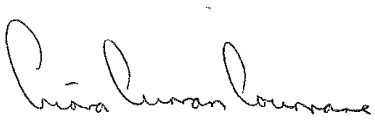
Soil Quality of Drystock Sites in the Auckland Region in 2010

Changes since 1995–2000

Technical Report 2011/011

Auckland Council
Technical Report 2011/011
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)
ISBN 978-1-927169-30-8 (Print)
ISBN 978-1-927169-31-5 (PDF)

Reviewed by:



Name: Dr Fiona Curran-Cournane

Position: Project Leader- Land and Soil

Organisation: Auckland Council
Date: 12 August 2011

Approved for Auckland Council publication by:

Name: Greg Holland

Position: Team Leader- Environmental Science

Organisation: Auckland Council
Date: 12 August 2011

Recommended Citation:
Fraser, S and Stevenson, B. (2011). Soil Quality of Drystock Sites in the Auckland Region 2010. Prepared by Landcare Research for Auckland Council.

Soil Quality of Drystock Sites in the Auckland Region in 2010 Changes since 1995-2000

S. Fraser
B. Stevenson

Prepared for
Auckland Council

Landcare Research
Private Bag 3127
Hamilton
New Zealand

Landcare Research Contract Report: LC203

Contents

1 Executive Summary

1.1 Project and client

The Auckland Regional Council (ARC, now known as Auckland Council) participated in two national soil quality monitoring projects in 1995–1998 and 1999–2001. The two projects, co-funded from the Ministry for the Environment Sustainable Management Fund (SMF), identified methods and protocols for soil quality monitoring (Hill et al. 2003). These protocols were used to examine a range of sites, soils, and land uses in the Auckland Region. Annual reports were provided by the science providers to the Auckland Regional Council and MFE (eg, Sparling et al. 1998) and scientific summary reports of the whole national project are available (eg, Sparling and Schipper 2004). At the end of these SMF projects, collectively known as the "500 Soils Project", the Auckland Regional Council had more soil quality data (on an area basis) than any other region. However, after 2001, ARC did not participate in further similar soil quality monitoring until 2008. The strategy chosen by ARC was again to sample those sites established under the earlier projects and considered to be most at risk of soil quality degradation. The focus for the 2008 sampling was market gardens, arable cropping, and horticulture; for 2009, the focus was dairy sites; and for 2010, the focus was for drystock sites.

1.2 Objectives

- Complete laboratory analyses on soil samples provided by the Auckland Regional Council staff, of soil quality on 17 sites, using methodologies consistent with those established under the 500 Soils Project.
- Identify which of the seven key indicators, soil pH, total C, total N, mineralisable N, Olsen P, bulk density, and macroporosity, were of most concern.
- Compare the current status of the soils against the condition when first sampled between 1995 and 2000 to identify any consistent changes in soil quality
- Provide an interpretive report to the Auckland Council for use in landholder education and policy development.

1.3 Methods

- ARC staff collected soil samples using the recommended methods under the 500 Soils Project protocol. Soil analyses were completed using the same protocols and were consistent with those of earlier samplings.

- Seven key soil quality indicators, soil pH, total C, total N, mineralisable N, Olsen P, bulk density, and macroporosity were used to estimate the quality status of the soils and to determine whether the measured values fell within suggested target ranges specific to that soil and land use.
- The proportion of sites meeting the suggested target ranges for the seven indicators was calculated.
- The current status of the sites was compared with archive data from previous soil quality samples collected from the same sites between 1995 and 2000.

1.4 Results

- Seventeen sites, all under drystock were re-sampled.
- Of the 17 sites, two met all the suggested targets (11%), 11 sites (65%) had one characteristic not meeting the suggested range, a further three sites (18%) had two characteristics not meeting the suggested range, and one site (6%) had three characteristics outside the suggested range.
- The seven soil quality indicators were measured at each of the 17 sites for a total of 119 characteristics. Of those individual characteristics, 99 (83%) fell within the recommended range and 20 (17%) were outside the target range.
- Low macroporosity (at –5 kPa; indicating soil compaction) was the main indicator falling outside the recommended target range (on 15 of the 17 sites – 88%). Eleven of the 17 sites (65%) were outside the recommended range for macroporosity at –10 kPa (air filled porosity). Mineralisable N was above the target range on two sites (12%), total N above the target range on one site (6%) and Olsen P was below the target range on two sites (12%).
- On a volumetric basis, total C, total N, mineralisable N, and Olsen P were significantly greater for data collected in 2010 in comparison to earlier sampling times (1995–2000). Bulk density was also greater and the soil C/N ratio and macroporosity were less.
- The volumetric changes in total C, total N, mineralisable N and Olsen P appeared to be largely driven by the increase in bulk density because comparison of these data on a gravimetric basis did not indicate statistically significant increases between the sampling dates. The significant decrease in the soil C/N ratio does however suggest that soil N has increased in the soil relative to C.

1.5 Conclusions

- As assessed by seven key indicators, two of the 17 sites sampled in 2010 fell within the suggested target ranges. Eleven sites had one characteristic outside the suggested ranges and four sites had two or more characteristics outside target ranges.
- The characteristic of concern was low macroporosity (values <10% on pastoral land uses) indicating soil compaction on 15 of the sites 17 sites sampled.
- Soil nutrient status is trending upwards; however, only two sites had mineralisable N above target, one site had total N above target, while at two sites Olsen P was below target.
- Measured bulk density has increased at eleven of 17 sites, accentuating small increases in concentration of total C, total N, mineralisable N, and Olsen P.

1.6 Recommendations

- Auckland Council to continue the present strategy of re-sampling established soil quality sites, and establish new sites as resources allow.
- It would be advantageous for Auckland Council to adopt a longer-term policy to obtain four or five repeat samples over a period of time from established sites to establish whether there are any trends in soil quality attributes.
- The current sampling methods should be retained to allow ready comparisons between samples collected over time.
- Auckland Council to consider trialing greater replication of soil physical measurements in future sampling to better determine the extent of increase in bulk density and decrease in macroporosity values that have recently been measured in dairy and drystock sites.

2 Introduction

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". To assist Councils to assess soil quality in their regions, between 1995–1997 and 1998–2001 the Ministry for the Environment (MfE) co-funded two Sustainable Management Fund (SMF) Projects which collectively became known as the 500 Soils Project (Hill et al. 2003; Sparling et al. 2004). The Auckland Regional Council (ARC) participated in both these projects and by the end of the SMF projects, had more soil quality data (on an area basis) than any other region. Annual reports were provided to ARC and MfE (eg, Sparling et al. 1998) and scientific summary reports of the whole national project are available (see, for example, Sparling and Schipper 2004). However, once SMF support ceased, ARC opted not to participate in further similar soil quality monitoring until the current initiative in 2008.

The strategy chosen by the ARC for soil quality reporting in 2008 was to target sites and land uses considered to be most at risk of soil quality degradation. For the Auckland Region the highest priority sites were deemed to be those under the more intensive land uses such as market gardens and horticulture. Data for the region were available from the 500 Soils Project from 7 to12 years earlier, and the opportunity existed to assess the current status of those sites and determine how soil quality had changed during the intervening period

3 Objectives

- Complete laboratory analyses on the 17 soil samples provided by the Auckland Regional Council staff, using methodologies consistent with those established under the 500 Soils Project.
- Identify which of the seven key indicators, soil pH, total C, total N, mineralisable N, Olsen P, bulk density, and macroporosity, were of most concern.
- Compare the current status of the soils against the condition when first sampled between 1995 and 2000 to identify any consistent changes in soil quality.
- Provide an interpretive report to the Auckland Council for use in landholder education and policy development.

4 Methods

4.1 Site selection

Sites were selected by ARC staff for soil quality monitoring. All sites selected for re-sampling were originally drystock sites and ARC records indicated that all sites chosen for re-sampling were still in drystock. ARC staff collected soil samples using the methods recommended by the 500 Soils Project protocol. Soil analyses were completed by Landcare Research using the 500 Soils Project protocols and consistent with those of earlier samplings.

4.2 Soil quality assessment

Seven key soil quality indicators (soil pH, total C, total N, mineralisable N, Olsen P, bulk density, and macroporosity) were used to estimate the quality status of the soils. These indicators have been described in earlier reports to ARC (eg, Sparling et al. 2001). The target ranges, specific to soil order and land use, were taken from the provisional values suggested by Sparling et al. 2003. For each site, the number of times a value failed to meet the target range was recorded. The proportion of sites meeting the suggested target ranges for the 7 indicators was calculated. The current status of the sites was compared with archive data from previous samples collected between 1995 and 2000 (See Appendix 11.3).

4.3 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).

4.4 Chemical properties

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

4.5 Physical properties

Macroporosity and air filled porosity were determined by subtraction of volumetric water content at –5 and –10 kPa respectively (by drainage on pressure plates) from total porosity as described by Klute 1986. Bulk density was measured on a sub sampled core dried at 105°C (Klute 1986) and the remaining soil analysed for particle density (Klute 1986).

The general definition of macroporosity has recently been expanded to cover a slightly larger range of pore sizes than the original definition. Several Regional Councils have adopted a macroporosity measurement based on volumetric water content at –10 kPa (technically referred to as air filled porosity or air capacity) and this measurement has generally been used for comparison to target values. In order to be consistent with the original data, ARC has requested in past re-samplings that the –5 kPa macroporosity data be used in reference to target values, and for comparison to older data. We have followed that convention here. The –10 kPa data is also included for comparison.

4.6 Statistics and data presentation

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

5 Results

5.1 Soils and land-use categories

Seventeen sites, covering six NZSC soil orders (Allophanic, Brown, Gley, Granular, Recent, Ultic) and 9 NZSC soil subgroups (Hewitt, 1998), were sampled for their current soil quality characteristics (Table 1). The subgroups sampled were: Typic Orthic Allophanic, Typic Orthic Brown, Typic Sandy Brown, Typic Orthic Gley, Typic Orthic Granular, Allophanic Oxidic Granular, Weathered Fluvial Recent, Perch-gley Albic Ultic, Typic Yellow Ultic. All sites were in the drystock land use category when originally sampled and are also currently under this land use.

The current characteristics of the sites are shown in Table 2. Items shown in bold type are outside the recommended range for that soil order and land use. For the reports produced in colour print or electronic versions the bold numbers in red are below the recommended range, and those bold numbers in blue are greater than the recommended range.

The large range in values for some soil attributes, in part reflects differences in soil type and land management. For soil macroporosity (total porosity less volumetric water content at –5 kPa) 15 out of the 17 sites were below the recommended 10%v/v indicating soil compaction is affecting the majority of sites. Eleven of the 17 sites (65%) were outside the recommended range for macroporosity at –10 kPa (air-filled porosity). Olsen P was below target at two of the 17 sites, while total N and mineralisable N were high at one and two sites respectively.

All six soil orders had soil quality indicators outside the target range, with two of the four Brown soils meeting all target values.

The full suite of physical and chemical analyses is presented in Appendices 11.1 and 11.2. Site profile descriptions are presented in Appendix 11.4.

Table 1 Soils and land use classes in the Auckland region sampled in 2010 for soil quality attributes

ARC Code	LCR Site Code	Year established	Land cover	Current land use	NZSC subgroup	Soil Series
1995-02-01	1995_02	1995	Pasture	Drystock	Allophanic Oxidic Granular	Patumahoe clay loam
1996-04-01	1996_02	1996	Pasture	Drystock	Typic Yellow Ultic	Whangaripo clay loam
1998-18-01	1998_06	1998	Pasture	Drystock	Typic Yellow Ultic	Warkworth clay loam
1998-21-01	1998_09	1998	Pasture	Drystock	Typic Sandy Brown	Red Hill sand
1998-27-01	1998_15	1998	Pasture	Drystock	Perch-gley Albic Ultic	Waikare clay
1998-30-01	1998_18	1998	Pasture	Drystock	Weathered Fluvial Recent	Whakapara silt loam
1999-46-01	1999_09	1999	Pasture	Drystock	Typic Orthic Granular	Ararimu clay
1999-48-01	1999_11	1999	Pasture	Drystock	Typic Orthic Brown	Marua clay loam
1999-50-01	1999_13	1999	Pasture	Drystock	Typic Orthic Brown	Pinaki sand
1999-51-01	1999_14	1999	Pasture	Drystock	Typic Orthic Brown	Pinaki sand
1999-61-01	1999_24	1999	Pasture	Drystock	Typic Orthic Granular	Parau clay
2000-63-01	2000_01	2000	Pasture	Drystock	Typic Orthic Allophanic	Karaka silt loam
2000-69-01	2000_07	2000	Pasture	Drystock	Typic Orthic Granular	Patumahoe silt loam
2000-74-01	2000_12	2000	Pasture	Drystock	Typic Orthic Gley	Kaipara clay
2000-76-01	2000_14	2000	Pasture	Drystock	Typic Orthic Gley	Waitemata complex
2000-78-01	2000_16	2000	Pasture	Drystock	Typic Yellow Ultic	Warkworth clay loam
2000-84-01	2000_22	2000	Pasture	Drystock	Typic Orthic Granular	Cornwallis clay

Table 2 Soil chemical and physical characteristics in 2010 of drystock sites sampled in the Auckland region. Chemical attributes are presented on a volumetric basis

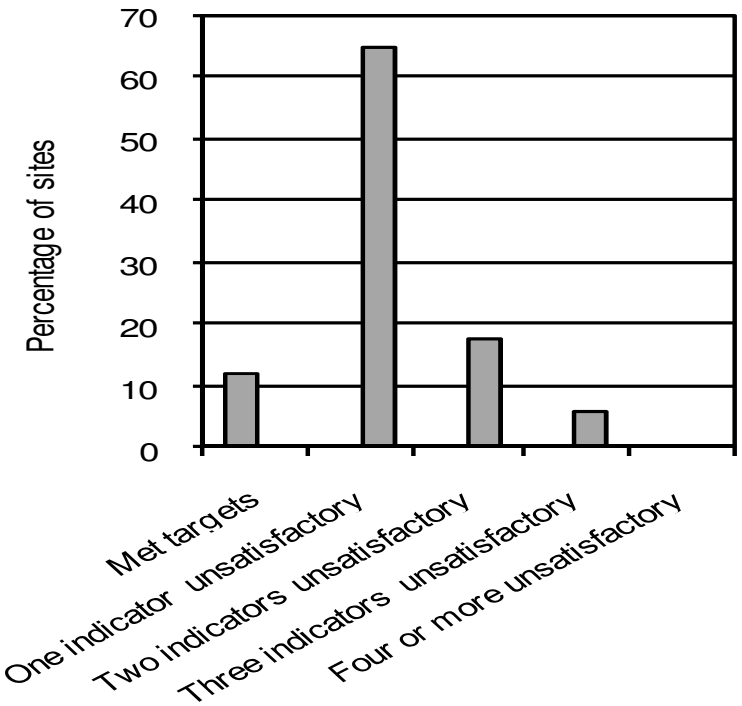
Site code	Soil series	Land use	pH	Total C	Total N	AMN	Olsen P	Bulk Density	Macropores (-5kPa)
				mg/cm^3	mg/cm^3	$\mu g/cm^3$	$\mu g/cm^3$	T/m^3	%v/v
1995_02	Patumahoe clay loam	Drystock	6.19	69.4	6.15	217	38	0.98	**2.2**
1996_02	Whangaripo clay loam	Drystock	5.63	53.6	5.01	234	**9**	0.89	**4.3**
1998_06	Warkworth clay loam	Drystock	5.94	57.2	5.19	162	21	1.04	**4.5**
1998_09	Red Hill sand	Drystock	5.78	52.6	5.28	145	58	1.23	**0.5**
1998_15	Waikare clay	Drystock	6.3	66.8	6.54	198	25	0.73	**5.8**
1998_18	Whakapara silt loam	Drystock	5.88	44.2	4.13	162	40	1.12	**3.9**
1999_09	Ararimu clay	Drystock	5.74	77.8	6.96	231	83	0.95	**4.8**
1999_11	Marua clay loam	Drystock	5.5	54.5	4.37	145	20	1.13	**6.4**
1999_13	Pinaki sand	Drystock	6.01	50.4	4.52	124	16	1.08	12.3
1999_14	Pinaki sand	Drystock	5.46	42.1	3.42	96	35	0.99	16.0
1999_24	Parau clay	Drystock	5.96	89.7	**8.00**	**261**	19	0.98	**3.8**
2000_01	Karaka silt loam	Drystock	5.85	71.8	6.68	167	19	0.81	**8.7**
2000_07	Patumahoe silt loam	Drystock	6.04	74.8	6.85	229	**10**	0.86	**7.8**
2000_12	Kaipara clay	Drystock	5.55	74.6	6.97	**310**	32	0.93	**1.0**
2000_14	Waitemata complex	Drystock	5.83	72.1	6.48	178	84	1.03	**3.0**
2000_16	Warkworth clay loam	Drystock	6.08	58.0	4.15	151	24	1.16	**4.4**
2000_22	Cornwallis clay	Drystock	6.59	66.7	6.03	203	50	1.07	**1.0**

5.2 Overall soil quality of drystock sites in 2010

Seventeen sites were sampled in the drystock category. Of these, two sites met all the recommended targets (12%), eleven sites (65%) had one characteristic not meeting the recommended targets, a further three sites (18%) had two characteristics not meeting the recommended targets, and one site (6%) had three characteristics not meeting the recommended targets (Fig. 1). Low macroporosity (indicating soil compaction) was the main indicator falling outside the recommended range (Fig. 2).

The seven soil quality indicators were measured at each of the seventeen sites for a total of 119 characteristics. Of those individual characteristics, 99 fell within the target range (83%) and 20 (17%) were outside the target range.

Figure 1 Percentage of drystock sites meeting suggested soil quality targets (Auckland Region, 2010).



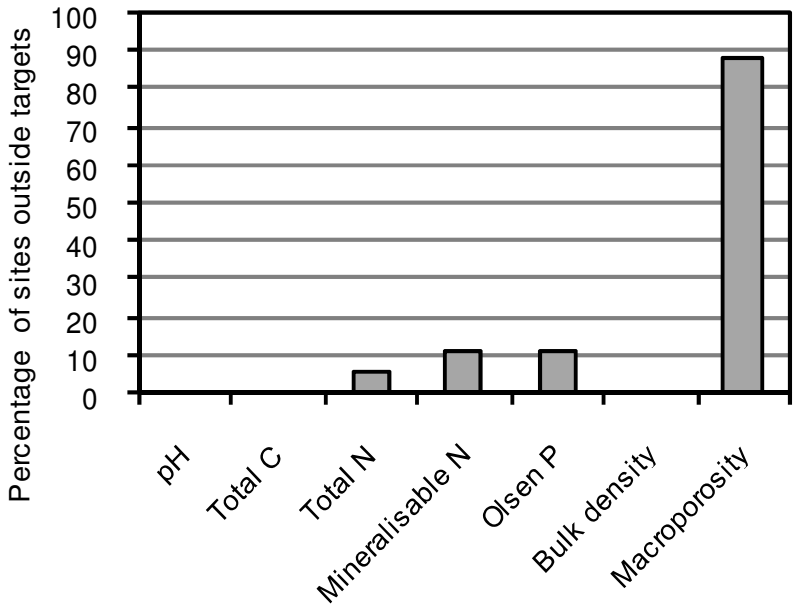


Figure 2 Soil quality concerns for drystock sites in Auckland region, 2010.

5.3 Changes in soil quality between 1995–2000 and 2010

The current soil quality status of the drystock sites sampled in 2010 was compared with archive soil quality data collected between 1995 and 2000, using the same collection and analysis methodologies. Full data for the archive samples are provided in Appendix 11.3.

Absolute changes in values of individual characteristics since the earlier sampling are shown in Table 3, and as percentage change ([2010 value – original value)]/original value x100) in Table 4. Total C, total N, mineralisable N and Olsen P all increased significantly, while the C/N and macroporosity decreased significantly ($P<0.01$). Bulk density also had a small but significant decrease (Table 4). When presented as a percentage change soil chemical attributes (C, N and P) appear to have undergone some important changes; however, as these figures are presented on a volumetric basis, changes in bulk density need to be considered as bulk density at time of sampling is used to convert gravimetric data to a volumetric basis. The soil chemical indicators that are reported on a volumetric basis are presented on a gravimetric basis in Table 5 as absolute change and Table 6 as percentage change since earlier sampling. When presented on a gravimetric basis none of these indicators shows a significant change over time, indicating that most of the differences are due to differences in the measured bulk densities between sampling periods.

Table 3 Change in soil quality attributes of drystock sites in Auckland Region between 1995–2000 and 2010. Chemical attributes are presented on a volumetric basis

Site Code	First sample date	Second sample date	Soil series	Soil pH	Total C	Total N	C/N	Mineralisable N	Olsen P	Bulk Density	Macroporosity (-5kpa)
					mg/cm^3	mg/cm^3		$\mu g/cm^3$	$\mu g/cm^3$		%v/v
1995_02	1995	2010	Patumahoe clay loam	-0.1	16.8	1.2	0.7	119.0	24	0.11	-7.3
1996_02	1996	2010	Whangaripo clay loam	-0.2	2.8	0.6	-0.8	95	4	0.11	-5.5
1998_06	1998	2010	Warkworth clay loam	0.1	1.8	0.9	-1.8	55	11	-0.05	-9.6
1998_09	1998	2010	Red Hill sand	0.2	-14.3	-1.5	0.1	-32	37	0.22	-6.0
1998_15	1998	2010	Waikare clay	0.7	12.2	1.6	-0.9	61	16	0.09	-5.5
1998_18	1998	2010	Whakapara silt loam	0.2	-16.0	-1.4	-0.2	24	7	0.20	-8.4
1999_09	1999	2010	Ararimu clay	0.0	6.4	1.1	-0.9	72	33	0.00	-0.8
1999_11	1999	2010	Marua clay loam	0.0	7.0	0.8	-0.9	30	-33	0.07	0.0
1999_13	1999	2010	Pinaki sand	-0.1	13.0	1.5	-1.1	44	0	0.20	-9.9
1999_14	1999	2010	Pinaki sand	0.0	8.2	0.9	-1.3	44	18	-0.18	0.9
1999_24	1999	2010	Parau clay	0.5	15.9	2.0	-1.1	90	10	-0.02	0.9
2000_01	2000	2010	Karaka silt loam	-0.7	14.1	1.7	-0.8	9	-4	0.04	-5.7
2000_07	2000	2010	Patumahoe silt loam	0.0	6.8	0.7	-0.2	2	0	0.02	-4.5
2000_12	2000	2010	Kaipara clay	0.0	19.5	2.3	-1.1	99	-3	0.09	-9.5
2000_14	2000	2010	Waitemata complex	-0.2	10.1	1.5	-1.4	-53	-2	0.03	-5.9
2000_16	2000	2010	Warkworth clay loam	-0.3	11.8	0.4	1.8	-56	10	0.31	-6.0
2000_22	2000	2010	Cornwallis clay	0.1	-6.6	0.5	-2.1	-53	39	0.12	-3.6
			Mean	0.0	6.4	0.9	-0.7	32	10	0.08	-5.1
			Std Dev	0.3	10.3	1.0	0.9	56	18	0.12	3.5
			Significance	NS	P<0.05	P<0.01	P<0.01	P<0.05	P<0.05	P<0.05	P<0.01

Table 4 Percentage change in soil quality attributes of drystock sites in Auckland Region between 1995–2000 and 2010. Chemical attributes are presented on a volumetric basis

Site Code	First sample date	Second sample date	Soil series	Soil pH	Total C	Total N	C/N	Mineralisable N	Olsen P	Bulk Density	Macroporosity (-5kpa)
					mg/cm^3	mg/cm^3		µg/cm^3	µg/cm^3		%v/v
1995_02	1995	2010	Patumahoe clay loam	-1.7	31.8	23.4	6.8	121	172	12.22	-76.7
1996_02	1996	2010	Whangaripo clay loam	-3.8	5.6	13.4	-6.9	68	69	14.15	-56.3
1998_06	1998	2010	Warkworth clay loam	1.4	3.2	19.9	-13.9	51	112	-4.37	-68.1
1998_09	1998	2010	Red Hill sand	4.1	-21.4	-22.2	0.9	-18	171	21.62	-92.3
1998_15	1998	2010	Waikare clay	11.7	22.4	33.0	-8.0	44	185	13.33	-48.6
1998_18	1998	2010	Whakapara silt loam	3.7	-26.6	-25.5	-1.5	18	22	21.99	-68.2
1999_09	1999	2010	Ararimu clay	-0.3	9.0	18.3	-7.8	45	65	0.46	-14.7
1999_11	1999	2010	Marua clay loam	-0.4	14.7	23.4	-7.0	26	-62	6.67	0.5
1999_13	1999	2010	Pinaki sand	-1.5	34.8	47.9	-8.8	55	2	23.18	-44.5
1999_14	1999	2010	Pinaki sand	-0.5	24.0	36.8	-9.3	85	104	-15.38	5.8
1999_24	1999	2010	Parau clay	9.2	21.6	34.0	-9.3	53	120	-1.90	29.9
2000_01	2000	2010	Karaka silt loam	-11.2	24.4	34.1	-7.3	5	-17	5.30	-39.7
2000_07	2000	2010	Patumahoe silt loam	-0.2	10.1	12.2	-1.9	1	3	2.66	-36.9
2000_12	2000	2010	Kaipara clay	0.9	35.3	49.4	-9.4	47	-9	11.13	-90.9
2000_14	2000	2010	Waitemata complex	-2.7	16.4	30.8	-11.0	-23	-3	2.53	-66.4
2000_16	2000	2010	Warkworth clay loam	-4.7	25.5	9.7	14.4	-27	75	36.98	-57.8
2000_22	2000	2010	Cornwallis clay	1.4	-9.0	8.2	-15.9	-21	344	12.56	-78.3
			Mean change (%)	0.3	13.0	20.4	-5.6	31	80	9.60	-47.3

Table 5 Change in C, N and P of drystock sites in Auckland Region between 1995–2000 and 2010, on a gravimetric basis

Site Code	First sample date	Second sample date	Soil series	Total C	Total N	Mineralisable N	Olsen P
				%	%	mg/kg	mg/kg
1995_02	1995	2010	Patumahoe clay loam	1.1	0.1	110	23
1996_02	1996	2010	Whangaripo clay loam	-0.5	0.0	85	3
1998_06	1998	2010	Warkworth clay loam	0.4	0.1	57	11
1998_09	1998	2010	Red Hill sand	-2.3	-0.2	-57	26
1998_15	1998	2010	Waikare clay	0.7	0.1	58	21
1998_18	1998	2010	Whakapara silt loam	-2.6	-0.2	-5	0
1999_09	1999	2010	Ararimu clay	0.6	0.1	75	34
1999_11	1999	2010	Marua clay loam	0.3	0.1	20	-32
1999_13	1999	2010	Pinaki sand	0.4	0.1	23	-3
1999_14	1999	2010	Pinaki sand	1.4	0.1	53	21
1999_24	1999	2010	Parau clay	1.8	0.2	95	11
2000_01	2000	2010	Karaka silt loam	1.4	0.2	0	-6
2000_07	2000	2010	Patumahoe silt loam	0.6	0.1	-5	0
2000_12	2000	2010	Kaipara clay	1.4	0.2	81	-8
2000_14	2000	2010	Waitemata complex	0.8	0.1	-57	-4
2000_16	2000	2010	Warkworth clay loam	-0.5	-0.1	-114	4
2000_22	2000	2010	Cornwallis clay	-1.5	0.0	-80	35
			Mean	0.2	0.1	20	8
			Std Dev	1.3	0.1	66	17
			Significance	NS	NS	NS	NS

Table 6 Percentage change in C, N and P of drystock sites in Auckland Region between 1995–2000 and 2010, on a gravimetric basis

Site Code	First sample date	Second sample date	Soil series	Total C	Total N	Mineralisable N	Olsen P
				%	%	mg/kg	mg/kg
1995_02	1995	2010	Patumahoe clay loam	17.5	10.0	97	142
1996_02	1996	2010	Whangaripo clay loam	-7.5	-0.7	47	48
1998_06	1998	2010	Warkworth clay loam	8.0	25.4	58	122
1998_09	1998	2010	Red Hill sand	-35.4	-36.0	-33	122
1998_15	1998	2010	Waikare clay	8.0	17.4	27	152
1998_18	1998	2010	Whakapara silt loam	-39.9	-38.9	-4	0
1999_09	1999	2010	Ararimu clay	8.5	17.8	45	64
1999_11	1999	2010	Marua clay loam	7.5	15.6	18	-64
1999_13	1999	2010	Pinaki sand	9.5	20.0	25	-17
1999_14	1999	2010	Pinaki sand	46.6	61.6	118	142
1999_24	1999	2010	Parau clay	23.9	36.6	55	124
2000_01	2000	2010	Karaka silt loam	18.1	27.4	0	-21
2000_07	2000	2010	Patumahoe silt loam	7.2	9.3	-2	0
2000_12	2000	2010	Kaipara clay	21.8	34.5	32	-18
2000_14	2000	2010	Waitemata complex	13.5	27.6	-25	-5
2000_16	2000	2010	Warkworth clay loam	-8.4	-19.9	-47	28
2000_22	2000	2010	Cornwallis clay	-19.2	-3.9	-30	294
			Mean change (%)	4.7	12.0	23	65

6 Discussion

The current national trend is for greater land intensification (Parliamentary Commission for the Environment 2004). As a result, state-of-the-environment reporting is becoming increasingly important at both regional and national scales "to provide information and analysis on understanding the linkages between agriculture and the environment to help governments design and implement environmentally effective and economically efficient policies" (Agri-Environmental Indicators April 2008).

Soil quality assessment of drystock land use in the Auckland Region in 2010 indicates that this land use is following similar trends to those observed with dairy land use (Soil Quality of Dairy Sites in the Auckland region in 2009, Stevenson, 2010). The main soil quality indicator of concern for drystock, as for dairy, is low macroporosity indicating compaction. While high nutrient status was also of concern for dairying (representing 30% of the characteristics that were outside the target range), this is less so with drystock (18% of the characteristics that were outside the target range), but nutrient status does appear to be increasing substantially with total N, mineralisable N and Olsen P increasing by 20%, 31% and 80% respectively. Further evidence of increased N storage is the 6% decrease in C/N, despite an apparent 13% increase in total C. As discussed in section 5.3, changes in nutrient status are largely a result of significant increases (10%) in measured bulk density rather than significant changes in soil concentration of these elements; however, two points need to be highlighted here. First, dropping C/N indicating greater N storage is not affected by changes in bulk density. Second, while there may be concerns over the low replication of bulk density measures at individual sites, bulk density trends are very similar for both dairy and drystock sites; of the 38 sites measured in the last two years, 31 sites (82%) have had a increase in measured bulk density, suggesting this is a real change rather than an artifact of low replication at individual sites.

While low macroporosity values are a concern for dairying in other regions, to date there has not been the same level of concern with drystock. The 2009 and 2010 sampling in the Auckland Region suggests that low macroporosity is a concern for all soils under pastoral land use in the Region. Low macroporosity (< 10% at -10 kPa) may inhibit pasture growth (Drewry et al. 1999; Singleton et al. 2000) and continued compaction (without sufficient intervals for root growth and soil faunal activity to restore porosity in the soil) can result in decreased pasture production. Additionally, the pugging and surface changes in soil structure associated with a decrease in macroporosity could potentially result in decreased infiltration and increased runoff (containing surface applied fertilisers and animal excreta) into waterways (Beare et al. 2007).

While there was a small (1.5 mg/cm^3) and insignificant increase in total C under dairy between sampling periods, there was a significant increase in total C under drystock (6.4 mg/cm^3, $P<0.05$). Assuming topsoil depth has not changed between sampling periods, this represents an increase in topsoil C of 6.4 t/ha or 13% (over an average of

13 years this equates to 0.5 t/ha/yr). An alternative explanation maybe that through compaction or erosion topsoil depth has actually decreased, and total topsoil C has not changed significantly (as indicated by the gravimetric data in Table 5). Schipper et al. 2010, showed that over approximately 27 years, soil C stocks in New Zealand decreased by 0.7 t ha yr in dairy pasture on flat land, stayed the same in drystock pasture on flat land, and increased by 0.5 t ha yr in drystock pasture on hill country. However, they provided evidence that this was due to changes in soil C concentration rather than bulk density changes.

The current results should be treated with caution as the changes observed in the volumetric data may be due to sampling variability in bulk density rather than a real change in per ha stocks of these elements. The recent re-sampling of both dairy and drystock sites have indicated directional changes in soil physical characteristics and it is advisable to further corroborate these results. When formulating the sampling strategy for soil quality monitoring, Sparling et al 1998 and Schipper and Sparling 2000 reported coefficients of variation (CV) for bulk density and macroporosity of approximately 7% and 29% respectively. The reported CV for bulk density was similar to that of total C and total N. Given the current trends, it is worth reexamining the within site variation with respect to soil bulk density, particularly since the measure is important in conversion of the data to a volumetric basis. We would suggest a follow-up study increasing the number of soil physical samples along the transect and also taking additional cores in other parts of the paddock (high traffic areas such as near troughs and low traffic areas such as underneath fences).

7 Conclusions

- As assessed by seven key indicators, two of the 17 sites sampled in 2010 fell within the suggested target ranges. Eleven sites had one characteristic outside the suggested ranges and four sites had two or more characteristics outside target ranges.
- The characteristic of concern was low macroporosity (values <10% on pastoral land uses) indicating soil compaction (likely due to land use intensification) on 15 of the sites 17 sites sampled.
- Soil nutrient status is trending upwards; however, only two sites had mineralisable N above target, one site with total N above target, while at two sites Olsen P was below target.
- Measured bulk density has increased at eleven of 17 sites, accentuating small increases in concentration of total C, total N, mineralisable N and Olsen P.

8 Recommendations

- Auckland Council to continue the present strategy of re-sampling established soil quality sites, and establish new sites as resources allow.
- Auckland Council to adopt a longer-term policy to obtain four or five repeat samples over a period of time from established sites to establish whether there are any trends in soil quality attributes.
- The current sampling methods should be retained to allow ready comparisons between samples collected at different times.
- Auckland Council to consider greater replication of bulk density in future sampling to better determine extent of changes in C, N and P.

9 Acknowledgements

Soil samples were collected by Auckland Regional Council. We thank the landowners for allowing access to their properties and for supplying management information. Laboratory analyses were completed at Landcare Research at the Soil Physics Laboratory, Hamilton and Environmental Chemistry Laboratory, Palmerston North. Original soil descriptions (in appendix) were by Wim Rijkse and Doug Hicks.

10 References

Blakemore L C, Searle P L, Daly B K. 1987. *Methods for Chemical Analysis of Soils*. New Zealand Soil Bureau Scientific Report No. 80, 1–103. Lower Hutt, DSIR Soil Bureau.

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

Hewitt A E. 1998. *New Zealand Soil Classificatio*n, 2nd ed. Lincoln, Manaaki Whenua Press.

Hill R B, Sparling G, Frampton C, Cuff J. 2003. *National Soil Quality Review and Programme Design, Technical Paper 75, Land*, Wellington, Ministry for the Environment.

Keeney D R, Bremner J M. 1966. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. *Agronomy Journal,* 58, 498–503.

Klute A. 1986. Water retention laboratory methods. In: Klute A ed. *Methods of Soil Analysis Part 1: Physical and Mineralogical Methods*. second ed, 635–632. Madison WI, Soil Science Society of America.

New Zealand Government 1991. *Resource Management Act 1991*. Wellington, New Zealand Government.

Olsen S R, Cole C V, Watanabe F S, Dean L A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *US Department of Agriculture Circular 939*. Washington DC, US Department of Agriculture.

Schipper L A, Parfitt R L, Ross C, Baisden W T, Claydon J J, Fraser S. 2010. Gains and losses in C and N stocks of New Zealand pasture soils depend on land use. *Agriculture, Ecosystems and Environment,* 139, 611-617.

Schipper L A, Sparling G. 2000. Performance of soil quality indicators across taxonomic groups and land uses. *Soil Science Society of America Journal*, 64: 300–311.

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

Sparling G, Lilburne L, Vojvodic-Vucovic M. 2003. *Provisional Targets for Soil Quality Indicators in New Zealand.* Landcare Research, PO Box 40, Lincoln 8152.

Sparling G, Schipper L A. 2004. Soil quality monitoring in New Zealand: trends and issues arising from a broadscale survey. *Agriculture Ecosystems and Environment,* 104: 545–552.

Sparling G, Schipper L A, Bettjeman W, Hill. R. 2004. Soil quality monitoring in New Zealand: practical lessons from a 6-year trial. *Agriculture Ecosystems and Environment* 104, 523–534.

Sparling G, Schipper L A, McLeod M, Basher L, Rijkse W. 1998. Trialing soil quality indicators for the state of the environment monitoring. Research Report for 1997/1998. Landcare Research Contract Report LC9798/141. Landcare Research, Palmerston North.

Stevenson B. 2010. *Soil Quality of Dairy Sites in the Auckland Region in 2009. Changes since 1995-2000*. Auckland Regional Council Technical Report 2010/026.

11 Appendices

11.1 2010 soil physics data

ARC 2010 Soil Quality											
Moisture Release Results											
Job Number:	682202-0098										
March 2011											
Lab Number	Client ID	Transect position	BD 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)
HP4306a	Site 84	15m	1601	40.2	1.10	2.50	56.0	0.4	2.9	55.6	53.1
HP4306b		30m	1218	45.8	1.01	2.47	59.0	1.1	3.1	57.9	55.9
HP4306c		45m	1502	37.8	1.09	2.48	56.3	1.4	4.2	54.9	52.1
HP4307a	Site 69	15m	1503	59.1	0.88	2.41	63.7	8.9	11.5	54.8	52.2
HP4307b		30m	1638	64.6	0.82	2.38	65.7	7.6	10.6	58.1	55.1
HP4307c		45m	1264	61.1	0.89	2.44	63.4	6.8	10.1	56.7	53.3
HP4308a	Site 48	15m	1076	37.0	1.11	2.47	55.1	6.9	9.1	48.2	46.0
HP4308b		30m	1539	33.7	1.15	2.49	53.9	6.7	9.5	47.2	44.4
HP4308c		45m	1389	33.7	1.13	2.47	54.1	5.6	8.5	48.5	45.6
HP4309a	Site 76	15m	1574	38.1	1.10	2.46	55.1	4.7	6.7	50.5	48.4
HP4309b		30m	1552	47.6	1.02	2.45	58.2	1.8	3.6	56.4	54.6
HP4309c		45m	1673	52.9	0.95	2.40	60.2	2.5	5.2	57.7	55.0
HP4310a	Site 30	15m	1635	35.6	1.23	2.56	51.9	2.6	4.9	49.3	47.0
HP4310b		30m	1557	44.0	1.10	2.53	56.5	4.4	7.1	52.1	49.4
HP4310c		45m	1182	48.2	1.04	2.50	58.6	4.7	7.2	53.9	51.4
HP4311a	Site 18	15m	1083	55.0	0.98	2.44	59.7	2.6	4.9	57.2	54.8
HP4311b		30m	1363	46.7	1.06	2.46	57.1	5.1	7.4	52.0	49.7
HP4311c		45m	1044	43.9	1.09	2.49	56.2	5.8	8.9	50.4	47.3
HP4312a	Site 51	15m	1347	42.7	0.87	2.61	66.6	13.0	25.4	53.6	41.2
HP4312b		30m	1069	35.3	0.96	2.61	63.3	15.7	25.3	47.6	38.0
HP4312c		45m	1223	15.6	1.14	2.71	57.9	19.3	30.2	38.6	27.7
HP4313a	Site 2	15m	1015	58.0	0.98	2.48	60.4	>1	1.9	61.1	58.5
HP4313b		30m	1548	56.5	0.95	2.47	61.4	4.3	7.2	57.1	54.2
HP4313c		45m	1529	54.8	0.99	2.47	59.8	1.8	4.6	58.0	55.2
HP4314a	Site 21	15m	1517	33.4	1.20	2.68	55.2	>1	1.3	57.4	53.9
HP4314b		30m	1242	32.3	1.26	2.76	54.3	0.1	6.4	54.2	47.9
HP4314c		45m	1144	34.8	1.22	2.74	55.4	0.1	4.9	55.3	50.5
HP4315a	Site 46	15m	1336	54.4	0.89	2.37	62.3	10.5	12.2	51.9	50.1
HP4315b		30m	1093	50.8	0.99	2.41	59.0	3.4	5.8	55.6	53.2
HP4315c		45m	1383	56.7	0.98	2.40	59.1	0.3	3.3	58.8	55.8
HP4316a	Site 74	15m	1615	61.4	0.95	2.49	61.9	1.4	3.2	60.5	58.7
HP4316b		30m	1022	67.9	0.92	2.43	62.2	>1	0.8	63.3	61.4
HP4316c		45m	1033	78.8	0.76	2.38	67.9	8.1	11.9	59.8	56.0
HP4317a	Site 78	15m	1394	38.9	1.16	2.55	54.4	6.5	8.7	47.9	45.7
HP4317b		30m	1059	44.0	1.16	2.54	54.2	2.2	4.0	52.0	50.2
HP4317c		45m	1514	174.1	0.39	2.15	81.7	14.2	18.7	67.5	63.0
HP4318a	Site 27	15m	1667	103.3	0.65	2.34	72.1	2.3	5.4	69.8	66.7
HP4318b		30m	1609	74.1	0.81	2.44	67.0	5.1	7.5	61.9	59.5
HP4318c		45m	1594	78.9	0.72	2.35	69.5	9.9	12.5	59.6	57.0
HP4319a	Site 63	15m	1243	74.8	0.74	2.36	68.6	10.2	14.1	58.4	54.5
HP4319b		30m	1009	63.4	0.81	2.39	66.0	10.0	13.9	56.0	52.1
HP4319c		45m	1370	54.9	0.89	2.42	63.3	5.9	10.4	57.4	52.9
HP4320a	Site 50	15m	1245	20.9	1.06	2.63	59.6	13.5	23.3	46.0	36.3
HP4320b		30m	1204	20.3	1.12	2.62	57.2	15.4	24.1	41.8	33.1
HP4320c		45m	1185	20.6	1.07	2.61	59.1	8.0	21.5	51.1	37.6
HP4321a	Site 4	15m	1256	55.8	0.97	2.51	61.2	5.7	8.4	55.5	52.8
HP4321b		30m	1634	58.9	0.93	2.51	63.0	6.6	9.2	56.4	53.8
HP4321c		45m	1309	85.1	0.77	2.38	67.7	0.4	3.2	67.3	64.5
HP4322a	Site 61	15m	1031	52.5	0.98	2.41	59.3	2.5	4.3	56.8	55.0
HP4322b		30m	1556	46.5	1.03	2.45	58.2	4.8	6.5	53.4	51.7
HP4322c		45m	1622	50.6	0.94	2.38	60.6	4.0	6.6	56.6	54.0
Note:	The following samples differed in appearance to their replicates: Site 76 - 15m (HP4309a), Site 51 - 45m (HP4312c), Site 46 - 15m (HP4315a), Site 63 - 45m (HP4319c).										
	Site 27 (HP4318a-c): all the replicates differed in appearance.										
	Site 78 - 45m: sample was predominantly composed of organic matter.										
	Site 74 - 45m: this sample was disturbed. It contained a pine cone which was removed, and the void repacked, but not without disturbance to the sample.										
Analyst:	DT										

11.2 2010 soil chemistry data

Client ID	Sample No.	Water Content (method 105) (% dry wt)	pH (water) (method 106)	Organic C (method 114) (%)	Total N (method 114) (%)	KCl-extractable NO3-N (method 118) (mg/kg)	KCl-extractable NH4-N (method 118) (mg/kg)	Anaerobic Mineralisable-N (method (120) (mg/kg)	Olsen P (method 124) (mg/kg)
Site 2 1995-02-01	M10/3104	58.5	6.2	7.1	0.63	19.3	0.6	222	38
Site 4 1996-04-01	M10/3105	59.1	5.6	6.0	0.56	38.5	4.9	263	10
Site 18 1998-18-01	M10/3106	49.3	5.9	5.5	0.50	26.4	1.2	155	20
Site 21 1998-21-01	M10/3107	29.9	5.8	4.3	0.43	17.3	4.0	118	47
Site 27 1998-27-01	M10/3108	74.5	6.3	9.2	0.90	27.6	1.4	273	35
Site 30 1998-30-01	M10/3109	42.3	5.9	3.9	0.37	13.1	2.6	145	35
Site 46 1999-46-01	M10/3110	55.7	5.7	8.1	0.73	26.2	1.3	242	87
Site 48 1999-48-01	M10/3111	40.1	5.5	4.8	0.39	6.7	10.1	128	18
Site 50 1999-50-01	M10/3112	17.8	6.0	4.7	0.42	12.5	1.7	114	15
Site 51 1999-51-01	M10/3113	22.0	5.5	4.3	0.35	17.7	7.2	97	35
Site 61 1999-61-01	M10/3114	51.4	6.0	9.1	0.82	19.9	1.0	266	19
Site 63 2000-63-01	M10/3115	61.9	5.9	8.8	0.82	20.5	3.2	205	23
Site 69 2000-69-01	M10/3116	58.8	6.0	8.7	0.80	25.5	1.1	266	12
Site 74 2000-74-01	M10/3117	77.1	5.6	8.0	0.75	72.4	12.6	332	35
Site 76 2000-76-01	M10/3118	44.6	5.8	7.0	0.63	21.3	2.7	174	81
Site 78 2000-78-01	M10/3119	49.7	6.1	5.0	0.36	25.0	1.4	130	20
Site 84 2000-84-01	M10/3120	38.0	6.6	6.3	0.57	13.0	1.3	191	47

11.3 Archived soil chemical and physical data:

used to assess changes in soil quality of drystock sites compiled from annual reports 1995–2001 for the 500 Soils Projects.

ARC Code	Soil pH	Total C	Total N	C/N	Mineralisable N	Olsen P	Bulk Density	Macroporosity
		mg/cm^3	mg/cm^3	C:N	$\mu g/cm^3$	$\mu g/cm^3$	Mg/m^3	-5kpa
1995-02-01	6.30	52.64	4.98	10.57	98.00	13.80	0.87	9.46
1996-04-01	5.85	50.76	4.42	11.48	139.00	5.50	0.78	9.76
1998-18-01	5.86	55.44	4.33	12.80	107.00	9.70	1.09	14.10
1998-21-01	5.55	66.90	6.78	9.87	177.00	21.50	1.01	6.47
1998-27-01	5.64	54.61	4.92	11.10	137.00	8.90	0.64	11.23
1998-30-01	5.67	60.28	5.55	10.86	138.00	32.70	0.92	12.27
1999-46-01	5.76	71.33	5.88	12.13	159.00	50.30	0.95	5.63
1999-48-01	5.52	47.51	3.54	13.42	115.00	53.00	1.06	6.37
1999-50-01	6.10	37.40	3.06	12.22	80.00	16.10	0.88	22.17
1999-51-01	5.49	33.98	2.50	13.59	52.00	17.10	1.17	15.13
1999-61-01	5.46	73.80	5.97	12.36	171.00	8.50	1.00	2.90
2000-63-01	6.59	57.77	4.98	11.60	158.06	22.83	0.77	14.43
2000-69-01	6.05	67.92	6.11	11.12	227.12	10.17	0.84	12.30
2000-74-01	5.50	55.12	4.66	11.82	210.49	35.58	0.84	10.43
2000-76-01	5.99	61.93	4.95	12.50	231.08	85.75	1.00	8.93
2000-78-01	6.38	46.19	3.79	12.20	207.03	13.60	0.85	10.30
2000-84-01	6.50	73.36	5.58	13.15	256.19	11.35	0.95	4.60

11.4 Site and soil profile descriptions

Site: ARC 95-02

Soil series	Patumahoe clay loam
Classification	Allophanic Oxidic Granular
Land use	Grass site: pasture grasses for at least ten years, no record of cultivation for market garden, minimal fertiliser inputs recently.
Vegetation	Bare
Slope	2°
Landform	Foot slope
Annual rainfall (mm)	1200 mm
Elevation (m)	100 m
Parent material	Hamilton ash formation
Drainage	Imperfectly drained

Description

Horizon	Depth	Description
Ap1	0–6 cm	7.5YR 3/2 silt loam; friable; strongly developed medium and coarse nut structure crushing under pressure to moderately developed fine crumb structure; few black Mn nodules up to 8 mm; abundant roots; many coarse pores; distinct irregular boundary
Ap2	6–15 cm	near 10YR 3/3 silt loam; moderately firm; brittle; weakly developed fine nut structure crushing under pressure to weakly developed crumb structure; few distinct inclusions of underlying B horizon; few fine hard black Mn concretions; few fine distinct 2.5YR 4/8 nodules (porcelinite); many roots; few coarse and medium pores; few very fine black charcoal fragments; diffuse wavy boundary
Ap3	15–26 cm	10YR 3/3 heavy silt loam; moderately firm; brittle; moderately developed coarse and medium granular structure; many roots; many large (to 4 cm) inclusions of B horizon; abundant coarse and medium pores (few up to 5mm); many black Mn concretions; distinct irregular boundary
Bt1	26–38 cm	7.5YR 4/6 crushing to 7.5YR 5/8 clay loam; moderately firm; brittle; few distinct fine inclusions of overlying horizons; many roots, few coarse and many medium pores; abundant continuous very thin cutans (skeletans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; moderately sticky; non plastic; diffuse wavy boundary
Bt2	38–58 cm	7.5YR 4/6 crushing to 5 YR 5/8 clay loam; moderately weak; brittle; slightly sticky; non plastic; strongly developed coarse block structure crushing to strongly developed coarse and medium crumb structure; few roots; few fine distinct 5YR 4/4 hard mottles; few coarse pores; many thin discontinuous cutans (skeletans); diffuse wavy boundary
Bt3	58–82 cm	Between 7.5YR 5/6 and 5YR 5/6 crushing to near 5YR 5/8 clay loam; very weak; brittle; slightly sticky; slightly plastic; few coarse diffuse 5YR 4/6 soft mottles; few roots; few coarse and medium pores; many thin discontinuous cutans (skeletans); moderately developed fine block structure crushing to strongly developed coarse crumb structure; distinct wavy boundary.

Site: ARC 96_02

Soil series	Whangaripo clay loam
Classification	Typic Yellow Ultic
Land use	Permanent pasture
Vegetation	Pasture rye-grass white clover
Slope	9-15 degrees
Landform	Easy rolling and rolling crests, spurs and plateaus
Annual rainfall (mm)	
Elevation (m)	
Parent material	Strongly weathered fine sandstone
Drainage	Imperfectly drained

Description

Horizon	Depth	Description
Ap	0–12cm	Brown (10YR4/3) clay loam; sticky; slightly plastic; moderately weak soil strength; friable; weakly developed medium nut structure; many fine roots; distinct wavy boundary.
Bw(f)	12–25 cm	Olive brown (2.5Y4/4) clay with common yellowish red (5YR5/8) mottles; sticky; plastic; moderately firm soil strength; deformable; weakly developed medium blocky structure; common very fine roots, indistinct wavy boundary.
Bt(f)	25–45 cm	Light olive brown (2.5Y5/4) clay with common yellowish red (5YR5/8) mottles, sticky; plastic; moderately firm soil strength; deformable; common distinct clay coatings; weakly developed medium blocky structure, few very fine roots; distinct wavy boundary.
Bw(g)	45–77 cm	Olive grey (5Y6/2) clay with many yellowish red (5YR5/8) mottles; sticky, plastic; moderately firm soil strength; deformable; massive; few medium roots; diffuse wavy boundary.
BC	77–100+ cm	Pale yellow (2.5Y7/4) and yellowish brown (10YR5/8) silty clay, sticky, plastic; deformable, very firm soil strength; massive; few fine roots.

Site: ARC 98/6 pasture on Warkworth clay loam

Soil series	Warkworth clay loam
Map reference	R09 669 268
Classification	Typic Yellow Ultic Soil
Location	Algies Bay Mahurangi, owner Rod Miller
Land use	Drystock
Vegetation	Pasture
Slope	15 degrees, length 60 m, SE aspect
Landform	Rolling country
Annual rainfall (mm)	1400
Elevation (m)	50
Parent material	Strongly weathered sandstone
Drainage	Well drained

Description.

Horizon	Depth	Description
Ah	0–12 cm	Very dark greyish brown (10YR 3/2) clay loam; sticky, slightly plastic; moderately weak soil strength; friable failure; earthy; common medium roots; distinct irregular boundary,
Bw	12–70 cm	Dark yellowish brown (10YR 4/6) clay; sticky, plastic; moderately firm soil strength; deformable failure; weakly pedal; few fine roots; diffuse, wavy boundary,
BC	70–100 cm	Yellowish brown (10Yr 5/6) clay with few medium distinct strong brown (7.5YR 5/6) mottles (parent material); sticky, plastic; moderately firm soil strength; deformable failure; few fine roots; few fine sandstone gravels at base.

Site: ARC 98/9 Red Hill sand under pasture

Soil series	Red Hill sand
Map reference	R12 507 528
Classification	Typic Sandy Brown Soil
Location	Matakawau area, north of Kohekohe, owner David Craig
Land use	Drystock
Vegetation	Pasture
Slope	2 to 4 degrees
Landform	Rolling country
Annual rainfall (mm)	1200
Elevation (m)	210
Parent material	Sandstone
Drainage	Somewhat excessively drained

Description

Horizon	Depth	Description
Ap	0–18 cm	Very dark greyish brown (10YR 3/2) loamy very fine sand; non sticky non plastic; very weak soil strength; friable; earthy; many fine roots; diffuse smooth boundary,
AB	18–51 cm	Very dark greyish brown (10YR 3/2) sand; very weak soil strength; friable; weakly pedal to massive; few fine roots; distinct smooth boundary,
Bw1	51–74 cm	Dark yellowish brown (10YR 4/6) loamy fine sand; moderately weak soil strength; friable; massive; no live roots; indistinct wavy boundary,
Bw2	74–100 cm+	Dark yellowish brown (10YR 4/6) sandy loam; slightly sticky, non plastic; moderately weak soil strength; friable; massive

Site: ARC 98/15 Waikare clay under drystock

Soil series	Waikare clay
Map reference	Q09 446 419
Classification	Perch-gleyed Albic Ultic Soil
Location	Adjacent to Flaxman Scenic Reserve, Wellsford area
Land use	Drystock
Vegetation	Pasture
Slope	3 to 4 degree concavo-convex midslope
Landform	Rolling country
Annual rainfall (mm)	1400
Elevation (m)	70
Parent material	Strongly weathered cretaceous claystone
Drainage	Imperfectly drained

Description

Horizon	Depth	Description
Ah	0–10 cm	Very dark greyish brown (10YR 3/2) clay; sticky, plastic; moderately weak soil strength; friable failure; earthy; common medium roots; distinct smooth boundary,
Bw	10–22 cm	Brown(10YR 5/3) clay; sticky, plastic; moderately weak soil strength; friable failure; weakly pedal; common fine and medium roots; indistinct wavy boundary,
Bg	22–38 cm	Brown (10YR 5/3) clay with common medium distinct yellowish brown mottles; sticky, plastic; moderately firm soil strength; semi-deformable failure; weakly pedal; few medium roots; indistinct wavy boundary,
BC1	38–72 cm	Light grey (2.5Y 7/2 clay; with common medium distinct yellowish brown mottles; sticky, plastic; moderately firm soil strength; semi-deformable failure; weakly pedal; few medium and fine roots; diffuse wavy boundary,
BC2	72–100 cm	Light grey (2.5Y 7/2) clay; with few medium distinct strong brown mottles; sticky, plastic; moderately firm soil strength; semi-deformable failure; massive; few distinct yellowish red areas of charcoal.

Site: ARC98/18 Whakapara silt loam under drystock

Soil series	Whakapara silt loam
Map reference	R09 532 475
Classification	Weathered Fluvial Recent Soil
Location	Near Logues Bush at Tomarata Valley Road
Land use	Drystock farming
Vegetation	Pasture
Slope	Flat
Landform	Alluvial plain
Annual rainfall (mm)	1400
Elevation (m)	40
Parent material	Alluvium
Drainage	Imperfectly to poorly drained

Description.

Horizon	Depth	Description
Ah	0–10 cm	Very dark grey (10YR 3/1) silt loam; slightly sticky, plastic; moderately weak soil strength; friable failure; earthy; common fine and medium roots; indistinct wavy boundary,
Bw	10–23 cm	Dark greyish brown to olive brown (2.5Y 4/3) clay loam; sticky, plastic; moderately weak soil strength; friable failure; weakly pedal; few fine roots; indistinct wavy boundary,
Bf	23–31 cm	Dark greyish brown to olive brown (2.5Y 4/3) clay loam; with common fine grained yellowish brown mottles; sticky, plastic; moderately firm soil strength; semi-deformable failure; massive breaking to weakly pedal; common distinct black manganese mottles; few fine and very fine roots ;indistinct wavy boundary,
Bg1	31–50 cm	Light olive brown (2.5Y 5/4) clay; with many medium distinct yellowish brown mottles; sticky, plastic; moderately firm soil strength; deformable failure; massive; few very fine roots; indistinct wavy boundary,
Bg2	50–74 cm	Light brownish grey (2.5Y 6/2) clay with many medium prominent yellowish brown and strong brown mottles; sticky, plastic; moderately firm soil strength; deformable failure; massive; no live roots.

Site ARC 99/9

Soil series	Ararimu clay
Map reference	NZMS 260 sheet S12 945 573
Location	Hunua area, Whites Road , paddock in A.R.White property adjacent to 99/8 site
Classification	Typic Orthic Granular Soil
Land use	Drystock (for 26 years)
Vegetation	Ryegrass–white clover pasture
Slope	5° planar midslope
Landform	Rolling, weakly dissected country
Annual rainfall (mm)	1400
Elevation (m)	90
Parent material	Patchy tephra on Waitemata sediments (sandstone?)
Drainage	Imperfectly drained

Description

Horizon	Depth	Description
Ap	0–15 cm	Very dark greyish brown (10YR 3/2) clay loam; sticky; slightly plastic; moderately weak soil strength; friable failure; earthy; many fine and very fine roots; distinct smooth boundary,
Bw	15–26 cm	Brown (10YR 4/3) clay loam; sticky; slightly plastic; moderately weak soil strength; friable failure; weakly pedal; common very fine roots; indistinct wavy boundary,
2Bw	26–40 cm	Yellowish brown (10YR 5/8) clay; sticky; plastic; moderately firm soil strength; deformable; weakly pedal; few very fine roots; distinct smooth boundary,
2BCg1	40–75 cm	Light grey (5Y 7/1) and yellowish brown (10YR 5/6) clay; with common medium distinct strong brown (7.5YR 5/8) mottles; sticky; plastic; moderately firm soil strength; semi-deformable; massive; no live roots; indistinct wavy boundary,
2BCg2	75–100 cm+	Light grey (5Y 7/1) clay; with common medium prominent yellowish brown (10YR 5/6) mottles; sticky; plastic; very firm soil strength; deformable failure; massive; no live roots.

Site ARC 99/11

Soil series	Marua clay loam
Map reference	NZMS 260 sheet S11 954 747
Location	Duders Regional Park (owned by ARC)
Classification	Typic Orthic Brown Soil
Land use	Drystock farming (beef) for 140 years
Vegetation	Ryegrass–white clover pasture
Slope	23° midslope with teracettes
Landform	Moderately dissected coastal hill country
Annual rainfall (mm)	1250
Elevation (m)	40
Parent material	Greywacke
Drainage	Well drained

Description

Horizon	Depth	Description
Ap	0–13 cm	Very dark greyish brown (2.5Y 3/2) and olive brown (2.5Y 4/4) clay loam; sticky; slightly plastic; moderately weak soil strength; friable failure; moderately pedal; many fine roots; indistinct wavy boundary,
Bw	13–75 cm	Yellowish brown (10YR 5/6) clay; sticky; plastic; moderately firm soil strength; deformable; weakly pedal; few fine roots; indistinct wavy boundary,
BC	75–100 cm+	Yellowish brown (10YR 5/6) clay; with few fine distinct yellowish brown (10YR 5/8) and olive yellow (2.5Y 6/6) mottles; sticky; plastic; moderately firm soil strength; deformable; massive; no live roots.

Site ARC 99/13

Soil series	Pinaki sand
Map reference	NZMS 260 sheet Q10 262 124
Location	West of Helensville, Wilsons Road, Leighton property.(just NW of house)
Classification	Typic Sandy Brown Soil
Land use	Deer farming, fertilised
Vegetation	Top-dressed pasture (2.5 to 3 cwt super/acre)
Slope	5° convex crest and midslope
Landform	Inland dunes (easy rolling dunes)
Annual rainfall (mm)	1200
Elevation (m)	120
Parent material	Wind-blown sand
Drainage	Somewhat excessively drained

Description

Horizon	Depth	Description
Ap	0–14 cm	Very dark brown (10YR 2/2) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; earthy; many fine and medium roots; distinct smooth boundary,
Bw	14–28 cm	Dark yellowish brown (10YR 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots; distinct smooth boundary,
BC	28–35 cm	Olive brown (2.5Y 4/4) to dark yellowish brown (10YR 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots; indistinct wavy boundary,
C	35–100 cm+	Olive brown (2.5Y 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots.

Site ARC 99/14

Soil series	Pinaki sand
Map reference	NZMS 260 sheet Q10 254 129
Location	West of Helensville, Wilson road on the Leighton property, about 800 m west of lake on the western side of the property
Classification	Typic Sandy Brown Soil
Land use	Deer farming, not fertilised
Vegetation	Pasture
Slope	4° convex crest
Landform	Inland dunes (easy rolling dunes)
Annual rainfall (mm)	1200
Elevation (m)	100
Parent material	Wind-blown sand
Drainage	Somewhat excessively drained

Description similar to profile ARC 99/13, except the topsoil is only 8 cm thick.

Horizon	Depth	Description
Ap	0–8 cm	Very dark brown (10YR 2/2) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; earthy; many fine and medium roots; distinct smooth boundary,
Bw	8–28 cm	Dark yellowish brown (10YR 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots; distinct smooth boundary,
BC	28–35 cm	Olive brown (2.5Y 4/4) to dark yellowish brown (10YR 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots; indistinct wavy boundary,
C	35–100 cm+	Olive brown (2.5Y 4/4) sand; non-sticky; non-plastic; moderately weak soil strength; friable failure; massive breaking to single grain; few fine roots.

Site ARC 99/24

Soil series	Parau clay
Map reference	NZMS 260 sheet Q10 442 926
Location	1 km northeast of Waimauku, cnr Waikoku and Taylor Roads, Keith Hunt property, paddock behind house
Classification	Typic Orthic Granular Soil
Land use	Drystock farming (for more than 25 years), top-dressed with poultry manure
Vegetation	Pasture
Slope	15° planar midslope and shoulder
Landform	Weakly dissected hill country
Annual rainfall (mm)	1200
Elevation (m)	40
Parent material	Andesitic conglomerate (Manukau breccia)
Drainage	Moderately well drained

Description

Horizon	Depth	Description
Ap	0–13 cm	Very dark greyish brown (10YR 3/2) clay; sticky; plastic; moderately firm soil strength; friable failure; strongly pedal; many fine and very fine roots; distinct smooth boundary,
Bw	13–30 cm	Dark yellowish brown (10YR 4/4) clay; sticky; plastic; moderately firm soil strength; friable failure; strongly pedal; common fine and medium roots; indistinct wavy boundary,
Bg1	30–65 cm	Olive brown (2.5Y 4/4) clay; with many medium distinct red (2.5YR 4/8) mottles; sticky; plastic; very firm soil strength; deformable failure; moderately pedal; few fine and very fine roots; indistinct wavy boundary,
Bg2	65–90 cm	Light olive brown (2.5Y 5/4) clay; with many medium distinct strong brown (7.5YR 5/8) mottles; sticky; plastic; very firm soil strength; deformable failure; massive; few small (2–8 mm diam) andesitic gravels; no live roots; indistinct wavy boundary,
BCg	90–100 cm+	Light grey (2.5Y 7/2) gravelly sandy loam; with many medium distinct strong brown (7.5YR 5/8) mottles; non-sticky; non-plastic; very firm soil strength; brittle failure; many moderately weathered subangular andesitic gravels; no live roots.

Site ARC00_ 1

Soil type	Karaka silt loam
Map reference	260 Sheet R12
GPS coordinates	E2677757 N6456479
Location	Karaka North Road (Papakura area)
Transect length and direction °	40 m, S 20°
Local contact person	Kevin and Sandra Michell, 203b Karaka Road, RD1, Karaka, ph 2927511
Classification	Typic Orthic Allophanic Soil
Land use	Drystock
Date sampled	20/11/00
Land-use history	Has had no fertiliser in the last 12 years
Present vegetation	Poor pasture, hay paddock
Slope	Flat
Landform	Plain
Annual rain (mm)	1300
Elevation (m)	22
Parent material	Tephra (andesitic)
Drainage	Moderately well drained
Topsoil depth (cm)	20
Total rooting depth (cm)	100
Limiting horizon	Heavy soil texture and wetness below 100 cm
Sampled by:	W. Rijkse and D. Hicks

Description ARC00_01

Horizon	Depth (cm)	Description
Ap	0–20	Very dark greyish brown (10YR 3/2) plus 5% yellowish brown (10YR 5/6) silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; earthy; many fine and very fine roots; indistinct smooth boundary.
A	20–45	Very dark brown (10YR 2/2) silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; weakly pedal; few fine and very fine roots; distinct smooth boundary.
Bw	45–60	Light olive brown (2.5Y 5/4) silt loam; sticky; plastic; slightly firm soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary.
Bw(f)	60–90	Light olive brown (2.5Y 5/4) with few medium distinct strong brown (7.5YR 5/6) mottles; clay; sticky; plastic; firm soil strength; massive; few very fine roots; indistinct smooth boundary.
Bg	90–100+	Light brownish grey (2.5Y 6/2) with common medium prominent strong brown (7.5YR 5/6) mottles; clay; sticky; plastic; firm soil strength; massive; no live roots.

Note: Some disturbance in the paddock due to levelling

Site ARC00_ 7

Soil Type	Patumahoe silt loam
Map reference	260 Sheet R12
GPS coordinates	E2666362 N6437603
Location	1510 Waiuku Road
Transect length and direction °	40 m, NE 60°
Local contact person	Owner Jason and Anisa Clarke
Classification	Typic Orthic Granular Soil
Land use	Drystock
Date sampled	21/11/00
Land-use history	In organic farming for 4 years
Present vegetation	Rye grass-white clover pasture
Slope	0°
Landform	Flat midslope of rolling country
Annual rain (mm)	1300
Elevation (m)	61
Parent material	Strongly weathered tephra
Drainage	Well drained
Topsoil depth (cm)	18
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse and D. Hicks

Description ARC00_ 7

Horizon	Depth (cm)	Description
Ap	0–18	Dark brown (10YR 3/3) silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; moderately pedal; many fine and very fine roots; distinct smooth boundary; weak NaF reaction.
Bw1	18–48	Brown (7.5YR 4/4) silt loam; slightly sticky; slightly plastic; slightly firm soil strength; friable failure; moderately pedal; common distinct strong brown (7.5YR 4/6) clay skins on peds; common fine and very fine roots; distinct smooth boundary; moderate NaF reaction.
Bw2	48–65	Brown (7.5YR 4/4) clay; sticky; slightly plastic; firm soil strength; deformable failure; moderately pedal; few fine and very fine roots; indistinct smooth boundary.
Bw3	65–120+	Brown (7.5YR 4/4) clay; sticky; plastic; very firm soil strength; deformable failure; massive; few very fine roots.

Site ARC00_ 12

Soil Type	Kaipara clay
Map reference	260 Sheet Q10
GPS coordinates	E2638023 N6504205050
Location	Helensville area, South Head Road, across the road from ARC00_ 11
Transect length and direction	40 m, N 0°
Local contact person	Dennis Shepherd, Parakai, 75a Market Road, Epsom, ph 5221824
Classification	Typic Orthic Gley Soil
Land use	Drystock
Date sampled	22/11/00
Land-use history	Drystock sheep and beef for the past 20 years, no fertiliser for 20 years, before that time cropped for kumera
Present vegetation	Buttercup, rye grass-white clover pasture
Slope	0°
Landform	Former estuarine flat
Annual rain (mm)	1200
Elevation (m)	2
Parent material	Alluvium
Drainage	Poorly drained
Topsoil depth (cm)	13
Total rooting depth (cm)	60
Limiting horizon	60 cm, compact heavily textured subsoil and high fluctuating ground water levels
Sampled by:	W. Rijkse and D. Hicks

Description

Horizon	Depth (cm)	Description
Agp	0–18	Very dark grey (10YR 3/1) clay; few fine and medium distinct yellowish brown (10YR 5/8) mottles; sticky; plastic; weak soil strength; friable failure; earthy; abundant fine and very fine roots; distinct smooth boundary.
Bg1	18–35	Greyish brown (10YR 5/2) clay; profuse medium prominent yellowish red (5YR 5/6) mottles; very sticky; slightly plastic; firm soil strength; deformable failure; weakly pedal; many fine and very fine roots; indistinct smooth boundary.
Bg2	35–60	Greyish brown (2.5Y 5/2) clay; common fine and medium distinct strong brown (7.5YR 5/8) mottles; very sticky; plastic; firm soil strength; deformable failure; weakly pedal; few very fine roots; indistinct smooth boundary.
Bg3	60–80	Greyish brown (2.5Y 5/2) clay; many coarse and medium distinct yellowish brown (10YR 5/8) mottles; very sticky; very plastic; firm soil strength; deformable failure; massive; no roots; indistinct smooth boundary.
Bg4	80–120+	Light brownish grey (2.5Y 6/2) clay; common medium prominent yellowish brown (10YR 5/8) mottles; sticky; plastic; slightly firm soil strength; deformable failure; no roots.

Site ARC00_ 14

Soil Type	Waitemata complex
Map reference	260 Sheet Q10
GPS coordinates	E2649719 N6505605
Location	Waitoki area, Forestry Road
Transect length and direction °	40 m, NW 300°
Local contact person	Ewen Honore, Forestry road, Waitoki; RD1 Kaukapakapa, ph 4205494
Classification	Typic Orthic Gley Soil
Land use	Drystock
Date sampled	22/11/00
Land-use history	Hay paddock, gets 3 cwt 15% potassic super, lime every three years
Present vegetation	Rye grass-white clover pasture
Slope	0°
Landform	Terrace
Annual rain (mm)	1200
Elevation (m)	30
Parent material	Alluvium
Drainage	Imperfectly drained
Topsoil depth (cm)	25
Total rooting depth (cm)	80
Limiting horizon	Compact heavily textured subsoil below 55 cm depth
Sampled by:	W. Rijkse and D. Hicks

Description ARC00_ 14

Horizon	Depth	Description
A	0–25	Very dark grey (10YR 3/1) silt loam; slightly sticky; slightly plastic; weak soil strength; friable failure; earthy; common fine and very fine roots; distinct smooth boundary.
Bg1	25–55	Greyish brown (5Y 5/2) clay loam; many medium distinct yellowish brown (10Yr 5/6) mottles; sticky; plastic; slightly firm soil strength; friable failure; weakly pedal; few fine and very fine roots; indistinct smooth boundary.
Bg2	55–120+	Light olive grey (5Y 6/2) clay; common medium and coarse prominent yellowish brown (10YR 5/6) mottles; sticky; plastic; deformable failure; firm soil strength; massive; no roots.

Site ARC00_ 16

Soil Type	Warkworth clay loam
Map reference	260 Sheet R9
GPS coordinates	E2658763 N6535151
Location	North of Warkworth, Goatley Road, paddock beside home
Transect length and direction °	40 m, NE 60°
Local contact person	Andrew Rockfort (owner), Rockford Road, RD, Warkworth, ph 4257629
Classification	Typic Yellow Ultic Soil
Land use	Organic drystock
Date sampled	23/11/00
Land-use history	In organic farming for 10 years, applications of fish manure
Present vegetation	Rye grass-white clover pasture
Slope	15°, concavo-convex midslope
Landform	Moderately dissected hill country
Annual rain (mm)	1400
Elevation (m)	89
Parent material	Fine strongly weathered sandstone
Drainage	Well drained
Topsoil depth (cm)	18
Total rooting depth (cm)	120+
Limiting horizon	None
Sampled by:	W. Rijkse and D. Hicks

Description ARC00_ 16

Horizon	Depth	Description
Ap	0–18	Dark brown (10YR 3/3) clay loam; sticky; slightly plastic; weak soil strength; friable failure; moderately pedal; common fine and very fine roots; distinct smooth boundary.
Bt	18–32	Dark yellowish brown (10YR 4/4) clay; sticky; plastic; slightly firm soil strength; friable failure; common distinct dark yellowish brown (10YR 3/4) clay coatings on peds; few fine and very fine roots; distinct wavy boundary.
Bw	32–120+	Yellowish brown (10YR 5/6) clay; few medium faint yellowish red (5YR 5/8) mottles; sticky; plastic; slightly firm soil strength; deformable failure; moderately pedal; few fine and very fine roots.

Site ARC00_ 22

Soil Type	Cornwallis clay
Map reference	260 Sheet Q10
GPS coordinates	E2643472 N6516025
Location	218 Makarau Road, north of Kaukapakapa
Transect length and direction °	40 m, NE 40°
Local contact person	Gary Jackson, Makarau Road, Kaukapakapa
Classification	Typic Orthic Granular Soil
Land use	Drystock
Date sampled	27/11/00
Land-use history	In drystock for some time. Had lime recently
Present vegetation	Rye grass-white clover pasture
Slope	9°, planar shoulder
Landform	Moderately dissected hill country
Annual rain (mm)	1400
Elevation (m)	40
Parent material	Andesitic tuffs
Drainage	Well drained
Topsoil depth (cm)	16
Total rooting depth (cm)	82
Limiting horizon	Heavy clay subsoil.
Sampled by:	W. Rijkse and D. Hicks

Description ARC00_ 22

Horizon	Depth (cm)	Description
Ap	0–16	Black (10YR 2/1) clay; very sticky; plastic; slightly firm soil strength; friable failure; strongly pedal; abundant fine and very fine roots; distinct smooth boundary.
Bt1	16–62	Dark yellowish brown (10YR 4/4) clay; very sticky; plastic; slightly firm soil strength; friable failure; strongly pedal; many distinct dark yellowish brown (10YR 4/6) clay coatings on peds; common fine and very fine roots; indistinct wavy boundary.
Bt2	62–82	Light olive brown (2.5Y 5/4) clay; common medium distinct strong brown (7.5YR 5/6) mottles; very sticky; plastic; slightly firm soil strength; deformable failure; moderately pedal; few prominent yellowish red (5YR 5/8) iron coatings on peds; few very fine roots; indistinct wavy boundary.
BC	82–120+	Light olive brown (2.5Y 5/4) clay with red (2.5YR 5/8) weathered andesite; clay; very sticky; very plastic; firm soil strength; deformable failure; massive; no roots.