Environment Waikato Technical Report 2004/14

Implementing Soil Quality Indicators for Land: Waikato Region 2003-2004

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As part of its Annual Plan, Environment Waikato undertakes regular sampling to assess soil quality in the region. There are now some 80 identified and characterised sites throughout the region. These sites provide a "snapshot" of soil quality within the region, specific to the time the sites were sampled, between 1995 and 2002. The strategy for sampling in 2003/2004 was to revisit a subset of characterised sites to determine what changes in soil quality characteristics had occurred since the initial sampling. The rates and direction of changes in soil quality properties are useful to determine which land managements are sustainable in the longer term, and whether undesirable trends are emerging.

Pastoral land uses dominate in the region and this land use was targeted for resampling.

Soil quality on the sites was appraised using a set of soil chemical, physical and biological indicators tested in the 500 Soils Project (Hill et al. 2003).

Objectives

- In conjunction with Environment Waikato staff, identify up to 15 field sites predominantly under pastoral land use in the Waikato Region
- Describe the soils and sites, and using the same methods as previously employed, collect and analyse new samples to characterise their chemical, physical and biological characteristics
- Relate soil quality status to land use and soil type.
- With reference to previous data, calculate changes over time on the resampled sites, and identify any overall trends that could affect that land use in the longer term
- Provide comment on the overall soil quality and sustainability in the Waikato region.

Methods

- Sites were preselected by EW land resource staff and then visited by Landcare Research and EW staff.
- The site location, current land use and brief history were recorded and the soil profile described. Surface soil samples (0–10 cm) were collected using methods established by the 500 Soils Project.
- A standard suite of 12 soil properties was used to characterise the chemical, biochemical and physical attributes and assess soil quality of the various soil and land-use combinations.
- Sites with unusual characteristics were identified by comparison with the expected characteristics for that soil and land use combination.
- Changes through time were calculated by reference to the previously published reports where the same collection methods, soil properties and analytical methods had been used.

Results

- Thirteen sites analysed in 1998 or 1999 were located and sampled in November 2003. Land uses included pasture for drystock farming (sheep and beef), pasture for dairy farming, pines on former pasture, and one arable cropping site for fodder maize.

- Soil pH, Olsen P, total C, total N and mineralisable N were generally within the ranges expected for those soils and land uses. However, macroporosity was below the advisable range (<10%) on the majority of pasture sites, and was lower than when previously sampled in 1998/99.

Conclusions

- The majority of soil quality characteristics fell within acceptable ranges for those soils and land uses
- Pasture soils showed evidence of compaction and low macroporosity
- There has been a marked increase in soil compaction (low macroporosity) in pasture sites since the earlier sampling, and the majority of sites were below the advisory 10% threshhold.

Recommendations

- Environment Waikato continues the policy of resampling previously characterised sites to confirm the trends in soil quality attributes arising from the current data. For reliable long-term detection and prediction of trends, at least 3 and preferably 5 points along a time sequence should be obtained.
- Farmers be made aware of the trend in decreasing macroporosity (compaction) of pasture soils, the potential effects of low macroporosity on pasture production, and be encouraged to adopt mitigation techniques.
- The new data and interpretative findings should be incorporated with existing information on the “Environmental Indicators” topic pages of the Environment Waikato website for public information.

1 Introduction

1.1 Background

As part of its Annual Plan, Environment Waikato undertakes regular sampling to assess soil quality in the region. There are now some 80 identified and characterised sites throughout the region. These sites provide a "snapshot" of soil quality within the region, specific to the time the sites were sampled, between 1995 and 2002. The strategy for sampling in 2003/2004 was to revisit a subset of characterised sites to determine what changes in soil quality characteristics had occurred since the initial sampling. The rates and direction of changes in soil quality properties are useful to determine which land management practices are sustainable in the longer term, and whether undesirable trends are emerging.

Pastoral land uses dominate in the region and this land use was targeted for resampling.

Soil quality on the sites was appraised using a set of soil chemical, physical and biological indicators tested in the 500 Soils Project (Hill et al. 2003).

1.2 Objectives

- In conjunction with Environment Waikato staff, identify up to 15 field sites predominantly under pastoral land use in the Waikato Region
- Describe the soils and sites, and, using the same methods as previously employed, collect and analyse new samples to characterise their chemical physical and biological characteristics
- Relate soil quality status to land use and soil type
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- Provide comment on the overall soil quality and sustainability in the Waikato region.

2 Methods

Most of the methodologies have been described in earlier reports (Sparling et al. 1996, 2001), and only brief details are given here.

2.1 Soil sampling

A 50-m transect was laid out at each site. Soil cores of 2.5 cm diameter to a depth of 10 cm were taken every 2 m along the transect, for chemical and biochemical analyses. The 25 individual cores were bulked and mixed before analyses at the Landcare Research laboratory at Palmerston North. Three undisturbed soil samples for physical analyses were taken at 15-, 30- and 45-m positions along the transect, by pressing steel liners, 75-mm depth by 100-mm diameter, into the topsoil. The liner and soil cores were removed as a unit by careful excavation around the liner, bagged, loaded into padded crates and transported to the Landcare Research laboratory in Hamilton. Subsamples of the cores were then taken for particle size analyses, bulk density and water release characteristics. Where necessary, samples were stored at 5°C until analyses.

2.2 Soil-quality measurements

The primary soil properties measured to assess soil quality are shown in Table 1. Chemical characteristics were assessed by the total C content, total N content, C:N ratio, Olsen P, exchangeable cations (Ca, Mg, K) and soil pH. Potentially mineralisable nitrogen (N) provided an estimate of the nitrogen status of soil organic matter, and a surrogate measure for soil microbial biomass. The mineralisable N also provided measures of extractable ammonium and nitrate. Soil physical condition was assessed using bulk density, particle density and water release characteristics (providing information on total porosity, macroporosity, total available water and readily available water). As specified by the Regional Council Land Monitoring Forum (Hill et al. 2003), macroporosity was determined at –10 kPa. However, to be consistent with soil physics terminology this measure is more correctly termed "air-filled porosity". For completeness, both measures are reported here –the macroporosity calculated from the tension at –5 kPa, and the air-filled porosity calculated from the tension at –10 kPa.

Table 1: Indicators used for soil quality assessment

Indicators	Soil Quality Information	Method
Chemical properties		
Total C content	Organic matter status	Dry combustion, CNS Analyser
Total N content	Organic N reserves	Dry combustion, CNS Analyser
Soil pH	Acidity or alkalinity	Glass electrode pH meter, 1:2.5 in water
Olsen P	Plant available phosphate	Bicarbonate extraction, molybdenum blue method.
Exchangeable Ca, K and Mg	Plant available cations	QuickTest extraction.
Biological properties		
Potentially mineralisable N	Readily mineralised N reserves (also provides extractable ammonium and nitrate concentrations	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 porosity, air capacity and macroporosity	Soil compaction, root environment, aeration, voids	Pressure plates
Total and readily available water	Water for plant growth and soil biology	Pressure plates

2.3 Analyses

Chemical properties

Total C and N were determined by dry combustion of air-dry/air-dried, finely ground soils using a Leco 2000 CNS analyser (Blakemore et al. 1987). 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 2.5:1 water-to-soil ratio (Blakemore et al. 1987).

Exchangeable cations were determined using “QuickTest” methodology. The shaking extraction (1:50 soil:extractant, 1M ammonium acetate, pH 7.0, 1 hour shake) was adapted from the method described by Daly et al. (1984). Caesium was added to eliminate ionization interference in the determination of potassium and sodium, and strontium was added to prevent chemical interference in the determination of calcium and magnesium by atomic absorption spectrometry. Concentrations are presented as centimoles of positive charge per kg (cmol(+)/kg). This has the same numeric value as the old meq/100g. These values are then converted to QuickTest units if required.

Biochemical properties

Potentially mineralisable N was estimated by the anaerobic (waterlogged) incubation method; the increase in NH^+_4-N concentration was measured after incubation for 7 days at 40°C and extraction in 2 M KCl (Keeney & Bremner 1966). This assay also provided data on NH_4^+-N and NO_3^--N concentrations at the start of incubation.

Physical properties

Water release was determined by drainage on pressure plates at 5, 10, 100 and 1500 kPa (Klute 1986). Dry bulk density was measured on a subsampled core dried at 105°C (Klute 1986) and the remaining soil analysed for particle size and density by the pipette method. Readily available water, total available water, macroporosity (-5 kPa), air capacity (-10 kPa) and total porosity were calculated as described by Klute (1986).

2.4 Statistics and data display

All data were expressed on a weight/volume or volume/volume basis to allow comparison between soils with differing bulk density. Where appropriate, data from the same land-use category or soil type were combined to allow statistical testing. Values from the current samples were compared against archive data, mainly from 1998/99, to calculate the extent of change in soil properties.

3 Results

3.1 Soils and sites

Thirteen of the 15 original sites were relocated and access gained for sampling in November 2003–2004. Summaries of the site characteristics and land uses are shown in Table 2. Full site descriptions, detailed soil information and soil physical data on individual cores, are provided in the Appendix.

Table 2: Soils and land uses sampled for soil quality characteristics in the Waikato, December 2003

Code	Soil type and classification	Current land use and history	Previous samples	
			Date	Site Code
EW03-01	Wairama hill soils; Typic Orthic Brown	Dry stock farming	1998/99	WAI 98/11
EW03-02	Wairama hill soils; Typic Orthic Brown	Pinus radiata (12 yr)	1998/99	WAI98/13
EW03-03	Tirau silt loam, Typic Orthic Allophanic	Dairy pasture converted in 2001 from long-term sheep and beef pasture	1995/96	WAI 95 site2
			1998/9	WAI 98/3
EW03-04	Tirau silt loam, Typic Orthic Allophanic	Pinus radiata planted in 1993 previously long term sheep-beef pasture	1995/96	WAI 95 site 3
			1998/99	WAI98/2
EW03-05	Tirau silt loam, Typic Orthic Allophanic	Sheep-beef pasture (new site, previous drystock sites now converted to dairy)	1998/99	WAI98/3
EW03-06	Tirau silt loam, Typic Orthic Allophanic	Dairy pasture converted in 1993 from long-term sheep and beef pasture	1995/6	WAI95 site1
			1998/9	WAI98/1
EW03-07	Oruanui sand; Podzolic Orthic Pumice	Dairy pasture converted from drystock in 1995	1998/9	WAI98/7
EW03-08	Oruanui sand; Podzolic Orthic Pumice	Dairy pasture converted from drystock in 2000	1998/9	WAI98/6
EW03-09	Rukuhia peat; Acid or Mellow Fibric Organic	Dairy pasture, long-term	1998/9	WAI98/15
EW03-10	Rukuhia peat; Acid or Mellow Fibric Organic	Arable cropping, silage maize	new	none
EW03-11	Korakonui sandy loam; Typic Tephric Recent	Dairy pasture, long-term, formerly fertilised with poultry manure	1999/00	WAI99/10
EW03-12	Korakonui sandy loam; Typic Tephric Recent	Dairy pasture, long-term, conventional inorganic fertilizers	1999/00	WAI99/11
EW03-13	Te Kuiti loam; Typic Orthic Allophanic	Dairy pasture, long-term	1999/00	WAI99/9

3.2 Chemical and physical characteristics

Chemical and mean physical data are shown in Tables 3–5. Data have been grouped by soil type to make land-use contrasts more obvious. Individual values that fell outside the target ranges as specified by Sparling et al. (2003) are shown in bold type.

Chemical characteristics for the Wairama hill soils, Tirau silt loam, Oranui sand, Rukuhia peat, Korokanui silt loam and Te Kuiti loam were generally satisfactory for the land use concerned and fell within acceptable ranges. Olsen P was high (>50 µg/cm^3) on Oranui sand (site EW03_07) and Korakonui silt loam (EW03_11), both used for long-term dairy farming (Table 3).

There was a high incidence of low macroporosity, signifying soil compaction, on all soil types. All the sites with compacted soils were used for dairy or sheep-beef pastures.

Equivalent soils used for Radiata pine plantations were not compacted (>10% v/v). Air-filled porosity showed a similar pattern, being low (<12%), on all the pasture soils (Table 5).

3.3 Change in soil quality characteristic over time

The current data were compared against those previously collected. The data and percentage change are shown as a series of tables in the Appendix. However, the percentage change can vary markedly for some characteristics, particularly where the denominator value is small and there has been a relatively large change. For compact presentation, I have presented the changes as graphs for each of the soil characteristics. Where there has been no change in a characteristic between the two sampling dates, the point falls on the 1:1 line. Where a point falls *below* the 1:1 line it signifies the characteristic has *increased* since last measured, where the point falls *above* the line, it signifies the soil characteristic has *decreased* since last measured (See Fig. 1)

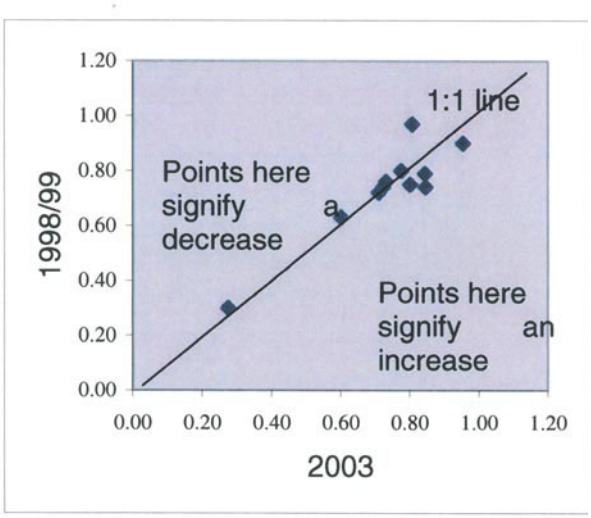


Figure 1: Example of the layout used to display change in soil quality characteristics.

Soil pH
Soil pH had increased on most of the resampled sites (Fig. 2). The values were in the acceptable range for pastures.

Total C
Total C showed no consistent change over the sampling period (Fig. 2).

Total N content
Total N also showed no consistent trends across the sites (Fig. 3), although a single site EW03-01, Wairama hill soil used for drystock farming showed a large increase in total N content. No known management changes can account for the large increase on that single site, and further sampling would be necessary to confirm the observation, particularly as there was no corresponding increase in mineralisable N.

Mineralisable N
Mineralisable N contents increased on some sites, decreased on others, and showed no consistent trend (Fig. 3). Overall, mineralisable N contents were in the range expected for dairy and drystock pastures.

Olsen P
Overall, Olsen P levels were similar to those when first sampled (Fig. 4), but site EW03-7 a dairy conversion in 1995 on Oruanui sand, and site EW03-11 a long-term dairy pasture on Korakanui sandy loam, had elevated Olsen P contents of 82 and 87 $\mu g/cm^{-3}$, respectively. Such values a well above the maximum levels (*ca.* 50 $\mu g/cm^{-3}$) required for pasture production (Roberts & Morton 1999).

Bulk density
Bulk density was relatively unchanged between the two sampling times (Fig. 5).

Macroporosity

The majority of pasture sites showed a marked decline in macroporosity compared with the earlier samples (Fig. 5). The two sites under pine plantation showed little change in macroporosity and were well above the suggested 10% macroporosity threshold. In contrast, all the pasture sites were below that limit, some markedly so.

Table 3: Soil chemical characteristics, Waikato Region 2003–2004, grouped by soil type

Code	Soil type	Land use	pH	Total C mg/cm^3	Total N mg/cm^3	C:N ratio	Olsen P µg/cm^3	NO_3^--N µg/cm^3	NH_4^+-N µg/cm^3	Anaer Min-N µg/cm^3
EW03-01	Wairama hill soils	Dry stock	5.65	103.3	9.14	11.3	24.0	14.4	1.3	165
EW03-02	Wairama hill soils	Pinus radiata (12yr)	4.87	68.9	4.63	14.9	8.0	7.8	10.3	47
EW03-03	Tirau silt loam	Dairy pasture since 2001	6.13	68.9	6.59	10.5	29.6	66.4	7.0	177
EW03-04	Tirau silt loam	Pinus radiata since1993	5.92	62.7	5.74	10.9	12.5	42.9	9.3	140
EW03-05	Tirau silt loam	Sheep-beef pasture	5.50	57.4	5.31	10.8	53.0	15.7	2.8	150
EW03-06	Tirau silt loam	Dairy pasture since 1993	6.24	66.6	6.58	10.1	35.4	20.0	6.5	171
EW03-07	Oruanui sand	Dairy pasture since 1995	6.09	53.8	4.27	12.6	**81.9**	32.7	9.9	130
EW03-08	Oruanui sand	Dairy pasture since 2000	6.46	51.6	3.75	13.8	25.3	8.6	18.5	95
EW03-09	Rukuhia peat	Dairy pasture, long-term	6.28	139.9	5.86	23.9	23.8	5.8	1.7	68
EW03-10	Rukuhia peat	Arable, silage maize	5.99	123.0	6.00	20.5	37.0	96.5	30.0	67
EW03-11	Korakonui s. l.	Dairy pasture, long-term	6.15	52.8	5.24	10.1	**86.7**	22.2	1.5	176
EW03-12	Korakonui s. l.	Dairy pasture, long-term,	6.22	49.1	4.79	10.2	48.0	9.7	3.1	178
EW03-13	Te Kuiti loam	Dairy pasture, long-term	6.34	85.4	8.53	10.0	17.9	8.9	2.6	192

*Items in bold type fell outside recommended ranges for that land use and soil order

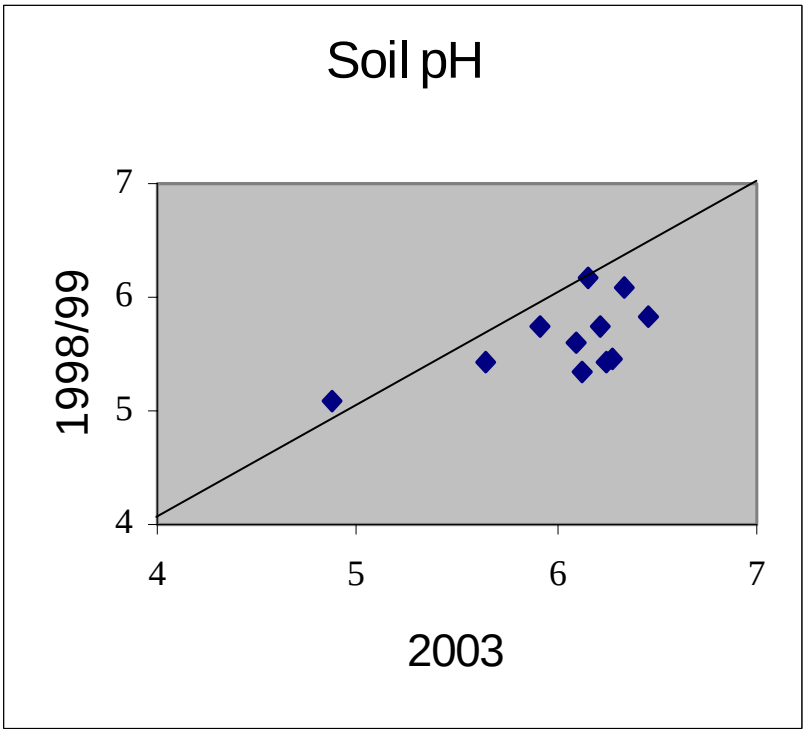
Table 4: Exchangeable cations by QuickTest methods for soil quality sites in the Waikato Region 2003–2004, grouped

			Exchangeable cations, QuickTest method cmol$^{(+)}$/kg			
Code	Soil	Land use	Ca	Mg	K	Na
EW03-01	Wairama hill soils	Dry stock	9.8	1.71	1.18	0.20
EW03-02	Wairama hill soils	Pinus radiata since 1991	5.7	4.68	0.76	0.64
EW03-03	Tirau silt loam	Dairy pasture since 2001	15.9	1.21	0.50	0.18
EW03-04	Tirau silt loam	Pinus radiata since1993	7.3	1.09	0.77	0.22
EW03-05	Tirau silt loam	Sheep-beef pasture	4.6	0.86	1.05	0.14
EW03-06	Tirau silt loam	Dairy pasture since 1993	13.6	2.02	1.04	0.19
EW03-07	Oruanui sand	Dairy pasture since 1995	10.1	0.84	0.50	0.05
EW03-08	Oruanui sand	Dairy pasture since 2000	11.8	0.63	0.36	0.08
EW03-09	Rukuhia peat	Dairy pasture, long-term	26.4	1.31	0.32	0.11
EW03-10	Rukuhia peat	Arable silage maize	27.8	1.49	1.01	0.10
EW03-11	Korakonui s. l.	Dairy pasture, long-term	11.0	2.42	1.88	0.16
EW03-12	Korakonui s. l.	Dairy pasture, long-term	12.7	1.53	0.59	0.13
EW03-13	Te Kuiti loam	Dairy pasture, long-term	14.1	1.88	0.63	0.16

Table 5: Soil physical characteristics sites sampled in the Waikato Region, 2003–2004, grouped by soil type and land use

Code	Soil type	Land use	Bulk density Mg m^3	Particle density Mg/m^3	Macro-porosity @ -5 kPa %v/v	Air-filled porosity @ -10kPa %v/v	Total porosity %v/v	Readily available water %v/v	Total available water %v/v
EW03-01	Wairama hill soils	Dry stock	0.807	2.28	**2.4**	**4.3**	65.5	12.9	29.0
EW03-02	Wairama hill soils	Pinus radiata since 1991	0.955	2.43	15.3	17.5	60.7	8.4	17.4
EW03-03	Tirau silt loam	Dairy pasture since 2001	0.802	2.25	**3.2**	**4.3**	65.5	10.3	31.7
EW03-04	Tirau silt loam	Pinus radiata since1993	0.724	2.26	16.9	21.4	67.9	10.3	19.9
EW03-05	Tirau silt loam	Sheep-beef pasture	0.782	2.30	**6.4**	**9.8**	66.0	11.4	31.9
EW03-06	Tirau silt loam	Dairy pasture since 1993	0.776	2.24	**2.6**	**5.0**	65.3	11.4	31.8
EW03-07	Oruanui sand	Dairy pasture since 1995	0.733	2.22	**4.8**	**8.4**	66.9	12.9	40.4
EW03-08	Oruanui sand	Dairy pasture since 2000	0.846	2.34	**9.8**	18.6	63.9	19.0	34.6
EW03-09	Rukuhia peat	Dairy pasture, long-term	0.289	1.579	**9.3**	13.7	81.7	16.6	42.1
EW03-10	Rukuhia peat	Arable silage maize	0.284	1.626	24.9	30.2	82.6	11.9	28.9
EW03-11	Korakonui s. l.	Dairy pasture, long-term	0.845	2.36	**3.3**	**6.0**	64.3	11.7	34.1
EW03-12	Korakonui s. l.	Dairy pasture, long-term	0.711	2.35	**7.4**	**10.7**	69.8	11.1	33.7
EW03-13	Te Kuiti loam	Dairy pasture, long-term	0.602	2.18	**6.2**	**8.7**	72.4	11.0	31.4

*Items in bold type fell outside recommended ranges for that land use and soil order



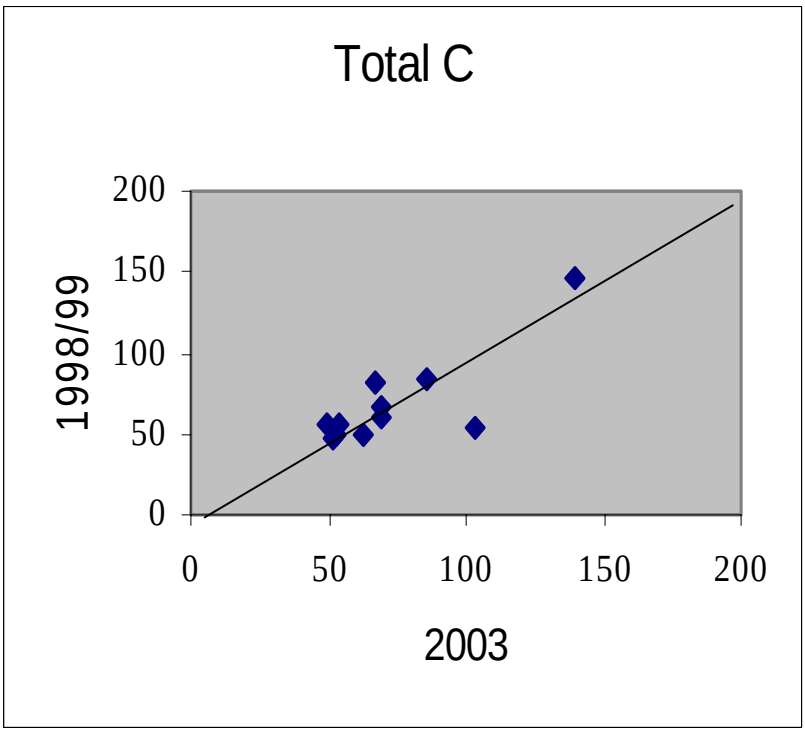
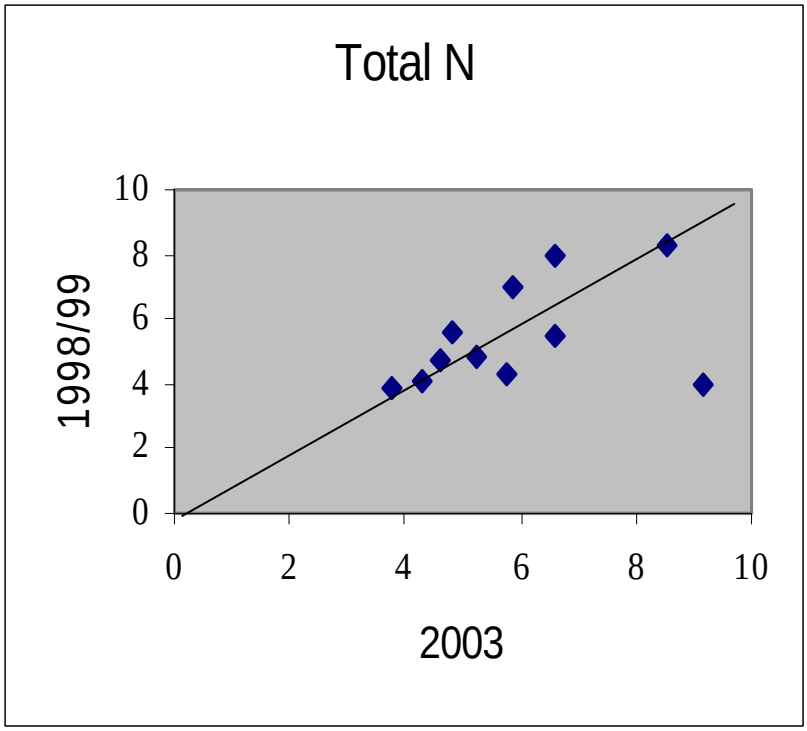


Figure 2: Soil pH and total C (µg/cm-3) in 11 Waikato sites in 2003 and 1998/9. Points below the line represent in increase since 1998/9; points above the line represent a decrease



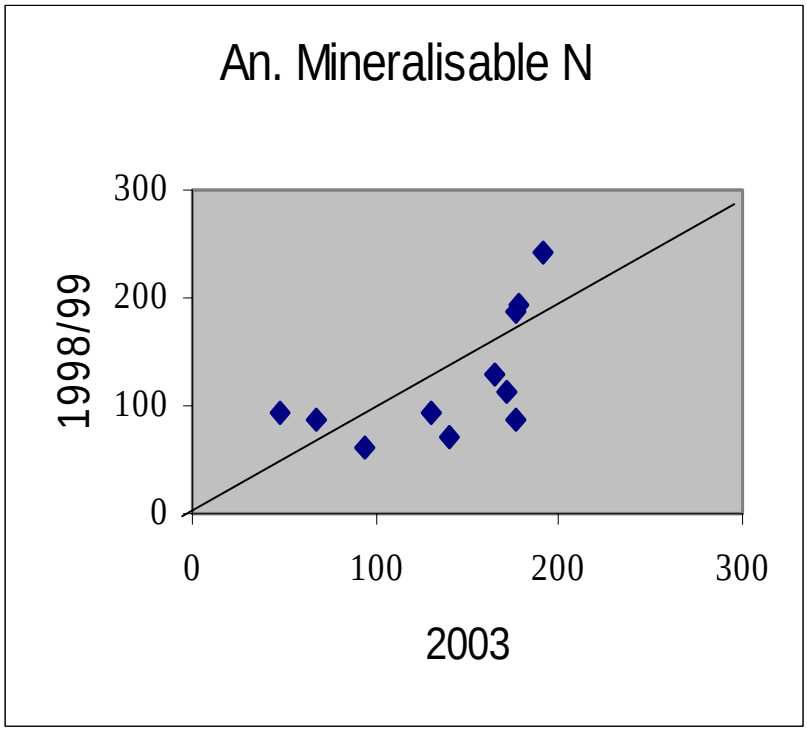


Figure 3: Total N and mineralisable N (µg/cm-3) in 11 Waikato sites in 2003 and 1998/9. Points below the line represent in increase since 1998/9; points above the line represent a decrease

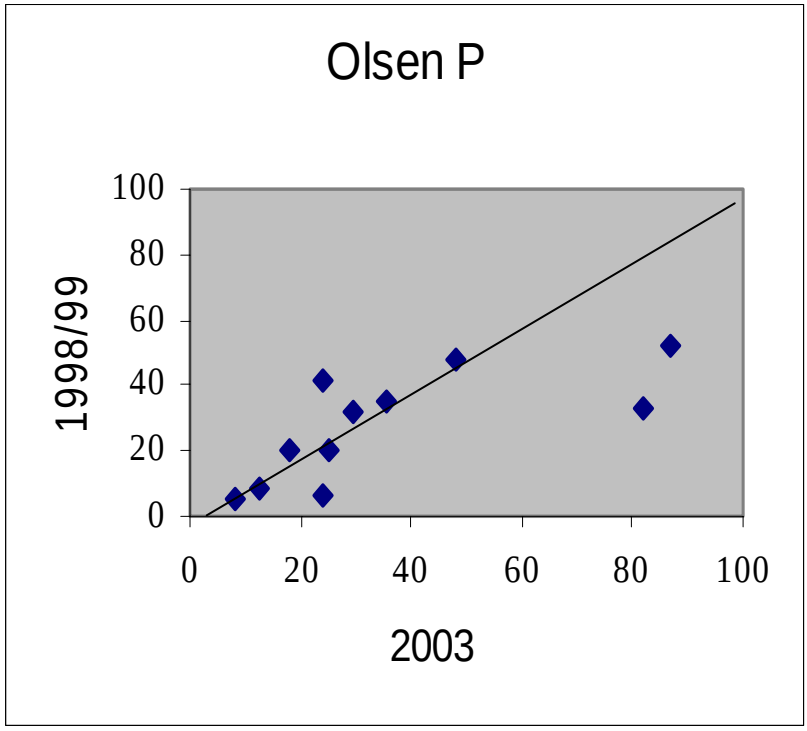
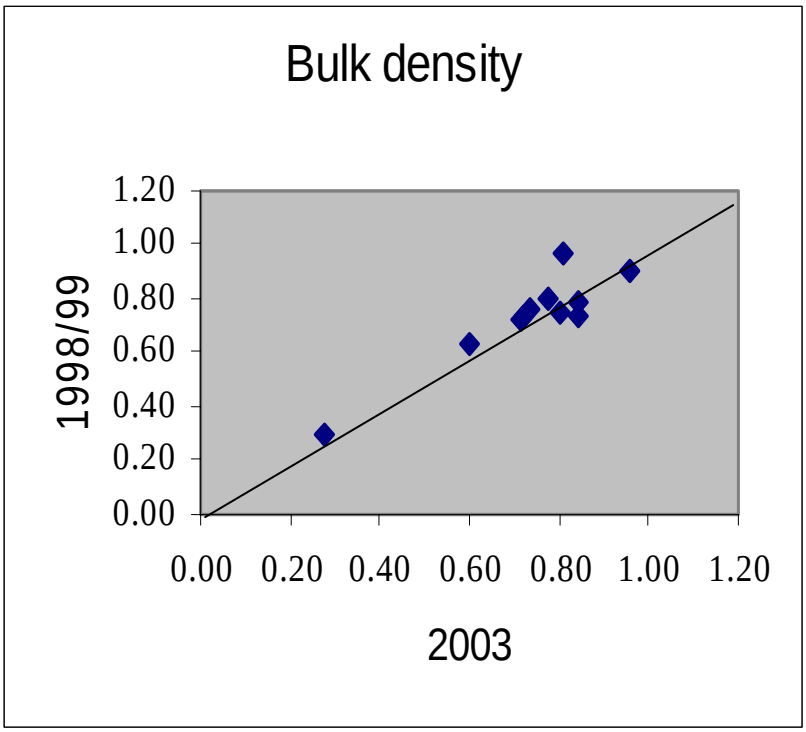


Figure 4: Olsen P (µg/cm-3) in 11 Waikato sites in 2003 and 1998/9. Points below the line represent in increase since 1998/9; points above the line represent a decrease



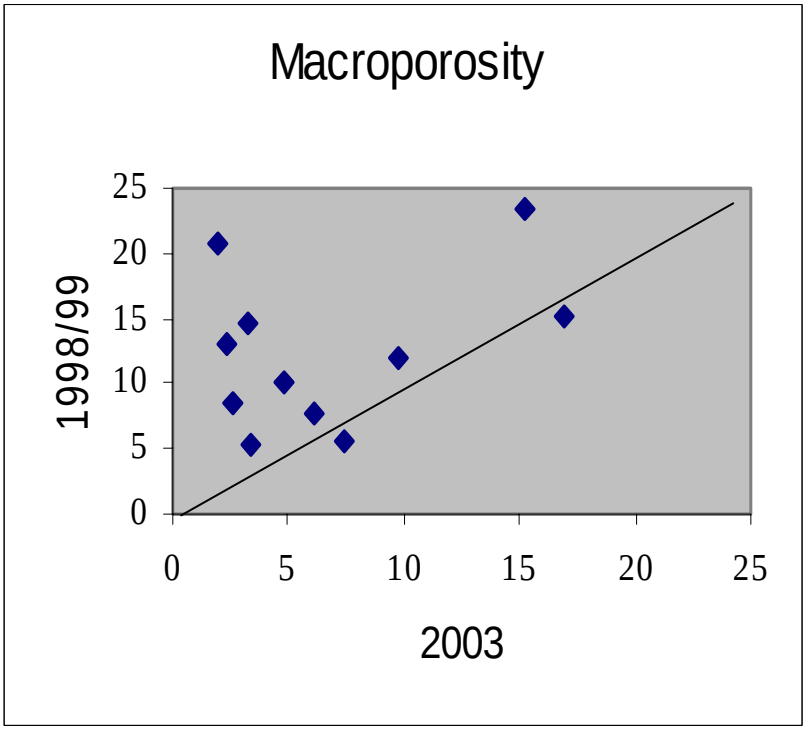


Figure 5: Bulk density (Mg/m-3) and macroporosity (%v/v) in 11 Waikato sites in 2003 and 1998/9. Points below the line represent in increase since 1998/9; points above the line represent a decrease

4 Discussion

The most distinct trend detected after resampling the sites after a 4–5 year period was a marked decrease in soil macroporosity on pasture sites. There was very little detectable change in bulk density demonstrating the much greater sensitivity of the macroporosity measure to soil compaction.

A decrease in macroporosity signifies soil compaction, and this occurred on all soil types measured. A number of the sites (EW03-03, EW03-08) had converted from sheep-beef to dairy farming since the first set of analyses, which could have been expected to increase treading by cattle. However, sites under long-term dry stock farming (EW03-01) also showed a marked decrease in macroporosity. In contrast, the two sites under pines both had high macroporosity. The decrease under pastures is of concern because the absolute values were frequently less than 10%v/v, which has been shown to reduce pasture production (Drewry et al. 2002). It seems likely that the lower macroporosity is a result of compaction caused by livestock treading. It would be useful to confirm whether stocking rates have increased on those farms, or whether pugging occurred due to animals being on the paddocks for extended periods during wet weather when the soil was below the plastic limit. There was no visual evidence of pugging when the sites were visited, and the soil surface had good grass cover with a moderately smooth soil surface.

Overall, other soil quality indicators were in acceptable ranges for those soils and land uses, although some (e.g., soil pH and Olsen P) had shown both increases and decreases between the two sampling dates. The timing of lime and fertiliser applications would have influenced these latter changes.

5 Conclusions

- The majority of soil quality characteristics fell within acceptable ranges for those soils and land uses
- Pasture soils showed evidence of compaction and low macroporosity
- There has been a marked increase in soil compaction (low macroporosity) in pasture sites since the earlier sampling, and the majority of sites were below the advisory 10% threshhold.

6 Recommendations

- Environment Waikato continues the policy of resampling previously characterised sites to confirm the trends in soil quality attributes arising from the current data. For reliable long-term detection and prediction of trends, at least 3 and preferably 5 points along a time sequence should be obtained.
- Farmers be made aware of the trend in decreasing macroporosity (compaction) of pasture soils, the potential effects of low macroporosity on pasture production, and be encouraged to adopt mitigation techniques.
- The new data and interpretative findings should be incorporated with existing information on the “Environmental Indicators” topic pages of the Environment Waikato website for public information

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Appendix I: Soil Analysis Results

Environmental Chemistry Laboratory

Client: Graham Sparling, Landcare Research, Hamilton

Job No.: LJ03071 Date In: 10/12/2003
Date Out: 10/02/2004

Client ID	Sample No.	pH(water)	Total C	Total N	KCl-extractable		Anaerobic Mineralisable-N	Olsen P	Exchangeable			
					NO3-N	NH4-N			Ca	Mg	K	Na
		(method 106)	(method 114) (%)	(method 114) (%)	(method 118) (mg/kg)		(method (120) (mg/kg)	(method 124) (mg/kg)	(method 142) (cmol(+)/kg)			
EW03_01	M3/1657	5.65	12.8	1.13	17.8	1.6	205	30	12.1	2.12	1.47	0.25
EW03_02	M3/1658	4.87	7.22	0.49	8.1	10.8	50	8	5.94	4.91	0.80	0.67
EW03_03	M3/1659	6.13	8.59	0.82	82.7	8.7	220	37	19.9	1.51	0.62	0.23
EW03_04	M3/1660	5.92	8.65	0.79	59.2	12.9	193	17	10.0	1.50	1.07	0.30
EW03_05	M3/1661	5.50	7.34	0.68	20.1	3.6	192	68	5.91	1.10	1.34	0.17
EW03_06	M3/1662	6.24	8.58	0.85	25.8	8.4	221	46	17.5	2.61	1.34	0.25
EW03_07	M3/1663	6.09	7.34	0.58	44.6	13.5	178	112	13.8	1.15	0.68	0.07
EW03_08	M3/1664	6.46	6.10	0.44	10.1	21.9	112	30	13.9	0.75	0.43	0.09
EW03_09	M3/1665	6.28	50.7	2.12	21.1	6.3	245	86	95.5	4.74	1.18	0.41
EW03_10	M3/1666	5.99	43.5	2.12	341	106	235	131	98.2	5.25	3.58	0.36
EW03_11	M3/1667	6.15	6.25	0.62	26.3	1.8	208	103	13.0	2.86	2.23	0.19
EW03_12	M3/1668	6.22	6.90	0.67	13.7	4.4	250	67	17.9	2.14	0.83	0.18
EW03_13	M3/1669	6.34	14.2	1.42	14.7	4.4	318	30	23.3	3.13	1.05	0.27

Lab Number	Client Id.	Initial Water Content (%, w/w)	Dry Bulk Density (t/m3)	Particle Density (t/m3)	Total Porosity (%, v/v)	Macro Porosity (10kPa) (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)	Vol. WC 100kPa (%, v/v)	Vol. WC 1500kPa (%, v/v)	Readily Available Water (%, v/v)	Total Available Water (%, v/v)
HP2115a	EW 03_01a	65.1	0.78	2.27	65.7	3.1	62.6	59.2	47.7	33.3	11.5	25.9
HP2115b	b	64.1	0.76	2.24	65.9	1.6	64.3	60.6	45.3	31.5	15.3	29.0
HP2115c	c	65.6	0.88	2.33	65.0	<1	65.0	64.0	52.2	31.9	11.8	32.1
HP2116a	EW 03_02a	38.7	0.94	2.39	60.9	20.3	40.6	38.8	32.8	29.3	6.0	9.5
HP2116b	b	41.0	0.95	2.41	60.8	14.7	46.1	43.3	31.6	22.6	11.6	20.6
HP2116c	c	40.9	0.98	2.49	60.5	10.8	49.7	47.7	40.2	25.5	7.5	22.2
HP2117a	EW 03_03a	63.2	0.83	2.29	63.8	1.4	62.3	60.0	50.2	28.8	9.8	31.2
HP2117b	b	66.6	0.85	2.27	65.9	<1	65.9	64.5	53.7	28.4	10.7	36.1
HP2117c	c	66.7	0.73	2.18	66.7	5.0	61.7	58.9	48.5	31.1	10.4	27.9
HP2118a	EW 03_04a	45.8	0.74	2.26	67.5	14.4	53.0	48.6	38.7	27.0	9.9	21.5
HP2118b	b	43.7	0.73	2.27	68.0	15.9	52.2	47.1	36.0	27.5	11.1	19.6
HP2118c	c	44.1	0.71	2.23	68.2	20.5	47.7	43.7	33.8	25.1	9.9	18.6
HP2119a	EW 03_05a	57.3	0.83	2.30	64.0	6.3	57.7	54.3	43.4	24.9	10.8	29.3
HP2119b	b	69.1	0.79	2.37	66.8	5.5	61.3	58.6	46.9	21.3	11.7	37.3
HP2119c	c	60.0	0.73	2.22	67.1	7.5	59.7	55.6	44.0	26.7	11.7	29.0
HP2120a	EW 03_06a	56.0	0.82	2.28	64.3	3.0	61.3	59.8	48.3	25.5	11.5	34.2
HP2120b	b	64.5	0.77	2.22	65.0	0.8	64.2	61.9	50.8	31.4	11.1	30.5
HP2120c	c	59.6	0.74	2.22	66.7	4.1	62.6	59.4	47.9	28.8	11.5	30.6
HP2121a	EW 03_07a	71.0	0.76	2.23	66.0	3.0	63.0	60.0	46.9	19.4	13.1	40.6
HP2121b	b	79.0	0.68	2.21	69.4	5.2	64.2	60.5	46.2	16.0	14.2	44.4
HP2121c	c	70.1	0.77	2.21	65.4	6.1	59.3	55.2	43.9	19.1	11.4	36.1
HP2122a	EW 03_08a	47.7	0.85	2.34	63.9	9.8	54.1	45.3	26.3	10.7	19.0	34.6
HP2122b	b	72.3	0.81	2.28	65.3	<1	65.3	63.0	46.6	14.1	16.4	48.9
HP2122c	c	71.8	0.76	2.28	66.6	5.5	61.2	57.6	40.5	13.8	17.2	43.8

Lab Number	Client Id.	Initial Water Content (%, w/w)	Dry Bulk Density (t/m3)	Particle Density (t/m3)	Total Porosity (%, v/v)	Macro Porosity (10kPa) (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)	Vol. WC 100kPa (%, v/v)	Vol. WC 1500kPa (%, v/v)	Readily Available Water (%, v/v)	Total Available Water (%, v/v)
HP2123a	EW 03_09a	278.3	0.28	1.57	82.5	1.9	80.6	76.7	59.6	27.6	17.0	49.1
HP2123b	b	212.6	0.30	1.60	81.5	14.1	67.4	62.9	49.2	22.2	13.7	40.6
HP2123c	c	223.7	0.30	1.56	81.1	11.9	69.3	64.5	45.4	28.0	19.2	36.6
HP2124a	EW 03_10a	186.4	0.28	1.64	82.8	27.2	55.6	50.3	40.0	24.0	10.3	26.3
HP2124b	b	197.7	0.26	1.61	84.1	29.7	54.3	48.6	36.0	22.1	12.5	26.5
HP2124c	c	193.9	0.31	1.63	80.8	17.7	63.1	58.3	45.3	24.5	13.0	33.8
HP2125a	EW 03_11a	65.8	0.81	2.33	65.4	3.0	62.4	60.3	49.4	24.7	10.9	35.7
HP2125b	b	57.9	0.83	2.38	64.9	5.8	59.2	56.4	45.9	24.1	10.5	32.4
HP2125c	c	59.8	0.89	2.38	62.5	1.2	61.3	58.2	44.3	24.0	13.8	34.2
HP2126a	EW 03_12a	77.7	0.69	2.34	70.6	7.6	63.0	59.8	49.3	23.6	10.5	36.2
HP2126b	b	61.1	0.66	2.36	71.9	13.9	58.0	54.2	43.0	25.6	11.1	28.5
HP2126c	c	72.5	0.78	2.36	66.8	0.7	66.1	63.2	51.4	26.8	11.8	36.4
HP2127a	EW 03_13a	95.1	0.60	2.16	72.1	5.2	67.0	64.6	52.9	32.9	11.6	31.7
HP2127b	b	92.2	0.59	2.20	73.2	8.3	64.8	62.1	51.7	30.4	10.4	31.7
HP2127c	c	91.1	0.61	2.19	72.0	5.0	67.0	64.6	53.6	33.6	11.0	30.9

Appendix II Site and Soil Profile Descriptions

13 Waikato Sites for Soil Quality Assessment

Paul Smith and Reece Hill
Environment Waikato.

Graham Sparling
Landcare Research, Hamilton

Site: EW03-1

Previously sampled in 1998 (WAI 98/11)

Soil Series	Wairama hill soils
GPS coordinates	R14 787 861 E2679337 N6385837
Location	Raglan,1 km down Clemens Road from Ruakiwi Road, opposite large house, Ruakiwi,
Transect length and direction °	50 m
Local contact person	Owner Tapp, 32 Clements Road,
Classification	Typic Orthic Brown Soil
Land use	Dry stock beef
Date sampled	4 December 2003
Land use history	Long-term pasture
Present vegetation	Pasture
Slope °	27 degree concavo convex midslope
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	100
Parent material	Siltstone
Drainage	Well drained
Topsoil depth (cm)	15
Total rooting depth (cm)	35
Limiting horizon	None identified
Sampled by	P. Smith, R. Hill, G. Sparling

Description:

Horizon	Depth	Description
Ah	0–15 cm	Dark brown (10YR 3/3) clay loam; sticky, slightly plastic; moderately weak soil strength; friable failure; moderately pedal; few weakly weathered angular siltstone gravels; many fine roots; distinct wavy boundary,
Bw1	15–30 cm	Brown (10YR 4/3) and dark yellowish brown (10YR 4/5) clay; sticky, plastic; moderately firm soil strength; friable failure; moderately pedal; common weakly weathered angular siltstone stones; common fine roots; indistinct wavy boundary,
Bw2	30–50 cm	Light yellowish brown (2.5Y 6/4) clay loam; few medium distinct yellowish brown mottles; sticky, plastic; moderately firm soil strength; brittle failure; weakly pedal; few fine roots; indistinct wavy boundary,
BC	50–100 cm	Light yellowish brown (2.5Y 6/4) clay; no mottles; sticky, plastic; moderately firm soil strength; deformable failure; no stones; massive.

Site: EW03-2

Previously sampled 1998 (WAI98/13)

Soil Series	Wairama hill soils
GPS coordinates	R14 783 872
Location	Raglan, 2 km west of Ruakiwi Road, 100 m west of Richardson Road, northern side of road; Ruakiwi.
Transect length and direction °	50 m along contour.
Local contact person	Owner Tapp, 32 Clements Road
Classification	Typic Orthic Brown Soil
Land use	Plantation forest
Date sampled	4 December 2003
Land use history	Pasture conveted to pine
Present vegetation	Pinus radiata, 12 yrs old
Slope °	25 degree concav o convex midslope, with teracettes
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	100
Parent material	Mudstone/Siltstone
Drainage	
Topsoil depth (cm)	8
Total rooting depth (cm)	27
Limiting horizon	Heavy clay at 60 cm
Sampled by	P. Smith, R. Hill, G. Sparling

Description:

Similar to profile of EW03/01 (WAI 98/11) site, but with common yellowish brown mottles in the BC horizon.

Site: EW03-3

Previously sampled in 1995/6 (WAI 95_2) and 1998/9 as (WAI98/3) when drystock pasture

Soil Series	Tirau silt loam
GPS coordinates	NZMS 260, sheet T15, 471569
Location	Mains Farm, Main Rd before Tirau. No. 77733. Site located in top paddock, turn right at the"Y"to top gate
Transect length and direction °	50 m, follow contour below water tank.
Local contact person	Andrew Main, RD 1, Tirau, Phone 078831693
Classification	Typic Orthic Allophanic Soil
Land use	Dairy pasture
Date sampled	4 December 2003
Land use history	Dairy farm, fertilised, converted in 2001 from long-term sheep and beef
Present vegetation	Improved ryegrass-clover pasture
Slope °	2°
Landform	Crest of strongly rolling landscape
Annual rain (mm)	1600
Elevation (m)	Ca. 180
Parent material	Rhyolitic tephra
Drainage	Well drained
Topsoil depth (cm)	
Total rooting depth (cm)	
Limiting horizon	
Sampled by	P. Smith, R. Hill, G. Sparling

Description:

The profile described for **site 2 (dry stock area)** was the same as that on site 1 (dairy) except the 2Bw horizon with the slow NaF test started at 120 cm depth

Site: EW03-4

Previously sampled 1995 (WAI 95 site 3) and 1998 (WAI98/2)

Soil Series	Tirau silt loam
GPS coordinates	NZMS 260, sheet T15, 471569 E2747724 N6355981
Location	Mains Farm, Main Rd before Tirau. No. 77733. Woodlot adjacent to dairy paddock
Transect length and direction °	50 m, follow stay on flat area at top of ridge use triangular transect
Local contact person	Andrew Main, RD 1, Tirau, Phone 078831693
Classification	Typic Orthic Allophanic Soil
Land use	Woodlot/
Date sampled	4 December 2003
Land use history	Pinus radiata planted in 1993, into long-term sheep-beef pasture.
Present vegetation	Radiata pine, sparse ferns weeds in understorey
Slope °	2°
Landform	Crest of strongly rolling landscape
Annual rain (mm)	1600
Elevation (m)	Ca 180
Parent material	Rhyolitic tephra
Drainage	Well drained
Topsoil depth (cm)	18
Total rooting depth (cm)	38
Limiting horizon	None identified
Sampled by	R Hill, P. Smith, G. Sparling

Description:

The profile for **site 3 (young pine forest)** is the same as that described for site 1 (dairy) except the 2Bw horizon with the slow NaF test started at about 120 cm depth

Site: EW03-05

(New Site) Previous drystock sites on same farm were WAI98/3 and WAI95 site 2.

Soil Series	Tirau silt loam
GPS coordinates	NZMS 260, sheet T15, 471569 E2746980 N6356845
Location	Mains Farm, Main Rd before Tirau. No. 77733. Drystock area adjacent to dairy site and woodlot. Transect on flat area at crest of ridge, follow contour.
Transect length and direction °	50 m, follow
Local contact person	Andrew Main, RD 1, Tirau, Phone 078831693
Classification	Typic Orthic Allophanic Soil
Land use	Sheep-beef pasture
Date sampled	4 December 2003
Land use history	Longterm sheep-beef pasture.
Present vegetation	Pasture for sheep and cattle
Slope °	2°
Landform	Crest of strongly rolling landscape
Annual rain (mm)	1600
Elevation (m)	182
Parent material	Rhyolitic tephra
Drainage	Well drained
Topsoil depth (cm)	18
Total rooting depth (cm)	55
Limiting horizon	None identified
Sampled by	R Hill, P. Smith, G. Sparling

Description: (from 1998/99 Report)

Horizon	Depth	Description
Ap	0–20 cm	Very dark brown (10 YR 2/2) loamy silt; moderately weak soil strength; moderately pedal with 2 to 6 mm polyhedral peds; abundant very fine roots; distinct wavy boundary; positive NaF test,
Bw1	20–35 cm	Dark yellowish brown (10 YR 3/6) silt loam; moderately weak soil strength; weakly pedal with 2 to 6 mm polyhedral peds; common very fine roots; indistinct wavy boundary, positive NaF test,
Bw2	35–40 cm	Dark yellowish brown (10 YR 4/4) silt loam; moderately weak soil strength; weakly pedal with 2 to 6 mm polyhedral peds; common very fine roots; distinct wavy boundary, very strong NaF test,
2Bw3	40–100 cm+	Yellowish brown (10 YR 5/4) silt loam; moderately weak soil strength; earthy; massive; few very fine roots; very slow NaF test

Site: EW03-6

Previously sampled 1995 (WAI Site 1) and 1998/99 (WAI98/1)

Soil Series	Tirau silt loam
GPS coordinates	NZMS 260, sheet T15, 471569 E2746980 N6356845
Location	Mains Farm, Main Rd before Tirau. No. 77733. Woodlot adjacent to dairy paddock
Transect length and direction °	50 m, follow contour below water tank.
Local contact person	Andrew Main, RD 1, Tirau, Phone 078831693
Classification	Typic Orthic Allophanic Soil
Land use	Dairy pasture
Date sampled	4 December 2003
Land use history	Long-term drystock pasture, converted to dairy pasture in 1993. Recently fertilised.
Present vegetation	Improved pasture, ryegrass-clover
Slope °	2°
Landform	Crest of strongly rolling landscape
Annual rain (mm)	1600
Elevation (m)	182
Parent material	Rhyolitic tephra
Drainage	Well drained
Topsoil depth (cm)	15
Total rooting depth (cm)	48
Limiting horizon	None identified
Sampled by	R Hill, P. Smith, G. Sparling

Description:

Horizon	Depth (cm)	Description
Ap	0–20 cm	Very dark brown (10 YR 2/2) loamy silt; moderately weak soil strength; moderately pedal with 2 to 6 mm polyhedral peds; abundant very fine roots; distinct wavy boundary; positive NaF test,
Bw1	20–35 cm	Dark yellowish brown (10 YR 3/6) silt loam; moderately weak soil strength; weakly pedal with 2 to 6 mm polyhedral peds; common very fine roots; indistinct wavy boundary, positive NaF test,
Bw2	35–40 cm	Dark yellowish brown (10 YR 3/6) silt loam; moderately weak soil strength; weakly pedal with 2 to 6 mm polyhedral peds; common very fine roots; indistinct wavy boundary, positive NaF test,
2Bw3	40–100 cm	Yellowish brown (10 YR 5/4) silt loam; moderately weak soil strength; earthy; massive; few very fine roots; very slow NaF test

Site: EW03-7

Previously sampled 1998/99 (WAI98/7)

Soil Series	Oruanui sand
GPS coordinates	U17 772873; E2777520, N6287746
Location	No 770 State Highway 1, close to Palmer Mill Road, (north Taupo),
Transect length and direction °	50 m along crest
Local contact person	R.D.J.McNae, Phone 07 378 0946, owner
Classification	Podzolic Orthic Pumice Soil
Land use	Dairy pasture
Date sampled	5 December 2003
Land use history	Long term dry stock pasture converted to dairy in 1995
Present vegetation	Pasture
Slope °	2 to 3 degree crest
Landform	Rolling country
Annual rain (mm)	1400
Elevation (m)	567
Parent material	Taupo Pumice
Drainage	Well drained
Topsoil depth (cm)	10–15
Total rooting depth (cm)	60
Limiting horizon	None identified
Sampled by	P. Smith, G. Sparling

Description:

Horizon	Depth	Description
Ap	0–16 cm	Black (10 YR 2/1) loamy sand; very weak soil strength; friable failure; earthy; few weakly weathered subrounded Taupo lapilli; common fine roots; distinct wavy boundary,
Bs	16–27 cm	Strong brown (7.5 YR 4/6) sand; very weak soil strength; friable failure; weakly pedal; common fine roots; distinct wavy boundary,
Bw	27–65 cm	Light yellowish brown (2.5 Y 6/4) sand; very weak soil strength; friable failure; massive; few fine roots; distinct smooth boundary,

Site: EW03-8

Previously sampled in 1998 (WAI98/06)

Soil Series	Oruanui sand
GPS coordinates	U17 772873: E2776952, N6287918 ±12m
Location	No. 770 State Highway 1, close to Palmer Mill Road, (north Taupo)
Transect length and direction °	50 m along crest
Local contact person	Owner R.D.J.McNac, Phone 07 378 0946
Classification	Podzolic Orthic Pumice Soil
Land use	Long-term pasture
Date sampled	5 December 2003
Land use history	Recent dairy conversion in 2000. Former drystock
Present vegetation	Pasture
Slope °	2 to 3 degree crest
Landform	Rolling country
Annual rain (mm)	1400
Elevation (m)	564
Parent material	Taupo Pumice
Drainage	
Topsoil depth (cm)	Variable 8–18 cm
Total rooting depth (cm)	
Limiting horizon	None identified
Sampled by	P. Smith, G. Sparling

Description: (From WAI98-06)

Horizon	Depth	Description
Ap	0–16 cm	Black (10 YR 2/1) loamy sand; very weak soil strength; friable failure; earthy; few weakly weathered subrounded Taupo lapilli; common fine roots; distinct wavy boundary,
Bs	16–27 cm	Strong brown (7.5 YR 4/6) sand; very weak soil strength; friable failure; weakly pedal; common fine roots; distinct wavy boundary,
Bw	27–65 cm	Light yellowish brown (2.5 Y 6/4) sand; very weak soil strength; friable failure; massive; few fine roots; distinct smooth boundary,
BC	65–100 cm+	Light yellowish brown (2.5 Y 6/4) pumice gravel; loose; single grain; no live roots; (Taupo lapilli)

Site: EW03-9

Previously sampled 1998 (WAI 98-15)

Soil Series	Rukuhia peat
GPS coordinates	S15 186 615 E2719601 N6362052
Location	Moanatuatua swamp, Dairy 73515; approach from Wallace Road, past dairy shed, along race to paddock G8.
Transect length and direction °	50 m – parallel to shelter-belt, 50 m distant. Midcrest.
Local contact person	Wallace Farm, Cambridge, Phone 827 7892
Classification	Acid or Mellow Fibric Organic Soil
Land use	Dairy pasture
Date sampled	9 December 2003
Land use history	Long-term pasture for dairying
Present vegetation	Pasture
Slope °	Flat
Landform	Swamp in basin
Annual rain (mm)	1400
Elevation (m)	45
Parent material	Peat
Drainage	Very poorly drained, artificially well drained on raised humps
Topsoil depth (cm)	NA
Total rooting depth (cm)	32
Limiting horizon	Shallow water table
Sampled by	R. Hill, P. Smith, G. Sparling

Description:

Horizon	Depth	Description
Oh	0–12 cm	Black (5 YR 2/1) peat; non-sticky, non-plastic; very weak soil strength; very friable failure; earthy; many fine roots; distinct smooth boundary,
Om	12–34 cm	Dark reddish brown (5 YR 2/2) peat; very weak soil strength; friable failure; massive; few fine roots; indistinct wavy boundary,
Of	34–100 cm	Dark reddish brown (5 YR 2/2) peat; very weak soil strength; friable failure; massive no roots

Site: EW03-10

Soil Series	Rukuhia peat
GPS coordinates	E2719096 N6361599
Location	Moanatuatua swamp, Dairy 73515; approach from Wallace Road, past dairy shed, along race to paddock G7 (adjacent to pasture site G8)
Transect length and direction °	50 m, 25 n from shelter belt, parallel to windbreak
Local contact person	Wallace Farm, Cambridge, Phone 827 7892
Classification	Acid or Mellow Fibric Organic Soil
Land use	Arable, maize for silage, fodder
Date sampled	9 December 2003
Land use history	Dairy farming, pasture currently in fodder maize.
Present vegetation	Maize
Slope °	Flat
Landform	Swamp in basin
Annual rain (mm)	1400
Elevation (m)	45
Parent material	Peat
Drainage	Very poorly drained
Topsoil depth (cm)	
Total rooting depth (cm)	30
Limiting horizon	Seasonal waterlogging at variable depth
Sampled by	R. Hill, P. Smith, G. Sparling

Description:

Horizon	Depth	Description
Oh	0–12 cm	Black (5 YR 2/1) peat; non-sticky, non-plastic; very weak soil strength; very friable failure; earthy; many fine roots; distinct smooth boundary,
Om	12–34 cm	Dark reddish brown (5 YR 2/2) peat; very weak soil strength; friable failure; massive; few fine roots; indistinct wavy boundary,
Of	34–100 cm	Dark reddish brown (5 YR 2/2) peat; very weak soil strength; friable failure; massive no roots

Site: EW03-11

Previously sampled 1999 (WAI99/10)

Soil Series	Korakonui sandy loam
GPS coordinates	S16 056 323 E2705706 N6332179
Location	2 km southeast of Otorohanga, Rangiatea Road, 200 m north of Rangiatea Road, 40 m west of dairy shed. Paddock 19
Transect length and direction °	50 m
Local contact person	
Classification	Typic Tephric Recent Soil
Land use	Dairying using fowl manure (receives 3.5 tonnes/year) and trace elements
Date sampled	8 December 2003
Land use history	Dairying using fowl manure (receives 3.5 tonnes/year) and trace elements until 2002.
Present vegetation	Improved pasture rye grass - white clovere
Slope °	Flat
Landform	River flat
Annual rain (mm)	1400
Elevation (m)	40
Parent material	Alluvium derived from Taupo Pumice
Drainage	Moderately well drained
Topsoil depth (cm)	12
Total rooting depth (cm)	20
Limiting horizon	None identified
Sampled by	R.Hill, P. Smith, G. Sparling

Description:

Horizon	Depth (cm)	Description
Ap	0–15 cm	Dark brown (10 YR 3/3) sandy loam; slightly sticky; non-plastic; moderately weak soil strength; friable failure; earthy; few weakly weathered rounded pumice gravels to 2 cm diam.; common fine and very fine roots; sharp wavy boundary,
Bw	15–20 cm	Light olive brown (2.5 Y 5/4) fine sand; with few fine faint yellowish brown (10 YR 5/4) mottles; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few weakly weathered rounded pumice gravels to 2 cm diam.; few fine and very fine roots; indistinct wavy boundary,
C1	20–35 cm	Light yellowish brown (2.5 Y 6/4) gravelly fine sand; no mottles; very weak soil strength; friable failure; massive breaking to single grain; common weakly weathered rounded pumice gravels (2 to 20 mm diam.); few very fine roots; distinct smooth boundary,
C2	35–100cm	Light yellowish brown (2.5 Y 6/4) sand; few fine and medium distinct yellowish brown (10 YR 5/6) mottles; very weak soil strength; friable failure; massive breaking to single grain; no live roots; distinct smooth boundary,
Cg	100–120 cm+	Greyish brown (2.5 Y 5/2) fine sand; with few medium distinct strong brown (7.5 YR 5/6) mottles; very weak soil strength; friable failure; massive; no live roots.

Site: EW03-12

Previously sampled in 1999 (WAI99/11)

Soil Series	Korakonui sandy loam
GPS coordinates	S16 064 317; E2706059, N6331805
Location	3 km southeast of Otorohanga, Rangiatea Road, (see sketch on field sheet) Dairy no. 74462
Transect length and direction °	50m, 25 m from fenceline looking at transformer box
Local contact person	Owner Stuart Phillips; RD2; Otorohanga
Classification	Typic Tephric Recent Soil
Land use	Dairy pasture
Date sampled	8 December 2003
Land use history	(uses little 30% potassic super)
Present vegetation	Improved rye grass-white clover pasture
Slope °	Flat
Landform	River flat
Annual rain (mm)	1400
Elevation (m)	40
Parent material	Alluvium derived from Taupo Pumice
Drainage	Moderately well drained
Topsoil depth (cm)	17
Total rooting depth (cm)	38
Limiting horizon	None identified
Sampled by	R. Hill, P. Smith, G. Sparling

Description:
Description: see profile of WAI 99/10

Horizon	Depth (cm)	Description
Ap	0–15 cm	Dark brown (10 YR 3/3) sandy loam; slightly sticky; non-plastic; moderately weak soil strength; friable failure; earthy; few weakly weathered rounded pumice gravels to 2 cm diam.; common fine and very fine roots; sharp wavy boundary,
Bw	15–20 cm	Light olive brown (2.5Y 5/4) fine sand; with few fine faint yellowish brown (10YR 5/4) mottles; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few weakly weathered rounded pumice gravels to 2 cm diam.; few fine and very fine roots; indistinct wavy boundary,
C1	20–35 cm	Light yellowish brown (2.5 Y 6/4) gravelly fine sand; no mottles; very weak soil strength; friable failure; massive breaking to single grain; common weakly weathered rounded pumice gravels (2 to 20 mm diam.); few very fine roots; distinct smooth boundary,
C2	35–100cm	Light yellowish brown (2.5 Y 6/4) sand; few fine and medium distinct yellowish brown (10 YR 5/6) mottles; very weak soil strength; friable failure; massive breaking to single grain; no live roots; distinct smooth boundary,
Cg	100–120 cm+	Greyish brown (2.5 Y 5/2) fine sand; with few medium distinct strong brown (7.5 YR 5/6) mottles; very weak soil strength; friable failure; massive; no live roots.

Site: EW03-13

Previously sampled in 1999 (WAI99-9)

Soil Series	Te Kuiti loam
GPS coordinates	S16 135 225 E2713547 N6322636 ±5m
Location	Southeast of Otorohanga; Barber Road, west of Toa Bridge. Turn rt at RAN 644 Barber Rd, continue up track to top of knoll before the tank
Transect length and direction °	50 m along crest
Local contact person	Owner Leslie Dunn, 565 Barber Road, RD 5, Otorohanga
Classification	Typic Orthic Allophanic Soil
Land use	Dairying:
Date sampled	8 December 2003
Land use history	Longterm pasture, receives 15% potassic super and 1 ton of lime annually, also N, Mg 3 yearly
Present vegetation	Improved pasture rye grass-white clover
Slope °	2°
Landform	Planar to convex broad hill crest
Annual rain (mm)	1600
Elevation (m)	310
Parent material	Rhyolitic and some andesitic tephra
Drainage	Well drained
Topsoil depth (cm)	14
Total rooting depth (cm)	55
Limiting horizon	None identified
Sampled by	R. Hill, P. Smith, G. Sparling

Description:

Horizon	Depth (cm)	Description
Ap	0–18 cm	Very dark greyish brown (10 YR 3/2) loam; slightly sticky; non-plastic; moderately weak soil strength; friable failure; moderately pedal; many fine and very fine roots; distinct smooth boundary,
Bw1	18–60 cm	Strong brown (10 YR 4/6) loam; slightly sticky; non-plastic; moderately weak soil strength; friable failure; weakly pedal; common very fine and fine roots; distinct wavy boundary,
Bw2	60–100 cm+	Strong brown to dark yellowish brown (7.5 YR to 10 YR 4/6) silt loam; slightly sticky; on plastic; moderately firm soil strength; friable failure; weakly pedal; few very fine roots.

Appendix III: Changes in soil quality characteristics on a site by site basis

Table 6: Changes in soil quality characteristic of Wairama hill soil between sampling times in 1998 and 2001 (EW03-01 and WAI98-11)

Wairama hill soils, Dry stock	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.43	5.65	No change	4
Total C (mg/cm^3)	54.1	103.3	Increase	48
Total N (mg/cm^3)	4.00	9.14	Increase	56
Anaerobic min-N (µg/cm^3)	129.	165	Increase	22
Olsen P (µg/cm^3)	6.0	24.0	Increase	75
Bulk density (Mg/m^3)	0.97	0.807	Decrease	-20
Particle density (Mg/m^3)	2.51	2.28	Decrease	-10
Total porosity (%v/v)	61.2	65.5	No change	7
Macroporosity (%v/v)	12.9	2.4	Decrease	-449
Air-filled porosity		4.3		
Readily available water (%v/v)	6.40	12.9	Increase	50
Total available water (%v/v)	17.40	29.0	Increase	40

Table 7: Changes in soil quality characteristic of Wairama hill soils between sampling times in 1998 and 2001 (EW03_02, WAI98_3)

Wairama hill soils, Pines 12 yr	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.10	4.87	Decrease	-5
Total C (mg/cm^3)	66.7	68.9	No change	3
Total N (mg/cm^3)	4.7	4.63	No change	-1
Anaerobic min-N (µg/cm^3)	93	47	Decrease	-98
Olsen P (µg/cm^3)	5.1	8.0	No change	36
Bulk density (Mg/m^3)	0.90	0.955	No change	6
Particle density (Mg/m^3)	2.41	2.43	No change	1
Total porosity (%v/v)	62.3	60.7	No change	-3
Macroporosity (%v/v)	23.4	15.3	Decrease	-53
Air-filled porosity		17.5		
Readily available water (%v/v)	5.0	8.4	Increase	40
Total available water (%v/v)	12.6	17.4	Increase	28

Table 8: Changes in soil quality characteristic of Tirau silt loamsoil between sampling times in 1998 and 2001 (EW03_03; WAI98_3)

Tirau silt loam, dairy since 2001	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.33	6.13	Increase	13
Total C (mg/cm^3)	60.8	68.9	Increase	12
Total N (mg/cm^3)	5.5	6.59	Increase	17
Anaerobic min-N (µg/cm^3)	87.2	177	Increase	51
Olsen P (µg/cm^3)	31.4	29.6	Decrease	-6
Bulk density (Mg/m^3)	0.75	0.802	Increase	6
Particle density (Mg/m^3)	2.26	2.25	No change	0
Total porosity (%v/v)	66.7	65.5	No change	-2
Macroporosity (%v/v)	14.5	3.2	Decrease	-353
Air-filled porosity		4.3		
Readily available water (%v/v)	9.6	10.3	Increase	7
Total available water (%v/v)	25.6	31.7	Increase	19

Table 9: Changes in soil quality characteristic of Tirau silt loam between sampling times in 1998 and 2001 (EW03_04; WAI98_2)

Tirau silt loam, Pines since 1993	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.8	5.92	No change	3
Total C (mg/cm^3)	49.3	62.7	Increase	21
Total N (mg/cm^3)	4.3	5.74	Increase	25
Anaerobic min-N (µg/cm^3)	71.5	140	Increase	49
Olsen P (µg/cm^3)	8.3	12.5	Increase	34
Bulk density (Mg/m^3)	0.74	0.724	No change	-2
Particle density (Mg/m^3)	2.27	2.26	No change	-1
Total porosity (%v/v)	67.4	67.9	No change	1
Macroporosity (%v/v)	15.2	16.9	Increase	10
Air-filled porosity		21.4		
Readily available water (%v/v)	9.7	10.3	Increase	6
Total available water (%v/v)	27.3	19.9	Decrease	-37

Table 10: Changes in soil quality characteristic of Tirau silt loam between sampling times in 1998 and 2001 (EW03_06; WAI98_1)

Tirau silt loam, Dairy since 1993	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.42	6.24	Increase	13
Total C (mg/cm^3)	81.8	66.6	Decrease	-23
Total N (mg/cm^3)	8.00	6.58	Decrease	-22
Anaerobic min-N (µg/cm^3)	113	17	Increase	34
Olsen P (µg/cm^3)	34.9	35.4	No change	1
Bulk density (Mg/m^3)	0.80	0.78	No change	-3
Particle density (Mg/m^3)	2.23	2.24	No change	0
Total porosity (%v/v)	64.3	65.3	No change	2
Macroporosity (%v/v)	8.60	2.6	Decrease	-227
Air-filled porosity		5.0		
Readily available water (%v/v)	9.3	11.4	Increase	18
Total available water (%v/v)	26.0	31.8	Increase	18

Table 11: Changes in soil quality characteristic of Oruanui sand between sampling times in 1998 and 2001 (EW03_07; WAI98_7)

Oruanui sand, Dairy since 1995	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.59	6.09	Increase	8
Total C (mg/cm^3)	55.4	53.8	Decrease	-3
Total N (mg/cm^3)	4.1	4.27	No change	4
Anaerobic min-N (µg/cm^3)	92.1	130	Increase	29
Olsen P (µg/cm^3)	32.6	81.9	Increase	60
Bulk density (Mg/m^3)	0.76	0.733	No change	-4
Particle density (Mg/m^3)	2.25	2.22	No change	-2
Total porosity (%v/v)	66.4	66.9	No change	1
Macroporosity (%v/v)	10	4.8	Decrease	-110
Air-filled porosity		8.4		
Readily available water (%v/v)	17.5	12.9	Decrease	-36
Total available water (%v/v)	37.3	40.4	Increase	8

Table 12: Changes in soil quality characteristic of Oruanui sand between sampling times in 1998 and 2003

Oruanui sand, dairy since 2000	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.84	6.46	Increase	10
Total C (mg/cm^3)	47.6	51.6	Increase	8
Total N (mg/cm^3)	3.9	3.75	No change	-4
Anaerobic min-N (µg/cm^3)	60.5	95	Increase	36
Olsen P (µg/cm^3)	19.7	25.3	Increase	22
Bulk density (Mg/m^3)	0.74	0.846	Increase	13
Particle density (Mg/m^3)	2.19	2.34	Increase	7
Total porosity (%v/v)	66.1	63.9	Decrease	-3
Macroporosity (%v/v)	12	9.8	Decrease	-22
Air-filled porosity		18.6		
Readily available water (%v/v)	15.4	19.0	Increase	19
Total available water (%v/v)	34.6	34.6	No change	0

Table 13: Changes in soil quality characteristic of Oruanui sand between sampling times in 1998 and 2003

Oruanui sand, dairy since 2000	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.84	6.46	Increase	10
Total C (mg/cm^3)	47.6	51.6	Increase	8
Total N (mg/cm^3)	3.9	3.75	No change	-4
Anaerobic min-N (µg/cm^3)	60.5	95	Increase	36
Olsen P (µg/cm^3)	19.7	25.3	Increase	22
Bulk density (Mg/m^3)	0.74	0.846	Increase	13
Particle density (Mg/m^3)	2.19	2.34	Increase	7
Total porosity (%v/v)	66.1	63.9	Decrease	-3
Macroporosity (%v/v)	12	9.8	Decrease	-22
Air-filled porosity		18.6		
Readily available water (%v/v)	15.4	19.0	Increase	19
Total available water (%v/v)	34.6	34.6	No change	0

Table 14: Changes in soil quality characteristic of Rukuhia peat between sampling times in 1998 and 2003 (EW03_09; WAI98_15)

Rukuhia peat, long-term dairy	Dates sampled			
Soil property	1998	2003		Change (%)
Soil pH	5.46	6.28	Increase	13
Total C (mg/cm^3)	146.5	139.9	No change	-5
Total N (mg/cm^3)	7	5.86	Decrease	-19
Anaerobic min-N (µg/cm^3)	86.1	68	Decrease	-27
Olsen P (µg/cm^3)	41.3	23.8	Decrease	-74
Bulk density (Mg/m^3)	0.3	0.29	Decrease	-4
Particle density (Mg/m^3)	1.59	1.58	No change	-1
Total porosity (%v/v)	81	81.7	No change	1
Macroporosity (%v/v)	20.8	9.3	Decrease	-124
Air-filled porosity	ND	13.7		
Readily available water (%v/v)	14.2	16.6	Increase	15
Total available water (%v/v)	30.6	42.1	Increase	27

Table 15: Changes in soil quality characteristic of Korakonui sandy loam between sampling times in 1998 and 2003 (EW03_11; WAI99_10

Korakonui sandy loam, long-term dairy (organic manures)	Dates sampled			
Soil property	1999	2003		Change (%)
Soil pH	6.17	6.15	No change	0
Total C (mg/cm^3)	48.4	52.8	Increase	8
Total N (mg/cm^3)	4.89	5.24	Increase	7
Anaerobic min-N (µg/cm^3)	187	176	Decrease	-6
Olsen P (µg/cm^3)	51.6	86.7	Increase	41
Bulk density (Mg/m^3)	0.79	0.845	Increase	6
Particle density (Mg/m^3)	2.33	2.36	No change	1
Total porosity (%v/v)	65.9	64.3	No change	-3
Macroporosity (%v/v)	5.3	3.3	Decrease	-59
Air-filled porosity		6.0		
Readily available water (%v/v)	13.3	11.7	Decrease	-13
Total available water (%v/v)	34.2	34.1	No change	0

Table 16: Changes in soil quality characteristic of Korakonui sandy loam between sampling times in 1999 and 2003

Korakonui sandy loam, long-term dairy (conventional)	Dates sampled			
Soil property	1999	2003		Change (%)
Soil pH	5.73	6.22	Increase	8
Total C (mg/cm^3)	55.9	49.1	Decrease	-14
Total N (mg/cm^3)	5.54	4.79	Decrease	-16
Anaerobic min-N (µg/cm^3)	194.5	178	Increase	-9
Olsen P (µg/cm^3)	47.8	48.0	No change	0
Bulk density (Mg/m^3)	0.72	0.711	No change	-1
Particle density (Mg/m^3)	2.33	2.35	No change	1
Total porosity (%v/v)	69.6	69.8	No change	0
Macroporosity (%v/v)	5.5	7.4	Increase	26
Air-filled porosity		10.7		
Readily available water (%v/v)	11.7	11.1	No change	-5
Total available water (%v/v)	39.1	33.7	Decrease	-16

Table 17: Changes in soil quality characteristic of Te Kuiti loam between sampling times in 1999 and 2003

Te Kuiti loam, long-term dairy (conventional)	Dates sampled			
Soil property	1999	2003		Change (%)
Soil pH	6.09	6.34	No change	4
Total C (mg/cm^3)	83.5	85.4	No change	2
Total N (mg/cm^3)	8.29	8.53	No change	3
Anaerobic min-N (µg/cm^3)	241.8	192	Decrease	-26
Olsen P (µg/cm^3)	19.8	17.9	Decrease	-11
Bulk density (Mg/m^3)	0.63	0.602	No change	-5
Particle density (Mg/m^3)	2.21	2.18	No change	-1
Total porosity (%v/v)	71.6	72.4	No change	1
Macroporosity (%v/v)	7.6	6.2	Decrease	-23
Air-filled porosity		8.7		
Readily available water (%v/v)	10.2	11.0	Increase	7
Total available water (%v/v)	28.5	31.4	Increase	9