Soil quality in Northland 2007: comparison with previous samplings in 2001

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Contents

Summary

Project and Client

Northland Regional Council (NRC) participated in the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" in 2000–2001. That project ceased in June 2001. NRC resampled sites in 2007 to determine the extent and direction of changes in soil condition. Soil quality analysis using the same protocols has also been followed by Environment Waikato, Environment BOP, and Greater Wellington Regional Council with current sampling by Taranaki RC, and Marlborough DC.

The NRC staff with responsibility for land resources resampled original sites and supplied them to Landcare Research for analyses and interpretation.

Soil quality on the sites was appraised using a standard set of soil chemical, physical and biochemical characteristics as defined under the 500 Soils Project protocols, and currently used by other regional councils in New Zealand. A suite of metals was also analysed on the samples.

Objectives

- Complete analyses on soil samples provided by NRC staff.
- Provide an assessment of the current soil quality status of the soils as related to soil class and land use.
- Provide interpretation of changes in soil characteristics in relation to previous samples taken in 2001.

Methods

- NRC land resource staff resampled sites and supplied soil samples to Landcare Research.
- A standard set of 7 soil characteristics was used by Landcare Research to assess soil quality of the various soil and land-use combinations. The concentrations of a range of trace metals were also measured.
- 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 25 sites were tested for a total of 175 soil quality characteristics, 20 (11%) of which were outside target ranges. Nine sites (36%) met all targets, 13 sites (52%) did not meet the target range for one characteristic, two sites (8%) did not meet the target ranges for two characteristics and one site (4%), a recent conversion from market garden farming to drystock, did not meet the target range for three characteristics.
- Low macroporosity (an indication of soil compaction), primarily on dairy and drystock sites, was the soil quality indicator most often outside of target ranges (11 of the 20 instances where target values were outside of ranges). Other indicators outside

target values included low Olsen P values (3 instances on drystock sites) and pH values (2 instances of low pH, a drystock site and a dairy site, and 2 instances of high pH, on a drystock site recently converted from market gardening, and an indigenous vegetation site).
- The majority of sites not meeting all targets were generally dairy sites (7 of 7 sites not meeting targets, largely due to low macroposoity) or drystock sites (6 of 8 sites not meeting targets, most due to low macroporosity or low Olsen P values).
- In comparison with samples taken during 2001, macroporosity was significantly lower on dairy and drystock sites. Mineralisable nitrogen was also significantly lower on dairy and drystock sites, but in the absence of change in other indicators (and a general trend across several landuses), this was may be due to difference in seasonal fluctuations in biological activity or a changes in timing of sampling.
- Few significant changes (either positive or negative) occurred on forestry or horticultural and cropping sites.

Conclusions

- The low macroporosity values (and decrease in values since the previous sampling) on dairy and drystock sites mirror results from other regions of the country and are a general result of intensification of these land-use practices.
- Primary concerns are (1) compaction of soils on dairy and drystock sites; (2) the low nutrient (Olsen P) status of drystock sites. Soil pH was also below target values on several sites. Macroporosity and mineralisable nitrogen values were lower than the previous sampling in 2001, otherwise, few consistent changes (either positive or negative) were apparent.
- The majority of instances of poor soil quality could be reversed by appropriate management.

Recommendations

- NRC should continue with its programme of resampling existing sites to determine the extent and direction of any changes since original sampling. To obtain a broader overview of soils in Northland, consideration should be given to increasing the number of sites monitored. Selection of sites should focus on balancing the actual area of land uses in the Northland region on representative soil types with the intensity of land use activity.
- 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 3–4 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.
- Land managers are informed of the soil quality on their properties, and if remedial action is justified, they are advised on possible management strategies.
- NRC continues activities to educate land managers on strategies to protect the environment while achieving an economic return from the land.

1. Introduction

Northland Regional Council (NRC) participated in the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" in 2000–2001. Sites sampled in 2001 were resampled in 2007 and Landcare Research was contracted to analyse and interpret changes in soil quality that had occurred in the intervening years.

Soil quality was appraised using the set of 7 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). The various properties target the dynamic aspects of soil health, rather than land-use capability, contamination, or erosion. The 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 characteristic since the earlier samplings are used to assess the extent and direction of change.

2. Objectives

- Complete laboratory analyses on soil samples provided by the NRC.
- Provide an assessment of the current soil quality status of the soils as related to soil class and land use.
- Provide interpretation of changes in soil characteristics in relation to previous samples taken in 2001.

3. Methods

Most of the 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 NRC 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 25 individual samples for soil chemical and biological characteristics were analysed at Landcare Research laboratory at Palmerston North. Soil physical analyses were completed at 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 the total C content, total N content, 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 macro-porosity measured using –5 kPa tension. These soil physical measurements also provide 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 2.5:1 water-to-soil ratio (Blakemore et al. 1987).

Physical properties

Macroporosity was determined by drainage on pressure plates at –5 kPa (Klute 1986). Dry bulk density was measured on a subsampled core dried at 105°C (Klute 1986). Macroporosity and total porosity were calculated as described by Klute (1986).

3.4. Data presentation

All data were expressed on a weight/volume or volume/volume basis to allow comparison between soils with differing bulk density (except for metals expressed as mg/kg). Where appropriate, data from the same land-use category or soil type were combined to allow statistical testing.

Table 1 Indicators used for soil quality assessment

Indicators	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, 2.5:1 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	Soil compaction, root environment, aeration	Pressure plates
Aggregate stability	Amount and stability of soil crumbs	Wet sieving

4. Results

4.1. Soils and sites

Updated site information was provided by NRC staff as several sites had undergone change in landuse since the previous sampling (three dairy sites and one market garden site converted to drystock and one drystock site converted to dairy). The original site and soil profile descriptions and updated site information are provided in the Appendix.

4.2. Soil samples supplied to Landcare Research

Summarized site and soil information is given in Table 2, chemical and physical data are shown in Tables 3, 4 and 5.

Since Landcare Research was not involved in the sampling of sites, it is assumed all samples were taken using the standard 500 soil protocols. We emphasize that for valid comparisons, soil samples need to be collected in a consistent manner, from specified sampling sites, and using established protocol.

Table 2 Site codes, soil types, soil orders and land uses resampled in April 2007

Site code	Soil type	Subgroup, Group, Order	Land use
NRC00_1	Marua clay	Typic Orthic Granular	Drystock for 2 yrs, previously dairy
NRC00_ 2	Marua clay	Typic Orthic Granular	Drystock
NRC00_ 3	Marua clay	Mottled Orthic Brown (?)	Drystock for 2 yrs, previously dairy (irrigated)
NRC00_ 4	Waiotira clay	Mottled Acid Brown	Dairy, non-irrigated
NRC00_ 5	Waiotira clay	Mottled Acid Brown	Dairying, irrigated
NRC00_ 6	Waiotira clay	Mottled Acid Brown	Indigenous forest (some stock browsing)
NRC00_ 7	Waiotira clay loam	Mottled Acid Brown	Drystock
NRC00_ 8	Waiotira clay loam	Mottled Acid Brown	Forestry, second rotation pine
NRC00_ 9	Waiotira clay	Mottled Acid Brown	Drystock
NRC00_ 10	Red Hill sandy loam	Typic Orthic Allophanic	Drystock for 18 mos, previously mixed cropping
NRC00_ 11	Red Hill sandy loam	Typic Orthic Allophanic	Forestry, second rotation pine
NRC00_ 12	Red Hill loamy sand	Typic Orthic Allophanic	Dairy, non-irrigated
NRC00_ 13	Red Hill loamy sand	Typic Orthic Allophanic	Drystock
NRC00_ 14	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Dairy (less intensive), previously drystock
NRC00_ 15	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Dairy (intensive), non-irrigated
NRC00_ 16	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Forestry, first rotation pine after pasture
NRC00_ 17	Marua clay loam	Typic Orthic Brown	Forestry, first rotation pine after pasture
NRC00_ 18	Marua clay loam	Typic Orthic Brown	Indigenous forest, bush on previous pasture
NRC00_ 19	Awarua clay loam	Acidic Oxidic Granular	Dairying, non-irrigated
NRC00_ 20	Awarua clay loam	Acidic Oxidic Granular	Indigenous forest (evidence of stock access)
NRC00_ 21	Awarua clay loam	Acidic Oxidic Granular	Dairy, irrigated
NRC00_ 22	Awarua clay loam	Acidic Oxidic Granular	Forestry, first rotation, clear felled after pasture
NRC00_ 23	Kiripaka bouldery clay loam	Typic Orthic Allophanic	Drystock, previously dairy, non-irrigated
NRC00_ 24	Kiripaka bouldery clay loam	Typic Orthic Allophanic	Indigenous forest
NRC00_ 25	Kiripaka bouldery clay loam	Typic Orthic Allophanic	Citrus orchard

Table 3 Soil characteristics of sites sampled in 2007

Code	Soil and land use	pH	Total C mg/cm^3	Total N mg/cm^3	C:N ratio	Olsen P µg/cm^3	NH_4-N µg/cm^3	NO_3-N µg/cm^3	Mineralisable N µg/cm^3
NRC00_1	Marua clay, drystock	5.43	60.9	5.9	10.4	25	40.9	29.0	144
NRC00_ 2	Marua clay, drystock	5.69	59.3	5.1	11.7	16	0.5	17.7	157
NRC00_ 3	Marua clay, drystock	5.32	66.6	5.8	11.5	52	13.6	18.2	162
NRC00_ 4	Waiotira clay, dairy	6.15	72.2	6.0	12.0	82	51.1	17.5	142
NRC00_ 5	Waiotira clay, dairy, irrigated	6.19	63.5	5.6	11.3	43	42.8	13.6	141
NRC00_ 6	Waiotira clay, indigenous forest	5.28	60.6	3.7	16.5	9	44.4	18.2	134
NRC00_ 7	Waiotira clay loam, drystock	6.49	65.8	5.8	11.4	**12**	44.0	18.5	138
NRC00_ 8	Waiotira clay loam, pines	5.07	57.6	3.4	17.2	16	5.0	16.1	47
NRC00_ 9	Waiotira clay, drystock	5.64	48.9	3.8	12.9	**8**	25.7	29.3	92
NRC00_ 10	Red Hill sandy loam, drystock	**7.20**	50.4	3.8	13.2	40	20.7	21.2	**41**
NRC00_ 11	Red Hill sandy loam, pines	6.36	40.6	2.2	18.2	6	0.9	14.5	55
NRC00_ 12	Red Hill loamy sand, dairy	6.09	50.9	5.0	10.2	56	64.8	24.5	101
NRC00_ 13	Red Hill loamy sand, drystock	5.77	59.7	5.1	11.6	**13**	42.2	34.3	108
NRC00_ 14	Wharekohe silt loam, dairy	**4.85**	57.2	4.6	12.5	58	107.5	35.9	116
NRC00_ 15	Wharekohe silt loam, dairy	**4.90**	51.0	4.3	11.7	56	83.7	27.3	110
NRC00_ 16	Wharekohe silt loam, pines	4.46	63.2	4.0	15.9	8	0.6	25.8	50
NRC00_ 17	Marua clay loam, pines	4.97	54.5	3.0	18.2	24	9.3	35.6	66
NRC00_ 18	Marua clay loam, indigenous forest	4.64	58.0	3.0	19.2	13	1.9	35.6	44
NRC00_ 19	Awarua clay loam, dairy	5.78	83.0	6.2	13.4	16	38.9	27.4	142
NRC00_ 20	Awarua clay loam, indigenous forest	4.84	99.5	5.2	19.1	7	12.0	36.7	132
NRC00_ 21	Awarua clay loam, dairy, irrigated	6.28	73.3	6.1	12.0	35	59.8	33.0	154
NRC00_ 22	Awarua clay loam, pines	4.98	80.0	3.4	23.7	18	0.0	37.1	90
NRC00_ 23	Kiripaka bouldery clay loam, drystock	5.53	75.0	6.8	11.1	45	68.0	16.6	164
NRC00_ 24	Kiripaka bouldery clay loam, indigenous	**6.48**	84.1	5.7	14.7	7	28.1	12.8	174
NRC00_ 25	Kiripaka bouldery clay loam, orchard	6.07	61.4	5.2	11.9	74	39.3	18.6	137

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

Table 4 Soil physical characteristics of sites sampled in 2007

Code	Soil and land use	Bulk density Mg m^3	Particle density Mg/m^3	Total porosity %v/v	Macro porosity %v/v	Moisture content @ -5 kPa %v/v	Moisture content @ -10 kPa %v/v
NRC00_1	Marua clay, drystock	0.84	2.44	65.7	12.4	53.3	51.6
NRC00_ 2	Marua clay, drystock	1.00	2.49	59.9	**9.2**	50.7	48.9
NRC00_ 3	Marua clay, drystock	1.02	2.51	59.4	**8.0**	51.4	49.6
NRC00_ 4	Waiotira clay, dairy	1.05	2.48	57.7	**4.2**	53.6	52.5
NRC00_ 5	Waiotira clay, dairy, irrigated	0.89	2.46	63.6	**6.2**	57.4	55.9
NRC00_ 6	Waiotira clay, indigenous forest	1.10	2.59	57.5	**6.9**	50.6	49.3
NRC00_ 7	Waiotira clay loam, drystock	0.88	2.49	64.6	12.2	52.4	50.9
NRC00_ 8	Waiotira clay loam, pines	0.94	2.47	62.4	22.9	39.5	38.6
NRC00_ 9	Waiotira clay, drystock	0.93	2.49	62.8	**7.6**	55.2	52.9
NRC00_ 10	Red Hill sandy loam, drystock	1.22	2.60	53.0	**5.2**	47.8	44.7
NRC00_ 11	Red Hill sandy loam, pines	0.80	2.56	68.9	**30.5**	38.4	30.8
NRC00_ 12	Red Hill loamy sand, dairy	1.04	2.54	59.2	**3.1**	56.1	53.9
NRC00_ 13	Red Hill loamy sand, drystock	0.86	2.50	65.7	13.9	51.9	46.1
NRC00_ 14	Wharekohe silt loam, dairy	0.79	2.40	67.0	10.7	56.3	53.7
NRC00_ 15	Wharekohe silt loam, dairy	0.73	2.36	69.0	**4.5**	64.5	61.6
NRC00_ 16	Wharekohe silt loam, pines	1.00	2.53	60.5	23.8	36.6	35.7
NRC00_ 17	Marua clay loam, pines	0.96	2.52	62.0	22.0	40.0	38.3
NRC00_ 18	Marua clay loam, indigenous forest	0.91	2.54	64.2	15.8	48.4	47.2
NRC00_ 19	Awarua clay loam, dairy	0.78	2.51	68.9	**7.7**	61.3	59.7
NRC00_ 20	Awarua clay loam, indigenous forest	0.80	2.62	69.6	12.0	57.6	56.2
NRC00_ 21	Awarua clay loam, dairy, irrigated	0.88	2.57	65.9	**7.7**	58.2	56.4
NRC00_ 22	Awarua clay loam, pines	0.84	2.69	68.8	14.3	54.5	53.4
NRC00_ 23	Kiripaka bouldery clay loam, drystock	0.94	2.49	62.2	10.1	52.1	50.3
NRC00_ 24	Kiripaka bouldery clay loam, indigenous	0.68	2.48	72.5	27.7	44.8	42.1
NRC00_ 25	Kiripaka bouldery clay loam, orchard	1.00	2.62	61.9	10.4	51.5	49.7

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

Table 5 Soil heavy metal content of sites sampled in 2007 (grouped by land use)

Code	Land Use and Soil Class	As mg/kg	Cd mg/kg	Cr mg/kg	Co mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
NRC00_4	Dairy, Brown	<0.5	<0.5	29.7	6.1	17.6	10.2	3.0	41.2
NRC00_5	Dairy, Brown	<0.5	<0.5	25.6	4.7	15.6	8.3	3.2	41.0
NRC00_12	Dairy, Allophanic	5.1	<0.5	15.2	4.6	6.1	8.4	3.5	49.9
NRC00_14	Dairy, Ultic	<0.5	<0.5	8.6	0.2	5.4	1.7	3.2	18.3
NRC00_15	Dairy, Ultic	<0.5	<0.5	8.5	1.1	10.6	3.6	21.4	29.4
NRC00_19	Dairy, Granular	<0.5	<0.5	58.8	11.2	30.1	32.7	0.9	43.9
NRC00_21	Dairy, Granular	<0.5	<0.5	47.1	11.2	31.6	27.1	1.7	133
	Mean*	0.9	0.3	27.6	5.6	16.7	13.1	5.3	51.0
	sd	1.8	0.0	19.3	4.4	10.7	11.9	7.2	37.7
NRC00_1	Drystock, Granular	<0.5	<0.5	13.1	6.4	16.4	12.4	9.3	45.8
NRC00_2	Drystock, Granular	<0.5	<0.5	17.0	7.6	18.3	13.0	12.1	55.1
NRC00_3	Drystock, Brown	<0.5	<0.5	14.0	5.5	8.4	9.9	9.3	28.8
NRC00_7	Drystock, Brown	<0.5	<0.5	35.2	4.5	23.5	16.0	6.6	46.2
NRC00_9	Drystock, Brown	<0.5	<0.5	14.1	2.6	8.1	5.9	5.0	23.5
NRC00_10	Drystock, Allophanic	5.6	<0.5	16.0	5.1	7.9	8.7	3.9	31.2
NRC00_13	Drystock, Allophanic	10.5	<0.5	14.0	4.4	9.5	8.6	3.6	37.7
NRC00_23	Drystock, Allophanic	<0.5	<0.5	69.2	22.4	45.7	50.1	12.1	108
	Mean	2.2	0.3	24.1	7.3	17.2	15.6	7.7	47.0
	sd	3.8	0.0	19.6	6.3	12.9	14.3	3.5	26.7
NRC00_8	Plantation Forestry, Brown	<0.5	<0.5	14.2	3.2	9.4	7.4	6.7	30.0
NRC00_11	Plantation Forestry, Allophanic	5.7	<0.5	13.0	5.8	17.1	11.0	8.0	53.5
NRC00_16	Plantation Forestry, Ultic	<0.5	<0.5	5.7	1.6	5.3	3.6	3.6	9.2
NRC00_17	Plantation Forestry, Brown	12	<0.5	15.4	3.9	5.7	8.9	9.8	24.5
NRC00_22	Plantation Forestry, Granular	<0.5	<0.5	144.0	13.4	27.6	37.5	2.7	49.7
	Mean	3.6	0.3	38.5	5.6	13.0	13.7	6.2	33.4
	sd	5.1	0.0	59.1	4.6	9.4	13.6	3.0	18.4

Code	Land Use and Soil Class	As mg/kg	Cd mg/kg	Cr mg/kg	Co mg/kg	Cu mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
NRC00_6	Indigenous, Brown	<0.5	<0.5	17.5	9.2	21.2	11.5	8.4	58.6
NRC00_18	Indigenous, Brown	<0.5	<0.5	11.8	5.0	11.3	9.5	9.5	29.5
NRC00_20	Indigenous, Granular	<0.5	<0.5	61.1	25.5	45.0	43.7	0.1	59.7
NRC00_24	Indigenous, Allophanic	<0.5	<0.5	73.2	27.3	41.9	46.0	11.1	91.2
	Mean	0.3	0.3	40.9	16.7	29.8	27.7	7.3	59.8
	sd	0.0	0.0	30.8	11.3	16.3	19.9	4.9	25.2
NRC00_25	Crop/Hort, Allophanic	<0.5	<0.5	67.8	27.9	102	40.3	11.9	80.5

* For means and standard deviations, values below detection limit (<0.5) were assumed to be ½ that of detection limit (0.25 mg/kg).

4.3. Soil chemical characteristics

Soil chemical characteristics that fell outside target ranges were generally confined to Olsen P and pH (Table 3). Olsen P was below target ranges on NRC00_7, NRC00_9 and NRC00_13, all of which were drystock sites. Soil pH was below target ranges on NRC00_14 and NRC00_15 (both dairy sites) and above the target range on NRC00_ 10 (recently converted from market garden to drystock pasture) and NRC00_ 24 (an indigenous vegetation site).

4.4 Soil physical characteristics

Approximately half of all sites monitored had values outside of target ranges for macroporosity (Table 4); the vast majority of these cases being low (<10 %) macroporosity on dairy sites (6 of 7 sites) and drystock sites (4 of 8 sites) indicating compacted soil.

4.5 Overall soil quality

The 25 sites were tested for a total of 175 soil quality characteristics. For all indicators across all sites, 89% (155 out of 175) fell within target ranges. Across all land uses, nine of the 25 sites (36%) met all targets (0 of 7 dairy sites, 2 of 8 drystock sites, 4 of 5 plantation forestry sites, 1 of 1 hort/crop sites, and 2 of 4 indigeneous sites). Thirteen sites (52%) did not meet the target range for one characteristic, two sites (8%) did not meet the target ranges for two characteristics and one site (NRC00_10, recently converted from market garden to drystock) did not meet target ranges for three characteristics.

Macroporosity was the specific indicator that failed to meet target ranges on the most sites (approximately 48% of all site). Olsen P and pH each failed to meet target ranges on approximately 12% and 15 % of sites respectively.

When viewed by land use, specific trends in the indicators can be seen more distinctly. Within dairy sites, macroporosity values were below target values for six of the seven sites monitored (Fig. 3). On drystock sites, low macroporsity and low Olsen P values (50% and 38% of sites respectively) (Fig 4.) were the largest contributors to these sites not meeting target values. Macroporosity was the only indicator outside target ranges in plantation forestry sites. Two of the four indigenous vegetation sites had indicators not meeting target ranges (one site for high pH and one site for low macroporosity); however, indigenous systems are more inherently variable (e.g., see Giltrap and Hewitt) and without detailed site information it is not possible to determine whether these values are abnormal or due to natural variation with the system.

4.6 Soil heavy metal concentrations

Heavy metals varied across landuses and there were few trends among land-use categories (Table 4). Natural levels of many metals can vary greatly depending on geologic parent material. Heavy metals were not analysed in the 2001 sampling so comparison with the originally sampling is not possible.

The New Zealand Water and Wastes Association (NZWWA, 2003) suggested limits for land biosolid application provide some guidelines on acceptable heavy metal concentrations in soils. The NZWWA suggests upper soil limits (in mg metal concentration per kg dry weight soil) of: 20 mg/kg for arsenic (As), 1 mg/kg for cadmium (Cd), 600 mg/kg for chromium (Cr), 100 mg/kg for copper (Cu), 300 mg/kg for lead (Pb), 1 mg/kg for mercury, 60 mg/kg for

nickel (Ni), and 300 mg/kg for zinc (Zn). Measured levels of all trace metals were below these levels except NRC_25 (an orchard site) where Cu measured approximately 102 mg/kg.

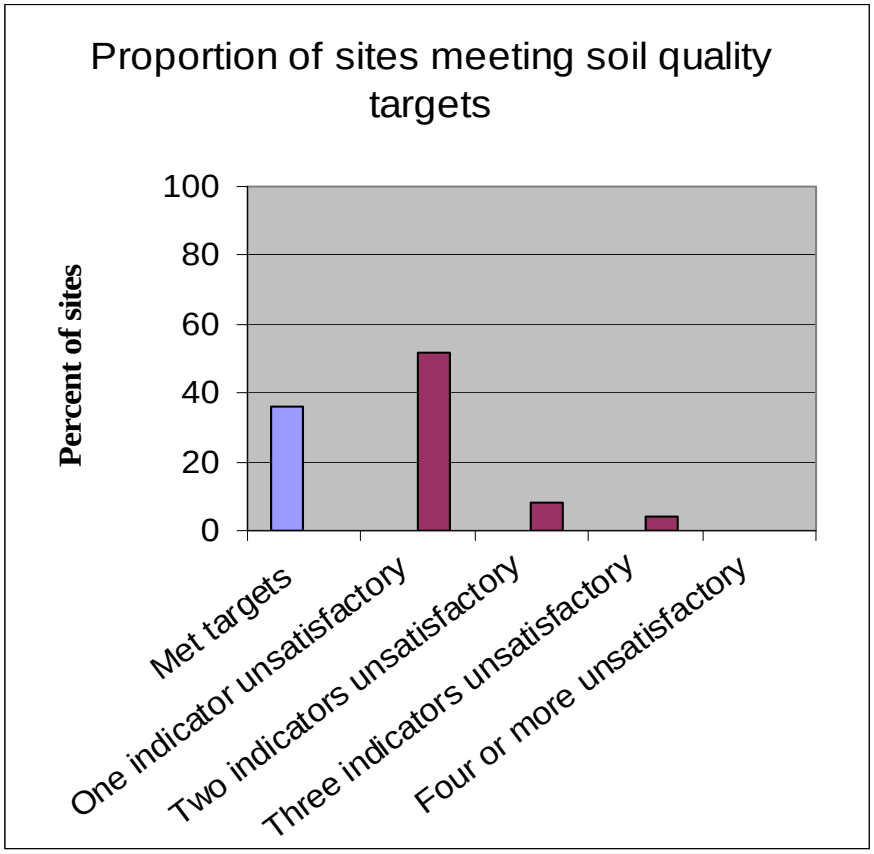

Fig. 1 Proportions of all sites (25 sites monitored) meeting targets for soil quality indicators

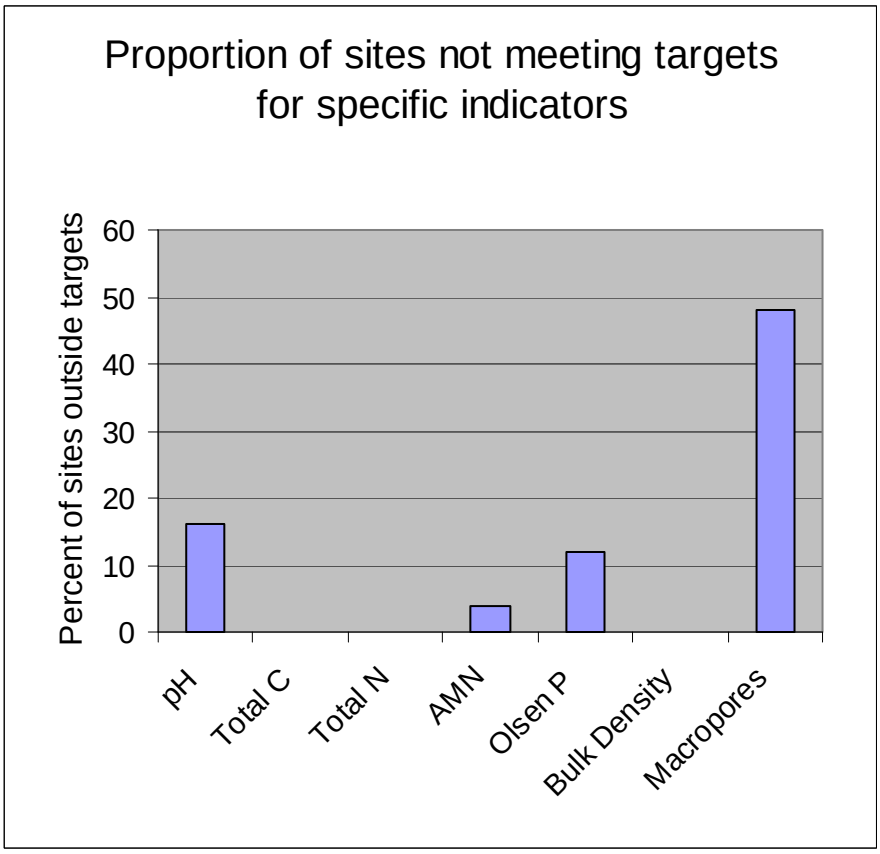

Fig. 2 Proportions of all sites (25 sites monitored) failing to meet target ranges for specific indicators

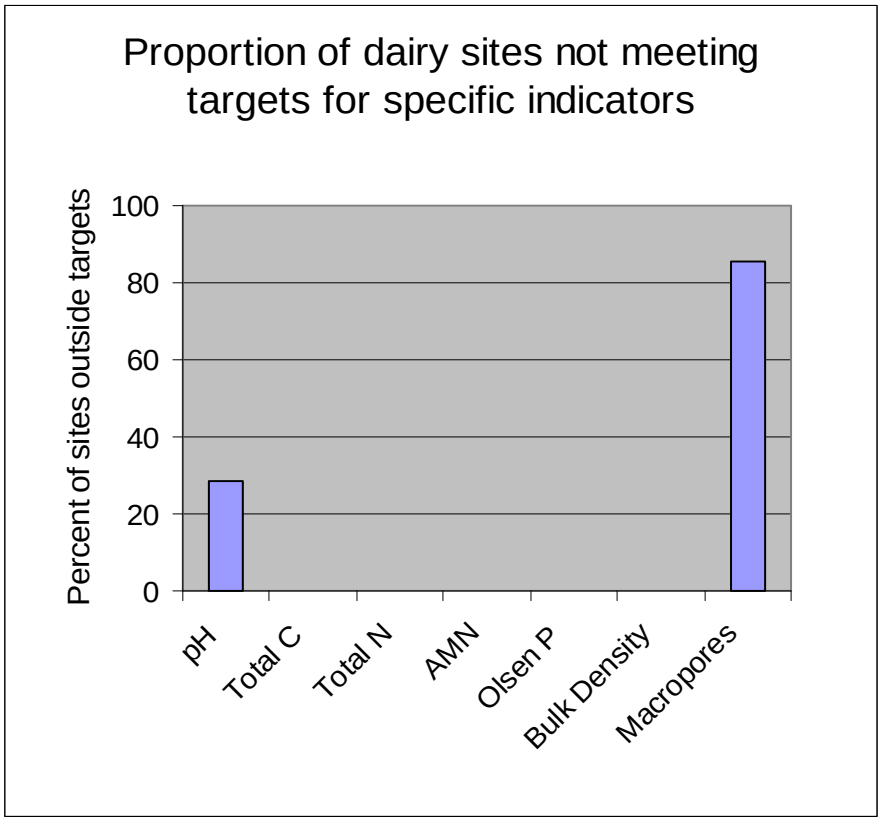

Fig. 3 Proportions of dairy sites (7 sites monitored) failing to meet target ranges for specific indicators

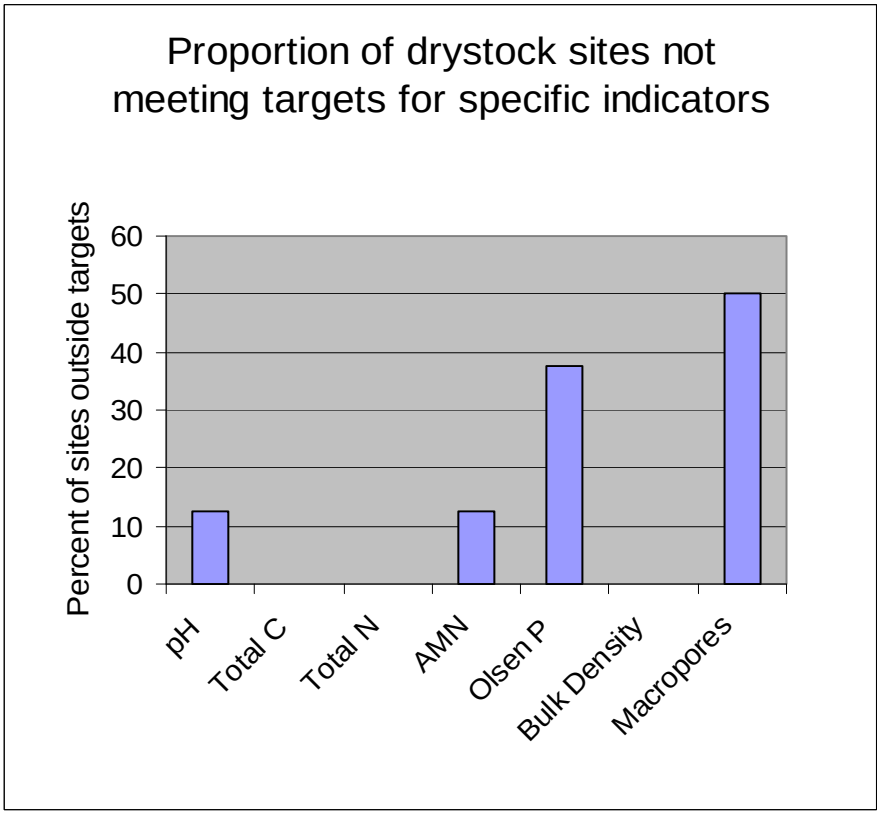

Fig. 4 Proportions of drystock forest sites (8 sites monitored) failing to meet target ranges for specific indicators

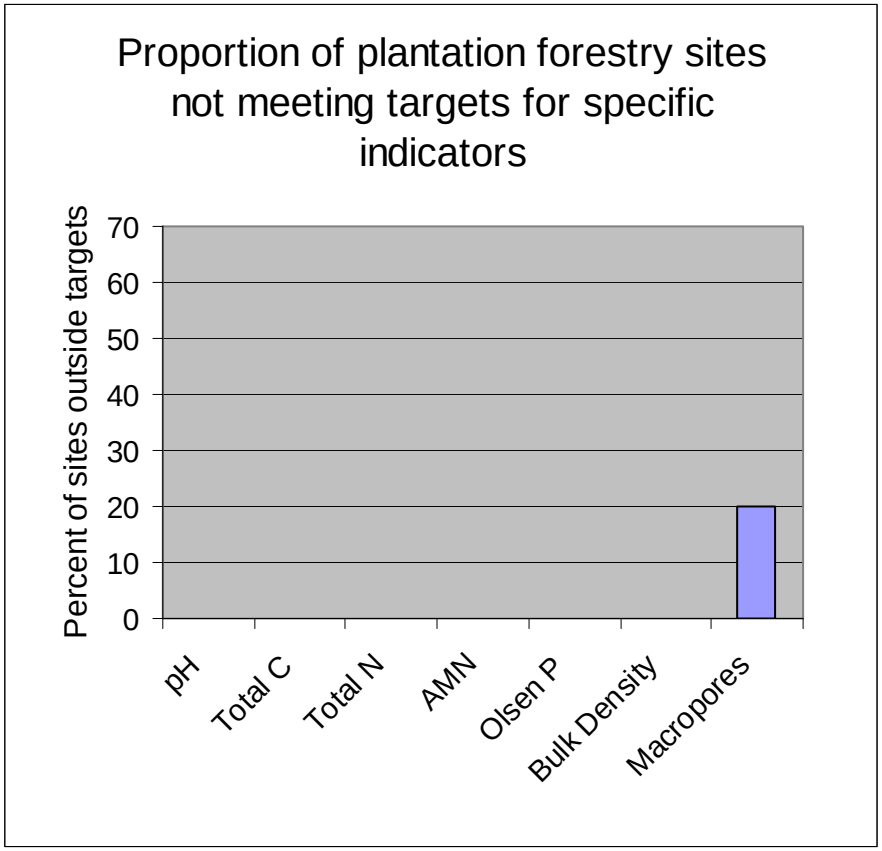

Fig. 5 Proportions of plantation forestry sites (5 sites monitored) failing to meet target ranges for specific indicators

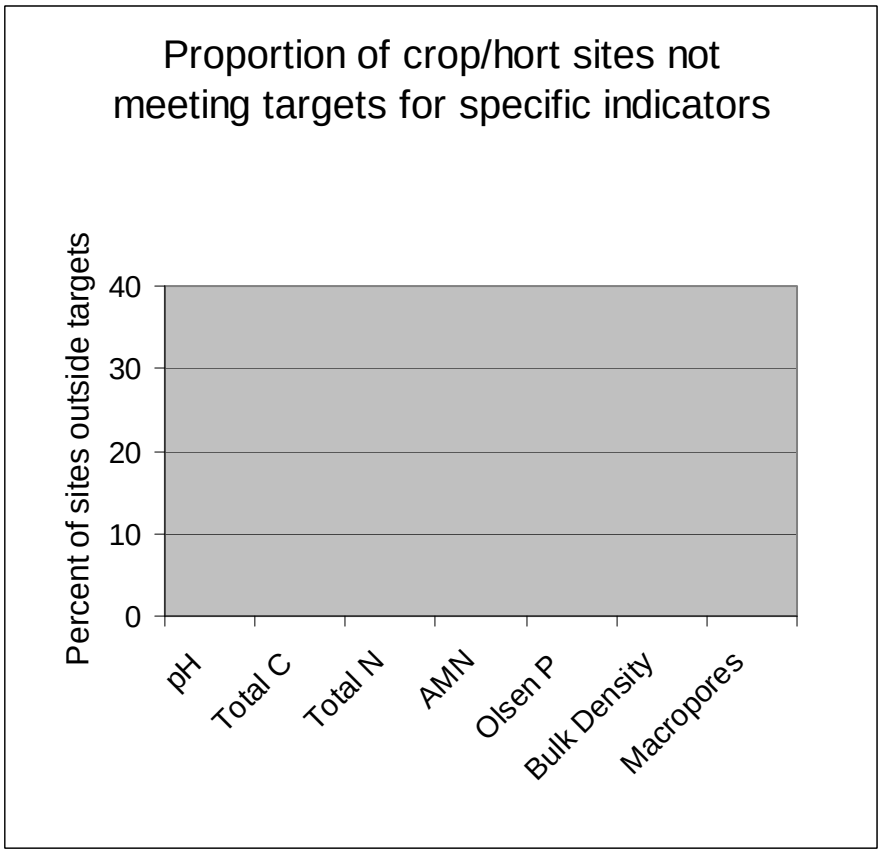

Fig. 6 Proportions of Hort/Crop sites (1 site monitored) failing to meet target ranges for specific indicators

4.7 Changes in soil quality since previous sampling

The current data were compared against those obtained in the previous sampling (Sparling et al. 2001a) to determine the extent and direction of any change. The volumetric data used for comparison between each sampling period are provided in the Appendix. The difference for each indicator between the current and previous sampling is shown for dairy, drystock, plantation forestry, indigenous and cropping and horticulture sites in Tables 6–10. The data in the Tables are presented as the accumulated change across all the sites in that land-use group (Sum), the standard deviation as a measure of variance, and the mean to show the averaged change (in units for that particular indicator) across all sites in the group. Average change (by land use as above) for each indicator is shown in Figures 7–11.

Dairy Farms (Table 6, Fig. 7)
Seven dairy farms were resampled. Since the earlier sampling there has been an overall decrease in mineralisable nitrogen and macroporosity.

The significant decrease in macroporosity mirrors changes observed in other regions of New Zealand as intensification of dairy activity has increased. Increased compaction is a concern as several studies (Drewery et al. 1999; Singleton et al. 2000) have concluded that macroporosity levels below 10% can result in decreased pasture production. Additionally, compacted soils may result in increased runoff and deposition of nitrogen and phosphorus into surface waters.

In the absence of changes in other measures (and a general decrease across several landuses), the decrease in mineralisable N is likely due to seasonal variation in biological activity or change in time of sampling rather than overall change in microbial biomass.

Overall, there was no significant change in total C on dairy sites. Several sites exhibited changes that were larger than could reasonably be explained by typical land use practices (e.g. NRC00_12, and NRC00_14, NRC00_15). Caution is needed in interpreting large one-off shifts in soil characteristics at a single site until more data is obtained (as explained more fully below and in the discussion).

Drystock (Table 7, Fig. 8)

Eight drystock sites were resampled. Overall, there were significant decreases in macroporosity and mineralisable N (see above explanations).

The continued low Olsen P values on some drystock sites indicate they are not receiving adequate P fertilisation to compensate for loss due to grazing. Long-term P deficits will likely result in substandard pasture growth and may hasten overgrazed conditions and invasion by weedy species.

As noted for dairy, several sites showed larger changes in total C than could be explained by land use (NRC00_3 and NRC00_9). For example, the increase in soil C content of NRC00_3 was about 15 mg/cm^3. The bulk density for this soil was approximately 1.0 Mg/m^3. Converting the units to a mass basis; the C increase was equivalent to 15 mgC /g soil (1 cm^3 of this soil weighs 1 g as the density happens to be 1.0). If we convert this to an area basis then 1 ha of this soil to 10 cm depth weighs around a thousand tonnes (a hectare is 100 m by 100 m, and the soil was sampled to 0.1 m depth, so the volume of soil is 100 x 100 x 0.1 cubic meters (m^3), which works out to be 1000 m^3, equivalent to 1000 tonnes). To change the C

content of 1000 tonnes of soil by 15 mgC/g requires an increase of 15 kg C/tonne (note 1 tonne = 1 Mg). If there are 1000 tonne of soil then the C increase needs to be 15 tonnes per ha. This amount of C corresponds to a change of around 36 tonnes dry matter production per ha (above and below ground). Total organic C inputs to high producing pasture and maize cropping in Waikato have been estimated to be around 10 tonnes per year (Parfitt et al. 2002). Unless major alterations to pasture have occurred (such as mulching or reconditioning involving incorporation of organic matter), it seems unlikely that these large changes in organic matter C can be explained by changes in organic matter inputs. More likely reasons are slight variations in sampling location or technique. An increase in the number of sites measured and the repeated measurement of the same site help to minimize the significance of such variability.

Plantation forestry, Indigenous and Crop/Hort (Table 8–10, Figures 9–11)

Overall there was little change in soil quality status of plantation forestry, indigenous vegetation and cropping and horticulture sites. There was a small but statistically significant change in bulk density and particle density of indigenous sites. This could indicate evidence of erosion and topsoil loss, but the changes (though statistically significant) are small, and in the absence of decreased C and N content of the soil are probably due to natural variation.

Table 6 Changes in soil quality attributes of dairy soils between 2001 and 2007

		Change in soil quality characteristic since earlier sampling (positive numbers indicate increasing values from 2001 to 2007)								
Code	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	Mineralisable N $\mu g/cm^3$	Olsen P $\mu g/cm^3$	C/N ratio Ratio	Dry bulk density $Mg\ m^3$	Particle density $Mg\ m^3$	Macro-porosity %v/v
NRC00_4	Brown	-0.09	6.8	0.69	-48	23	-0.03	0.21	0.08	-17.43
NRC00_5	Brown	-0.01	-9.8	-0.18	-106	-12	-1.75	-0.17	0.02	-1.37
NRC00_12	Allophanic	0.02	**-23.1**	-1.38	-45	-3	-1.80	-0.16	0.00	-11.23
NRC00_14	Ultic	-0.95	**-10.2**	-1.02	-81	6	0.48	-0.26	-0.04	2.20
NRC00_15	Ultic	-0.64	**-20.0**	-1.89	-34	-6	0.75	-0.09	-0.01	-12.33
NRC00_19	Granular	0.04	6.6	0.66	-8	2	-0.64	0.05	-0.02	-17.03
NRC00_21	Granular	0.08	3.2	0.37	-24	-5	-0.02	0.05	0.05	-6.10
	Sum	-1.55	-46.53	-2.73	-346.68	5.87	-3.00	-0.37	0.08	-63.30
	sd	0.41	12.40	1.04	33.93	11.21	1.02	0.16	0.04	7.57
	Mean	-0.22	-6.65	-0.39	-49.53*	0.84	-0.43	-0.05	0.01	-9.04*

*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 attributes of drystock pasture soils between 2001 and 2007

		Change in soil quality characteristic since earlier sampling (positive numbers indicate increasing values from 2001 to 2007)								
Code	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	Mineralisable N µg/cm^3	Olsen P µg/cm^3	C/N ratio Ratio	Dry bulk density Mg m^3	Particle density Mg m^3	Macro-porosity %v/v
NRC00_1	Granular	-0.18	1.8	0.61	-111	6	-0.60	-0.01	-0.02	-4.70
NRC00_2	Granular	0.34	4.7	0.45	-36	7	-0.35	0.15	0.01	-12.80
NRC00_3	Brown	-0.06	**15.2**	1.45	-109	8	-0.48	0.04	0.02	-5.27
NRC00_7	Brown	0.85	0.1	0.37	-32	3	-0.57	-0.03	0.02	-6.93
NRC00_9	Brown	0.47	**-13.4**	-0.34	-19	2	-2.06	-0.03	-0.01	-13.17
NRC00_10	Allophanic	-0.05	10.5	1.34	12	22	-2.81	0.36	0.05	-25.50
NRC00_13	Allophanic	-0.55	-8.6	-0.74	-63	-3	-0.40	0.02	0.03	-7.53
NRC00_23	Allophanic	-0.39	8.0	0.77	3	-2	0.11	0.00	0.08	-3.00
	Sum	0.43	18.23	3.91	-355.83	42.04	-7.14	0.50	0.18	-78.90
	sd	0.47	9.58	0.75	46.76	7.94	0.99	0.13	0.03	7.30
	Mean	0.05	2.28	0.49	-44.48*	5.26	-0.89	0.06	0.02	-9.86*

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

Bold indicates particularly large changes observed between sampling dates

Table 8 Changes in soil quality attributes of plantation forestry soils between 2001 and 2007

		Change in soil quality characteristic since earlier sampling (positive numbers indicate increasing values from 2001 to 2007)								
Code	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	Mineralisable N $\mu g/cm^3$	Olsen P $\mu g/cm^3$	C/N Ratio	Dry bulk density $Mg\ m^3$	Particle density $Mg\ m^3$	Macro-porosity %v/v
NRC00_8	Brown	0.08	8.4	0.82	-13	3	-1.82	0.21	0.07	-11.63
NRC00_11	Allophanic	0.08	0.2	0.16	1	-3	-1.80	-0.11	0.09	3.77
NRC00_16	Ultic	-0.47	9.0	-0.09	-68	-14	2.89	0.09	0.07	-2.97
NRC00_17	Brown	0.02	**-17.3**	-0.82	-80	11	-0.84	0.04	0.09	-3.37
NRC00_22	Granular	-0.33	1.4	-0.38	-33	12	2.71	-0.02	0.08	5.50
	Sum	-0.62	1.6	-0.30	-193	9	1.14	0.20	0.39	-8.70
	sd	0.26	10.6	0.61	35	11	2.38	0.12	0.01	6.80
	Mean	-0.12	0.3	-0.06	-39	2	0.23	0.04	0.08	-1.74

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

Bold indicates particularly large changes observed between sampling dates

Table 9 Changes in soil quality attributes of indigenous soils between 2001 and 2007

		Change in soil quality characteristic since earlier sampling (positive numbers indicate increasing values from 2001 to 2007)								
Code	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	Mineralisable N µg/cm^3	Olsen P µg/cm^3	C/N Ratio	Dry bulk density Mg m^3	Particle density Mg m^3	Macro-porosity %v/v
NRC00_6	Brown	-0.34	1.8	0.13	-46	-2	-0.49	0.08	0.08	-6.77
NRC00_18	Brown	0.04	4.3	0.01	-11	6	1.23	0.11	0.02	3.37
NRC00_20	Granular	0.02	**12.4**	0.71	1	-13	0.08	0.14	0.07	-12.50
NRC00_24	Allophanic	0.08	**27.3**	1.36	26	4	1.73	0.02	0.09	9.30
	Sum	-0.20	45.7	2.20	-30	-4	2.55	0.35	0.26	-6.60
	sd	0.19	11.5	0.62	30	9	1.02	0.05	0.03	9.81
	Mean	-0.05	11.4	0.55	-8	-1	0.64	0.09*	0.06*	-1.65

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

Bold indicates particularly large changes observed between sampling dates

Table 10 Changes in soil quality attributes of cropping and horticulture soils between 2001 and 2007

		Change in soil quality characteristic since earlier sampling (positive numbers indicate increasing values from 2001 to 2007)								
Code	Soil Order	pH	Total C mg/cm^3	Total N mg/cm^3	Mineralisable N µg/cm^3	Olsen P µg/cm^3	C/N Ratio	Dry bulk density Mg m^3	Particle density Mg m^3	Macro-porosity %v/v
NRC00_25	Allophanic	-0.1	1.9	-0.18	-11	-3	0.89	0.05	-0.01	-3.70

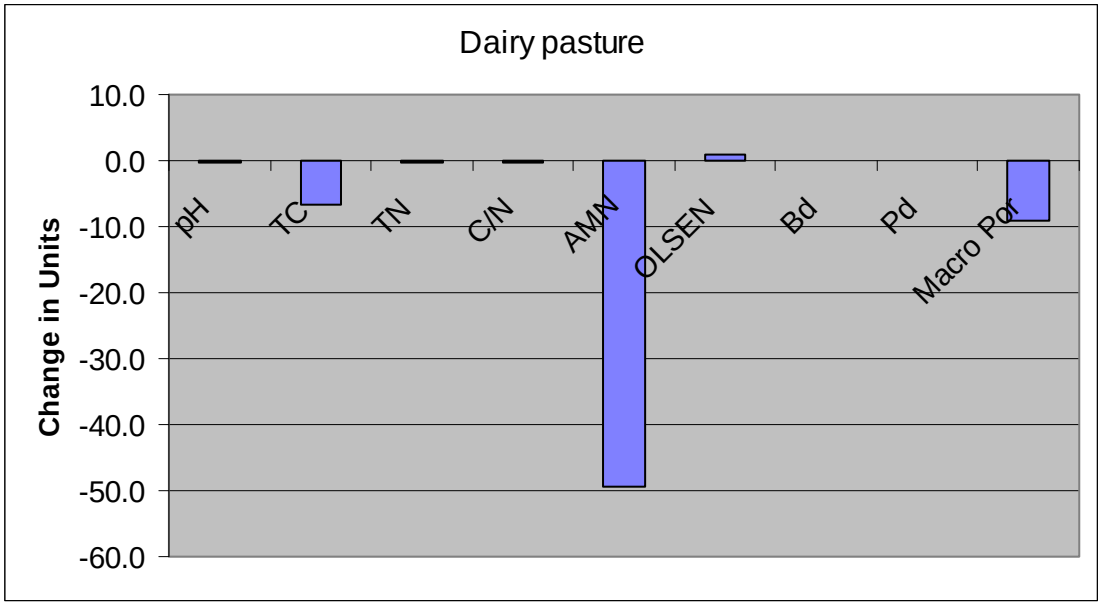

Fig. 7 Average change in attribute units between 2001 and 2007 for dairy soils

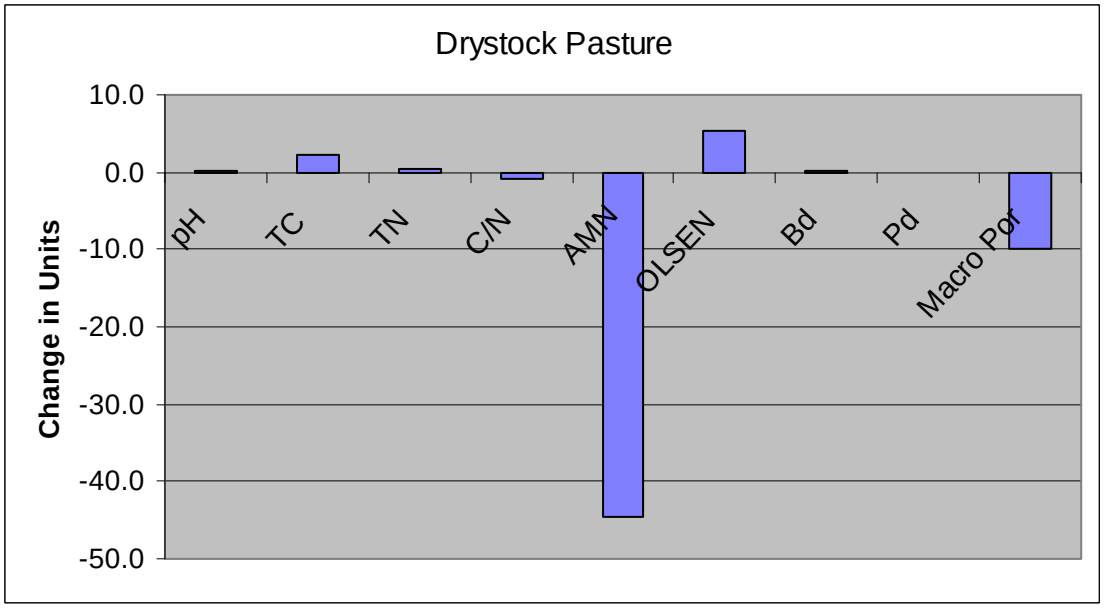

Fig. 8 Average change in attribute units from 2001 to 2007 for Drystock soils

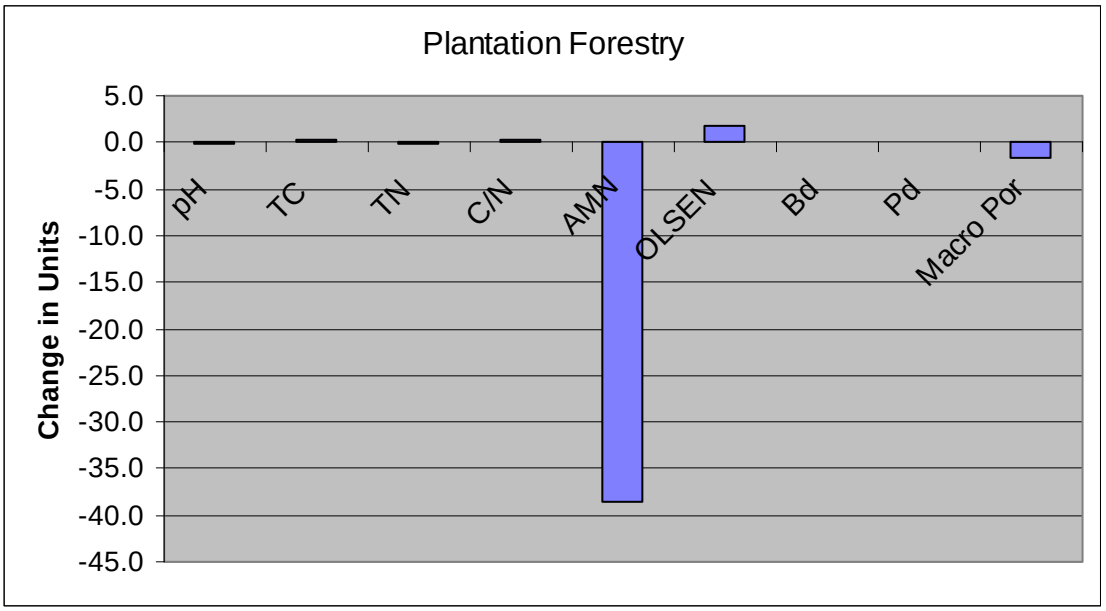

Fig. 9 Average change in attribute units from 2001 to 2007 for plantation forestry soils

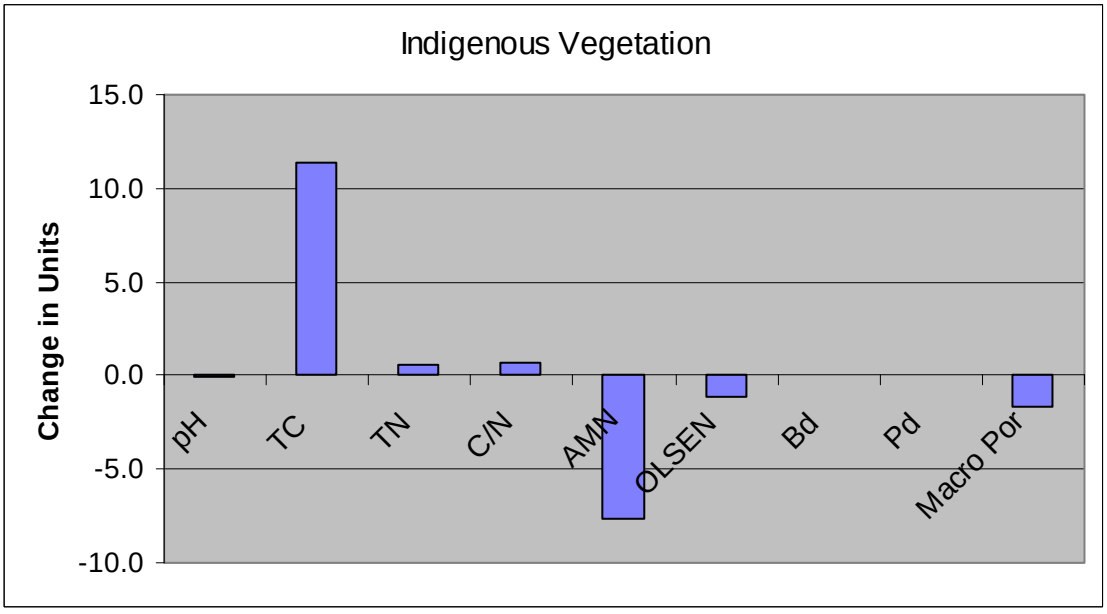

Fig. 10 Average change in attribute units from 2001 to 2007 for indigenous vegetation soils

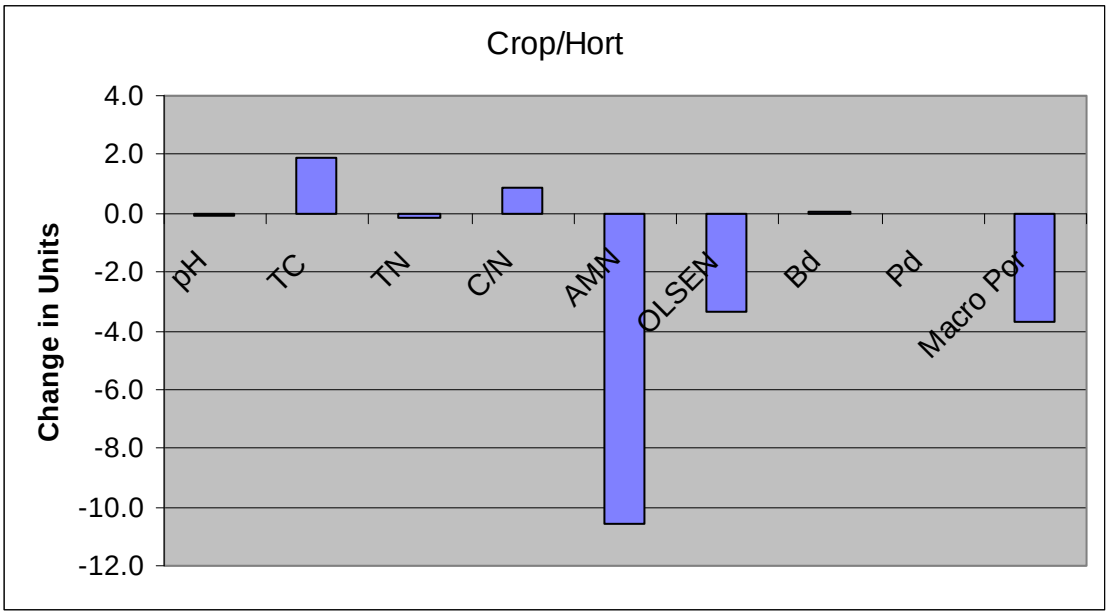

Fig. 11 Average change in attribute units from 2001 to 2007 for cropping and horticulture soils

5. Discussion

The current national trend is for greater land intensification (Parliamentary Commission for the Environment 2004). Earlier reports (e.g., Sparling et al. 2001b, 2004; Sparling & Schipper 2004) have highlighted issues such as widespread compaction in dairy farms and optimal soil fertility. They also gave examples of possible management options such as use of run-off pads on dairy farms, rapid movement of cattle 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, and use of minimum and zero tillage in arable farming. All the soil quality characteristics reported can be modified (reversed) by suitable management. Education of land owners and land managers is an integral part of this strategy, and NRC should encourage and expand activities in this area.

Soil quality characteristics of sites sampled in 2007 followed some of the same trends as those seen in other regions. Land use was the major driver of soil quality characteristics. Compaction on dairy and drystock sites remains a particular concern (both in Northland and nationally), as comparison of soil quality parameters between 2001 and 2007 suggests an overall decline in macroporosity. Unlike many other regions however, excess soil fertility (e.g., high N and P levels) does not appear to be a concern in these particular sites. On the contrary, low Olsen P levels observed on drystock sites indicate pasture production is likely to be suboptimal and could eventually lead to overgrazed conditions. The instances of low pH on dairy and drystock soils could be remedied by lime application.

In comparing data from resampled sites, several values were noted as showing excessively large differences. Caution is suggested in interpreting apparent changes (both positive and negative) until more data are obtained and consistent trends are recorded. These large "one-off" changes in parameters may be caused by a variety of factors including changes in land use or management, recent fertilisation, or slight variation in sampling location or procedure. Precise relocation of sampling location along with an increase in the number of similar land use sites sampled helps to minimize statistical variation inherent in soil sampling.

Accurate site history data are often difficult to obtain during field sampling but can be valuable in determining the cause of large changes in soil quality values (for instance, how recently has the site been fertilised?) as well as evaluating the effects of land use and or management changes on soil quality indicators. To strengthen the validity of resampling original locations, it would also be advisable to locate sites as accurately as possible. Modern hand-held GPS modules are much more precise than those available earlier, and if the site is being visited, the location (both start and endpoint of the transect) should be confirmed and updated using modern equipment. Resampling from as near the original location as possible will increase confidence in any changes detected.

6. Conclusions

- The low macroporosity values (and decrease in values since the previous sampling) on dairy and drystock sites mirror results from other regions of the country and is a general result of intensification of these landuse practices.
- Primary concerns are (1) compaction of soils on dairy and drystock sites; (2) the low nutrient (Olsen P) status of drystock sites. Soil pH was also below target values on several

sites. Macroporosity and mineralisable nitrogen values were lower than the previous sampling in 2001, otherwise, few consistent changes (either positive or negative) were apparent.
- The majority of instances of poor soil quality could be reversed by appropriate management.

7. Recommendations

- NRC should continue with its programme of resampling existing sites to determine the extent and direction of any changes since original sampling. To obtain a broader overview of soils in Northland, consideration should be given to increasing the number of sites monitored. Selection of sites should focus on balancing the actual area of land uses in the Northland region on representative soil types with the intensity of land use activity.
- 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 3–4 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 for each site (particularly in reference to land use history), 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.
- Land managers are informed of the soil quality on their properties, and if remedial action is justified, they are advised on possible management strategies.
- NRC continues activities to educate land managers on strategies to protect the environment while achieving an economic return from the land.

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. Graham Sparling is thanked for his guidance and input into the report.

9. References

Blakemore LC, Searle PL, Daly BK 1987. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report No. 80. Lower Hutt, DSIR Soil Bureau. 103 p.

Drewry JJ, Lowe JAH, Paton RJ 1999. Effect of sheep stocking intensity on soil physical properties and dry matter production on a Pallic Soil in Southland. New Zealand Journal of Agricultural Research 42: 493–499.

Giltrap DJ, Hewitt AE 2004. Spatial variability of soil quality indicators in New Zealand. soils and land uses. New Zealand Journal of Agricultural Research 47: 167–177.

Keeney DR, Bremner JM 1966. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agronomy Journal 58: 498–503.

Klute A 1986. Water retention laboratory methods. In: Klute A ed. Methods of soil analysis Part 1: Physical and mineralogical methods. 2nd ed. Madison WI, Soil Science Society of America. Pp. 635–632.

New Zealand Water and Wastes Association 2003. Guidelines for the safe appkication of biosolids to land in New Zealand. NZWWA, Wellington, 177 p.

Olsen SR, Cole CV, Watanabe FS, Dean LA 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture Circular 939. Washington DC, US Department of Agriculture.

Parliamentary Commissioner for the Environment 2004. Growing for good: Intensive farming, sustainability and the New Zealand environment. Wellington, Parliamentary Commissioner for the Environment. 236 p.

Parfitt RL, Parshotam A, Salt GJ 2002. Carbon turnover in two soils with contrasting mineralogy under long-term maize and pasture. Australian Journal of Soil Research 40: 127–136.

Singleton PL, Boyes M, Addison B 2000. Effect of treading by dairy cattle on topsoil physical conditions for six contrasting soil types in Waikato and Northland, New Zealand, with implications for monitoring. New Zealand Journal of Agricultural Research 43: 559–567.

Sparling GP 2004. Implementing soil quality indicators for land: Wellington Region 2003–2004. Unpublished Landcare Research Report LC0405/010. Hamilton, Landcare Research.

Sparling GP 2005. Implementing soil quality indicators for land: Wellington Region 2004–2005. Unpublished Landcare Research Report LC0405/070. Hamilton, Landcare Research.

Sparling G P, Schipper LA 2004. Soil quality monitoring in New Zealand: Trends and issues arising from a broad-scale survey. Agriculture Ecosystem & Environment 104: 545–552.

Sparling G P, Schipper LA, Bettjeman W, Hill R 2004. Soil quality monitoring in New Zealand: Practical lessons from a six-year trial. Agriculture Ecosystems & Environment 104: 523–534.

Sparling G, Schipper L, McLeod M, Basher L, Rijkse W 1996. Trialing soil quality indicators for State of the Environment monitoring: Research report for 1995/1996. Unpublished Landcare Research Contract Report LC9596/149. Hamilton, Landcare Research.

Sparling GP, Rijkse W, Wilde RH, van der Weerden T, Beare MH, Francis GS 2001a. Implementing soil quality indicators for land. Research Report for 2000/2001 and Final Report for MfE Project Number 5089. Unpublished Landcare Research Contract Report LC0102/015. Hamilton, Landcare Research.

Sparling GP, Rijkse W, Wilde RH, van der Weerden T, Beare MH, Francis GS 2001b. Implementing soil quality indicators for land: Research report for 1999/2000. Unpublished Landcare Research Contract Report 0001/059. Hamilton, Landcare Research.

10. Appendices

Site and soil descriptions from original samplings

Soil Chemical and Physical Analysis Data Tables

Site NRC00_1

Soil Type	Marua clay
Map reference	260 Sheet Q06
GPS coordinates	E2638281 N6609317
Location	10 km NE of Whangarei, SE of Parkes Road
Transect length and direction °	40 m, SW 280°
Classification	Typic Orthic Granular Soil
Land use	Dairying, non-irrigated
Date sampled	12/02/01
Land-use history	
Present vegetation	Rye grass, white clover, paspalum
Slope	12° convex midslope
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	151
Parent material	Strongly weathered greywacke
Drainage	Well drained
Topsoil depth (cm)	17
Total rooting depth (cm)	80
Limiting horizon	Heavy textured compact subsoil
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–17	Dark brown (10YR 3/3) clay; sticky; plastic; weak soil strength; friable failure; moderately pedal; many fine and very fine roots; distinct smooth boundary.
Bt	17–49	Yellowish brown (10YR 5/6) clay; sticky; plastic; slightly firm soil strength; friable failure; strongly pedal with many distinct dark yellowish brown (10YR 4/6) clay coatings; common fine and very fine roots; indistinct smooth boundary.
Bw	49–80	Yellowish brown (10YR 5/6) clay; few fine and medium distinct yellowish red (5YR 5/6) mottles; sticky; plastic; slightly firm soil strength; deformable failure; moderately pedal; few fine and very fine roots; distinct smooth boundary.
C1	80–100	Light olive brown (2.5Y 5/6) and yellowish brown (10YR 5/6) clay loam; sticky; plastic; firm soil strength; deformable failure; massive; no live roots; sharp smooth boundary.
C2	100–120+	Light olive brown (2.5Y 5/6) clay loam; slightly sticky; slightly plastic; very firm soil strength; brittle; massive; no roots.

Site NRC00_2

Soil Type	Marua clay
Map reference	260 Sheet Q06
GPS coordinates	E2638250 N6609212
Location	10 km NE of Whangarei, SE of Parkes Road, about 500 m South of site NRC00_1
Transect length and direction °	40 m, S 180°
Classification	Typic Orthic Granular Soil
Land use	Drystock
Date sampled	12/02/01
Land-use history	
Present vegetation	Brown-top, rye grass, white clover, paspalum
Slope	20° , planar midslope, with terracettes
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	166
Parent material	Strongly weathered greywacke
Drainage	Well drained
Topsoil depth (cm)	16
Total rooting depth (cm)	80
Limiting horizon	Heavy textured compact subsoil
Sampled by:	W. Rijkse

Description see site NRC00_1

Site NRC00_3

Soil Type	Marua clay
Map reference	260 Sheet Q06
GPS coordinates	E2639392 N6608159
Location	10 km NE of Whangarei, SE of Parkes Road. Owner Harris, same location as NRC00_1, and 2
Transect length and direction °	40 m, E 110°
Classification	Mottled Orthic Brown Soil?
Land use	Dairying, irrigated
Date sampled	12/02/01
Land-use history	
Present vegetation	Rye grass, white clover, paspalum
Slope	17° planar midslope
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	139
Parent material	Strongly weathered greywacke
Drainage	Moderately well drained
Topsoil depth (cm)	10
Total rooting depth (cm)	120+
Limiting horizon	Heavily textured compact wet subsoil,
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–10	Dark brown (10YR 3/3) clay loam; sticky; plastic; weak soil strength; friable failure; moderately pedal; abundant fine and very fine roots; distinct smooth boundary.
Bt	10–28	Yellowish brown (10YR 5/6) clay; few fine and medium faint strong brown (7.5YR 5/6) mottles; sticky; plastic; slightly firm soil strength; friable failure; many distinct brown (10YR 5/3) clay coatings; strongly pedal; many fine and very fine roots; indistinct smooth boundary.
Bg1	28–60	Yellowish brown (10YR 5/6) clay; common medium distinct strong brown (7.5YR 5/8) mottles; sticky; plastic; slightly firm soil strength; friable failure; strongly pedal; common fine and very fine roots; indistinct smooth boundary.
Bg2	60–120+	Yellowish brown (10YR 5/6) clay; sticky; plastic; firm soil strength; deformable failure; massive; few very fine roots.

Site NRC00_4

Soil Type	Waiotira clay
Map reference	260 Sheet Q07
GPS coordinates	E2623162 N6585338
Location	Waiotera area, southwest of Whangarei
Transect length and direction °	40 m, SW 240°
Classification	Mottled Acid Brown Soil
Land use	Dairying, non-irrigated
Date sampled	13/02/01
Land-use history	
Present vegetation	Rye grass, white clover, paspalum
Slope	17° convex crest
Landform	Weakly dissected hill country
Annual rain (mm)	1500
Elevation (m)	138
Parent material	Massive sandstone
Drainage	Poorly drained
Topsoil depth (cm)	19
Total rooting depth (cm)	80
Limiting horizon	Heavy textured compact subsoil with poor drainage
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–19	Very dark greyish brown (10YR 3/2) clay; sticky; slightly plastic; slightly firm soil strength; friable failure; earthy; many fine and very fine roots; distinct wavy boundary.
Bg1	19–45	Light olive brown (2.5Y 5/4) clay; many fine and medium distinct light brownish grey (2.5Y 6/2) and yellowish brown (10YR 5/8) mottles; sticky; plastic; firm soil strength; deformable failure; moderately pedal; common distinct clay and organic coatings (10YR 3/2- organic; 2.5Y 4/4- clay); common fine and very fine roots; indistinct wavy boundary.
Bg2	45–80	Light grey (2.5Y 7/2) clay; many medium prominent strong brown (7.5YR 5/8) and yellowish red (5YR 5/8) mottles; sticky; plastic; firm soil strength; deformable failure; common distinct dark brown (10YR 3/3) organic coatings; weakly pedal; few very fine roots; indistinct wavy boundary.
Bg3	80–120+	Light grey (2.5Y 7/1) clay; common medium prominent strong brown (7.5YR 5/8) mottles; very sticky; very plastic; firm soil strength; deformable failure; massive; no roots.

Site NRC00_5

Soil Type	Waiotira clay
Map reference	260 Sheet Q07
GPS coordinates	E2623179 N6585373
Location	Waiotera area, southwest of Whangarei, site adjacent (40 m) from NRC00_4
Transect length and direction °	40 m, SW 240°
Classification	Mottled Acid Brown Soil
Land use	Dairying, irrigated
Date sampled	13/02/01
Land-use history	
Present vegetation	Rye grass, white clover, paspalum
Slope	15° planar crest
Landform	Weakly dissected hill country
Annual rain (mm)	1500
Elevation (m)	138
Parent material	Massive sandstone
Drainage	Poorly drained
Topsoil depth (cm)	16
Total rooting depth (cm)	80
Limiting horizon	Heavy textured compact subsoil with poor drainage
Sampled by:	W. Rijkse

Description: see soil profile of NRC00_4, but with paler (low chroma) subsoil.

Site NRC00_6

Soil Type	Waiotira clay
Map reference	260 Sheet Q08
GPS coordinates	E2618632 N6575762
Location	Bull Road, southwest of Whangarei
Transect length and direction °	40 m, S 180°
Classification	Mottled Acid Brown Soil
Land use	Indigenous forest
Date sampled	13/02/01
Land-use history	Cut-over bush, well fenced off
Present vegetation	Totara, rimu, ponga, open forest floor
Slope	5° planar lower midslope, forest dimples
Landform	Weakly dissected hill country
Annual rain (mm)	1500
Elevation (m)	65
Parent material	Massive sandstone
Drainage	Poorly drained
Topsoil depth (cm)	18
Total rooting depth (cm)	120+
Limiting horizon	Heavy textured compact subsoil with poor drainage
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ah	0–18	Dark greyish brown (10YR 4/2) clay loam; sticky; plastic; weak soil strength; friable failure; earthy; many fine, medium and coarse roots; indistinct wavy boundary.
Btg	18–40	Light brownish grey (2.5Y 6/2) clay; many medium and coarse prominent yellowish brown (10YR 5/8) mottles; sticky; plastic; firm soil strength; deformable failure; moderately pedal; common fine and medium roots; indistinct wavy boundary.
Bg	40–120+	Light grey (2.5Y 7/2) clay; many medium prominent yellowish brown (10YR 5/8) mottles; sticky; plastic; very firm soil strength; deformable failure; massive; few fine and medium roots.

Site NRC00_7

Soil Type	Waiotira clay loam
Map reference	260 Sheet Q08
GPS coordinates	E2619002 N6575935
Location	Bull Road, southwest of Whangarei, site adjacent to NRC00_6
Transect length and direction °	40 m, S 180°
Classification	Mottled Acid Brown Soil
Land use	Drystock
Date sampled	13/02/01
Land-use history	
Present vegetation	Paspalum, weeds, white clover, rushes
Slope	17° concavo-convex midslope with forest dimples and terracettes
Landform	Weakly dissected hill country
Annual rain (mm)	1400
Elevation (m)	44
Parent material	Massive sandstone
Drainage	Imperfectly drained
Topsoil depth (cm)	16
Total rooting depth (cm)	80
Limiting horizon	Heavy textured compact subsoil with imperfect drainage
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–16	Very dark greyish brown (10YR 3/2) clay loam; sticky; slightly plastic; weak soil strength; friable failure; earthy; abundant fine and very fine roots; indistinct wavy boundary.
Bt	16–50	Light olive brown (2.5Y 5/4) clay; common fine and medium faint yellowish brown (10YR 5/6) mottles; sticky; plastic; slightly firm soil strength; deformable failure; moderately pedal; common distinct olive brown (2.5Y 4/4) clay coatings; common fine and very fine roots; indistinct wavy boundary.
Bw(f)	50–80	Light olive brown (2.5Y 5/4) clay; common coarse and medium prominent yellowish brown (10YR 5/8) mottles; sticky; plastic; firm soil strength; deformable failure; massive; common distinct pale yellow (2.5Y 7/4) fragments (of parent material?); few very fine roots; indistinct wavy boundary.
BC(f)	80–120+	Light olive brown (2.5Y 5/4) clay loam; many fine and medium prominent yellowish brown (10YR 5/8) and strong brown (7.5YR 5/6) mottles; sticky; slightly plastic; firm soil strength; semi-deformable failure; massive; no roots.

Site NRC00_8

Soil Type	Waiotira clay loam
Map reference	260 Sheet Q08
GPS coordinates	E2619041 N6575955
Location	Bull Road, southwest of Whangarei, site adjacent to NRC00_7
Transect length and direction °	40 m, N 340°
Classification	Mottled Acid Brown Soil
Land use	Plantation forestry
Date sampled	13/02/01
Land-use history	Converted from pasture about 40 years ago
Present vegetation	Pinus radiata, (2nd rotation), rushes, weeds
Slope	17° concavo-convex midslope with forest dimples and terracettes
Landform	Weakly dissected hill country
Annual rain (mm)	1400
Elevation (m)	57
Parent material	Massive sandstone
Drainage	Moderately well drained
Topsoil depth (cm)	7
Total rooting depth (cm)	85
Limiting horizon	None
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–7	Very dark greyish brown (10YR 3/2) clay loam; sticky; slightly plastic; weak soil strength; friable failure; earthy; common fine and medium roots; indistinct wavy boundary.
Bw	7–55	Light olive brown (2.5Y 5/4) clay; few fine and medium faint strong brown (7.5YR 5/6) and yellowish brown (10YR 5/6) mottles; sticky; plastic; firm soil strength; deformable failure; moderately pedal; common distinct olive brown (2.5Y 4/4) clay coatings; few very fine roots; indistinct wavy boundary.
Bw(f)	55–85	Olive yellow (2.5Y 6/6) clay; common fine distinct yellowish brown (10YR 5/6) mottles; sticky; plastic; firm soil strength; deformable failure; massive; few very fine roots; distinct wavy boundary.
BC	85–120+	Light yellowish brown (2.5Y 6/4) fine sand; non-sticky; non-plastic; slightly firm soil strength; brittle failure; massive; no roots.

Site NRC00_9

Soil Type	Waiotira clay
Map reference	260 Sheet Q08
GPS coordinates	E2618838 N6575921
Location	Bull Road, southwest of Whangarei, site adjacent to NRC00_6 under bush
Transect length and direction °	40 m, S 210
Classification	Mottled Acid Brown Soil
Land use	Drystock
Date sampled	13/02/01
Land-use history	
Present vegetation	Rushes, browntop, sweet vernal
Slope	25° concavo-convex midslope with forest dimples
Landform	Weakly dissected hill country
Annual rain (mm)	1400
Elevation (m)	63
Parent material	Massive sandstone
Drainage	Imperfectly drained
Topsoil depth (cm)	17
Total rooting depth (cm)	80
Limiting horizon	Heavily textured compact subsoil with imperfect drainage
Sampled by:	W. Rijkse

Description Similar to that of site NRC00_6, NRC00_4 and NRC00_5

Site NRC00_10

Soil Type	Red Hill sandy loam
Map reference	260 Sheet P07
GPS coordinates	E2585446 N6574864
Location	Mahuta Road, south of Dargaville and north of Red Hill
Transect length and direction °	40 m, S 180°
Classification	Typic Orthic Allophanic Soil
Land use	Cropping
Date sampled	14/02/01
Land-use history	Has been cropped discontinuously for some time
Present vegetation	Squash, weeds
Slope	1° planar crest of rolling country
Landform	Rolling dunes
Annual rain (mm)	1200
Elevation (m)	81
Parent material	Tephra overlying sandstone
Drainage	Well drained
Topsoil depth (cm)	16
Total rooting depth (cm)	80
Limiting horizon	None
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–16	Dark brown (7.5YR 3/2) sandy loam; non-sticky; non-plastic; weak soil strength; friable failure; earthy; many fine and very fine roots; sharp smooth boundary.(strong NaF reaction)
Bw1	16–42	Strong brown (7.5YR 4/6) sandy loam; slightly sticky; non-plastic; slightly firm soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary. (strong NaF reaction)
Bw2	42–80	Yellowish brown (10YR 5/8) silt loam; slightly sticky; non-plastic; firm soil strength; brittle failure; massive; few very fine roots; indistinct wavy boundary. (strong NaF reaction)
2BC	80–90	Brownish yellow (10YR 6/8) sandy loam; slightly sticky; non-plastic; firm soil strength; brittle failure; massive; no live roots; distinct smooth boundary.
2C	90–120+	Brownish yellow (10YR 6/8) sand; non-sticky; non-plastic; firm soil strength; brittle failure; massive; no roots.

Site NRC00_11

Soil Type	Red Hill sandy loam
Map reference	260 Sheet P07
GPS coordinates	E2585879 N6575323
Location	Mahuta Road, south of Dargaville and north of Red Hill
Transect length and direction °	40 m, SE 140°
Classification	Typic Orthic Allophanic Soil
Land use	Plantation forest
Date sampled	14/02/01
Land-use history	
Present vegetation	Pinus radiata 15 yrs old, 2nd rotation
Slope	16° planar midslope of rolling country
Landform	Rolling dunes
Annual rain (mm)	1200
Elevation (m)	50
Parent material	Tephra overlying sandstone
Drainage	Well drained
Topsoil depth (cm)	7
Total rooting depth (cm)	100+
Limiting horizon	None
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–7	Very dark greyish brown (10YR 3/2) sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; common fine and medium roots; distinct wavy boundary. (strong NaF reaction)
Bw	7–45	Strong brown (7.5YR 4/6) sandy loam; slightly sticky; non-plastic; very weak soil strength; friable failure; weakly pedal; common fine, medium and coarse roots; distinct smooth boundary. (strong NaF reaction)
2Bw	45–100+	Strong brown (7.5YR 4/6) silt loam; sticky; non-plastic; firm soil strength; friable failure; massive; few fine and medium roots.

Site NRC00_12

Soil Type	Red Hill loamy sand
Map reference	260 Sheet P07
GPS coordinates	E2585522 N6574477
Location	Mahuta Road, south of Dargaville and north of Red Hill
Transect length and direction °	40 m, E 100°
Classification	Typic Orthic Allophanic Soil
Land use	Dairying
Date sampled	14/02/01
Land-use history	
Present vegetation	Rye grass, white clover
Slope	1° planar crest of rolling country
Landform	Rolling dunes
Annual rain (mm)	1200
Elevation (m)	91
Parent material	Tephra overlying sandstone
Drainage	Well drained
Topsoil depth (cm)	20
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse

Description: Profile similar to that of NRC00_10

Site NRC00_13

Soil Type	Red Hill sandy loam
Map reference	260 Sheet P07
GPS coordinates	E2584976 N6575638
Location	Mahuta Road, south of Dargaville and north of Red Hill
Transect length and direction °	40 m, W 270°
Classification	Typic Orthic Allophanic Soil
Land use	Drystock
Date sampled	14/02/01
Land-use history	
Present vegetation	Rye grass, white clover, paspalum
Slope	2° planar crest and shoulder of rolling country
Landform	Rolling dunes
Annual rain (mm)	1200
Elevation (m)	96
Parent material	Tephra overlying sandstone
Drainage	Well drained
Topsoil depth (cm)	15
Total rooting depth (cm)	70
Limiting horizon	None
Sampled by:	W. Rijkse

Description: Soil profile similar to that of NRC00_10

Site NRC00_14

Soil Type	Wharekohe silt loam
Map reference	260 Sheet P07
GPS coordinates	E2609578 N6604244
Location	Brewer Road, 2 km southwest of Wharekohe
Transect length and direction °	40 m, NW 320°
Classification	Perch-gleyed Densipan Ultic Soil
Land use	Drystock
Date sampled	15/02/01
Land-use history	
Present vegetation	Ryegrass, white clover, paspalum
Slope	5° planar crest of rolling country
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	144
Parent material	Strongly weathered banded sandstone
Drainage	Imperfectly drained
Topsoil depth (cm)	13
Total rooting depth (cm)	75
Limiting horizon	Hard silicapan
Sampled by:	W. Rijkse

Description

Horizon	Depth (cm)	Description
Ap	0–13	Very dark greyish brown (10YR 3/2) silt loam; slightly sticky; slightly plastic; weak soil strength; earthy; many fine and very fine roots; distinct smooth boundary.
Ex	13–34	Light brownish grey (2.5Y 6/2) loamy very fine sand; few fine distinct yellowish brown (10YR 5/6) mottles; slightly sticky; slightly plastic; very hard soil strength; brittle; massive; few fine and very fine roots; distinct wavy boundary. (silica pan)
Bg1	34–75	Pale yellow (2.5Y 7/4) clay; many fine and medium distinct strong brown (7.5YR 5/6) mottles; sticky; plastic; very firm soil strength; deformable failure; moderately pedal; many prominent greyish brown (2.5Y 5/2) clay and organic coatings on peds; common fine and very fine roots; distinct smooth boundary.
Bg2	75–120+	White (2.5Y 8/2) silt loam; common medium prominent yellowish brown (10YR 5/6) mottles; slightly sticky; slightly plastic; firm soil strength; semi-deformable failure; massive; no live roots.

Note: profile described in adjacent track cutting.

Site NRC00_15

Soil Type	Wharekohe silt loam
Map reference	260 Sheet P07
GPS coordinates	E26010069 N6604213
Location	Brewer Road, 1 km southwest of Wharekohe
Transect length and direction °	40 m, E 100°
Classification	Perch-gleyed Densipan Ultic Soil
Land use	Dairying
Date sampled	15/02/01
Land-use history	
Present vegetation	Kikuyu, ryegrass, white clover, paspalum
Slope	1° planar midslope of rolling country
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	135
Parent material	Strongly weathered banded sandstone
Drainage	Imperfectly drained
Topsoil depth (cm)	11
Total rooting depth (cm)	120+
Limiting horizon	Seasonally hard silicapan
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
Ap	0–11	Very dark greyish brown (10YR 3/2) silt loam; sticky; slightly plastic; weak soil strength; friable failure; earthy; common fine and very fine roots; distinct smooth boundary.
E	11–24	Greyish brown (2.5Y 5/2) loamy fine sand; slightly sticky; non-plastic; firm soil strength; brittle failure; massive; few fine and very fine roots; distinct smooth boundary.
Bh	24–44	Dark brown (7.5YR 3/2) clay; sticky; plastic; firm soil strength; deformable failure; moderately pedal; common distinct dark greyish brown (10YR 4/2) organic coatings on peds; common fine and very fine roots; distinct wavy boundary.
Bg1	44–80	Light greyish brown (2.5Y 6/2) clay; common medium distinct yellowish brown (10YR 5/6) mottles; sticky; plastic; firm soil strength; deformable failure; moderately pedal; common distinct dark greyish brown (10YR 4/2) organic coatings on peds; few fine and very fine roots; diffuse smooth boundary.
Bg2	80–120+	Yellow (2.5Y 7/6) clay; profuse medium and coarse prominent yellowish brown (10YR 5/6) mottles; sticky; plastic; firm soil strength; deformable failure; massive; few fine and very fine roots.

Site NRC00_16

Soil Type	Wharekohe silt loam
Map reference	260 Sheet P07
GPS coordinates	E2611218 N6605181
Location	Brewer Road, 2 km northeast of Wharekohe
Transect length and direction °	40 m, SE 150°
Classification	Perch-gleyed Densipan Ultic Soil
Land use	Plantation forest
Date sampled	15/02/01
Land-use history	1st rotation after pasture
Present vegetation	*Pinus radiata* (7 years old), tall grasses, slash, thistles, blackberry
Slope	16° concavo-convex midslope
Landform	Moderately dissected hill country
Annual rain (mm)	1600
Elevation (m)	108
Parent material	Strongly weathered banded sandstone
Drainage	Imperfectly drained
Topsoil depth (cm)	10
Total rooting depth (cm)	120+
Limiting horizon	Seasonally hard silicapan
Sampled by:	W. Rijkse

Description: see profile NRC00_14

Site NRC00_17

Soil Type	Marua clay loam
Map reference	260 Sheet Q07
GPS coordinates	E2635121 N6606704
Location	Off Awaroa Creek Road, east of Whangarei
Transect length and direction °	40 m, SE 150°
Classification	Typic Orthic Brown Soil
Land use	Plantation forest
Date sampled	15/02/01
Land-use history	Has been in pasture before, drystock
Present vegetation	*Pinus radiata*, 25 to 30 years old, first generation.
Slope	12° convex midslope and shoulder
Landform	Moderately dissected hill country
Annual rain (mm)	1600
Elevation (m)	106
Parent material	Strongly weathered greywacke
Drainage	Well drained
Topsoil depth (cm)	17
Total rooting depth (cm)	80
Limiting horizon	Clayey very firm subsoil
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
Ap	0–17	Very dark greyish brown (10YR 3/2) clay loam; sticky; slightly plastic; weak soil strength; friable failure; earthy; common fine and medium roots; distinct smooth boundary.
Bt	17–45	Dark yellowish brown (10YR 4/6) clay; sticky; plastic; slightly firm soil strength; deformable failure; moderately pedal; common distinct very dark greyish brown (10YR 3/2) clay and organic coatings on peds; common fine roots; indistinct smooth boundary.
Bw	45–80	Yellowish brown (10YR 5/6) clay; sticky; plastic; firm soil strength; deformable failure; moderately pedal; few distinct very dark greyish brown (10YR 3/2) clay and organic coatings on peds; few fine roots; diffuse wavy boundary.
BC	80–120+	Yellowish brown (10YR 5/6) clay; sticky; plastic; very firm soil strength; deformable failure; massive; no roots.

Site NRC00_18

Soil Type	Marua clay loam
Map reference	260 Sheet Q07
GPS coordinates	E2636181 N6606740
Location	Off Awaroa Creek Road, off Bus Road ,east of Whangarei
Transect length and direction °	40 m, NW 340°
Classification	Typic Orthic Brown Soil
Land use	Indigenous forest
Date sampled	15/02/01
Land-use history	Cut-over bush, pasture before, drystock
Present vegetation	Pouriri, ponga, nikau
Slope	18° concavo-convex midslope
Landform	Moderately dissected hill country
Annual rain (mm)	1600
Elevation (m)	97
Parent material	Strongly weathered greywacke
Drainage	Well drained
Topsoil depth (cm)	3
Total rooting depth (cm)	120+
Limiting horizon	Clayey, very firm subsoil
Sampled by:	W. Rijkse

Description: Similar profile to that of site NRC00_17, but with much shallower topsoil, which could affect sampling results. Also common reddish brown mottles between 40 and 55 cm depth.

Site NRC00_19

Soil Type	Awarua clay loam
Map reference	260 Sheet P06
GPS coordinates	E2587147 N6630875
Location	South of Kaikohe, off Mangakahia Road
Transect length and direction °	40 m, E 110°
Classification	Acidic Oxidic Granular Soil
Land use	Dairying, non-irrigated
Date sampled	16/02/01
Land-use history	
Present vegetation	Cocksfoot, white clover, rye grass, paspalum
Slope	1° concave midslope
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	162
Parent material	Strongly weathered basalt
Drainage	Well drained
Topsoil depth (cm)	17
Total rooting depth (cm)	80
Limiting horizon	Clayey very firm subsoil
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
Ap	0–11	Very dark brown (10YR 2/2) clay loam; slightly sticky; slightly plastic; weak soil strength; friable failure; strongly pedal; abundant fine and very fine roots; distinct smooth boundary.
Bw1	11–32	Dark yellowish brown (10YR 4/6) clay; sticky; plastic; firm soil strength; friable failure; strongly pedal; common faint dark yellowish brown (10YR 4/4) clay coatings on peds; common fine and very fine roots; distinct smooth boundary.
Bw2	32–50	Olive brown (2.5Y 4/4) clay; sticky; plastic; firm soil strength; deformable failure; weakly pedal; few moderately weathered subangular gravels (1–4 mm diam.); few fine and very fine roots; indistinct smooth boundary.
BC1	50–80	Yellowish brown (10YR 5/8) clay; sticky; plastic; very firm soil strength; deformable failure; massive; few very fine roots; indistinct smooth boundary.
BC2	80–120+	Yellowish brown (10YR 5/8) clay; sticky; plastic; very firm soil strength; deformable failure; massive; few distinct strong brown (7.5YR 5/8) mottles; no roots.

Site NRC00_20

Soil Type	Awarua clay loam
Map reference	260 Sheet P06
GPS coordinates	E2587147 N6630875
Location	About 60 m south of site NRC00_19, south of Kaikohe, off Mangakahia Road
Transect length and direction °	40 m, E 100°
Classification	Acidic Oxidic Granular Soil
Land use	Indigenous forest
Date sampled	16/02/01
Land-use history	Cut-over bush
Present vegetation	Totara, kauri (open forest floor)
Slope	24° concavo-convex midslope
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	158
Parent material	Strongly weathered basalt
Drainage	Well drained
Topsoil depth (cm)	9
Total rooting depth (cm)	80
Limiting horizon	Clayey very firm subsoil
Sampled by:	W. Rijkse

Description: Similar profile as described for site NRC00_19, but a shallower topsoil, and only moderately pedal in the Bw horizons.

Site NRC00_21

Soil Type	Awarua clay loam
Map reference	260 Sheet P06
GPS coordinates	E2587143 N6630539
Location	South of Kaikohe, off Mangakahia, south of Kaikohe
Transect length and direction °	40 m, S 160°
Classification	Acidic Oxidic Granular Soil
Land use	Dairying, irrigated (with water)
Date sampled	16/02/01
Land-use history	
Present vegetation	Rye grass, white clover
Slope	1° planar crest
Landform	Weakly dissected hill country
Annual rain (mm)	1600
Elevation (m)	164
Parent material	Strongly weathered basalt
Drainage	Well drained
Topsoil depth (cm)	15
Total rooting depth (cm)	120+
Limiting horizon	Clayey very firm subsoil
Sampled by:	W. Rijkse

Description: see descriptions of NRC00_19 and 20 on the same property.

Site NRC00_22

Soil Type	Awarua clay loam
Map reference	260 Sheet P06
GPS coordinates	E2587147 N6630875
Location	South of Kaikohe, 2 km north of Awarua, along Mangakahia Road
Transect length and direction °	40 m, SE 160°
Classification	Acidic Oxidic Granular Soil
Land use	Plantation forest
Date sampled	16/02/01
Land-use history	Clear-felled first generation *Pinus radiata*. Was in pasture before that
Present vegetation	Blackberry, grasses, weeds, slash from clear-felling
Slope	1° planar midslope
Landform	Rolling country
Annual rain (mm)	1600
Elevation (m)	100
Parent material	Strongly weathered basalt
Drainage	Well drained
Topsoil depth (cm)	14
Total rooting depth (cm)	65
Limiting horizon	Clayey very firm subsoil
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
A	0–14	Dark brown (10YR 3/3) clay; sticky; plastic; weak soil strength; friable failure; moderately pedal; common medium and coarse roots; distinct smooth boundary.
Bt	14–42	Dark yellowish brown (10YR 4/4) clay; sticky; plastic; slightly firm soil strength; friable failure; strongly pedal; common distinct dark yellowish brown (10YR 4/6) clay coatings on peds; common fine and medium roots; indistinct smooth boundary.
Bw	42–65	Dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/6) clay; sticky; plastic; very firm soil strength; deformable failure; moderately pedal; few fine roots; distinct smooth boundary.
BC	65–120+	Dark yellowish brown (10YR 4/6) and 20% yellowish brown (10YR 5/6) clay; sticky; plastic; very firm soil strength; deformable failure; massive; no roots.

Note: Some disturbed areas from recent logging.

Site NRC00_23

Soil Type	Kiripaka bouldery clay loam
Map reference	260 Sheet Q06
GPS coordinates	E2634186 N6613793
Location	About 4 km northeast of Whangarei, south of Ngunguru Road
Transect length and direction °	40 m, N 340°
Classification	Typic Orthic Allophanic Soil
Land use	Dairying
Date sampled	16/02/01
Land-use history	Cleared of boulders at the surface, has been in dairying for a long period
Present vegetation	Paspalum, white clover
Slope	0° planar midslope
Landform	Rolling country
Annual rain (mm)	1600
Elevation (m)	109
Parent material	Basaltic flow
Drainage	Well drained
Topsoil depth (cm)	18
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
Ap	0–18	Very dark greyish brown (10YR 3/2) clay loam; sticky; plastic; weak soil strength; friable failure; weak soil strength; strongly pedal; few weakly weathered subrounded basaltic stones to 8 cm diam.; abundant fine and very fine roots; distinct smooth boundary.
Bw	18–45	Dark yellowish brown (10YR 3/4) clay loam; sticky; plastic; weak soil strength; friable failure; moderately pedal; common weakly weathered subrounded basaltic stones to 8 cm diam.; common fine and very fine roots; indistinct smooth boundary.
BC1	45–60	Dark yellowish brown (10YR 3/4) clay; sticky; plastic; slightly firm soil strength; semi-deformable; weakly pedal; common weakly weathered subrounded basaltic stones to 8 cm diam.; few fine and very fine roots; indistinct wavy boundary.
BC2	60–120+	Basaltic boulders and 10% dark yellowish brown (10YR 3/4) clay.

Site NRC00_24

Soil Type	Kiripaka bouldery clay loam
Map reference	260 Sheet Q06
GPS coordinates	E2634186 N6613793
Location	About 4 km northeast of Whangarei, south of Ngunguru Road, adjacent to site NRC00_23
Transect length and direction °	40 m, W 280°
Classification	Typic Orthic Allophanic Soil
Land use	Indigenous forest
Date sampled	16/02/01
Land-use history	Cut-over bush remnant, fenced off
Present vegetation	Pouri, ponga, kauri with open forest floor
Slope	1° planar midslope
Landform	Rolling country
Annual rain (mm)	1600
Elevation (m)	90
Parent material	Basaltic flow
Drainage	Well drained
Topsoil depth (cm)	14
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse

Description: See profile described for site NRC00_23 some 30 m away, but with some 30% basaltic boulders, stones and gravels at the surface and slightly shallower topsoil.

Site NRC00_25

Soil Type	Kiripaka bouldery clay loam
Map reference	260 Sheet Q06
GPS coordinates	E2633258 N6613898
Location	About 4 km northeast of Whangarei, Ngunguru Road Maruata Road intersection
Transect length and direction °	40 m, W 380°
Classification	Typic Orthic Allophanic Soil
Land use	Citrus orchard
Date sampled	16/02/01
Land-use history	
Present vegetation	Mandarins (25 yrs old), with weed strips between rows
Slope	0° planar midslope
Landform	Rolling country
Annual rain (mm)	1600
Elevation (m)	134
Parent material	Basaltic flow
Drainage	Well drained
Topsoil depth (cm)	25
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse

Description:

Horizon	Depth (cm)	Description
Ap	0–25	Dark brown (10YR 3/3) clay loam; sticky; slightly plastic; weak soil strength; friable failure; strongly pedal; few weakly weathered subrounded basaltic gravels; abundant medium and fine roots; indistinct smooth boundary.
Bw1	25–45	Brown (7.5YR 4/4) clay; sticky; plastic; slightly firm soil strength; friable failure; moderately pedal; common weakly weathered subrounded basaltic gravels, stones and boulders; common fine roots; indistinct wavy boundary.
Bw2	45–60+	Dark yellowish brown (10YR 3/4) clay; sticky; plastic; slightly firm soil strength; deformable failure; massive to weakly pedal; common weakly weathered subrounded stones, boulders and gravels increasing with depth; few very fine roots.

Table showing changes in landuse (provided by NRC)

Sample ID	Sample date	Sample time	Soil type	Cores numbered	Old land use	Current land use	Comments
NRC00_1	18/06/2007	1040	Marua clay	NRC001 A to C	Dairying, non-irrigated	Beef	Drystock for approx 2 years
NRC00_2	18/06/2007	1115	Marua clay	NRC002 A to C	Drystock	Beef	"
NRC00_3	18/06/2007	1230	Marua clay	NRC003 A to C	Dairying, irrigated	Beef	"
NRC00_4	19/06/2007	1230	Waiotira clay	NRC004 A to C	Dairying, non-irrigated	Dairying, non-irrigated	
NRC00_5	19/06/2007	1320	Waiotira clay	NRC005 A to C	Dairying, irrigated	Dairying, irrigated	
NRC00_6	19/06/2007	1200	Waiotira clay	NRC006 A to C	Indigenous forest	Indigenous forest	Some stock browsing - although 7 wire fence in good condition
NRC00_7	19/06/2007	1015	Waiotira clay	NRC007 A to C	Drystock	Drystock	Not overstocked
NRC00_8	19/06/2007	1045	Waiotira clay	NRC008 A to C	Plantation forestry	Plantation forestry	Trees thinned
NRC00_9	19/06/2007	1130	Waiotira clay	NRC009 A to C	Drystock	Drystock	Mild pugging, rushes indicating imperfect drainage.
NRC00_10	22/06/2007	1245	Red hill sandy loam	NRC0010 A to C	Cropping - squash	Drystock pasture	Was in onions until 18 months ago, light fertiliser dressing in April 07
NRC00_11	22/06/2007	1340	Red hill sandy loam	NRC0011 A to C	Plantation forestry	Approx 10 yr old pine	
NRC00_12	22/06/2007	1415	Red hill sandy loam	NRC0012 A to C	Dairying	Dairying	Possibly effluent irrigation - very high worm numbers
NRC00_13	22/06/2007	1220	Red hill sandy loam	NRC0013 A to C	Drystock	Drystock	Exposed
NRC00_14	19/06/2007	1515	Wharekohe silt loam	NRC0014 A to C	Drystock	Less intensive dairying	
NRC00_15	19/06/2007	1445	Wharekohe silt loam	NRC0015 A to C	Dairying	Intensive dairying	Recent superphosphate application
NRC00_16	21/06/2007	1515	Wharekohe silt loam	NRC0016 A to C	Plantation forestry	Plantation forestry	Blackberry has died back - possibly sprayed?
NRC00_17	18/06/2007	1630	Marua clay	NRC0017 A to C	Plantation forestry	Plantation forestry - planted 2002	
NRC00_18	18/06/2007	1700	Marua clay	NRC0018 A to C	Indigenous forestry	Indigenous forestry	
NRC00_19	21/06/2007	1230	Awarua clay	NRC0019 A to C	Dairying, non-irrigated	Dairying, non-irrigated	
NRC00_20	21/06/2007	1245	Awarua clay	NRC0020 A to C	Indigenous forest	Indigenous forest	Evidence of stock access
NRC00_21	21/06/2007	1325	Awarua clay	NRC0021 A to C	Dairying, irrigated (water)	Dairying, irrigated (water)	
NRC00_22	21/06/2007	1100	Awarua clay	NRC0022 A to C	Plantation forestry	6 yr old forestry with mix of young native	
NRC00_23	18/06/2007	1420	Kiripaka bouldery clay	NRC0023 A to C	Dairying	Drystock	Heavily trampled with stock
NRC00_24	18/06/2007	1415	Kiripaka bouldery clay	NRC0024 A to C	Indigenous forest	Indigenous forestry	
NRC00_25	18/06/2007	1350	Kiripaka bouldery clay	NRC0025 A to C	Citrus orchard, Huanui	Tangelo's - some new trees	

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

Dairy Sites

Code	Soil Order	pH	TC mg/cm^3	TN mg/cm^3	C:N ratio	AMN $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Bd Mg/m^3	Pd Mg/m^3	Macro Porosity %v/v	Tpor %v/v
Current (2007) Measurements – grouped by land use											
NRC00_4	Brown	6.15	72.21	6.03	12.0	142	82	1.05	2.48	4.2	57.7
NRC00_5	Brown	6.19	63.52	5.64	11.3	141	43	0.89	2.46	6.2	63.6
NRC00_12	Allophanic	6.09	50.92	4.99	10.2	101	56	1.04	2.54	3.1	59.2
NRC00_14	Ultic	4.85	57.23	4.58	12.5	116	58	0.79	2.40	10.7	67.0
NRC00_15	Ultic	4.9	50.99	4.34	11.7	110	56	0.73	2.36	4.5	69.0
NRC00_19	Granular	5.78	82.96	6.21	13.4	142	16	0.78	2.51	7.7	68.9
NRC00_21	Granular	6.28	73.26	6.11	12.0	154	35	0.88	2.57	7.7	65.9
Previous (2001) Measurements											
NRC00_ 4	Brown	6.24	65.4	5.34	12.0	190	59	0.84	2.4	21.6	65.1
NRC00_ 5	Brown	6.2	73.3	5.82	13.0	247	55	1.06	2.44	7.6	56.5
NRC00_ 12	Allophanic	6.07	74.00	6.37	12.0	146	59	1.2	2.54	14.3	52.7
NRC00_ 14	Ultic	5.80	67.40	5.60	12.0	197	52	1.05	2.44	8.5	57.0
NRC00_ 15	Ultic	5.54	71.00	6.23	11.0	144	62	0.82	2.37	16.8	65.3
NRC00_ 19	Granular	5.74	76.40	5.55	14.0	150	14	0.73	2.53	24.7	71.0
NRC00_ 21	Granular	6.20	70.10	5.74	12.0	178	40	0.83	2.52	13.8	67.2

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

Code	Soil Order	pH	TC mg/cm^3	TN mg/cm^3	C:N ratio	AMN $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Bd Mg/m^3	PD Mg/m^3	Macroporosity %v/v	Tpor %v/v
Current (2007) Measurements											
Drystock		New									
NRC00_1	Granular	5.43	60.93	5.86	10.4	144	25	0.84	2.44	12.4	65.7
NRC00_2	Granular	5.69	59.33	5.09	11.7	157	16	1.00	2.49	9.2	59.9
NRC00_3	Brown	5.32	66.58	5.78	11.5	162	52	1.02	2.51	8.0	59.4
NRC00_7	Brown	6.49	65.77	5.75	11.4	138	12	0.88	2.49	12.2	64.6
NRC00_9	Brown	5.64	48.89	3.78	12.9	92	8	0.93	2.49	7.6	62.8
NRC00_10	Allophanic	7.20	50.42	3.82	13.2	41	40	1.22	2.60	5.2	53.0
NRC00_13	Allophanic	5.77	59.69	5.14	11.6	108	13	0.86	2.50	13.9	65.7
NRC00_23	Allophanic	5.53	75.02	6.76	11.1	164	45	0.94	2.49	10.1	62.2
2001											
NRC00_1	Granular	5.61	59.10	5.25	11.0	255	19	0.85	2.46	17.1	65.3
NRC00_ 2	Granular	5.35	54.60	4.64	12.0	193	9	0.85	2.48	22	65.9
NRC00_ 3	Brown	5.38	51.4	4.33	12.0	271	44	0.98	2.49	13.3	60.5
NRC00_ 7	Brown	5.64	65.7	5.38	12.0	170	9	0.91	2.47	19.1	63.3
NRC00_ 9	Brown	5.17	62.3	4.12	15.0	111	6	0.96	2.5	20.8	62.1
NRC00_ 10	Allophanic	7.25	39.9	2.48	16.0	29	18	0.86	2.55	30.7	66.3
NRC00_ 13	Allophanic	6.32	68.30	5.88	12.0	171	16	0.84	2.47	21.4	66.4
NRC00_ 23	Allophanic	5.92	67.10	5.99	11.0	161	47	0.94	2.41	13.1	61.0

Table showing all current and previous chemical, biochemical and physical data on a volume basis for plantation forestry Sites

Code	Soil Order	pH	TC mg/cm^3	TN mg/cm^3	C:N ratio	AMN $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Bd Mg/m^3	PD Mg/m^3	Macroporosity %v/v	Tpor %v/v
		Current (2007) Measurements									
Plantation Forestry		New									
NRC00_8	Brown	5.07	57.58	3.35	17.2	47	16	0.94	2.47	22.9	62.4
NRC00_11	Allophanic	6.36	40.65	2.23	18.2	55	6	0.80	2.56	30.5	68.9
NRC00_16	Ultic	4.46	63.21	3.98	15.9	50	8	1.00	2.53	23.8	60.5
NRC00_17	Brown	4.97	54.49	3.00	18.2	66	24	0.96	2.52	22.0	62.0
NRC00_22	Granular	4.98	80.01	3.37	23.7	90	18	0.84	2.69	14.3	68.8
		2001									
NRC00_ 8	Brown	4.99	49.2	2.53	19.0	60	13	0.73	2.4	34.5	70.1
NRC00_ 11	Allophanic	6.28	40.5	2.07	20.0	54	9	0.91	2.47	26.7	63.2
NRC00_ 16	Ultic	4.93	54.20	4.07	13.0	118	22	0.91	2.46	26.8	63.2
NRC00_ 17	Brown	4.95	71.80	3.82	19.0	146	13	0.92	2.43	25.4	62.3
NRC00_ 22	Granular	5.31	78.60	3.75	21.0	123	6	0.86	2.61	8.8	67.0

Table showing all current and previous chemical, biochemical and physical data on a volume basis for indigenous and crop/hort sites

Code	Soil Order	pH	TC mg/cm^3	TN mg/cm^3	C:N ratio	AMN $\mu g/cm^3$	Olsen P $\mu g/cm^3$	Bd Mg/m^3	PD Mg/m^3	Macroporosity %v/v	Tpor %v/v
		Current (2007) Measurements									
Indigenous		New									
NRC00_6	Brown	5.28	60.56	3.67	16.5	134	9	1.10	2.59	6.9	57.5
NRC00_18	Brown	4.64	57.99	3.02	19.2	44	13	0.91	2.54	15.8	64.2
NRC00_20	Granular	4.84	99.49	5.22	19.1	132	7	0.80	2.62	12.0	69.6
NRC00_24	Allophanic	6.48	84.15	5.71	14.7	174	7	0.68	2.48	27.7	72.5
	2001										
NRC00_ 6	Brown	5.62	58.8	3.54	17.0	180	11	1.02	2.51	13.7	59.4
NRC00_ 18	Brown	4.60	53.70	3.01	18.0	55	7	0.8	2.52	12.4	68.4
NRC00_ 20	Granular	4.82	87.10	4.51	19.0	131	20	0.66	2.55	24.5	74.2
NRC00_ 24	Allophanic	6.40	56.90	4.35	13.0	148	3	0.66	2.39	18.4	72.6
Crop/hort											
NRC00_25	Allophanic	6.07	61.39	5.16	11.9	137	74	1.00	2.62	10.4	61.9
	2001										
NRC00_ 25	Allophanic	6.17	59.5	5.34	11.0	148	77	0.95	2.63	14.1	63.9

Table showing all current (2007) chemical data (mass basis)

Soil Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: Bryan Stevenson, Landcare Research, Hamilton **Date In:** 12/07/2007

Job No.: LJ07014 **Date Out:** 12/09/2007

Client ID	Sample No.	Water Content (% dry wt)	pH (water) (method 106)	Total C (method 114) (%)	Total N (method 114) (%)	KCl-extractable NO3-N (method 118) (mg/kg)	KCl-extractable NH4-N (method 118) (mg/kg)	Anaerobic Mineralisable-N (method (120) (mg/kg)	Olsen P (method 124) (mg/kg)	Total Arsenic (method 163) mg/kg	Total Cadmium (method 163) mg/kg	Total Chromium (method 163) mg/kg	Total Cobalt (method 163) mg/kg	Total Copper (method 163) mg/kg	Total Nickel (method 163) mg/kg	Total Lead (method 163) mg/kg	Total Zinc (method 163) mg/kg
NRC00_1	M7/1165	51	5.43	7.26	0.70	48.7	34.6	172	30	<0.5	<0.5	13.1	6.4	16.4	12.4	9.3	45.8
NRC00_2	M7/1166	43	5.69	5.92	0.51	0.52	17.6	156	16	<0.5	<0.5	17.0	7.6	18.3	13.0	12.1	55.1
NRC00_3	M7/1167	45	5.32	6.54	0.57	13.4	17.9	159	51	<0.5	<0.5	14.0	5.5	8.4	9.9	9.3	28.8
NRC00_4	M7/1168	47	6.15	6.89	0.58	48.7	16.7	135	78	<0.5	<0.5	29.7	6.1	17.6	10.2	3.0	41.2
NRC00_5	M7/1169	49	6.19	7.10	0.63	47.9	15.2	157	48	<0.5	<0.5	25.6	4.7	15.6	8.3	3.2	41.0
NRC00_6	M7/1170	56	5.28	5.51	0.33	40.4	16.5	122	8	<0.5	<0.5	17.5	9.2	21.2	11.5	8.4	58.6
NRC00_7	M7/1171	55	6.49	7.45	0.65	49.9	21.0	157	13	<0.5	<0.5	35.2	4.5	23.5	16.0	6.6	46.2
NRC00_8	M7/1172	33	5.07	6.16	0.36	5.34	17.2	50.1	17	<0.5	<0.5	14.2	3.2	9.4	7.4	6.7	30.0
NRC00_9	M7/1173	48	5.64	5.27	0.41	27.7	31.5	99.4	8	<0.5	<0.5	14.1	2.6	8.1	5.9	5.0	23.5
NRC00_10	M7/1174	37	7.20	4.13	0.31	17.0	17.3	33.5	33	6	<0.5	16.0	5.1	7.9	8.7	3.9	31.2
NRC00_11	M7/1175	39	6.36	5.10	0.28	1.07	18.2	69.1	8	6	<0.5	13.0	5.8	17.1	11.0	8.0	53.5
NRC00_12	M7/1176	45	6.09	4.91	0.48	62.5	23.6	97.2	54	5	<0.5	15.2	4.6	6.1	8.4	3.5	49.9
NRC00_13	M7/1177	51	5.77	6.98	0.60	49.3	40.1	126	15	10	<0.5	14.0	4.4	9.5	8.6	3.6	37.7
NRC00_14	M7/1178	54	4.85	7.21	0.58	135	45.2	146	74	<0.5	<0.5	8.6	0.2	5.4	1.7	3.2	18.3
NRC00_15	M7/1179	60	4.90	6.97	0.59	114	37.3	150	77	<0.5	<0.5	8.5	1.1	10.6	3.6	21.4	29.4
NRC00_16	M7/1180	33	4.46	6.32	0.40	0.60	25.8	50.4	8	<0.5	<0.5	5.7	1.6	5.3	3.6	3.6	9.2
NRC00_17	M7/1181	41	4.97	5.69	0.31	9.67	37.1	68.5	25	12	<0.5	15.4	3.9	5.7	8.9	9.8	24.5
NRC00_18	M7/1182	56	4.64	6.37	0.33	2.11	39.1	48.2	14	<0.5	<0.5	11.8	5.0	11.3	9.5	9.5	29.5
NRC00_19	M7/1183	74	5.78	10.7	0.80	50.0	35.2	183	21	<0.5	<0.5	58.8	11.2	30.1	32.7	0.9	43.9
NRC00_20	M7/1184	84	4.84	12.4	0.65	15.0	45.8	165	9	<0.5	<0.5	61.1	25.5	45.0	43.7	0.1	59.7
NRC00_21	M7/1185	67	6.28	8.36	0.70	68.2	37.7	176	40	<0.5	<0.5	47.1	11.2	31.6	27.1	1.7	133
NRC00_22	M7/1186	79	4.98	9.56	0.40	0.00	44.3	108	22	<0.5	<0.5	144.0	13.4	27.6	37.5	2.7	49.7
NRC00_23	M7/1187	56	5.53	7.99	0.72	72.4	17.7	174	48	<0.5	<0.5	69.2	22.4	45.7	50.1	12.1	108
NRC00_24	M7/1188	72	6.48	12.3	0.84	41.2	18.8	255	11	<0.5	<0.5	73.2	27.3	41.9	46.0	11.1	91.2
NRC00_25	M7/1189	53	6.07	6.15	0.52	39.4	18.7	138	74	<0.5	<0.5	67.8	27.9	102	40.3	11.9	80.5

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

Northland Soil Quality 2007
Moisture Release Results
Job Code: 334 202 7100
September 2007

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)
HP3405a	NRC00_1 A	68.2	0.70	2.44	71.2	17.8	19.6	53.4	51.6
HP3405b	B	58.6	0.81	2.40	66.1	12.9	14.7	53.2	51.4
HP3405c	C	49.0	1.00	2.49	59.9	6.5	8.1	53.4	51.8
HP3406a	NRC00_2 A	57.3	0.90	2.46	63.4	7.5	9.8	55.9	53.6
HP3406b	B	34.7	1.20	2.55	53.0	4.9	6.5	48.1	46.5
HP3406c	C	45.3	0.91	2.47	63.2	15.2	16.5	48.0	46.7
HP3407a	NRC00_3 A	38.8	1.11	2.52	55.8	6.3	8.1	49.5	47.7
HP3407b	B	50.5	0.92	2.48	62.7	8.5	10.9	54.2	51.8
HP3407c	C	45.0	1.02	2.53	59.7	9.3	10.5	50.4	49.2
HP3408a	NRC00_4 A	41.0	1.13	2.51	55.0	4.7	5.7	50.3	49.3
HP3408b	B	47.7	1.03	2.47	58.2	4.8	5.9	53.4	52.3
HP3408c	C	55.2	0.98	2.45	60.0	3.0	4.0	57.0	56.0
HP3409a	NRC00_5 A	53.9	0.90	2.46	63.4	8.0	9.4	55.4	54.0
HP3409b	B	70.4	0.81	2.45	67.1	4.8	6.6	62.3	60.5
HP3409c	C	48.4	0.97	2.46	60.4	5.9	7.1	54.5	53.3
HP3410a	NRC00_6 A	47.2	1.12	2.61	57.1	2.4	3.4	54.7	53.7
HP3410b	B	43.3	1.12	2.56	56.3	5.8	7.3	50.5	49.0
HP3410c	C	39.3	1.06	2.60	59.2	12.6	13.9	46.6	45.3
HP3411a	NRC00_7 A	49.5	0.87	2.50	65.1	14.5	15.9	50.6	49.2
HP3411b	B	46.1	0.94	2.51	62.6	14.5	16.1	48.1	46.5
HP3411c	C	67.3	0.83	2.46	66.1	7.5	9.1	58.6	57.0
HP3412a	NRC00_8 A	29.2	1.10	2.56	57.1	18.2	18.7	38.9	38.4
HP3412b	B	49.5	0.66	2.29	71.4	28.9	30.7	42.5	40.7
HP3412c	C	28.5	1.05	2.55	58.7	21.5	22.0	37.2	36.7
HP3413a	NRC00_9 A	68.6	0.87	2.43	64.4	4.8	7.2	59.6	57.2
HP3413b	B	46.5	0.98	2.54	61.5	13.3	15.0	48.2	46.5
HP3413c	C	61.4	0.94	2.51	62.5	4.8	7.4	57.7	55.1
HP3414a	NRC00_10 A	39.3	1.19	2.62	54.6	5.2	8.1	49.4	46.5
HP3414b	B	37.6	1.19	2.58	54.0	7.1	11.4	46.9	42.6
HP3414c	C	33.4	1.29	2.59	50.3	3.3	5.2	47.0	45.1
HP3415a	NRC00_11 A	23.1	0.77	2.59	70.1	39.6	44.3	30.5	25.8
HP3415b	B	34.2	0.78	2.56	69.4	26.7	34.0	42.7	35.4
HP3415c	C	29.9	0.83	2.53	67.1	25.1	35.8	42.0	31.3
HP3416a	NRC00_12 A	55.3	1.02	2.56	60.0	3.6	6.1	56.4	53.9
HP3416b	B	48.9	1.08	2.54	57.4	4.2	6.0	53.2	51.4
HP3416c	C	59.0	1.01	2.53	60.2	1.4	3.8	58.8	56.4
HP3417a	NRC00_13 A	66.0	0.86	2.50	65.8	10.1	16.2	55.7	49.6
HP3417b	B	66.0	0.76	2.47	69.4	18.8	24.0	50.6	45.4
HP3417c	C	49.6	0.96	2.52	62.0	12.7	18.7	49.3	43.3
HP3418a	NRC00_14 A	72.2	0.70	2.38	70.6	12.4	15.1	58.2	55.5
HP3418b	B	48.8	0.91	2.42	62.4	11.1	13.3	51.3	49.1
HP3418c	C	71.1	0.77	2.41	68.0	8.6	11.5	59.4	56.5
HP3419a	NRC00_15 A	110.0	0.60	2.29	73.7	8.4	12.2	65.3	61.5
HP3419b	B	81.0	0.79	2.43	67.3	3.5	6.0	63.8	61.3
HP3419c	C	81.4	0.80	2.36	66.0	1.5	3.9	64.5	62.1
HP3420a	NRC00_16 A	20.7	1.00	2.53	60.4	24.3	25.2	36.1	35.2
HP3420b	B	22.0	1.08	2.53	57.3	24.3	24.6	33.0	32.7
HP3420c	C	25.6	0.92	2.53	63.7	22.9	24.4	40.8	39.3
HP3421a	NRC00_17 A	33.3	1.04	2.52	58.7	14.1	15.4	44.6	43.3
HP3421b	B	41.5	0.85	2.49	66.0	27.2	29.4	38.8	36.6
HP3421c	C	25.8	0.98	2.54	61.3	24.8	26.3	36.5	35.0
HP3422a	NRC00_18 A	52.1	0.76	2.55	70.4	24.1	26.0	46.3	44.4
HP3422b	B	43.6	0.99	2.55	61.2	12.7	13.8	48.5	47.4
HP3422c	C	44.5	0.99	2.52	60.9	10.5	11.0	50.4	49.9
HP3423a	NRC00_19 A	88.5	0.69	2.52	72.6	7.7	8.8	64.9	63.8
HP3423b	B	65.5	0.86	2.49	65.3	7.9	9.6	57.4	55.7
HP3423c	C	78.6	0.78	2.52	68.9	7.4	9.4	61.5	59.5
HP3424a	NRC00_20 A	60.0	0.91	2.65	65.9	7.7	8.4	58.2	57.5
HP3424b	B	92.0	0.62	2.53	75.5	16.9	18.9	58.6	56.6
HP3424c	C	58.3	0.88	2.69	67.3	11.4	12.7	55.9	54.6
HP3425a	NRC00_21 A	65.6	0.88	2.56	65.5	7.6	9.1	57.9	56.4
HP3425b	B	65.4	0.88	2.54	65.5	7.8	9.6	57.7	55.9
HP3425c	C	67.9	0.87	2.62	66.8	7.7	10.0	59.1	56.8
HP3426a	NRC00_22 A	59.5	0.83	2.70	69.3	17.9	18.6	51.4	50.7
HP3426b	B	71.4	0.77	2.67	71.3	15.3	16.6	56.0	54.7
HP3426c	C	59.7	0.92	2.69	65.9	9.7	11.1	56.2	54.8
HP3427a	NRC00_23 A	56.3	0.86	2.45	64.8	13.6	15.1	51.2	49.7
HP3427b	B	56.6	0.92	2.50	63.4	9.2	11.1	54.2	52.3
HP3427c	C	46.2	1.04	2.51	58.5	7.5	9.6	51.0	48.9
HP3428a	NRC00_24 A	66.7	0.61	2.40	74.7	31.8	34.3	42.9	40.4
HP3428b	B	58.6	0.75	2.51	70.0	23.9	25.8	46.1	44.2
HP3428c	C	60.1	0.69	2.53	72.7	27.4	30.9	45.3	41.8
HP3429a	NRC00_25 A	50.9	0.98	2.62	62.5	10.3	12.3	52.2	50.2
HP3429b	B	37.2	1.09	2.66	59.1	14.8	16.7	44.3	42.4
HP3429c	C	60.0	0.92	2.57	64.1	6.1	7.5	58.0	56.6

Notes: