drystock	5.44	66.8	5.4	117	**6**	0.62	**32.1**
EW05 - 11	Granular	Drystock	6.25	96.1	**9.3**	150	18	0.75	10.5
EW05 - 12	Granular	Drystock	6.01	63.5	5.7	148	22	1.00	13.2
EW05 - 13	Granular	Drystock	6.01	72.0	6.3	133	21	1.01	15.5
EW05 - 14	Brown	Drystock	5.82	86.7	**8.5**	170	45	0.83	**9.3**
EW05 - 21	Brown	Drystock	5.55	64.4	5.0	156	**7**	0.91	18.2
EW07 - 24	Pumice	Drystock	5.55	58.9	4.7	113	25	0.66	**35.0**
EW07 - 25	Pumice	Drystock	5.88	48.0	3.9	149	55	0.73	21.8
EW07 - 26	Brown	Drystock	5.56	85.3	**8.3**	162	38	0.72	10.2
EW07 - 27	Allophanic	Drystock	5.37	85.1	**8.2**	183	30	0.66	14.3
EW07 - 28	Pumice	Drystock	5.63	67.9	5.2	150	25	0.66	15.1
EW08 - 17	Granular	Drystock	5.99	83.1	**7.8**	167	42	0.98	**7.9**
EW08 - 19	Brown	Drystock	5.8	52.7	5.3	135	18	0.90	**8.9**
EW08 - 21	Granular	Drystock	5.5	86.0	**7.8**	220	**122**	1.02	**5.3**
EW08 - 01	Allophanic	Drystock	5.88	76.2	**8.1**	157	23	0.72	**7.2**
EW08 - 02	Brown	Drystock	6.35	42.7	4.5	93	36	1.23	**2.0**
EW08 - 04	Allophanic	Drystock	5.62	88.3	**8.0**	134	**11**	0.57	14.4

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EW06 - 11	Ultic	Forestry	5.08	52.0	2.5	118	6	0.92	20.5
EW06 - 5	Brown	Forestry	5.08	63.2	4.7	152	14	1.03	14.2
EW06 - 6	Brown	Forestry	4.74	35.3	2.1	48	6	0.86	14.7
EW03 - 02	Brown	Forestry	4.87	68.9	4.6	47	8	0.96	17.5
EW03 - 04	Allophanic	Forestry	5.92	62.7	5.7	140	13	0.72	21.4
EW04 - 1	Pumice	Forestry	5.24	63.0	3.1	92	5	0.66	22.0
EW04 - 11	Recent	Forestry	5.6	91.1	6.6	93	**3**	**0.57**	17.1
EW04 - 2	Pumice	Forestry	5.27	45.8	2.5	82	**4**	**0.51**	**37.8**
EW04 - 4	Pumice	Forestry	4.41	62.7	2.2	24	**3**	**0.44**	**43.3**
EW04 - 5	Pumice	Forestry	5.57	41.6	2.4	79	18	0.60	**30.2**
EW04 - 6	Allophanic	Forestry	5.44	36.1	1.5	44	**4**	0.51	**43.1**
EW04 - 9	Podzol	Forestry	4.27	48.6	2.7	39	8	**0.46**	**33.3**
EW05 - 22	Brown	Forestry	5.6	61.2	3.0	133	6	0.92	22.2
EW07 - 02	Pumice	Forestry	5.03	38.5	2.7	57	36	**0.59**	**37.6**
EW07 - 03	Pumice	Forestry	5.24	56.6	2.5	75	**4**	**0.57**	**30.4**
EW07 - 06	Pumice	Forestry	5.28	31.0	1.5	72	10	0.64	**39.8**
EW07 - 08	Pumice	Forestry	5.11	35.3	1.8	46	12	**0.59**	**41.5**
EW07 - 09	Podzol	Forestry	4.58	56.3	2.1	49	**2**	**0.52**	**43.5**
EW07 - 10	Podzol	Forestry	5.26	36.3	1.7	36	**1**	**0.58**	28.6
EW08 - 03	Allophanic	Forestry	5.59	71.9	6.0	62	7	0.52	28.8
WAI95 - 4	Allophanic	Forestry	5.95	49.5	4.8	58	9	0.61	13.6
EW06 - 1	Allophanic	Indigenous	5.41	85.6	4.9	136	2	**0.43**	24.8
EW06 - 20	Allophanic	Indigenous	5.05	47.6	2.7	33	1	**0.49**	**35.7**
EW06 - 4	Brown	Indigenous	4.7	56.4	3.1	92	2	0.84	10.5
EW06 - 7	Recent	Indigenous	5.67	53.1	3.3	136	5	1.00	**3.9**
EW04 - 8	Podzol	Indigenous	4.56	37.3	2.2	48	8	**0.45**	**32.6**
EW05 - 20	Brown	Indigenous	4.93	54.9	2.3	69		0.71	9.4
EW07 - 18	Gley	Indigenous	4.62	55.5	3.7	89	42	**0.54**	24.9
EW08 - 18	Gley	Indigenous	**6.47**	54.6	3.9	93	8	0.96	**7.6**
EW08 - 20	Pumice	Indigenous	5.32	47.1	3.5	96	6	**0.42**	**31.8**
EW08 - 09	Organic	Indigenous	4.38	**45.3**	1.1	27	**1**	**0.09**	**57.1**
EW08 - 11	Granular	Indigenous	5.66	65.7	4.8	135	6	0.91	15.9

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