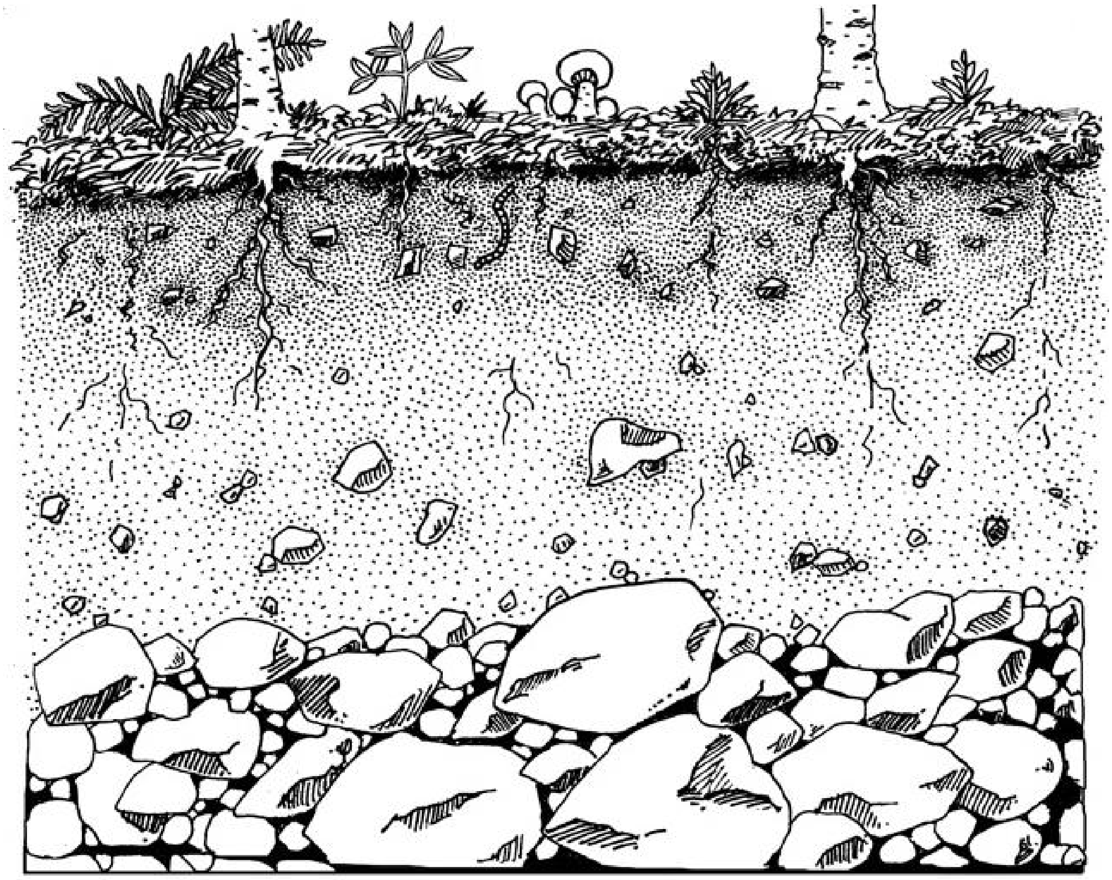
Soil Quality in Northland 2010-11: comparison with previous samplings in 2001 and 2006

Technical Report



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This report presents soil quality data from 24 individual sites chosen to represent the major soil types and land uses within the Northland Region. The sites were first sampled as part of the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" in 2000-01. These same sites were resampled in 2006, and again in 2010-11. The aim of this report is to analyse and interpret changes in soil quality that have occurred between 2001, 2006 and 2010-11. The earlier reports summarising soil quality in Northland are Sparling et al. (2001) and Stevenson (2007).

NRC staff resampled the original sites and supplied these samples to Landcare Research for analysis. 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. These samples were also analysed for a suite of trace elements.

Objectives

- Provide an assessment of the current soil quality status of the soils as related to soil class and land use using seven primary soil indicators.
- Provide an assessment of the current heavy metal (trace element) soil concentrations, and assess whether there has been any relevant changes in relation to previous sampling in 2006.
- Provide interpretation of changes in soil characteristics in relation to previous samples taken in 2001 and 2006.

Methods

- Soil samples were collected by NRC staff and supplied to Landcare Research for analysis.
- Seven primary soil indicators were measured to assess soil quality. These were used as input into the 'Soil Quality Indicators (SINDI)' model available online from Landcare Research. 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 soil type.

Results

- Twenty four sites were tested for a total of 168 soil quality characteristics. For all indicators across all sites, 88.4% (149 out of 168) fell within target ranges. Across all land uses, ten of the 24 sites (41.6%) met all targets (0 of 6 dairy sites, 1 of 8 drystock sites, 5 of 5 plantation forestry sites, 3 of 4 indigenous forestry sites, and 1 of 1 hort/crop site). Nine sites (37.5%) did not meet the target range for one characteristic, and five sites (20.8%) did not meet the target range for two characteristics. Apart from low Olsen P at one indigenous forest site, the only sites that did not meet target ranges were dairy and drystock sites.

- When broken down by land use, specific trends in the indicators can be seen more clearly. Within the six dairy sites, macroporosity values were below target values for 5 sites (83.3%), and mineralisable N and total nitrogen were above targets at 1 (16.6%) and 2 (33.3%) sites respectively. All other indicators were within target guidelines.
- On the 8 drystock sites, low macroporosity and low Olsen P values (62.5% and 25% respectively) were the largest contributors to these sites not meeting target ranges. In addition, there were high mineralisable nitrogen and total nitrogen levels at two separate sites.
- All indicators at plantation and indigenous forestry sites were within target guidelines except low Olsen P at an indigenous forest site. The solitary hort/crop site (citrus orchard) also had all indicators within target ranges.

Conclusion

- The ongoing trend of decreasing macroporosity values since previous sampling (2001; 2006) on dairy and drystock sites mirror results from other regions of the country. Decreased macroporosity is a symptom of pugging which results from poor management practices, but is more likely to occur under intensive stocking.
- The primary concerns are (1) compaction of soils on dairy and drystock sites; (2) the high nitrogen levels on some dairy and drystock sites; and (3) the low nutrient (Olsen P) status of some drystock sites. Soil pH was also above target values at one site. Mineralisable nitrogen values were higher than the previous sampling in 2006, 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 the program of resampling existing sites to determine the extent and direction of any changes since original sampling. The next resampling should be in 5 years (2015-16).
- As recommended in the review of NRC's soil monitoring program, Stevenson (2011) suggests increasing the number of sites monitored. He recommends adding a minimum of five to ten sites to help increase the ability to detect change between landuses, and decrease the bias between land use area and number of sites sampled. As the majority of existing sites were west of Whangarei, the additional sites should include soils further North (Bay of Islands and Kaitaia areas) where there are more Ultic and Oxic soils.
- To better represent the different landuses Stevenson (2011) suggests at a minimum, the addition of two to three drystock sites, one cropping site, one to three indigenous sites and possibly one dairy site.
- 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

As reported in Stevenson (2011), the Resource Management Act (1991) Section 35 requires Regional Councils to report on the "life supporting capacity of soil" and whether current practices will meet the "foreseeable needs of future generations". Section 30(1) of the Resource Management Act has as a function of the Regional Council the control of land use for the purpose of soil conservation, the maintenance and enhancement of the quality of water in water bodies and coastal waters, and the maintenance of the quantity of water in water bodies and coastal waters. Pursuant to Section 126 of the Soil Conservation and Rivers Control Act 1941 it is the duty of regional councils as "catchment boards" to prevent or lessen erosion or the likelihood of erosion and to promote soil conservation. Adverse changes in some soil quality parameters are indicators of increasing risk of soil erosion while improvements in these parameters are measures of increased resilience to not only soil erosion and sediment discharge but also to climatic extremes, particularly drought.

This report presents soil quality data from 24 individual sites chosen to represent the major soil types and land uses within the Northland Region. The sites were first sampled as part of the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" in 2000-01. These same sites were resampled in 2006, and again in 2010-11. The aim of this report is to analyse and interpret changes in soil quality that have occurred between 2001, 2006 and 2010-11. The earlier reports summarising soil quality in Northland are Sparling et al. (2001) and Stevenson (2007).

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 in the 500 Soils Project (Sparling et al. 2001). 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 soil capability (based on physical and chemical properties associated with soil type) and its actual use" (Stevenson, 2007 pg.3). Differences in soil characteristics since the earlier samplings are used to assess the extent and direction of change.

2 Objectives

(i) Provide an assessment of the current soil quality status of the soils as related to soil class and land use using seven primary soil indicators as input into the 'Soil Quality Indicators (SINDI)' model available online from Landcare Research.

(ii) Provide an assessment of the current heavy metal (trace element) soil concentrations, and assess whether there has been any changes in relation to previous sampling in 2006.

(iii) Provide interpretation of changes in soil characteristics in relation to previous samples taken in 2001 and 2006.

3 Methods

Most of the methodologies have been described in earlier reports (Sparling et al. 1996, 2001) and the following brief descriptions are taken from Stevenson (2007 pg.3).

3.1 Soil sampling

Soil samples were collected by NRC staff and supplied to Landcare Research for analysis. Due to resourcing limitations the samples were collected over two seasons with drystock and plantation forestry sites sampled in Nov-Dec 2010, and dairy, indigenous forestry, and horticulture sampled in Sep 2011. Dry soil conditions in Nov-Dec 2010 meant some of the samples were dry and had become fractured - either naturally or more likely through the field sampling. For this reason 6 samples (5 drystock and 1 plantation forestry) were resampled in Sep 2011. Site NRC_0023 (formally drystock) could not be resampled because the area has been developed into a school.

The samples were collected using the protocols established in the 500 Soils Project. The samples chemical, physical and biological characteristics were analysed by Landcare Research.

3.2 Soil quality indicators

Seven primary soil indicators were measured to assess soil quality (Table 1). These were used as input into the 'Soil Quality Indicators (SINDI)' model (see Fig 1. for an example of the output). The following information on these indicators is taken directly from the SINDI website (Landcare Research, 2011). The indicators selected to assess soil quality in SINDI reflect the idea that soil quality is not a single concept, but encompasses aspects of the soil physical structure, chemical fertility, nutrient storage, organic matter resources, and the biology in the soil. There are potentially many indicators that can be used, but for any extensive national or regional monitoring scheme it is not practical to have more than a small core number.

Table 1 Indicators used for soil quality assessment (Landcare Research, 2011)

Group	Indicator	Soil quality information
Group 1 - Fertility	Olsen phosphorus	Plant available phosphorus
Group 2 - Acidity	pH	Acidity or alkalinity of soil
Group 3 - Organic resources	Anaerobically mineralisable nitrogen	Availability of nitrogen reserve, surrogate measure for soil microbial biomass
	Total carbon	Organic matter reserves, soil structure, ability to retain water
	Total nitrogen	Organic nitrogen reserves
Group 4 - Physical properties	Bulk density	Soil compaction, physical environment for roots and soil organisms
	Macroporosity	Availability of water and air, retention of water, drainage properties

The indicators themselves do not measure soil quality. Soil quality is a value judgement about how suitable a soil is for a particular use. The indicators measure attributes of a soil (e.g. pH, bulk density). Consequently different target values for indicators are needed for different land uses (the target values can be found in the appendix). For example, soils with pH <5 may be of suitable quality to grow radiata pine, but not for a good crop of white clover. Soils that are stony and excessively free-draining may be of poor quality for pasture production, but of excellent quality for vineyards.

Group 1 - Olsen P

This property makes up the first group representing the fertility status of the soil. Olsen P is a measure of the plant-available phosphorus, which is greatly effected by fertiliser additions. In their natural state, most soils in New Zealand are of low nutrient status.

Group 2 - pH

One property makes up the second group representing the acidity status of the soil. Soil pH is the acidity or alkalinity of soil, which controls the availability of many nutrients to plants. The acidity of soil is greatly influenced by the applications of lime and fertilisers. In their natural state, most soils in New Zealand are acidic.

Group 3 - Anaerobic Nitrogen, Total carbon, Total nitrogen

This group of soil properties represent the soil's organic resources. This resource has an underlying supportive role for the other three groups. Total C and N provide a measure of the organic matter concentration and quality in a soil. Organic matter gives topsoil many of its unique characteristics, and provides a medium for water storage, a source of nutrients, habitat, and food supply for soil organisms, and retains soil chemicals within the root zone. These attributes characterise the intrinsic nature of a soil and are not readily modified.

Mineralisable nitrogen is a more dynamic measure of the organic N reserves of soil that are potentially mineralised by microorganisms into plant-available N. Being a measure of the mineralisable N reserves, and a surrogate for microbial biomass, the Mineralisable N measure provides an indicator of the biological status of soil. Mineralisable N can be markedly influenced by land use, particularly organic matter contents and N status of a soil.

Group 4 — Bulk density, Macroporosity

These properties formed the fourth group representing the physical status of soil. Bulk density is a measure of soil compaction i.e., the mass of soil in a defined volume. Total porosity is a measure of the holes or voids in the soil mass. Voids are important to allow air to penetrate the soil, but also to give the soil an open structure to enable it to retain water. The larger pores or macropores are of particular importance for infiltration and drainage, but are easily lost when soil is compacted. The physical characteristics and the susceptibility to compaction are much influenced by soil mineralogy and amounts of sand, silt and clay.

Heavy metals (trace elements)

Indicators for trace element monitoring were arsenic, cadmium, chromium, copper, fluoride, lead, mercury, nickel, uranium and zinc. These elements are considered environmentally sensitive.

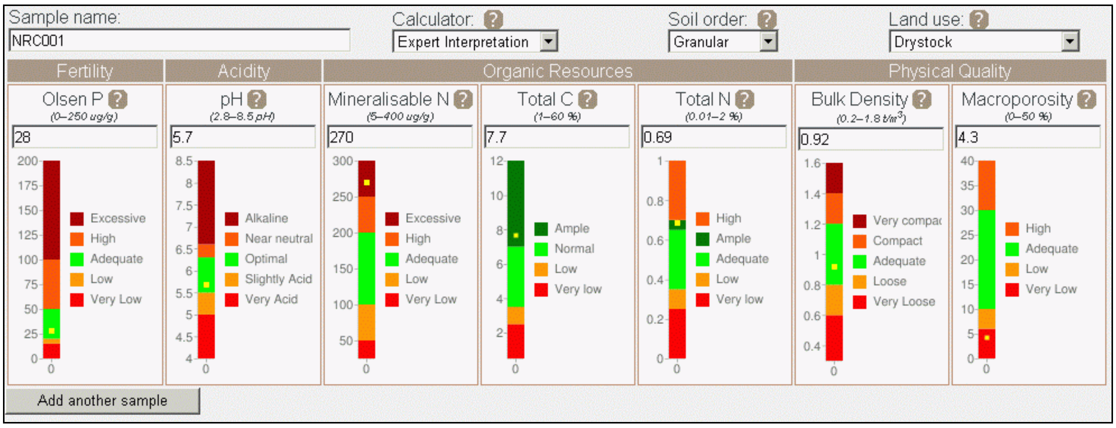


Figure 1 An example of the output from the SINDI model available from Landcare Research (2011)

3.3 Analyses

3.3.1 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 and Bremner 1966).

3.3.2 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, 2mm 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).

3.3.3 Physical properties

Macrosporosity was determined by drainage on pressure plates at -5kPa (Klute 1986). Dry bulk density was measured on a subsampled core dried at 105°C (Klute 1986). Macrosporosity and total porosity were calculated as described by Klute (1986). The values for each site were calculated from the mean of three repetitions.

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 was combined to allow statistical testing. An ANOVA was then used to test whether the means from each sample year (2001, 2006, 2010-11) were statistically different from one another.

4 Results

4.1 Soils and sites

Site information was updated as several sites had undergone change in land use since the previous sampling. Figure 2 shows the spatial location of each sample site and summarised site and soil information is given in Table 2.

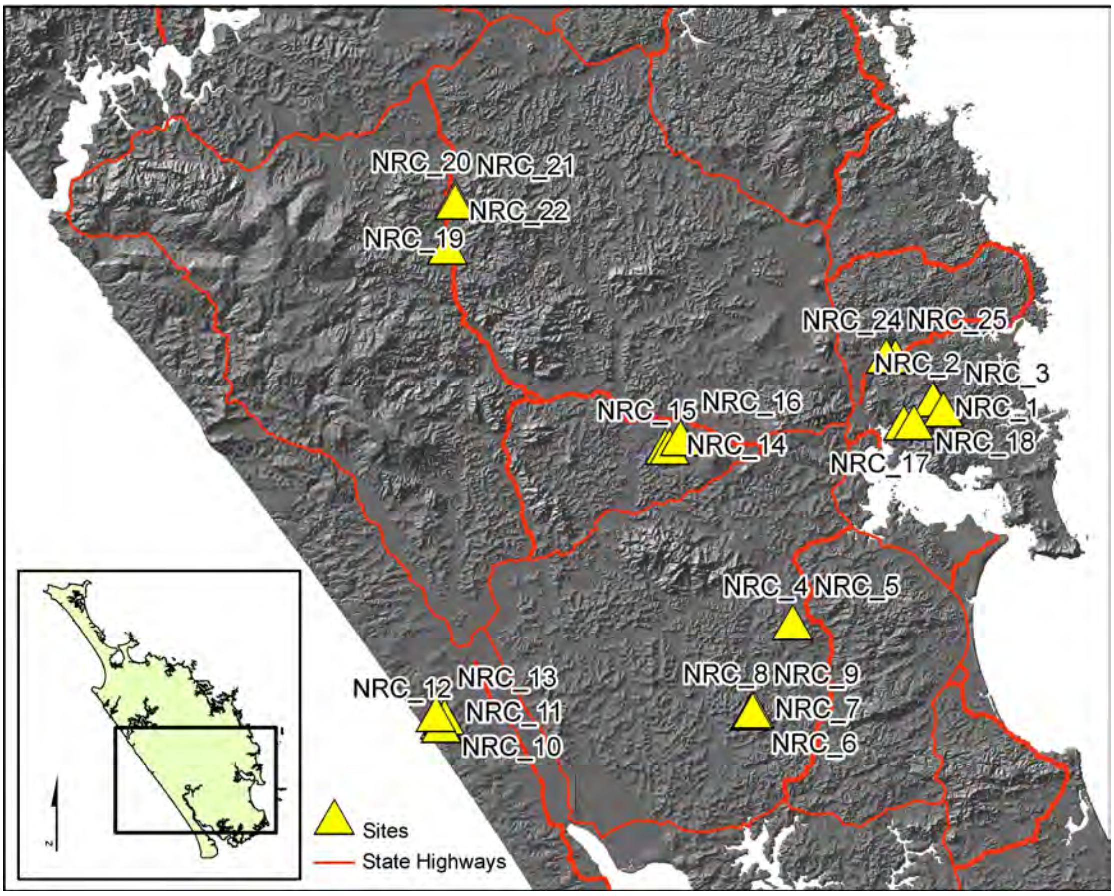


Figure 2 Soil sample sites in Northland region

4.2 Soil chemical characteristics

Soil chemical characteristics are displayed in tables 3 and 5. Olsen P was within target ranges at all sites apart from 2 drystock (25%). Soil pH was within target values at all sites apart from a drystock site (NRC_010) which was alkaline with a pH of 7 (although this seems very high for a Northland soil). Mineralisable N was above target ranges at one dairy site (1 of 6) and one drystock site (1 of 8). Total N was within target values at all sites except two dairy and one drystock site which recorded high levels. Total carbon levels were normal to ample at all sites.

4.3 Soil physical characteristics

Soil physical characteristics are displayed in tables 4 and 5. Bulk density was within target ranges at all sites. Macroporosity was the only indicator that failed to meet target ranges with the vast majority of these cases being very low (<10%) macroporosity on dairy sites (5 of 6 sites), and drystock sites (5 of 8 sites) indicating compacted soil.

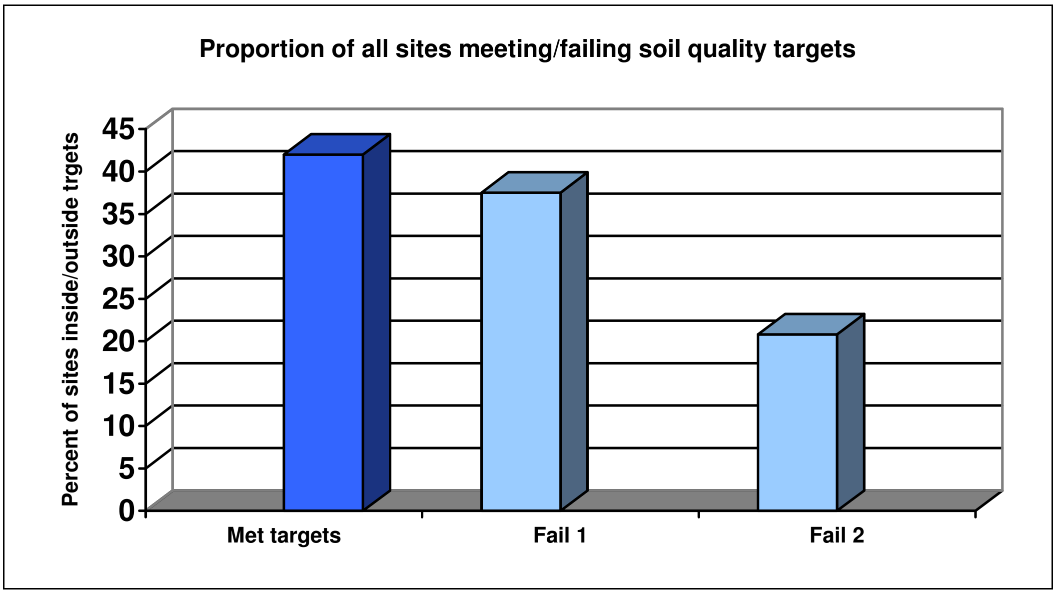
4.4 Overall soil quality

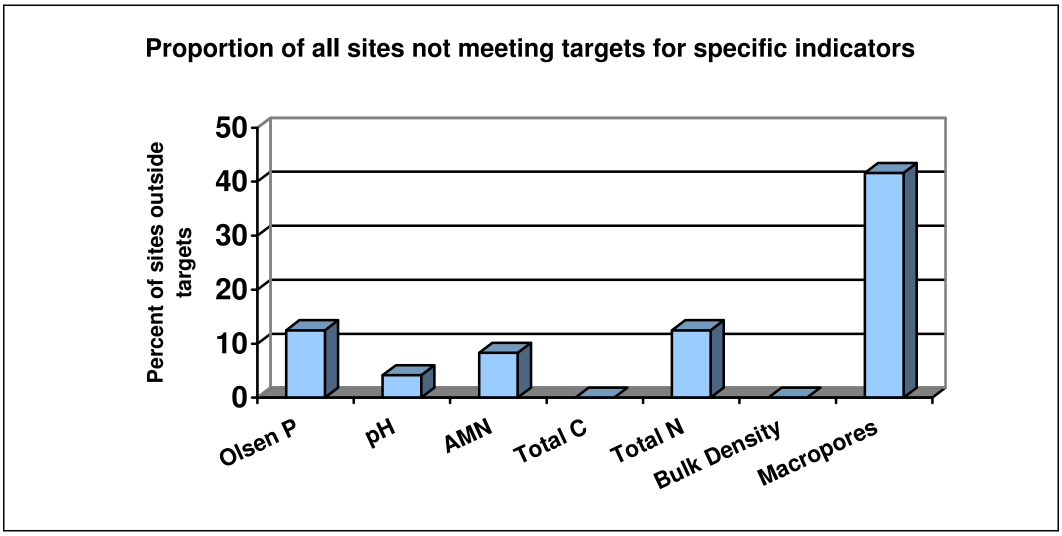
The 24 sites were tested for a total of 168 soil quality characteristics (see tables 3 and 4). For all indicators across all sites, 88.4% (149 out of 168) fell within target ranges. Across all land uses, ten of the 24 sites (41.6%) met all targets (0 of 6 dairy sites, 1 of 8 drystock sites, 5 of 5 plantation forestry sites, 3 of 4 indigenous forestry sites, and 1 of 1 hort/crop site). Nine sites (37.5%) did not meet the target range for one characteristic, and five sites (20.8%) did not meet the target range for two characteristics. Apart from low Olsen P at one indigenous forest site, the only sites that did not meet target ranges were dairy and drystock sites.

When broken down by land use, specific trends in the indicators can be seen more clearly. Within the six dairy sites, macroporosity values were below target values for 5 sites, and mineralisable N and total nitrogen were above targets at 1 and 2 sites respectively. All other indicators were within target guidelines.

On drystock sites, low macroporosity and low Olsen P values (62.5% and 25% respectively) were the largest contributors to these sites not meeting target ranges. In addition, there were high mineralisable nitrogen and total nitrogen levels at two separate sites.

All indicators at plantation and indigenous forestry sites were within target guidelines except low Olsen P at an indigenous forest site. The indigenous forestry sites are sampled as a control only, therefore no action is required in regards to soil management. The solitary hort/crop site (citrus orchard) also had all indicators within target ranges.




Proportion of all sites not meeting targets for specific indicators
Percent of sites outside targets
50
40
30
20
10
0
Olsen P
pH
AMN
Total C
Total N
Bulk Density
Macropores

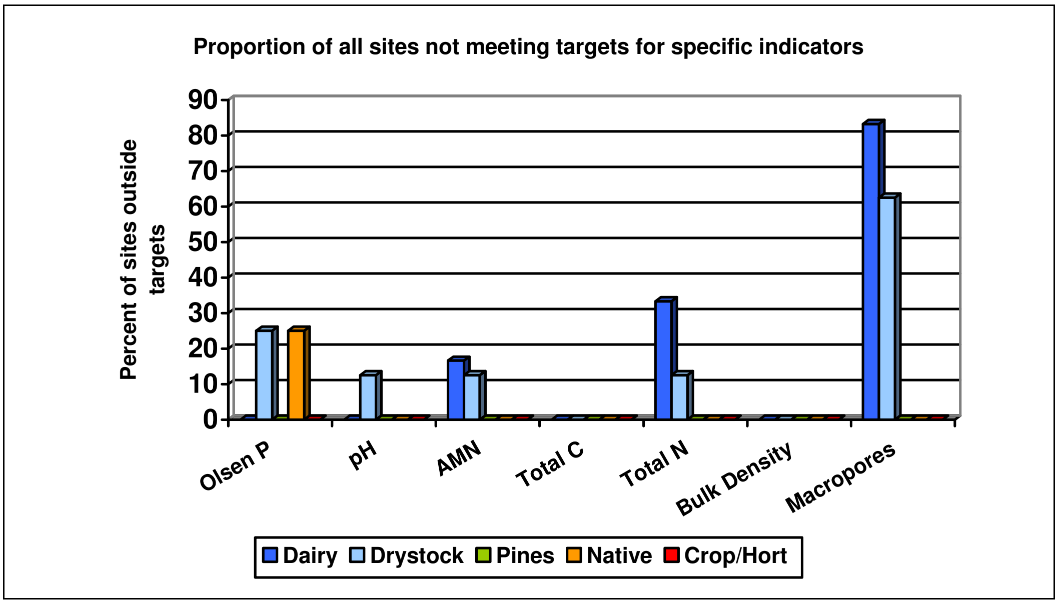

Proportion of all sites not meeting targets for specific indicators
Percent of sites outside targets
90
80
70
60
50
40
30
20
10
0
Olsen P
pH
AMN
Total C
Total N
Bulk Density
Macropores
Dairy
Drystock
Pines
Native
Crop/Hort

Table 2 Site codes, soil series, soil classification (Hewitt, 1998) and land uses resampled in 2010-11

Site code	Date sampled	Soil type	Subgroup, Group, Order	Land use
NRC00_1	Sep 2011	Marua clay	Typic Orthic Granular	Drystock for 12 yrs, previously dairy
NRC00_2	Sep 2011	Marua clay	Typic Orthic Granular	Drystock
NRC00_3	Sep 2011	Marua clay	Mottled Orthic Brown (?)	Drystock for 12 yrs (previously dairy)
NRC00_4	Sep 2011	Waiotira clay	Mottled Acid Brown	Dairy, non-irrigated
NRC00_5	Sep 2011	Waiotira clay	Mottled Acid Brown	Dairy, irrigated
NRC00_6	Sep 2011	Waiotira clay	Mottled Acid Brown	Indigenous forest (formally some stock browsing but now fenced)
NRC00_7	Sep 2011	Waiotira clay loam	Mottled Acid Brown	Drystock
NRC00_8	Sep 2011	Waiotira clay loam	Mottled Acid Brown	Plantation forestry (second rotation)
NRC00_9	Nov-Dec 2010	Waiotira clay	Mottled Acid Brown	Drystock
NRC00_10	Sep 2011	Red Hill sandy loam	Typic Allophanic Brown	Drystock for 13 yrs (previously mixed cropping)
NRC00_11	Nov-Dec 2010	Red Hill sandy loam	Typic Allophanic Brown	Plantation forestry (second rotation)
NRC00_12	Sep 2011	Red Hill loamy sand	Typic Allophanic Brown	Dairy, non-irrigated
NRC00_13	Sep 2011	Red Hill loamy sand	Typic Allophanic Brown	Drystock
NRC00_14	Nov-Dec 2010	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Dairy - less intensive (previously drystock)
NRC00_15	Sep 2011	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Dairy - intensive, non-irrigated
NRC00_16	Nov-Dec 2010	Wharekohe silt loam	Perch-gleyed Densipan Ultic	Plantation forestry (first rotation after pasture)
NRC00_17	Nov-Dec 2010	Marua clay loam	Typic Orthic Brown	Plantation forestry (first rotation after pasture)
NRC00_18	Sep 2011	Marua clay loam	Typic Orthic Brown	Indigenous forest (bush on previous pasture)
NRC00_19	Sep 2011	Awarua clay loam	Acidic Oxidic Granular	Dairying, non-irrigated
NRC00_20	Sep 2011	Awarua clay loam	Acidic Oxidic Granular	Indigenous forest (formally some stock browsing but now fenced)
NRC00_21	Sep 2011	Awarua clay loam	Acidic Oxidic Granular	Dairy, irrigated
NRC00_22	Nov-Dec 2010	Awarua clay loam	Acidic Oxidic Granular	Plantation forestry (first rotation after pasture)
NRC00_23	Nov-Dec 2010	Kiripaka bouldery clay loam	Typic Ortic Allophanic	School (previously drystock – not sampled in 2010-11)
NRC00_24	Sep 2011	Kiripaka bouldery clay loam	Typic Ortic Allophanic	Indigenous forest
NRC00_25	Sep 2011	Kiripaka bouldery clay loam	Typic Ortic Allophanic	Citrus orchard

Table 3 Soil chemical characteristics of sites sampled in 2010-11. The coloured values show if the indicator is either below (blue) or above (red) target ranges

Site code	Date sampled	Soil series/land use	pH	Total C mg/cm^3	Total N mg/cm3	C:N ratio	Olsen P µg/cm^3	NH4-N µg/cm^3	NO3-N µg/cm^3	Mineralisable N µg/cm^3
NRC00_5	Sep-11	Waiotira clay, dairy	6	7.56	0.69	11	81	1.6	120	190
NRC00_12	Sep-11	Red Hill loamy sand, dairy	6	4.42	0.39	11	60	1	46	91
NRC00_14	Nov-Dec 2010	Wharekohe silt loam, dairy	5	7	0.53	-	40	18.2	5.1	203
NRC00_15	Sep-11	Wharekohe silt loam, dairy	6	7.42	0.68	11	67	9.3	166	166
NRC00_19	Sep-11	Awarua clay loam, dairy	6	11	0.91	12	44	2.7	80	258
NRC00_21	Sep-11	Awarua clay loam, dairy (irrigated)	6	8.43	0.75	11	58	1.1	50	201
NRC00_1	Nov-Dec 2010	Marua clay, drystock	6	7.7	0.69	-	28	2	39.5	270
NRC00_2	Nov-Dec 2010	Marua clay, drystock	6	6.3	0.51	-	13	3.5	12	172
NRC00_3	Nov-Dec 2010	Marua clay, drystock	6	6.4	0.52	-	41	4.5	29.4	192
NRC00_4	Sep-11	Marua clay, drystock	6	6.75	0.55	12	63	2.3	86	127
NRC00_7	Nov-Dec 2010	Waiotira clay loam, drystock	6	6.5	0.53	-	15	4.6	45.4	228
NRC00_9	Nov-Dec 2010	Waiotira clay, drystock	6	5.2	0.35	-	9	7.9	2.4	99
NRC00_10	Nov-Dec 2010	Red Hill sandy loam, drystock	7	5.09	0.38	13	31	2	31	83
NRC00_13	Nov-Dec 2010	Red Hill loamy sand, drystock	6	7.6	0.71	-	25	35.9	14.1	188
NRC00_8	Nov-Dec 2010	Waiotira clay loam, pines	5	6.2	0.34	-	27	17	2.2	94
NRC00_11	Nov-Dec 2010	Red Hill sandy loam, pines	6	4.9	0.23	-	7	1.5	0.9	52
NRC00_16	Nov-Dec 2010	Wharekohe silt loam, pines	5	5.2	0.36	-	31	14.2	3.5	57
NRC00_17	Nov-Dec 2010	Marua clay loam, pines	5	5.5	0.28	-	10	38.8	2.2	83
NRC00_22	Nov-Dec 2010	Awarua clay loam, pines	5	11.5	0.47	-	13	20.5	5.6	167
NRC00_6	Nov-Dec 2010	Waiotira clay, indigenous forest	6	6.78	0.43	16	22	2.7	17	165
NRC00_18	Sep-11	Marua clay loam, indigenous forest	5	7.8	0.42	18	5	18.2	0.7	80
NRC00_20	Sep-11	Awarua clay loam, indigenous forest	5	9.2	0.51	18	8	13.4	19	147
NRC00_24	Nov-Dec 2010	Kiripaka bouldery clay loam, indigenous forest	6	9.46	0.67	14	6	0.9	81	209
NRC00_25	Sep-11	Kiripaka bouldery clay loam, orchard	6	6.28	0.57	11	77	1.1	42	135

Table 4 Soil physical characteristics of sites sampled in 2010-11. The coloured values show if the indicator is either below (blue) or above (red) target ranges

Site code	Date sampled	Soil series/land use	Bulk density Mg/m^3	Particle density Mg/m^3	Total porosity %v/v	Macro porosity %v/v	Moisture content @ -5kPa %v/v	Moisture content @ -10kPa %v/v
NRC00_5	Sep-11	Waiotira clay, dairy	1	2.5	59.1	2.7	56.6	54.4
NRC00_12	Sep-11	Red Hill loamy sand, dairy	1.2	2.6	53.1	5.2	49.7	46.6
NRC00_14	Nov-Dec 2010	Wharekohe silt loam, dairy	0.9	2.4	61.6	1.9	59.7	56.1
NRC00_15	Sep-11	Wharekohe silt loam, dairy	0.9	2.4	63.3	4.3	59	56.8
NRC00_19	Sep-11	Awarua clay loam, dairy	0.8	2.6	67.1	7.1	60	58.2
NRC00_21	Sep-11	Awarua clay loam, dairy (irrigated)	0.8	2.5	68	3.5	64.5	62.2
NRC00_1	Sep-11	Marua clay, drystock	0.9	2.5	62.8	2.9	59.9	57.1
NRC00_2	Sep-11	Marua clay, drystock	0.79	2.43	67.3	3.4	63.9	60.6
NRC00_3	Sep-11	Marua clay, drystock	0.8	2.5	65.5	11.8	57.8	54.8
NRC00_4	Sep-11	Marua clay, drystock	1	2.4	59.5	4.3	57.5	55.5
NRC00_7	Sep-11	Waiotira clay loam, drystock	0.9	2.5	63.5	1.9	61.7	59.6
NRC00_9	Nov-Dec 2010	Waiotira clay, drystock	1	2.5	58.3	12.1	46.2	43.9
NRC00_10	Sep-11	Red Hill sandy loam, drystock	1.1	2.5	55.9	3.1	52.8	48.8
NRC00_13	Sep-11	Red Hill loamy sand, drystock	0.8	2.4	66.1	16.2	49.9	44.8
NRC00_8	Sep-11	Waiotira clay loam, pines	0.9	2.4	64.4	20	44.4	40.4
NRC00_11	Nov-Dec 2010	Red Hill sandy loam, pines	1	2.6	63	25	39	30.9
NRC00_16	Nov-Dec 2010	Wharekohe silt loam, pines	1	2.5	58.4	15.5	42.9	41.1
NRC00_17	Nov-Dec 2010	Marua clay loam, pines	1	2.5	58.1	15.7	42.4	41.1
NRC00_22	Nov-Dec 2010	Awarua clay loam, pines	0.8	2.6	67.5	13.8	53.7	52.5
NRC00_6	Sep-11	Waiotira clay, indigenous forest	1	2.5	60.9	15.4	45.5	42.6
NRC00_18	Sep-11	Marua clay loam, indigenous forest	0.7	2.5	71.9	17	54.9	52.6
NRC00_20	Sep-11	Awarua clay loam, indigenous forest	0.7	2.6	73.6	19	54.6	51.3
NRC00_24	Nov-Dec 2010	Kiripaka bouldery clay loam, indigenous forest	0.6	2.4	77.2	20.7	56.5	54
NRC00_25	Sep-11	Kiripaka bouldery clay loam, orchard	0.85	2.7	67.9	19.2	48.8	45

4.5 Soil heavy metal concentrations

Heavy metals varied across land uses and there were few trends among landuse categories. Natural levels of many metals can vary greatly depending on geologic parent material. The New Zealand Water and Wastes Association (NZWWA 2003) suggested limits for land biosoilid application provide some guidelines on acceptable heavy metal concentrations in soils (Table 5).

Table 5 Guideline values for heavy metal concentrations in soils (NZWWA 2003)

Heavy metal	Upper soil limit (in mg metal concentration per kg dry weight soil)
Arsenic (As)	20 mg/kg
Cadmium (Cd)	1 mg/kg
Chromium (Cr)	600 mg/kg
Copper (Cu)	100 mg/kg
Lead (Pb)	300 mg/kg
Mercury	1 mg/kg
Zinc (Zn)	300 mg/kg

In both 2006 and 2010-11, measured levels of all trace metals were below guideline levels except for a dairy site (NRC_015) where cadmium levels (1.1 mg/kg) were just over the 1 mg/kg limit (tables 6 and 7). The mean cadmium levels since 2001 have increased at dairy, drystock and orchard sites (0., 0.4, 1.0 mg/kg respectively) and are approaching the recommended limit. As cadmium levels in agricultural soils is an emerging problem in New Zealand (Rys 2011), these values should be watched carefully in the future. In addition, copper levels at the citrus orchard (NRC_0025) decreased from 102 mg/kg (just above guidelines) in 2006 down to 83 mg/kg (within guidelines) in 2011. The only other issue of note was the 2010-11 drought which may have resulted in rapidly increased mineralisation of a whole range of minerals, both the trace metals and nitrogen. Despite this, all the Northland samples had trace metal concentrations within the ranges found in other regions of New Zealand (Kim and Taylor 2009).

Table 6 Soil heavy metal content of dairy and drystock sites sampled in 2006 and 2010-11. Numbers in brackets show the change between 2007 and 2010-11. Numbers in red show values above recommended guidelines.

Site code	Land use and soil Class	As mg/kg		Cd mg/kg		Cr mg/kg		Co mg/kg	
		2006	2010-11	2006	2010-11	2006	2010-11	2006	2010-11
NRC00_5	Dairy, Brown	<0.5	1.6 (1.4)	<0.5	0.8 (0.6)	25.6	31.0 (5.4)	4.7	3.0 (-1.7)
NRC00_12	Dairy, Allophanic	5.1	6.3 (1.2)	<0.5	<0.5 (0.0)	15.2	17.0 (1.8)	4.6	3.0 (-1.6)
NRC00_14	Dairy, Ultic	<0.5	<0.5 (0.0)	<0.5	<0.5 (0.0)	8.6	3.0 (-5.6)	0.2	1.0 (0.8)
NRC00_15	Dairy, Ultic	<0.5	<1 (0.5)	<0.5	1.1 (0.9)	8.5	18.0 (9.5)	1.1	1.0 (-0.1)
NRC00_19	Dairy, Granular	<0.5	<1 (0.5)	<0.5	0.6 (0.4)	58.8	107.0 (48.2)	11.2	5.0 (-6.2)
NRC00_21	Dairy, Granular	<0.5	<1 (0.5)	<0.5	0.9 (0.7)	47.1	98.0 (50.9)	11.2	6.0 (-5.2)
	Mean*	**1.1**	**2.7 (0.7)**	**0.3**	**0.7 (0.4)**	**27.3**	**45.7 (18.4)**	**5.5**	**3.2 (-2.3)**
	sd	2.0	3.2 (0.5)	0.0	0.3 (0.3)	21.2	45.0 (24.7)	4.8	2.0 (2.8)
NRC00_1	Drystock, Granular	10.5	4.1 (-6.4)	<0.5	0.8 (0.6)	13.1	15.0 (1.9)	6.4	6.0 (-0.4)
NRC00_2	Drystock, Granular	<0.5	5.5 (5.3)	<0.5	<0.5 (0.0)	17.0	18.0 (1.0)	7.6	6.0 (-1.6)
NRC00_3	Drystock, Brown	<0.5	3.5 (3.3)	<0.5	0.7 (0.5)	14.0	14.0 (0.0)	5.5	4.0 (-1.5)
NRC00_4	Drystock, Brown	<0.5	3.2 (3.0)	<0.5	<0.5 (0.0)	29.7	42.0 (12.3)	6.1	2.0 (-4.1)
NRC00_7	Drystock, Brown	<0.5	2.3 (2.1)	<0.5	0.5 (-0.3)	17.5	17 (-0.5)	9.2	5 (-4.2)
NRC00_9	Drystock, Brown	<0.5	3.0 (2.8)	<0.5	<0.5 (0.0)	14.1	15.0 (0.9)	2.6	4.0 (1.4)
NRC00_10	Drystock, Allophanic	5.6	8.0 (2.4)	<0.5	<0.5 (0.0)	16.0	22.0 (6.0)	5.1	3.0 (-2.1)
NRC00_13	Drystock, Allophanic	10.5	7.8 (-2.7)	<0.5	0.5 (0.30)	14.0	15.0 (1.0)	4.4	6.0 (1.6)
	Mean	**3.5**	**4.6 (1.8)**	**0.3**	**0.4 (0.2)**	**18.3**	**20.8 (3.3)**	**5.3**	**4.0 (-1.5)**
	sd	4.7	2.2 3.8	0.0	0.2 0.2	6.6	9.3 4.3	2.8	1.5 2.2

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

Table 6 continued

Site code	Land use and soil Class	Cu mg/kg		Pb mg/kg		Zn mg/kg	
		2006	2010-11	2006	2010-11	2006	2010-11
NRC00_5	Dairy, Brown	15.6	23.0 (7.4)	3.2	4.0 (0.8)	41.0	50.0 (9.0)
NRC00_12	Dairy, Allophanic	6.1	6.0 (-0.1)	3.5	4.0 (0.5)	49.9	40.0 (-9.9)
NRC00_14	Dairy, Ultic	5.4	2.0 (-3.4)	3.2	1.0 (-2.2)	18.3	6.0 (-12.3)
NRC00_15	Dairy, Ultic	10.6	13.0 (2.4)	21.4	36.0 (14.6)	29.4	41.0 (11.6)
NRC00_19	Dairy, Granular	30.1	32.0 (1.9)	0.9	4.0 (3.1)	43.9	46.0 (2.1)
NRC00_21	Dairy, Granular	31.6	35.0 (3.4)	1.7	4.0 (2.3)	133.0	138.0 (5.0)
	Mean	**16.6**	**18.5 (1.9)**	**5.7**	**8.8 (3.2)**	**52.6**	**53.5 (0.9)**
	sd	11.7	13.7 (3.6)	7.8	13.4 (5.9)	41.0	44.3 (9.9)
NRC00_1	Drystock, Granular	16.4	18.0 (1.6)	9.3	10.0 (0.7)	45.8	43.0 (-2.8)
NRC00_2	Drystock, Granular	18.3	18.0 (-0.3)	12.1	12.0 (-0.1)	55.1	45.0 (-10.1)
NRC00_3	Drystock, Brown	8.4	8.0 (-0.4)	9.3	9.0 (-0.3)	28.8	24.0 (-4.8)
NRC00_4	Drystock, Brown	17.6	21.0 (3.4)	3.0	16.0 (13.0)	41.2	37.0 (-4.2)
NRC00_7	Drystock, Brown	21.2	18.0 (-3.2)	8.4	5.0 (-3.4)	58.6	32.0 (-26.6)
NRC00_9	Drystock, Brown	8.1	7.0 (-1.1)	5.0	5.0 (0.0)	23.5	18.0 (-5.5)
NRC00_10	Drystock, Allophanic	7.9	6.0 (-1.9)	3.9	6.0 (2.1)	31.2	27.0 (-4.2)
NRC00_13	Drystock, Allophanic	9.5	11.0 (1.5)	3.6	4.0 (0.4)	37.7	37.0 (-0.7)
	Mean	**11.7**	**11.8 (-0.3)**	**5.2**	**7.5 (2.0)**	**37.8**	**29.2 (-7.7)**
	sd	6.4	6.0 (2.1)	2.2	4.2 (4.9)	15.1	9.4 (8.2)

Table 7 Soil heavy metal content of citrus, plantation and indigenous forestry sites sampled in 2006 and 2010-11. Numbers in brackets show the change between 2007 and 2010-11. Numbers in red show values above recommended guidelines.

Site code	Land use and soil Class	As mg/kg			Cd mg/kg			Cr mg/kg			Co mg/kg		
		2006	2010-11		2006	2010-11		2006	2010-11		2006	2010-11	
NRC00_8	Plantation forestry, Brown	<0.5	2.2	2.0	<0.5	<0.5	(0)	14.2	12.0	(-2.2)	3.2	6.0	(2.8)
NRC00_11	Plantation forestry, Allophanic	5.7	5.9	(0.2)	<0.5	<0.5	(0)	13	13	(0)	17.1	6	(-11.1)
NRC00_16	Plantation forestry, Ultic	<0.5	<0.5	(0)	<0.5	<0.5	(0)	5.7	6	(-0.3)	5.3	2	(-3.3)
NRC00_17	Plantation forestry, Brown	12	10.5	(-1.5)	<0.5	<0.5	(0)	27.6	23	(-4.6)	5.7	5	(-0.7)
NRC00_22	Plantation forestry, Granular	<0.5	<0.5	(0)	<0.5	<0.5	(0)	144	158	(14)	13.4	12	(-1.4)
	Mean*	**2.2**	**6.2**	**(-4)**	**0.3**	**0.25**	**(-0.1)**	**38.5**	**42.2**	**(3.7)**	**8.9**	**6.2**	**(-0.6)**
	sd	3.8	4.1	(-0.3)	0	0	(0)	59.1	64.7	(5.6)	4.6	3.5	(-1.1)
NRC00_6	Indigenous forest, Brown	<0.5	3.7	(3.5)	<0.5	<0.5	(0.0)	17.5	19.0	(1.5)	9.2	2.0	(-7.2)
NRC00_18	Indigenous forest, Brown	<0.5	4.3	(4.1)	<0.6	<0.5	(0)	11.8	22	(10.2)	5	6	(-1)
NRC00_20	Indigenous forest, Granular	<0.5	<1	(0.5)	<0.7	<0.5	(0)	61.1	144	(82.9)	25.5	10	(-15.5)
NRC00_24	Indigenous forest, Allophanic	<0.5	3.8	(3.6)	<0.8	<0.5	(0)	73.2	151	(77.8)	27.3	25	(-2.3)
	Mean*	**0.25**	**3.9**	**(2.9)**	**0.3**	**0.25**	**(0.0)**	**40.9**	**84.0**	**(43.1)**	**16.8**	**10.8**	**(-6.0)**
	sd	0.0	0.3	1.6	0.1	0.0	0.0	30.8	73.4	43.2	11.3	10.0	7.2
NRC00_25	Citrus orchard, Allophanic	<0.5	4.3	(4.1)	<0.5	1	(0.8)	68.8	123	(-54.2)	27.9	123	(-95.1)

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

Table 7 continued

Site code	Land use and soil Class	Cu mg/kg			Pb mg/kg			Zn mg/kg		
		2006	2010-11		2006	2010-11		2006	2010-11	
NRC00_8	Plantation forestry, Brown	9.4	11.0	(1.6)	6.7	6.0	(-0.7)	30.0	29.0	(-1.0)
NRC00_11	Plantation forestry, Allophanic	17.1	10.0	-(7.1)	8.0	5.0	(-3.0)	53.5	32.0	(-21.5)
NRC00_16	Plantation forestry, Ultic	5.3	8.0	(2.7)	3.6	1.0	(-2.6)	9.2	7.0	(-2.2)
NRC00_17	Plantation forestry, Brown	5.7	6.0	(0.3)	9.8	8.0	(-1.8)	24.5	18.0	(-6.5)
NRC00_22	Plantation forestry, Granular	27.6	25.0	(-2.6)	2.7	2.0	(-0.7)	49.7	38.0	(-11.7)
	Mean	**13.0**	**12.1**	**(-0.9)**	**6.2**	**4.7**	**(-1.5)**	**33.4**	**24.7**	**(-8.7)**
	sd	9.4	7.4	(-2.0)	3.0	2.7	(-0.3)	18.4	12.4	(-6.0)
NRC00_6	Indigenous forest, Brown	21.2	14.0	(-7.2)	8.4	7.0	(-1.4)	58.6	43.0	(-15.6)
NRC00_18	Indigenous forest, Brown	11.3	18.0	(6.7)	9.5	14.0	(4.5)	29.5	31.0	(1.5)
NRC00_20	Indigenous forest, Granular	45.0	42.0	(-3.0)	0.1	3.0	(2.9)	59.7	47.0	(-12.7)
NRC00_24	Indigenous forest, Allophanic	41.9	50.0	(8.1)	11.1	16.0	(4.9)	91.2	104.0	(12.8)
	Mean	**29.85**	**31.00**	**(1.15)**	**7.28**	**10.00**	**(2.73)**	**59.75**	**56.25**	**(-3.50)**
	sd	16.26	17.70	(7.44)	4.91	6.06	(2.88)	25.20	32.55	(13.19)
NRC00_25	Citrus orchard, Allophanic	**102.0**	83.0	(-19.0)	11.9	80.0	(68.1)	80.5	112.0	(31.5)

4.6 Changes in soil quality since previous sampling

The current data was compared against those obtained in the previous sampling (Sparling et al. 2001; Stevenson 2007) to determine the extent and direction of any change. The volumetric data used for comparison between each sampling period is provided in tables 8, 9, and 10. The data in the tables is presented as the averaged change (in units of that particular indicator) across all sites in that land-use group (Mean) with the numbers in brackets showing the change since the previous sampling period. The standard deviation is shown as a measure of variance. The data in the tables is illustrated using box plots (figures 3-9).

4.6.1 Dairy Farms

Six dairy farms were resampled in 2010-11. Overall, there was no significant change in Olsen P, pH, Total C and Total N on dairy sites. However, since the earlier sampling (2001 and 2006) there has been an overall increase in mineralisable nitrogen and a significant decrease in macroporosity (ANOVA p-value = 0.004).

The most sensitive indicator of compaction is macroporosity. The very low macroporosity levels continues the trend observed in earlier sampling with the mean for dairy sites having decreased by 71% since sampling first began in 2001. The significant decrease in macroporosity mirrors changes observed in other regions of New Zealand as intensification of dairy activity has increased (MfE 2010; Stevenson 2010; Gray 2011; Taylor 2011). The loss of macropores is a concern as several studies (Drewery et al. 1999; Singleton et al. 2000; Sparling et al 2003; Mackay et al 2006) have concluded that macroporosity levels below 10% can result in decreased pasture production through reduced soil aeration and drainage and increased gaseous losses of N. Additionally, compacted soils can result in increased runoff and deposition of nitrogen and phosphorus into surface waters.

Landcare Research (2011) reports that macroporosity can be improved by reducing mechanical impacts as much as possible. Clayey soils in particular are more susceptible to changes in pore structure when wet. Planning of grazing and tillage practices during wet weather can help to prevent compaction problems. For example, use of well-drained paddocks or standoff pads during wet weather and limiting traffic to light vehicles such as bikes instead of heavy tractors are examples of practices likely to have beneficial effects. In heavily compacted soils, drainage may be necessary to establish vigorous vegetation cover. Growing plants add organic matter to the soil through root growth and decomposition of litter, and stimulate increased burrowing activity of the soil fauna. This has the effect of 'puffing up' the soil volume and increasing porosity. If necessary, tillage or ripping may break up compacted layers (Landcare Research 2011).

In 2010-11 mineralisable N increased back to 2001 levels after dipping slightly in 2006. This could be attributed to a higher stocking rate and/or fertiliser use. Alternatively, when looking across all landuses there was a general decrease in mineralisable N levels in 2006, with levels in 2010-11 returning to 2001 levels. This could represent seasonal variation in biological activity or a change in time of sampling rather than overall change in microbial biomass. However, one site had excessive levels of mineralisable N, and high levels of Total Nitrogen. One further site also had high Total Nitrogen levels.

As mentioned above, high nitrogen levels are increasingly a problem for Northlands rivers and lakes. If levels are high, then any additional N inputs from fertiliser, dung and urine should be minimised, otherwise N will be in excess of demand. Adequate nutrient budgeting is the best way to ensure pasture or crops are getting sufficient N without applying excess fertiliser (Landcare Research 2011).

4.6.2 Drystock

Eight drystock sites were resampled in 2010-11. Overall, there was no significant change in Olsen P, pH, Total C and Total N on drystock sites. As noted for dairy, there has been significant decreases in macroporosity (ANOVA p-value = 0.000) with an average decrease of 63.4% since sampling first began in 2001 (see above explanations).

The continued low Olsen P values on some drystock sites (2 of 8) 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.

4.6.3 Plantation forestry, Indigenous and Crop/Hort

Overall, there was little difference in soil quality status of plantation forestry, indigenous vegetation and horticulture sites. There was a decrease in macroporosity in pines (26% since 2001). This could indicate evidence of erosion and topsoil loss, but the changes are small, and in the absence of decreased C and N content of the soil are probably due to natural variation. The indigenous forestry sites are used as a control although they are more inherently variable. Despite this there were no major changes in any indicators at indigenous sites. At the citrus orchard macroporosity has increased and soil pH has decreased with all indicators within an optimum range.

Table 8 Soil fertility and acidity in 2001, 2006, and 2010-11. The numbers in brackets show the change since the previous sampling period

SITE CODE	LAND USE & SOIL CLASS	FERTILITY Olsen P ($\mu g/cm^3$)					ACIDITY pH				
		2001	2006		2010-11		2001	2006		2010-11	
NRC00_5	Dairy, Brown	55	43	(-12)	81	(38)	6.20	6.19	(-0.01)	6.10	(-0.09)
NRC00_12	Dairy, Allophanic	59	56	(-3)	7	(-49)	6.07	6.09	(0.02)	6.10	(0.01)
NRC00_14	Dairy, Ultic	52	13	(-39)	40	(27)	5.80	5.77	(-0.03)	5.30	(-0.47)
NRC00_15	Dairy, Ultic	62	58	(-4)	67	(9)	5.54	4.85	(-0.69)	5.90	(1.05)
NRC00_19	Dairy, Granular	14	16	(2)	44	(28)	5.74	5.78	(0.04)	5.70	(-0.08)
NRC00_21	Dairy, Granular	40	35	(-5)	58	(23)	6.20	6.28	(0.08)	6.00	(-0.28)
	Mean	**47**	**37**	**(-10)**	**50**	**(13)**	**5.93**	**5.83**	**(-0.10)**	**5.85**	**(0.02)**
	sd	18	19	(1)	26	(6)	0.27	0.52	(0.25)	0.31	(-0.21)
NRC00_1	Drystock, Granular	19	25	(6)	28	(3)	5.61	5.43	(-0.18)	5.70	(0.27)
NRC00_2	Drystock, Granular	9	16	(7)	13	(-3)	5.35	5.69	(0.34)	5.90	(0.21)
NRC00_3	Drystock, Brown	44	52	(8)	41	(-11)	5.38	5.32	(-0.06)	5.80	(0.48)
NRC00_4	Drystock, Brown	59	82	(23)	63	(-19)	6.24	6.15	(-0.09)	5.50	(-0.65)
NRC00_7	Drystock, Brown	9	12	(3)	15	(3)	5.64	6.49	(0.85)	6.00	(-0.49)
NRC00_9	Drystock, Brown	6	8	(2)	9	(1)	5.17	5.64	(0.47)	5.80	(0.16)
NRC00_10	Drystock, Allophanic	18	40	(22)	31	(-9)	7.25	7.20	(-0.05)	7.10	(-0.10)
NRC00_13	Drystock, Allophanic	16	56	(40)	25	(-31)	6.07	6.09	(0.02)	5.80	(-0.29)
	Mean	**23**	**36**	**(14)**	**28**	**(-8)**	**5.84**	**6.00**	**(0.16)**	**5.95**	**(-0.05)**
	sd	19	26	(7)	18	(-8)	0.68	0.62	(-0.05)	0.49	(-0.14)

Table 8 continued

SITE CODE	LAND USE & SOIL CLASS	FERTILITY			ACIDITY		
		Olsen P ($\mu g/cm^3$)			pH		
		2001	**2006**	**2010-11**	**2001**	**2006**	**2010-11**
NRC00_8	Plantation forestry, Brown	13	16 (3)	27 (11)	4.99	5.07 (0.08)	5.30 (0.23)
NRC00_11	Plantation forestry, Allophanic	9	6 (-3)	7 (1)	6.28	6.36 (0.08)	6.10 (-0.26)
NRC00_16	Plantation forestry, Ultic	22	8 (-14)	31 (23)	4.93	4.46 (-0.47)	5.00 (0.54)
NRC00_17	Plantation forestry, Brown	13	24 (11)	10 (-14)	4.95	4.97 (0.02)	4.90 (-0.07)
NRC00_22	Plantation forestry, Granular	6	18 (12)	13 (-5)	5.31	4.98 (-0.33)	4.90 (-0.08)
	Mean	**13**	**14 (2)**	**18 (3)**	**5.29**	**5.17 (-0.12)**	**5.24 (0.07)**
	sd	6	7 (1)	11 (3)	0.57	0.71 (0.13)	0.51 (-0.20)
NRC00_6	Indigenous forest, Brown	11	9 (-2)	22 (13)	5.62	5.28 (-0.34)	6.10 (0.82)
NRC00_18	Indigenous forest, Brown	7	13 (6)	5 (-8)	4.60	4.64 (0.04)	4.50 (-0.14)
NRC00_20	Indigenous forest, Granular	20	7 (-13)	8 (1)	4.82	4.84 (0.02)	4.90 (0.06)
NRC00_24	Indigenous forest, Allophanic	3	7 (4)	6 (-1)	6.40	6.48 (0.08)	6.10 (-0.38)
	Mean	**10**	**9 (-1)**	**10 (1)**	**5.36**	**5.31 (-0.05)**	**5.40 (0.09)**
	sd	7	3 (-4)	8 (5)	0.82	0.82 (0.00)	0.82 (0.00)
NRC_0025	Citrus orchard, Allophanic	77	74 (-3)	77 (3)	6.17	6.07 (-0.10)	5.70 (-0.37)

Table 9 Soil organic resources in 2001, 2006, and 2010-11. The numbers in brackets show the change since the previous sampling period

SITE CODE	LAND USE & SOIL CLASS	ORGANIC RESOURCES								
		Mineralisable N ($\mu g/cm^3$)			Total C ($\mu g/cm^3$)			Total N ($\mu g/cm^3$)		
		2001	2006	2010-11	2001	2006	2010-11	2001	2006	2010-11
NRC00_5	Dairy, Brown	247	141 (-106)	190 (49)	73.30	63.50 (-9.80)	75.60 (12.10)	5.82	5.60 (-0.22)	6.90 (1.30)
NRC00_12	Dairy, Allophanic	146	101 (-45)	52 (-49)	74.00	50.90 (-23.10)	58.80 (7.90)	6.37	5.00 (-1.37)	2.76 (-2.24)
NRC00_14	Dairy, Ultic	197	108 (-89)	203 (95)	67.40	59.70 (-7.70)	63.00 (3.30)	5.60	5.10 (-0.50)	4.77 (-0.33)
NRC00_15	Dairy, Ultic	144	116 (-28)	166 (50)	71.00	57.20 (-13.80)	66.78 (9.58)	6.23	5.60 (-0.63)	6.12 (0.52)
NRC00_19	Dairy, Granular	150	142 (-8)	258 (116)	76.40	83.00 (6.60)	88.00 (5.00)	5.55	6.20 (0.65)	7.28 (1.08)
NRC00_21	Dairy, Granular	178	154 (-24)	201 (47)	70.10	73.30 (3.20)	67.44 (-5.86)	5.74	6.10 (0.36)	6.00 (-0.10)
	Mean	**177**	**127 (-50)**	**178 (51)**	**72.03**	**64.60 (-7.43)**	**72.04 (7.44)**	**5.89**	**5.60 (-0.29)**	**5.90 (0.30)**
	sd	69	3.19 (-66)	11.68 (8.5)	3.00	0.34 (-2.66)	0.49 (0.16)	0.35	0.2 (-0.17)	0.1 (-0.09)
NRC00_1	Drystock, Granular	255	144 (-111)	270 (126)	59.10	60.90 (1.80)	69.30 (8.40)	5.25	5.90 (0.65)	6.21 (0.31)
NRC00_2	Drystock, Granular	193	157 (-36)	172 (15)	54.60	59.30 (4.70)	49.77 (-9.53)	4.64	5.10 (0.46)	4.03 (-1.07)
NRC00_3	Drystock, Brown	271	162 (-109)	192 (30)	51.40	66.60 (15.20)	51.20 (-15.40)	4.33	5.80 (1.47)	4.16 (-1.64)
NRC00_4	Drystock, Brown	190	142 (-48)	127 (-15)	65.40	72.20 (6.80)	67.50 (-4.70)	5.34	6.00 (0.66)	5.50 (-0.50)
NRC00_7	Drystock, Brown	9	12 (3)	15 (3)	5.64	6.49 (0.85)	6.00 (-0.49)	170	138 (-32)	228 (90)
NRC00_9	Drystock, Brown	111	92 (-19)	99 (7)	62.30	48.90 (-13.40)	52.00 (3.10)	4.12	3.80 (-0.32)	3.50 (-0.30)
NRC00_10	Drystock, Allophanic	29	41 (12)	83 (42)	39.90	50.40 (10.50)	55.99 (5.59)	2.48	3.80 (1.32)	4.18 (0.38)
NRC00_13	Drystock, Allophanic	16	56 (40)	25 (-31)	6.07	6.09 (0.02)	5.80 (-0.29)	171	101 (-70)	188 (87)
	Mean	**174**	**122 (-52)**	**170 (48)**	**58.34**	**59.38 (1.04)**	**58.74 (-0.64)**	**4.68**	**5.15 (0.47)**	**4.84 (-0.31)**
	Sd	77	41 (-36)	64 (23)	9.42	8.64 (-0.79)	1.27 (-7.37)	1.07	0.91 (-0.16)	0.17 (-0.74)

Table 9 continued

SITE CODE	LAND USE & SOIL CLASS	ORGANIC RESOURCES								
		Mineralisable N ($\mu g/cm^3$)			Total C ($\mu g/cm^3$)			Total N ($\mu g/cm^3$)		
		2001	**2006**	**2010-11**	**2001**	**2006**	**2010-11**	**2001**	**2006**	**2010-11**
NRC00_8	Pines, Brown	13	16 (3)	27 (11)	4.99	5.07 (0.08)	5.30 (0.23)	60	47 (-13)	94 (47)
NRC00_11	Pines, Allophanic	9	6 (-3)	7 (1)	6.28	6.36 (0.08)	6.10 (-0.26)	54	55 (1)	52 (-3)
NRC00_16	Pines, Ultic	22	8 (-14)	31 (23)	4.93	4.46 (-0.47)	5.00 (0.54)	118	50 (-68)	57 (7)
NRC00_17	Pines, Brown	13	24 (11)	10 (-14)	4.95	4.97 (0.02)	4.90 (-0.07)	146	66 (-80)	83 (17)
NRC00_22	Pines, Granular	6	18 (12)	13 (-5)	5.31	4.98 (-0.33)	4.90 (-0.08)	123	90 (-33)	167 (77)
	Mean	**13**	**14 (2)**	**18 (3)**	**5.29**	**5.17 (-0.12)**	**5.24 (0.07)**	**100**	**62 (-39)**	**91 (29)**
	sd	6	7 (1)	11 (3)	0.57	0.71 (0.13)	0.51 (-0.20)	41	17 (-23)	46 (29)
NRC00_6	Native, Brown	11	9 (-2)	22 (13)	5.62	5.28 (-0.34)	6.10 (0.82)	180	134 (-46)	165 (31)
NRC00_18	Native, Brown	7	13 (6)	5 (-8)	4.60	4.64 (0.04)	4.50 (-0.14)	55	44 (-11)	80 (36)
NRC00_20	Native, Granular	20	7 (-13)	8 (1)	4.82	4.84 (0.02)	4.90 (0.06)	131	132 (1)	147 (15)
NRC00_24	Native, Allophanic	3	7 (4)	6 (-1)	6.40	6.48 (0.08)	6.10 (-0.38)	148	174 (26)	209 (35)
	Mean	**129**	**121 (-8)**	**150 (29)**	**64.13**	**75.55 (11.43)**	**61.99 (-13.56)**	**3.85**	**4.40 (0.55)**	**3.99 (-0.41)**
	sd	53	55 (2)	54 (-1)	15.46	19.82 (4.36)	2.23 (-17.59)	0.70	1.26 (0.56)	0.17 (-1.10)
NRC00_25	Orchard, Allophanic	77	74 (-3)	77 (3)	6.17	6.07 (-0.10)	5.70 (-0.37)	148	137 (-11)	135 (-2)

Table 10 Soil physical properties in 2001, 2006, and 2010-11. The numbers in brackets show the change since the previous sampling period

SITE CODE	LAND USE & SOIL CLASS	PHYSICAL PROPERTIES					
		Bulk density (%v/v)			Macroporosity (%v/v)		
		2001	2006	2010-11	2001	2006	2010-11
NRC00_5	Dairy, Brown	1.1	0.9 (-0.2)	1.0 (0.1)	7.6	6.2 (-1.4)	2.7 (-3.5)
NRC00_12	Dairy, Allophanic	1.2	1.0 (-0.2)	1.2 (0.2)	14.3	3.1 (-11.2)	5.2 (2.1)
NRC00_14	Dairy, Ultic	1.1	0.9 (-0.2)	0.9 (0.0)	8.5	13.9 (5.4)	1.9 (-12.0)
NRC00_15	Dairy, Ultic	0.8	0.8 (0.0)	0.9 (0.1)	16.8	10.7 (-6.1)	4.3 (-6.4)
NRC00_19	Dairy, Granular	0.7	0.8 (0.1)	0.8 (0.0)	24.7	7.7 (-17.0)	7.1 (-0.6)
NRC00_21	Dairy, Granular	0.8	0.9 (0.1)	0.8 (-0.1)	13.8	7.7 (-6.1)	3.5 (-4.2)
	Mean	**0.9**	**0.9 (-0.1)**	**0.9 (0.1)**	**14.3**	**8.2 (-6.1)**	**4.1 (-4.1)**
	sd	0.2	6.2 (6.0)	3.7 (-2.3)	1.9	3.7 (1.8)	1.9 (-1.8)
NRC00_1	Drystock, Granular	0.9	0.84 (0.0)	0.9 (0.1)	17.1	12.4 (-4.7)	2.9 (-9.5)
NRC00_2	Drystock, Granular	0.9	1.00 (0.2)	0.8 (-0.2)	22.0	9.2 (-12.8)	3.4 (-5.8)
NRC00_3	Drystock, Brown	1.0	1.02 (0.0)	0.8 (-0.2)	13.3	8.0 (-5.3)	11.8 (3.8)
NRC00_4	Drystock, Brown	0.8	1.05 (0.2)	1.0 (-0.1)	21.6	4.2 (-17.4)	4.3 (0.1)
NRC00_7	Drystock, Brown	0.9	0.9 (0.0)	0.9 (0.0)	19.1	12.2 (-6.9)	1.9 (-10.3)
NRC00_9	Drystock, Brown	1.0	0.9 (0.0)	1.0 (0.1)	20.8	7.6 (-13.2)	12.1 (4.5)
NRC00_10	Drystock, Allophanic	0.9	1.2 (0.4)	1.1 (-0.1)	30.7	5.2 (-25.5)	3.1 (-2.1)
NRC00_13	Drystock, Allophanic	0.8	1.0 (0.2)	0.8 (-0.2)	21.4	3.1 (-18.3)	16.2 (13.1)
	Mean	**0.9**	**1.0 (0.1)**	**0.9 (-0.1)**	**20.8**	**7.0 (-13.7)**	**7.0 (-0.1)**
	sd	0.1	0.2 (0.1)	0.1 (0.0)	5.0	3.9 (-1.1)	5.5 (1.6)

Table 10 continued

SITE CODE	LAND USE & SOIL CLASS	PHYSICAL PROPERTIES					
		Bulk density (%v/v)			Macroporosity (%v/v)		
		2001	**2006**	**2010-11**	**2001**	**2006**	**2010-11**
NRC00_8	Pines, Brown	0.7	0.9 (0.2)	0.9 (0.0)	34.5	22.9 (-11.6)	20.0 (-2.9)
NRC00_11	Pines, Allophanic	0.9	0.8 (-0.1)	1.0 (0.2)	26.7	30.5 (3.8)	25.0 (-5.5)
NRC00_16	Pines, Ultic	0.9	1.0 (0.1)	1.0 (0.0)	26.8	23.8 (-3.0)	15.5 (-8.3)
NRC00_17	Pines, Brown	0.9	1.0 (0.0)	1.0 (0.0)	25.4	22.0 (-3.4)	15.7 (-6.3)
NRC00_22	Pines, Granular	0.9	0.8 (0.0)	0.8 (0.0)	8.8	14.3 (5.5)	13.8 (-0.5)
	Mean	**0.9**	**0.9 (0.0)**	**0.9 (0.0)**	**24.4**	**22.7 (-1.7)**	**18.0 (-4.7)**
	sd	0.1	0.1	0.1	9.5	5.8	4.5
NRC00_6	Native, Brown	1.0	1.1 (0.1)	1.0 (-0.1)	13.7	6.9 (-6.8)	15.4 (8.5)
NRC00_18	Native, Brown	0.8	0.9 (0.1)	0.7 (-0.2)	12.4	15.8 (3.4)	17.0 (1.2)
NRC00_20	Native, Granular	0.7	0.8 (0.1)	0.7 (-0.1)	24.5	12.0 (-12.5)	19.0 (7.0)
NRC00_24	Native, Allophanic	0.7	0.7 (0.0)	0.6 (-0.1)	18.4	27.7 (9.3)	20.7 (-7.0)
	Mean	**0.8**	**0.9 (0.1)**	**0.8 (-0.1)**	**17.3**	**15.6 (-1.7)**	**18.0 (2.4)**
	sd	0.2	0.2 (0.0)	0.2 (0.0)	5.5	8.9 (3.4)	2.3 (-6.5)
NRC00_25	Citrus orchard, Allophanic	1.0	1.0 (0.1)	0.9 (-0.2)	14.1	10.4 (-3.7)	19.2 (8.8)

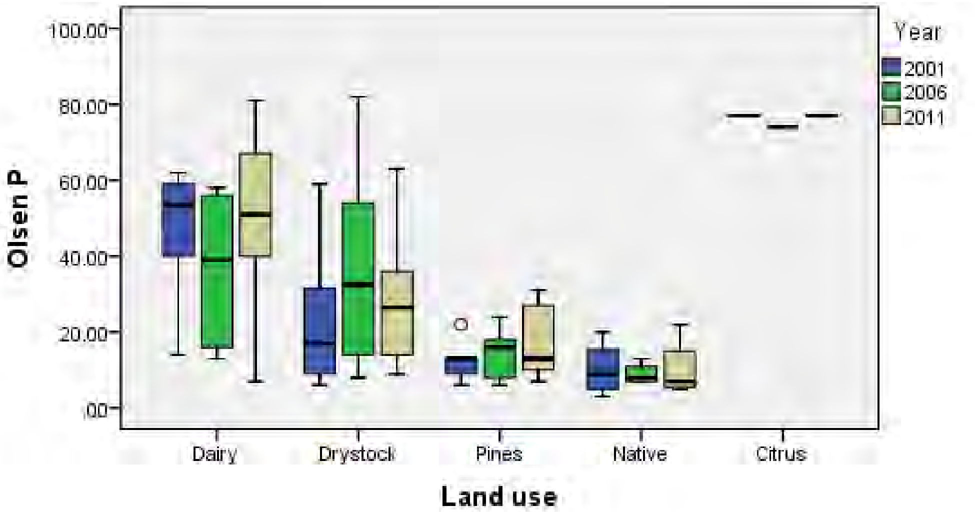


Figure 3 Olsen P ($\mu g/cm^3$) displayed by land use for each sampling year

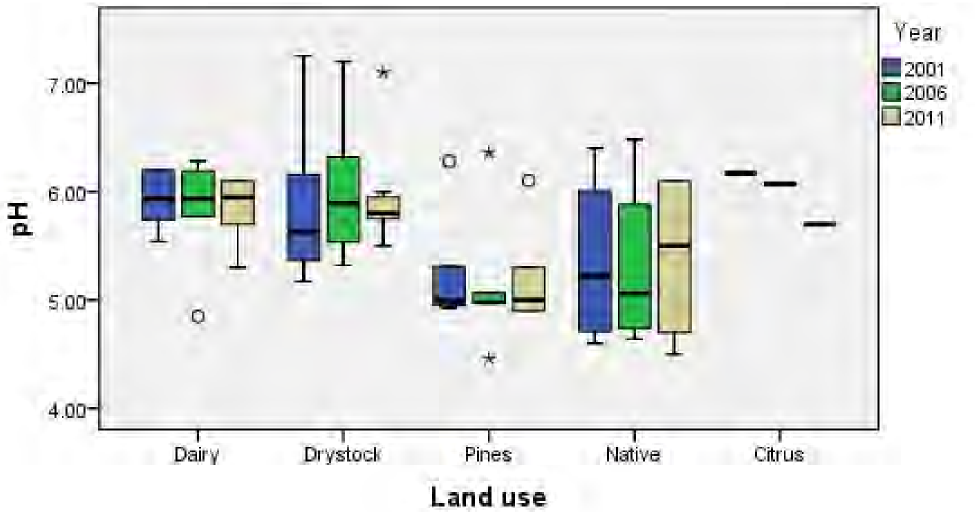


Figure 4 Acidity (pH) displayed by land use for each sampling year

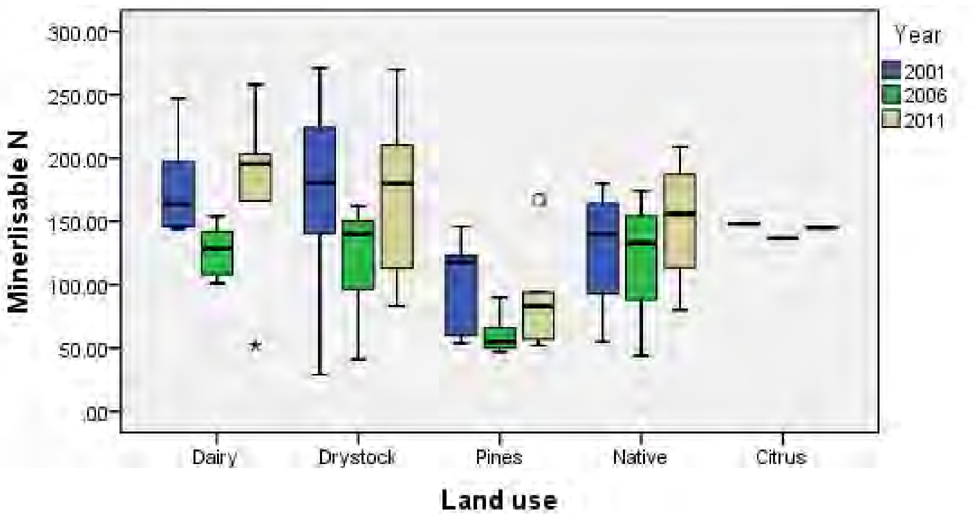


Figure 5 Mineralisable N ($\mu g/cm^3$) displayed by land use for each sampling year

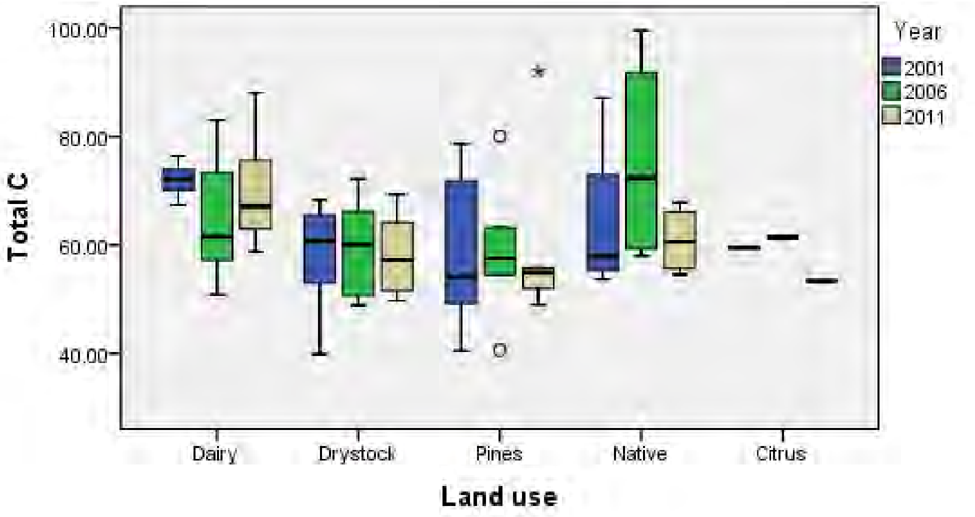


Figure 6 Total Carbon ($\mu g/cm^3$) displayed by land use for each sampling year

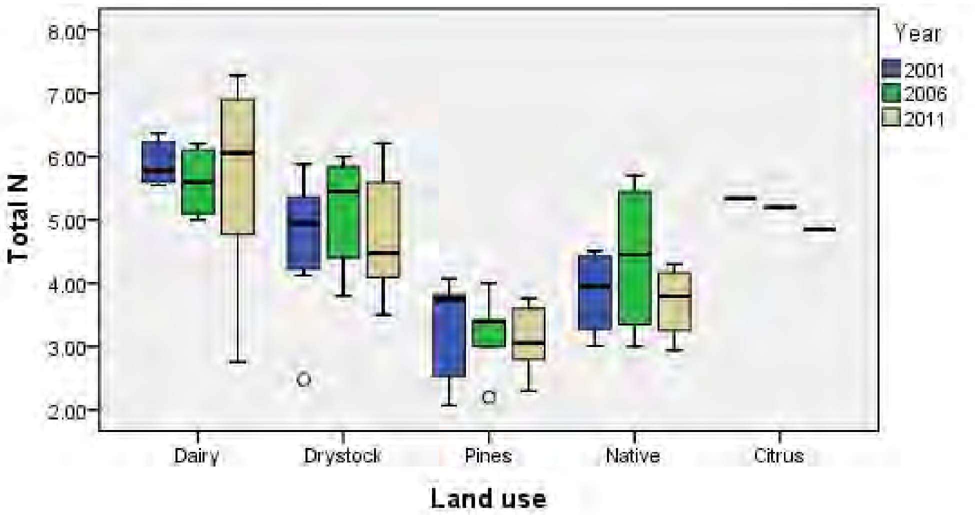


Figure 7 Total Nitrogen ($\mu g/cm^3$) displayed by land use for each sampling year

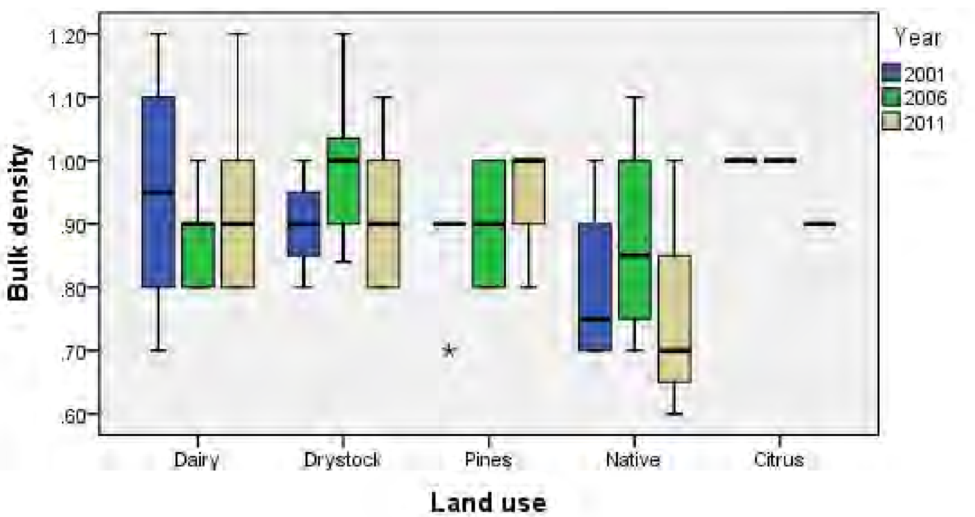


Figure 8 Bulk Density (Mg/m^3) displayed by land use for each sampling year

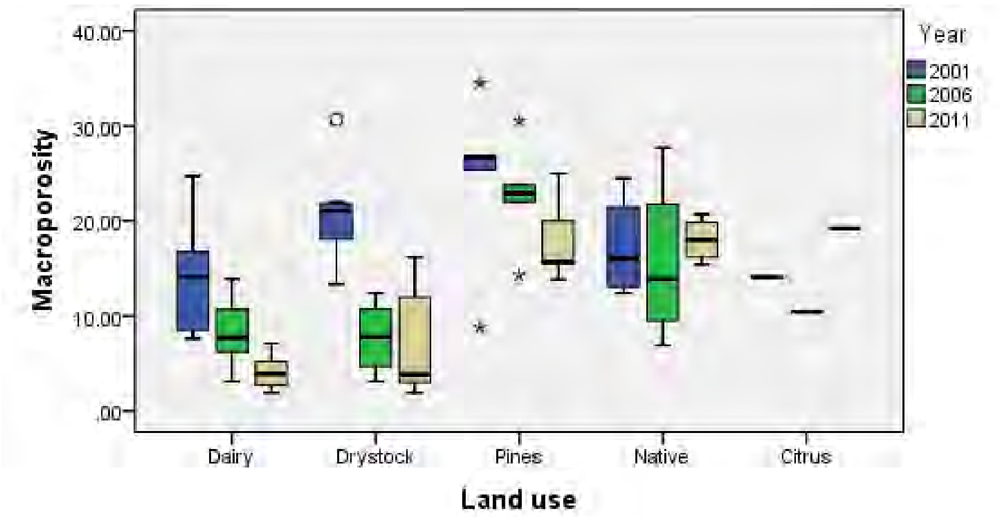


Figure 9 Macroporosity (Mg/m^3) displayed by land use for each sampling year

5 Discussion

Soil quality is being measured by reference to national optimum ranges for a number of indicators/parameters. If the indigenous forestry sites are used as a control, then the extent to which the samples from other land uses vary from the indigenous sites is a measure of the impact of each of those land uses on the soil. However, in the case of some of these Northland soils, the soil in its native state could be far from ideal (according to the national standards). The most important measures are the variations from earlier samples on the same sites. That is, what is the trend over time under the current land uses, accepting that many of Northlands soil types naturally fall well outside the ideal. As an aside, but totally relevant when considering trends, Northland soils have developed under a warm, generally moist climate and in most cases under forest. The Brown and Granular soils, Yellow Brown Earths, have developed under broadleaf-podocarp forest with podocarp-kauri dominant on more stable sites, that is, becoming podzolised>Ultic. The Allophanic (Redhill) soils, being midway down the Pinaki Suite, were formed under a broadleaf forest but which was being replaced with kauri and would have ended up as an Ultic (Te Kopuru) soil. Similarly, cover on the Allophanic Awarua soils, formed on Tangihua volcanics, will have become kauri dominant and become podzolised while the Kiripaka soils, formed on basalt, will have remained broadleaf dominant for much longer but ultimately being laterised to the ironstone Okaihau soils. Except on the indigenous sites, this process has been interrupted and, where converted to grass, reversed. For this reason, soil monitoring in Northland must be interpreted within the context of these soil-forming trends, in addition to the national target values (B Cathcart, 2012., pers. comm. 14 Feb).

The current national trend is for greater land intensification (Parliamentary Commission for the Environment 2004). Perhaps as a consequence reports from around New Zealand (e.g. Sparling and Schipper 2004; Stevenson 2007, 2010; Gray 2011; Taylor 2011) have highlighted issues such as widespread compaction on dairy farms and optimal soil fertility. Stevenson (2007) lists many possible management options including the use of run-off pads on dairy farms, rapid movement of cattle to minimize pugging, on-farm nutrient budgeting, disposal of effluent 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.

Soil quality characteristics of sites sampled in 2010-11 followed some of the same trends as those seen in other regions of New Zealand. 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, 2006, and 2010-11 suggests an overall significant decline in macroporosity. Like many other regions, high total nitrogen and mineralisable N levels are of concern, particularly on dairy and drystock sites. In contrast, low Olsen P levels observed on some drystock sites indicate pasture production is likely to be suboptimal and could eventually lead to overgrazed conditions. The instance of the high pH (alkaline) on the drystock site can be remedied by adding acidifying minerals or organic material to the soil.

It should be noted that due to the small number of sites the standard deviation (variation) is high for a lot of variables which makes it difficult to make generalisations about 2010-11 results. In addition, the climate variability between sampling years may have contributed to several sites/variables changing greatly from 2001 to 2006, and then returning to 2001 levels by 2010-11. Adding more sites to the programme and sampling at the same time of year will help to minimise this variation.

6 Conclusions

- The ongoing trend of decreasing macroporosity since previous sampling (2001; 2006) on dairy and drystock sites mirror results from other regions of the country and is a general result of intensification of these land use practices.

- The primary concerns are (1) compaction of soils on dairy and drystock sites; (2) the high nitrogen levels on some dairy and drystock sites; and (3) the low nutrient (Olsen P) status of some drystock sites. Soil pH was also below target values at two sites. Mineralisable nitrogen values were higher than the previous sampling in 2006; 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 the program of resampling existing sites to determine the extent and direction of any changes since original sampling. The next resampling should be in 5 years (2015-16).

- As recommended in the review of NRC's soil monitoring program, Stevenson (2011) suggests increasing the number of sites monitored. He recommends adding a minimum of five to ten sites to help increase the ability to detect change between landuses, and decrease the bias between land use area and number of sites sampled. As the majority of existing sites were west of Whangarei, the additional sites should include soils further North (Bay of Islands and Kaitaia areas) where there are more Ultic and Oxic soils.

- To better represent the different landuses Stevenson (2011) suggests at a minimum, the addition of two to three drystock sites, one cropping site, one to three indigenous sites and possibly one dairy site.

- 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 Acknowledgments

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This report was peer reviewed by Scott Fraser, Landcare Research, Hamilton.

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Appendix

Soil quality indicators – target ranges

Site and soil descriptions from original samplings

Soil chemical and physical analysis data tables

Soil quality indicators – target ranges

Table 11 Provisional quality classes and target ranges for total carbon

Allophanic	0.5	**3**	4	9	12
Semiarid, Pumice & Recent	0	**2**	3	5	12
All other soil orders except Organic	0.5	**2.5**	3.5	7	12
Organic	Exclusion				
	Very depleted	Depleted	Normal	Ample	

Notes: Applicable to all land uses. Organic Soils by definition must have >15% total C content, hence C content is not a quality indicator for that order and is defined as an'exclusion'. Target ranges for cropping and horticulture are also poorly defined.

Table 12 Provisional quality classes and target ranges for anaerobically mineralised nitrogen

Pasture	25	**50**	100	200	200	**250**	300
Forestry	5	**20**	40	120	150	**175**	200
Cropping & horticulture	5	**20**	100	150	150	**200**	225
	Very low	Low	Adequate	Ample	High	Excessive	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are poorly defined.

Table 13 Provisional quality classes and target ranges for total nitrogen

Pasture	0	**0.25**	0.35	0.65	**0.7**	1.0
Forestry	0	**0.10**	0.2	0.6	**0.7**	1.0
Cropping & horticulture	exclusion					
	Very depleted	Depleted	Adequate	Ample	High	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are not specified as target values will depend on the specific crop grown.

Table 14 Provisional quality classes and target ranges for pH

Pastures on all soils except Organic	4	**5**	5.5	6.3	**6.6**	8.5
Pastures on Organic Soils	4	**4.5**	5	6	**7.0**	
Cropping & horticulture on all soils except Organic	4	**5**	5.5	7.2	**7.6**	8.5
Cropping & horticulture on Organic Soils	4	**4.5**	5	7	**7.6**	
Forestry on all soils except Organic		**3.5**	4	7	**7.6**	
Forestry on Organic Soils	exclusion					

Very acid | Slightly acid | Optimal | Sub-optimal | Very alkaline

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are general averages and target values will depend on the specific crop grown. Exclusion is given for forestry on organic soils, as this combination is unlikely in real life because of windthrow.

Table 15 Provisional quality classes and target ranges for Olsen P

Pasture on Sedimentary & Allophanic soils	0	**15**	20	50	**100**	200
Pasture on Pumice & Organic soils	0	**15**	35	60	**100**	200
Cropping and horticulture on Sedimentary & Allophanic soils	0	**20**	50	100	**100**	200
Cropping and horticulture on Pumice & Organic soils	0	**25**	60	100	**100**	200
Forestry on all soil orders	0	**5**	10	100	**100**	200

Very low | Low | Adequate | Ample | High

Notes: Sedimentary soil (AgResearch classification system) includes all other soil orders except Allophanic (volcanic ash), Pumice, and Organic.

Table 16 Provisional quality classes and target ranges for Olsen P

Semiarid, Pallic & Recent soils	0.3	**0.7**	0.9	1.3	**1.4**	1.6
Allophanic Soils		**0.5**	0.6	0.9	**1.3**	
Organic Soils		**0.2**	0.4	0.6	**1.0**	
Pumice & Podzol soils		**0.6**	0.7	1.2	**1.4**	1.6
All other soils	0.3	**0.6**	0.8	1.2	**1.4**	1.6

Very loose | Loose | Adequate | Compact | Very compact

Notes: Applicable to all land uses. Target ranges for cropping and horticulture are poorly defined.

Table 17 Provisional quality classes and target ranges for macroporosity

Pasture, cropping & horticulture	0	**6**	8	**30**	40
Forestry	0	**8**	10	**30**	40
	Very low	Low	Adequate	High	

Notes: Applicable to all soil orders. Target ranges for cropping and horticulture are poorly defined, and almost nothing is known about indigenous forest species.

Site and soil descriptions from original samplings

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°
Local contact person	Harris, (owner)
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°
Local contact person	Harris
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°
Local contact person	Harris
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°
Local contact person	John Gunson
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°
Local contact person	John Gunson
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°
Local contact person	Wellwood
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°
Local contact person	Wellwood
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°
Local contact person	Wellwood
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
Local contact person	
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°
Local contact person	Owner Nash
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°
Local contact person	Owner Nash
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°
Local contact person	Owner J.Garille
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°
Local contact person	Owner Henwood
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°
Local contact person	Owner Nash
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°
Local contact person	Owner Wayne Chapman
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°
Local contact person	
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°
Local contact person	Dianne Coates, (forest owned by NRC)
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°
Local contact person	Dianne Coates, (forest owned by NRC)
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°
Local contact person	Ngatitara Farm
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°
Local contact person	Ngatitara Farm
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°
Local contact person	Ngatitara Farm.
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°
Local contact person	Tungrove Forest, Carter Holt Harvey forests
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°
Local contact person	Hutchingson (owner)
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°
Local contact person	Hutchingson (owner)
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°
Local contact person	Huanui Orchard
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	

Soil chemical and physical analysis data tables

Table 18 Raw chemical data supplied by Landcare Rersearch

Client ID	Date sampled	Sample No.	Water Content* (method 104ii) (% dry wt)	pH (2:5 Water) (method 106(i))	Organic C (method 114) (%)	Total N (method 114) (%)	C/N ratio (calculation)	KCl-extractable (method 118) (mg/kg)		Anaerobic Mineralisable-N (method (120) (mg/kg)
								NO3-N	NH4-N	
NRC 001	Nov-Dec 2010	M10/4136	28.4	5.7	7.7	0.69		39.5	2.0	270
NRC 002	Nov-Dec 2010	M10/4137	24.3	5.9	6.3	0.51		12.0	3.5	172
NRC 003	Nov-Dec 2010	M10/4138	27.5	5.8	6.4	0.52		29.4	4.5	192
NRC 004	Sep-11	M11/1293	47.3	5.5	6.75	0.55	12	86	2.3	127
NRC 005	Sep-11	M11/1294	48.3	6.1	7.56	0.69	11	120	1.6	190
NRC 006	Sep-11	M11/1295	44.1	6.1	6.78	0.43	16	17	2.7	165
NRC 007	Nov-Dec 2010	M10/4139	27.4	6.0	6.5	0.53		45.4	4.6	228
NRC 008	Nov-Dec 2010	M10/4140	19.6	5.3	6.2	0.34		2.2	17.0	94
NRC 009	Nov-Dec 2010	M10/4141	16.1	5.8	5.2	0.35		2.4	7.9	99
NRC 010	Sep-11	M11/1296	38.4	7.1	5.09	0.38	13	31	2.0	83
NRC 011	Nov-Dec 2010	M10/4142	14.5	6.1	4.9	0.23		0.9	1.5	52
NRC 012	Sep-11	M11/1297	34.1	6.3	4.42	0.39	11	46	1.0	91
NRC 013	Nov-Dec 2010	M10/4143	13.3	5.8	7.6	0.71		14.1	35.9	188
NRC 014	Nov-Dec 2010	M10/4144	15.1	5.3	7.0	0.53		5.1	18.2	203
NRC 015	Sep-11	M11/1298	52.7	5.9	7.42	0.68	11	75	9.3	166
NRC 016	Sep-11	M10/4145	16.8	5.0	5.2	0.36		3.5	14.2	57
NRC 017	Nov-Dec 2010	M10/4146	27.8	4.9	5.5	0.28		2.2	38.8	83
NRC 018	Sep-11	M11/1299	67.7	4.5	7.80	0.42	18	0.7	18.2	80
NRC 019	Sep-11	M11/1300	69.1	5.7	11.0	0.91	12	80	2.7	258
NRC 020	Sep-11	M11/1301	69.3	4.9	9.20	0.51	18	19	13.4	147
NRC 021	Sep-11	M11/1302	62.9	6.0	8.43	0.75	11	50	1.1	201
NRC 022	Nov-Dec 2010	M10/4147	49.5	4.9	11.5	0.47		5.6	20.5	167
NRC 024	Sep-11	M11/1303	78.9	6.1	9.46	0.67	14	81	0.9	209
NRC 025	Sep-11	M11/1304	46.6	5.7	6.28	0.57	11	42	1.1	135

Table 18 continued

Client ID	Date sampled	Sample No.	Olsen P (method 124) (mg/kg)	As	Cd	Cr	Co	Cu	Pb	Zn
				(method 163)* † (mg/kg)						
NRC 001	Nov-Dec 2010	M10/4136	28	4.1	0.8	15	6	18	10	43
NRC 002	Nov-Dec 2010	M10/4137	13	5.5	<0.5	18	6	18	12	45
NRC 003	Nov-Dec 2010	M10/4138	41	3.5	0.7	14	4	8	9	24
NRC 004	Sep-11	M11/1293	63	3.2	<0.5	42	2	21	16	37
NRC 005	Sep-11	M11/1294	81	1.6	0.8	31	3	23	4	50
NRC 006	Sep-11	M11/1295	22	3.7	<0.5	19	2	14	7	43
NRC 007	Nov-Dec 2010	M10/4139	15	2.3	0.5	17	5	18	5	32
NRC 008	Nov-Dec 2010	M10/4140	27	2.2	<0.5	12	6	11	6	29
NRC 009	Nov-Dec 2010	M10/4141	9	3.0	<0.5	15	4	7	5	18
NRC 010	Sep-11	M11/1296	31	8.0	<0.5	22	3	6	6	27
NRC 011	Nov-Dec 2010	M10/4142	7	5.9	<0.5	13	6	10	5	32
NRC 012	Sep-11	M11/1297	60	6.3	<0.5	17	3	6	4	40
NRC 013	Nov-Dec 2010	M10/4143	25	7.8	0.5	15	6	11	4	37
NRC 014	Nov-Dec 2010	M10/4144	40	<0.5	<0.5	3	1	2	1	6
NRC 015	Sep-11	M11/1298	67	<1	1.1	18	1	13	36	41
NRC 016	Sep-11	M10/4145	31	<0.5	<0.5	6	2	8	1	7
NRC 017	Nov-Dec 2010	M10/4146	10	10.5	<0.5	23	5	6	8	18
NRC 018	Sep-11	M11/1299	5	4.3	<0.5	22	6	18	14	31
NRC 019	Sep-11	M11/1300	44	<1	0.6	107	5	32	4	46
NRC 020	Sep-11	M11/1301	8	<1	<0.5	144	10	42	3	47
NRC 021	Sep-11	M11/1302	58	<1	0.9	98	6	35	4	138
NRC 022	Nov-Dec 2010	M10/4147	13	<0.5	<0.5	158	12	25	2	38
NRC 024	Sep-11	M11/1303	6	3.8	<0.5	151	25	50	16	104
NRC 025	Sep-11	M11/1304	77	4.3	1.0	123	83	80	15	112

Table 19 Raw physical data supplied by Landcare Rersearch

Northland Regional Council
Soil Quality 2010

Moisture Release Results

Job: 682202-0102

April 2011

Lab	Client	Initial	Dry Bulk	Particle	Total	Macro	Air	Vol. WC	Vol. WC
Number	ID	Water	Density	Density	Porosity	Porosity	Filled	5kPa	100kPa
		Content					Porosity		
		(%, w/w)	(t/m3)	(t/m3)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)
HP4502a	NRC 001	24.3	0.98	2.47	60.5	10.3	12.9	50.2	47.6
HP4502b		27.4	1.01	2.49	59.6	10.6	13.1	49.0	46.5
HP4502c		50.2	0.68	2.36	71.1	15.2	16.9	55.9	54.2
HP4503a	NRC 002	23.6	1.20	2.55	52.9	>1	0.4	53.8	52.5
HP4503b		29.6	0.91	2.48	63.5	13.1	15.8	50.5	47.7
HP4503c		26.7	1.09	2.50	56.4	3.0	5.1	53.3	51.3
HP4504a	NRC 003	28.1	1.00	2.46	59.5	6.3	8.4	53.2	51.1
HP4504b		28.9	1.04	2.51	58.4	5.0	6.3	53.5	52.1
HP4504c		47.1	0.84	2.36	64.6	4.7	6.7	59.9	57.9
HP4505a	NRC 0022	50.1	0.79	2.53	69.0	17.1	18.5	51.9	50.5
HP4505b		49.7	0.88	2.57	65.9	10.5	11.4	55.4	54.5
HP4505c									
HP4506a	NRC 0014	27.1	0.89	2.39	62.7	2.5	5.6	60.3	57.1

HP4506b		18.1	0.93	2.43	61.6	3.2	6.6	58.4	55.0
HP4506c		17.8	0.93	2.36	60.6	0.1	4.5	60.5	56.1
HP4507a	NRC 0016	21.7	1.00	2.52	60.2	14.3	15.0	45.9	45.2
HP4507b		13.5	1.15	2.51	54.3	12.1	14.6	42.2	39.7
HP4507c		16.4	0.96	2.44	60.7	20.2	22.2	40.5	38.5
HP4508a	NRC 0017	25.8	1.13	2.51	55.0	11.2	12.6	43.7	42.4
HP4508b		32.9	1.00	2.55	61.0	20.9	22.0	40.0	39.0
HP4508c		21.6	1.02	2.45	58.2	14.9	16.4	43.4	41.8
HP4509a	NRC 0011	15.8	0.89	2.56	65.1	21.2	31.8	43.9	33.3
HP4509b		10.0	1.00	2.60	61.4	23.3	31.2	38.1	30.2
HP4509c		14.1	0.96	2.57	62.6	30.6	33.3	32.0	29.3
HP4510a	NRC 0013	25.3	0.78	2.36	67.1	9.8	16.1	57.3	51.0
HP4510b		11.9	1.15	2.49	53.8	0.0	6.8	53.7	47.0
HP4510c		24.4	0.80	2.38	66.6	16.8	25.1	49.8	41.5
HP4511a	NRC 007	43.1	0.77	2.43	68.3	11.4	12.3	56.9	56.0
HP4511b		27.2	1.00	2.54	60.6	12.3	14.3	48.3	46.3
HP4511c		27.8	0.97	2.46	60.5	9.4	11.1	51.1	49.4
HP4512a	NRC 008	22.2	0.92	2.44	62.3	24.5	25.6	37.8	36.7
HP4512b		22.2	1.17	2.52	53.6	9.4	10.5	44.3	43.1
HP4512c		15.0	0.98	2.50	60.7	32.2	32.7	28.6	28.0
HP4513a	NRC 009	21.1	1.02	2.49	58.9	10.6	13.8	48.3	45.1
HP4513b		16.9	1.03	2.48	58.4	16.2	18.3	42.2	40.1
HP4513c		20.9	1.07	2.52	57.5	9.6	11.0	48.0	46.5

The accuracy of our results are dependent on the quality of sample collected. Many of the samples were dry and had become fractured - either naturally or more likely through the field sampling that took place during a prolonged dry spell. Results may have been affected.

Sample NRC 0022 rep 3 (HP4505c) was sampled from an organic horizon and was largely composed of litter material. It was totally different from its replicates. It was also hydrophobic and did not appear to wet up properly. Results were discarded.
Sample NRC 002 rep 2 (HP4503b) was so badly fractured and disturbed that it is suggested that the results be discarded.
The following samples were notably fractured: NRC 001 reps 1-3 (HP4502a-c), NRC 002 reps 1-3 (HP4503a-c), NRC 003 (HP4504a-c), NRC 0013 reps 1 and 3 (HP4510a and c), NRC 007 reps 1-3 (HP4511a-c), NRC 008 rep 3 (HP4512c) The following samples had colour differences across the replicates: NRC 0022 reps 1-3 (HP4505a-c), NRC 007 reps 1-3 (HP4511a-c), NRC 008 reps 1-3 (HP4512a-c), NRC 009 reps 1-3 (HP4513a-c)
The following samples differed from their replicates in colour: NRC 001 rep 3 (HP4502c), NRC 003 rep 3 (HP4504c), NRC 0017 rep 2 (HP4508b), NRC 0013 rep 2 (HP4510b)

Analyst: DT

Northland Regional Council Soil Quality

Moisture Release Results

Job: 682202-0119

December 2011

Lab Number	Cient ID	Sampled Liner Number	Initial Water Content	Dry Bulk Density	Particle Density	Total Porosity	Macro Porosity	Air Filled Porosity	Vol. WC 5kPa	Vol. WC 10kPa
			(%, w/w)	(t/m3)	(t/m3)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)	(%, v/v)
HP4826a	NRC001	1019	57.1	0.89	2.46	63.8	4.0	7.2	59.7	56.6
HP4826b		1142	48.8	1.02	2.47	58.8	0.1	2.4	58.7	56.4
HP4826c		1737	66.0	0.84	2.46	65.9	4.6	7.7	61.4	58.3
HP4827a	NRC002	1209	45.5	1.12	2.50	55.3	<1	<1	61.4	59.3
HP4827b		1294	57.2	0.75	2.40	68.7	13.4	16.0	55.3	52.7
HP4827c		1656	66.3	0.79	2.43	67.3	3.4	6.7	63.9	60.6
HP4828a	NRC003	1336	46.8	0.98	2.42	59.7	<1	2.0	60.1	57.7

HP4828b		1386	95.9	0.61	2.46	75.2	12.1	15.9	63.1	59.4
HP4828c		1403	42.4	0.95	2.49	61.7	11.5	14.5	50.2	47.2
HP4829a	NRC004	I2	51.2	0.84	2.38	64.6	6.9	9.7	57.7	54.9
HP4829b		1284	37.4	1.16	2.47	53.0	<1	<1	55.4	53.8
HP4829c		1549	55.3	0.95	2.43	60.9	1.6	3.2	59.3	57.7
HP4830a	NRC005	1196	49.4	0.88	2.42	63.5	6.3	8.6	57.2	54.9
HP4830b		1321	45.5	1.01	2.44	58.8	0.0	1.8	58.8	57.0
HP4830c		1366	36.2	1.12	2.49	55.1	1.8	3.9	53.2	51.2
HP4831a	NRC006	1669	33.3	1.04	2.55	59.3	16.1	18.5	43.3	40.8
HP4831b		1333	38.2	0.98	2.52	61.2	12.1	15.5	49.1	45.8
HP4831c		1280	40.1	0.96	2.54	62.1	17.9	20.9	44.2	41.2
HP4832a	NRC007	1267	69.4	0.82	2.41	66.1	2.3	4.6	63.8	61.5
HP4832b		1501	59.8	0.92	2.44	62.1	1.2	3.2	60.9	58.9
HP4832c		1392	62.4	0.95	2.53	62.4	2.1	4.0	60.3	58.4
HP4833a	NRC008	1615	32.6	0.98	2.48	60.5	12.5	16.5	48.0	44.0
HP4833b		1522	38.4	0.49	2.17	77.5	32.5	37.7	45.0	39.8
HP4833c		1078	22.4	1.11	2.49	55.2	14.9	17.9	40.3	37.4
HP4834a	NRC010	1673	39.9	1.07	2.55	57.9	2.6	7.3	55.3	50.6
HP4834b		1240	41.4	1.11	2.51	55.9	1.3	4.6	54.6	51.3
HP4834c		1577	34.8	1.18	2.55	53.8	5.5	9.2	48.4	44.6
HP4835a	NRC012	1168	38.2	1.14	2.54	55.3	2.8	5.9	52.4	49.4
HP4835b		1610	35.2	1.30	2.60	50.1	<1	1.4	50.3	48.7
HP4835c		1245	30.7	1.20	2.60	53.9	7.6	12.2	46.3	41.7
HP4836a	NRC013	1016	36.9	0.91	2.45	62.8	13.1	20.4	49.7	42.5
HP4836b		1047	51.5	0.86	2.48	65.2	14.3	18.1	50.9	47.1

HP4836c		1148	55.3	0.71	2.40	70.4	21.2	25.4	49.2	44.9
HP4837a	NRC015	1527	74.9	0.73	2.29	68.3	8.9	11.5	59.4	56.9
HP4837b		1645	66.5	0.89	2.38	62.8	0.3	2.3	62.5	60.4
HP4837c		1349	48.6	1.00	2.42	58.8	3.7	5.9	55.1	53.0
HP4838a	NRC018	1387	64.9	0.80	2.54	68.4	11.6	13.4	56.8	55.0
HP4838b		1099	81.4	0.52	2.42	78.3	24.9	28.0	53.5	50.3
HP4838c		1714	65.0	0.77	2.49	69.1	14.6	16.6	54.5	52.4
HP4839a	NRC019	1020	64.6	0.83	2.45	66.1	4.9	7.0	61.3	59.2
HP4839b		1243	53.6	0.91	2.64	65.5	8.4	9.9	57.1	55.7
HP4839c		1375	66.2	0.78	2.56	69.6	7.9	9.9	61.7	59.8
HP4840a	NRC020	1533	59.4	0.76	2.62	71.1	16.0	17.9	55.1	53.2
HP4840b		1726	64.2	0.76	2.58	70.6	14.2	16.0	56.4	54.6
HP4840c		1194	67.8	0.51	2.45	79.0	26.7	33.0	52.3	46.1
HP4841a	NRC021	1179	62.7	0.85	2.46	65.5	2.6	4.8	62.9	60.8
HP4841b		1185	82.4	0.71	2.45	70.9	6.2	8.3	64.7	62.6
HP4841c		1710	70.3	0.82	2.53	67.6	1.7	4.3	65.9	63.3
HP4842a	NRC024	1352	92.1	0.63	2.41	74.0	14.7	16.7	59.3	57.3
HP4842b		1317	98.7	0.49	2.38	79.5	27.1	29.5	52.3	50.0
HP4842c		1072	104.1	0.53	2.43	78.2	20.2	23.4	57.9	54.8
HP4843a	NRC025	1647	43.5	0.84	2.65	68.2	20.4	24.4	47.8	43.8
HP4843b		1396	50.7	0.90	2.50	63.8	12.9	15.1	50.9	48.7
HP4843c		1263	44.4	0.81	2.86	71.8	24.2	29.4	47.6	42.4

Note: Visual inspection of cores during sample preparation and then close inspection after analysis, including breaking the samples apart, showed the following information.
Comparison of the following notes matches variation in the data above.

NRC001, liners 1019 and 1737 contained roots.
NRC002, liner 1209 appeared compacted, and was significantly more dense than it's replicates.
NRC003, liner 1336 contained an amount of subsoil, liner 1386 contained roots.
NRC004, liner I2 contained more organic material than it's replicates, liner 1286 contained an amount of subsoil and was more dense than it's replicates.
NRC005, all replicates differ in colour and structure.
NRC008, liner 1522 contained higher levels of organic material compared to it's replicates.
NRC012, liner 1610 appeared compacted, and was significantly more dense than it's replicates.
NRC013, all replicates differ in colour.
NRC015, all replicates differ in colour and structure.
NRC018, liner 1099 contained higher levels of organic material compared to it's replicates and differed in colour.
NRC020, liner 1194 contained roots.

Checked by John Claydon - Laboratory manager
Analyst: RH