Manaaki Whenua
Landcare Research

Soil quality in the Taranaki Region 2017: current status and comparison with previous samplings

Prepared for: Taranaki Regional Council

May 2018

Soil Quality in the Taranaki Region 2017

Contract Report: LC3175

Bryan Stevenson, Nadia Laubscher

Manaaki Whenua – Landcare Research

Reviewed by:	*Approved for release by:*
Scott Fraser Pedologist Manaaki Whenua – Landcare Research	Chris Phillips Portfolio Leader – Managing Land & Water Manaaki Whenua – Landcare Research

Contents

Summary

Project and Client

- Taranaki Regional Council (TRC) has been monitoring soil quality on different soils and land uses in the Taranaki Region since 1995. The council participated in the 500 Soils Project soil quality assessment programme 1996–2001, and some 46 sites were characterised. To determine whether soil quality was changing, it was intended that the sites should be resampled at a future date, typically, 3–10 years later depending on the land use. The council decided to resample some sites in 2007–2008, and also to include new sites with 'low intervention'. These sites have been resampled in 2012 and 2017. Taranaki Regional Council land resources staff collected the soil samples. Landcare Research was contracted to supply sampling equipment, complete soil analyses, and provide an interpretive report.

Objectives

- Provide equipment to TRC staff for soil samples to be taken in October–November 2017.
- Complete analyses on soil samples including seven key soil quality indicators following protocols established in the 500 Soils Project.
- Report on biological activity (i.e. microbial biomass C and respiration).
- Relate soil quality status to land use, and identify extent and direction of any changes compared with samples previously analysed from these sites in 2012 (and 1998–2007) where applicable.

Methods

- Sites were pre-selected and sampled by Taranaki Regional Council staff and soil samples provided to Landcare Research.
- Soil quality was assessed using the seven key soil quality indicators: total C and N content, anaerobically mineralisable N, pH, Olsen P, bulk density, and macroporosity.
- The values were compared against recommended target ranges for those soils and land uses. Updated target ranges (Mackay et al., 2013) were used to be consistent with national reporting (e.g. MfE Our Land 2018).
- Biological functioning was assessed using microbial biomass by the fumigation-extraction and activity from soil respiration.
- Soil cadmium (Cd) was analysed for total (nitric/hydrochloric acid extractable) Cd and bioavailable (calcium nitrate extractable) Cd.
- Data from the current sampling were compared against any archive data for the same sites, to assess what changes had occurred.

Results

- Twenty sites were sampled including two indigenous sites. Target value statistics for chemical/biochemical indicators refer to gravimetric reporting except where noted for comparison to previous reports. The 18 managed sites were tested for seven primary

indicators giving a total of 126 soil quality characteristics, 90 (71%) of which were within target ranges. On a site basis, only one site (5.5% of sites) met all targets, three sites (17%) did not meet the target range for one characteristic, 10 sites (56%) did not meet the target ranges for two characteristics, and four sites (22 %) did not meet target ranges for three or more characteristics.

- For comparison with previous sampling using volumetric target values, two sites (11%) met all targets, seven sites (39%) did not meet targets for one indicator, seven (39%) sites did not meet targets for two indicators, and two sites (11%) did not meet targets for three or more indicators. This is in comparison with 11% of sites meeting all targets, 50% of sites not meeting the target range for one characteristic, 33% of sites not meet the target ranges for two characteristics, and 6% of sites not meet target ranges for three or more characteristics in the 2012 sampling.
- Compared with the previous sampling (on a volumetric basis), there is a decline in soil quality statistics, but this is partly due to the decreased Olsen P target values now in use.
- Nine of the thirteen dairy and drystock sites monitored (69%) were below target values for macroporosity.
- On a gravimetric basis, total N was over target limits on six of the seven dairy sites and two of the six drystock sites. On a volumetric basis three of the seven dairy sites and none of the six drystock sites were over target value limits.
- Olsen P was below target limits on 2 forestry sites and above target values on nine pastoral sites (5 dairy and 4 drystock) and 1 crop/hort site. The new Olsen P target values are more restrictive than the previous targets, but also more in line with current fertiliser recommendations.
- In direct comparison with samples from the previous sampling, only a few significant changes occurred. Most notably for dairy, there was a significant decrease in the soil C:N ratio. For forestry, there were decreases in AMN and MBC, which would be consistent with maturing exotic forests.
- Although there was some variation among individual samples for soil Cd, there was no overall significant change in soil Cd concentrations.
- Respiration and microbial biomass provided some indications of biological health and activity of the below-ground soil system, but in the absence of defined target ranges for these soil attributes we are only able to supply general comments. Cropping sites generally had the lowest microbial biomass and the lowest measured anaerobically mineralisable N, indications of low functioning and a poor habitat for micro-organisms, while indigenous sites generally had the highest microbial biomass.

Conclusions

- Overall there has been a decrease in soil quality statistics of sites monitored, but this is related to the more realistic Olsen P target range values (i.e. more sites are outside the new ranges than the old) rather than a trend in indicator values themselves. It is important to note, however, that Olsen P levels at several sites were still exceptionally high (in excess of 100 μg g^{-1}).
- The general patterns in soil quality are similar to those found in other regions.

- Primary concerns are (1) compaction of soils on dairy and drystock sites; (2) and generally high Olsen P and/or N levels on dairy and flatland drystock sites (where intensity of grazing often approaches that of dairy farms).
- Although target value statistics for total N were similar to the last reporting period when considered on a volumetric basis (and total sites meeting the mineralisable N targets improved), the downward movement of the C:N ratio for dairy does suggest these soils may be nearing N saturation.
- The low macroporosity values on dairy and drystock sites mirror results from other regions of the country where land use has intensified and soil compaction from intensive grazing remains a concern. The Allophanic Soils of the Taranaki region are generally more resilient than non-Allophanic Soils; however, even the Allophanic Soils are showing evidence of adverse compaction, indicated by low air capacity values. High N and/or Olsen P values on dairy sites are also of concern because of the risk to water quality.
- There was no overall significant change in Cd concentrations from the previous sampling, which suggests soil Cd levels may be plateauing, but further monitoring is required to confirm this trend. One site, however, has consistently been over the 1 mg kg^{-1} level.
- The lack of a distinct trend in Cd values between the current and previous sampling also suggests that the change in the analytical methodology for Cd analysis did not adversely affect the results.
- The majority of instances of poor soil quality could be reversed by appropriate management.
- Although the microbial health analyses (basal respiration, microbial biomass), showed differences between sites, due to the difficulty in defining target ranges it is not possible to provide a clear statement on functional and biodiversity status of Taranaki soils. However, comparison of these parameters over time may still provide useful indicators of microbial functioning.

Recommendations

- A soil-quality monitoring programme of resampling existing sites continues in order to determine the extent and direction of any changes since originally sampled.
- With the advent of national reporting (e.g. the recent MfE Land 2018 report), sampling protocols, indicators, and target values are currently being reviewed by the Environmental Monitoring and Reporting (EMaR) group with the aim of achieving a more unified sampling and reporting regime across regions. There are likely to be further changes in soil quality monitoring, and it is recommended that TRC have a voice in these changes through the Land Management Forum.
- Since the change in method for Cd analysis did not adversely affect results, we would recommend that TRC continue to use the US EPA nitric/hydrochloric acid digest. There was some variation in individual site Cd values, and while it may be worthwhile to consider having some of those samples rerun in the future, we do not consider that to be a pressing need at present.
- Taranaki Regional Council considers activities to educate land managers on strategies to protect the environment while achieving an economic return from the land. In

particular, awareness of the current recommendations on Olsen P levels and the general benefits of nutrient budgeting are recommended.

- After the next sampling, a number of sites will have been sampled five times. Although the number of sites is relatively small (on a statistical basis), TRC should consider formal statistical analysis of temporal trends for the next report.

1 Introduction

1.1 Background

Taranaki Regional Council (TRC) has been monitoring soil quality on different soils and land uses in the Taranaki Region since 1995. The council participated in the 500 Soils Project soil quality assessment programme 1996–2001, and some 46 sites were characterised (see Sparling et al. 2001a, b). To determine whether soil quality was changing, it was intended the sites should be resampled at a future date, typically, 3–10 years later, depending on the land use. In 2007, the council decided to resample some sites previously characterised from 1996 to 2001 over 2007–2008, and also to include new sites with 'low intervention' to contrast with the higher intensity dairy and arable land uses. The sites sampled in 2007 were resampled in 2012 and 2017, though two new drystock sites were added to replace two existing sites that were deemed to be no longer suitable for sampling. These new sites were included in target value statistics, but as there is no previous data they were not included in comparisons of indicator values between sampling dates.

Taranaki Regional Council land resources staff collected the soil samples (see Fig. 1 for a map of site locations). Landcare Research was contracted to complete soil analyses, and provide an interpretive report.

1.2 Objectives

- Provide equipment to TRC staff for soil samples to be taken in October/November 2017.
- Complete analyses on soil samples including seven key soil quality indicators following protocols established in the 500 Soils Project and previous reports.
- Provide an assessment of soil biological functioning by completing analyses of microbial biomass and respiration.
- Analyse soils for total extractable and bio-available cadmium.
- Relate soil quality status to land use, and identify extent and direction of any changes compared with previous analyses from these sites in 2012 (and 1996–2007 where applicable).

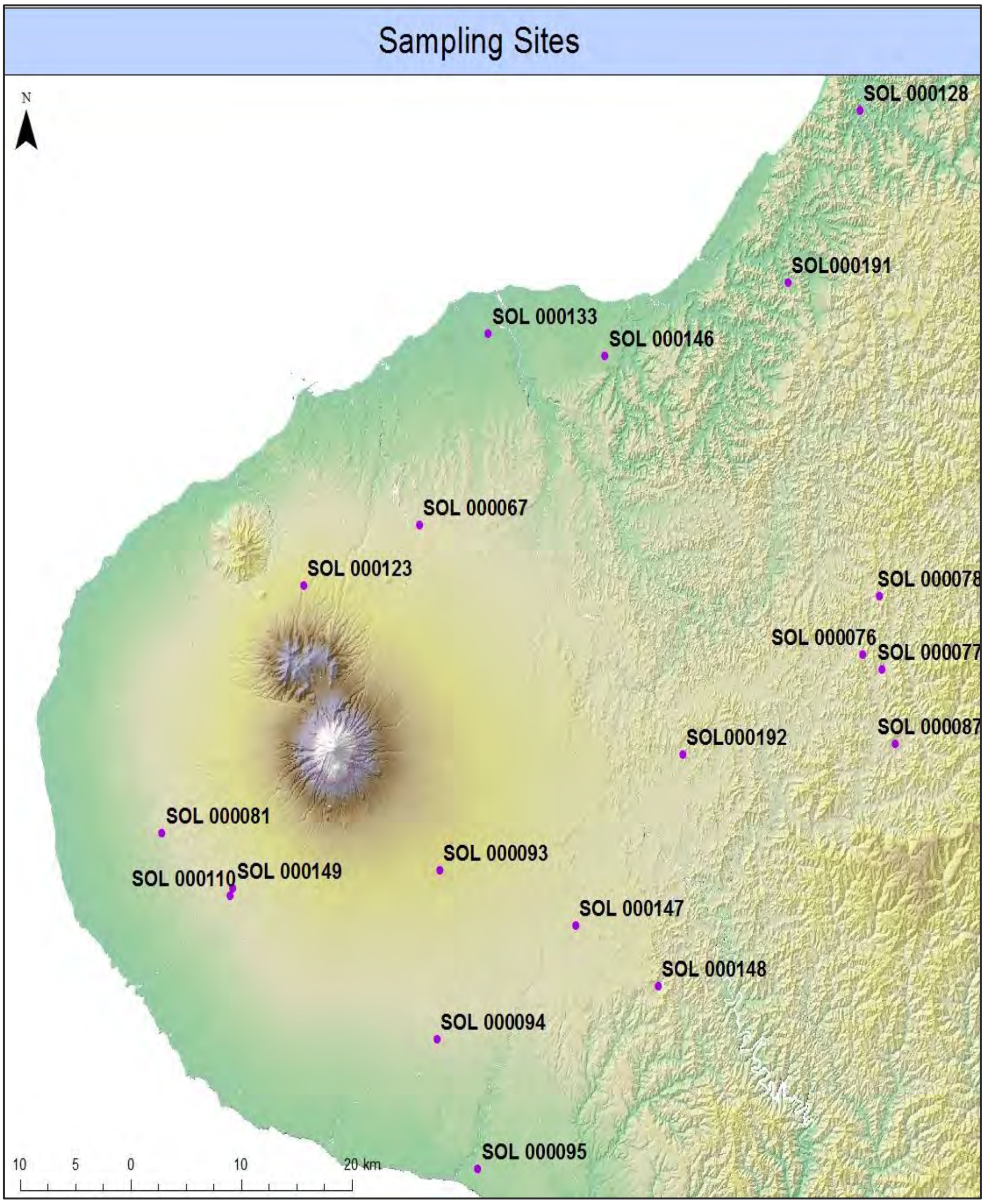

Figure 1 Location map showing sites in Taranaki Region sampled in 2017.

2 Methods

Most of the methodologies have been described in earlier reports (Sparling et al. 2001a, b; Sparling & Stevenson 2008) and only brief details are given here.

2.1 Soil sampling

Taranaki Regional Council field staff collected soil samples. Steel rings (10 cm diameter × 7.5 cm depth) were supplied to TRC staff to collect intact cores for soil physical measurements. Composite soil chemistry samples of 2.5-cm diameter were collected every 2 m along a 50-m transect at a 0–10 cm soil depth. The soil samples for chemical characteristics (except cadmium) and biological analyses were analysed at Landcare Research's Environmental Chemistry Laboratory at Palmerston North. Extracts for bioavailable cadmium were performed at the Landcare lab, and the extracts as well as total available cadmium (nitric/hydrochloric acid digest) were analysed by Hill Laboratories. The total cadmium analysis does differ slightly from previous methods used, but the US EPA nitric/hydrochloric acid digest method is generally the most commonly used method. In consultation with TRC, it was decided to use this method from the current sampling onwards. Soil physical analyses were completed at Landcare Research's Soil Physics Laboratory in Hamilton. Where necessary, samples were stored at 5°C.

2.2 Soil quality measurements

Seven primary soil properties (TC, TN, AMN, Olsen P, pH, BD, MP) were measured to assess soil quality (Table 1). Chemical and biochemical characteristics were assessed by the total C content, total N content, mineralisable N (AMN), Olsen P, soil pH, and derived measurements such as C/N ratio. Soil physical condition was assessed from the dry bulk density and air capacity (macro-porosity measured using –10 kPa tension). These soil physical measurements also provide measures of total porosity and particle density.

Soil biological functioning was assessed from the soil microbial biomass C and soil respiration. Soil Cd was analysed for total and bioavailable Cd fractions.

2.3 Analyses

Chemical and biochemical properties

Total C and N were determined by dry combustion of air-dry, finely ground soils using a Leco 2000 CNS analyser. Olsen P was determined by extracting <2 mm air-dry soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen et al. 1954) and measuring the PO_4^{3-} concentration by the molybdenum blue method. Soil pH was measured in water using glass electrodes and a 1:2.5 soil-to-water ratio (Blakemore et al. 1987). Potentially mineralisable N (or anaerobically mineralisable N, AMN) was estimated by the anaerobic (waterlogged) incubation method; the increase in inorganic N concentration (expressed as NH_4^+ under anaerobic conditions) was measured after incubation for 7 days at 40°C and extraction in 2M KCl (Keeney & Bremner 1966).

Table 1 Indicators used for soil quality assessment*

Indicators	Soil Quality Information	Method
	Chemical properties	
Total C content	Organic matter status	Dry combustion, CHN Analyser
Total N content	Approximates organic N reserves (the vast majority of N in the soil)	Dry combustion, CHN Analyser
Potentially mineralisable N (AMN)	Organic N that can be readily mineralise to a plant available form	Waterlogged incubation at 40°C for 7 days
pH	Acidity or alkalinity	Glass electrode pH meter, 1:2.5 in water
Olsen P	Plant available phosphate	Bicarbonate extraction, molybdenum blue method
	Biological properties	
Microbial biomass C	Biomass of living microbes in soil	Fumigation-extraction
Soil respiration	Total respiratory activity of aerobic soil microorganisms	CO2-efflux in confined chamber
	Physical properties	
Dry bulk density	Compaction, volumetric conversions	Intact soil cores
Macroporosity	Soil compaction, root environment, aeration	Pressure plates

*Associated data (such as total porosity, C/N ratio, extractable nitrate, and ammonium for chemical analyses and particle density, total porosity, and volumetric water contents) are included in Tables 3 and 5 respectively. These are used to derive the indicators above or may help explain changes in indicator status.

As additional analyses, total available Cd was analysed after a nitric/hydrochloric acid digest (US EPA method 200.2), and bioavailable Cd from a 0.01 M calcium nitrate extraction (McLaren et al. 2005). Extractions were performed at the LCR lab but samples were analysed by ICP-MS at Hill Laboratories. Total cadmium analyses for previous reports had used slightly different extraction methods (nitric acid/peroxide digest, Kovacs et al. 2000), but in consultation with TRC, it was decided to use the standard US EPA method as that is the mostly widely used method internationally.

Physical properties

Macroporosity and air capacity were determined by drainage on pressure plates at –5 and –10 kPa respectively (Klute 1986). For comparison with the 2012 resampled sites, the air-capacity measurement was used. For comparison of those sites that have been measured three times, the –5 kPa macroporosity measurement was used because the –10 kPa air-capacity measurement was not calculated for samples from 1998 to 2000. Dry bulk density was measured on a subsampled core dried at 105°C (Klute 1986). Air capacity and total porosity were calculated as described by Klute (1986).

2.4 Statistics and data presentation

Soil quality data were expressed on a weight/weight (gravimetric) basis for chemistry and biochemistry indicators. Gravimetric reporting is now preferred because the original target values were expressed on a gravimetric basis. In addition, changes over time can often be more easily observed in gravimetric data because changes in bulk density can either amplify or dampen changes in gravimetric data. However, in order to extrapolate data to a field stock, i.e. weight/hectare (e.g. for carbon stocks) a volumetric basis is required. In addition, the volumetric reporting has been retained to allow for comparison to earlier reports. We note in the discussion where differences in gravimetric versus volumetric reporting result in differences in interpretation of the results.

Values for the current sampling were compared against target values derived for specific land use / soil order combinations, thus it is important to note that a specific values maybe within target ranges for a particular soil order or land use, but outside target values for another. While the values derived in Sparling et al. (2008) still form the basis for target value reporting, revisions suggested in Mackay et al. (2013) have been used. The most significant change in target values is a decrease in the upper Olsen P target range to ~45 μg g^{-1} (dependent on soil type). While these values are much more restrictive than the original value of 100 μg g^{-1}, they are more in line with current recommended fertiliser practice.

Where appropriate, data from the same land-use category or soil type were combined to simplify presentation. A paired t-test was performed on resampled sites to assess whether change between sampling periods was statistically significant ($P < 0.05$).

We have excluded native sites from soil quality statistics as the soil quality target values are not particularly useful for indigenous sites as 1) there is little management that can be affected on indigenous lands to alter soil quality, and 2) indigenous sites tend to have greater spatial variability, rendering the up-scaling of a few soil quality sites sampled in a given region to the area of indigenous vegetation across that region suspect. It is important to note, however, that indigenous sites form an important baseline for comparison with the effects land use has on soils. We strongly urge that these sites continue to be monitored, and in fact encourage inclusion of more indigenous sites.

3 Results

3.1 Soils and sites

Twenty sites were sampled in the current batch. These comprised three plantation forests, seven dairy pastures, six dry stock pastures (pasture grazed predominantly by sheep and beef), two cropping/market garden sites, and two indigenous forest sites. Two new drystock sites (SOL000191 and SOL000192) were added to replace two existing sites (SOL000144, SOL000145) where sampling was not practical any longer. The two new drystock sites were included in generation of soil quality statistics, but were not included compared with previous soil quality indicator values as there were no previous data for these sites.

Summarized site and soil information is given in Table 2 (collected TRC site information is collected in the accompanying document, 500_Soils_site_codes_soil_types_profile_and _transects_2017_with_rainfall). Chemical and biochemical data are shown on a gravimetric basis in Table 3, but for comparison to earlier reports data on a volumetric basis is also reported (Table 4).

Physical data are presented in Table 5, biological data in Table 6, and cadmium data in Table 7.

Laboratory data sheets and available site and soil profile descriptions (provided by TRC) are contained in the Appendix.

Table 2 Site codes, soil type, soil classification, and current land use of sites sampled in 2017. Soil Classification inferred from data provided by TRC

TRC code	Soil type or map unit	Subgroup, Group, Order§	Land use in 2017
SOL 000067	Sandy clay loam	Typic Orthic Allophanic Soil	Drystock
SOL 000076	New Plymouth Brown Loam	Typic Orthic Allophanic Soil	Forestry
SOL 000077	New Plymouth Brown Loam	Typic Orthic Allophanic Soil	Forestry
SOL 000078	Whangamomona fine sandy loam steepland soil	Typic Orthic Recent Soil	Forestry
SOL 000081	Pihama Silt Loam	Mottled Orthic Allophanic Soil	Dairy
SOL 000087	New Plymouth Brown Loam	Typic Orthic Allophanic Soil	Drystock
SOL 000093	Egmont Brown Loam	Typic Orthic Allophanic Soil	Dairy
SOL 000094	New Plymouth Brown Loam	Typic Orthic Allophanic Soil	Dairy
SOL 000095	Egmont Black Loam	Typic Orthic Allophanic Soil	Dairy
SOL 000110*	Hangatahua Sandy Loam	Acidic Allophanic Brown Soil	Dairy
SOL 000123*	Patua Sandy Loam	Typic Orthic Allophanic Soil	Drystock
SOL 000128	Kaikarangi Silt Loam	Typic Recent Gley Soil	Drystock
SOL 000133	New Plymouth Black Silt Loam	Typic Orthic Allophanic Soil	Crop/Hort
SOL 000146	New Plymouth Black Loam	Typic Orthic Allophanic Soil	Crop/Hort
SOL 000147	Moutoa Humic clay	Acid recent Gley Soil	Dairy
SOL 000148	Whangamonona complex	Typic Orthic Allophanic Soil	Indigenous
SOL 000149	Tekiri-Punehu Association	Typic Perch-Gley Allophanic Soil	Indigenous
SOL 000150	Foxton Black sand	Typic Sandy Brown Soil	Dairy
SOL 000191	Kairanga Silty Clay	Typic Othric Gley Soil	Drystock
SOL 000192	Stratford fine sandy loam	Typic Othic Allophanic soil	Drystock

§Inferred from available data

*NSD Sites – SOL000110 is NSD site SB09318 and SOL000123 is NSD site SB10086

Table 3 Key soil quality chemical and biochemical characteristics (on a gravimetric basis) of TRC soils sampled in 2017

TRC code	Soil Order	Land use	pH	Total C (%)	Total N (%)	C:N (ratio)	NO_3-N (µg g^{-1})	NH_4-N (µg g^{-1})	AMN (µg g^{-1})	Olsen P (µg g^{-1})
SOL 000067	Allophanic	Drystock	5.69	5.79	0.53	11.00	8.3	1.2	125	164
SOL 000076	Allophanic	Forestry	5.35	11.60	0.78	14.90	10.4	1.7	164	4
SOL 000077	Allophanic	Forestry	4.96	13.99	0.98	14.28	19.4	1.5	139	6
SOL 000078	Recent	Forestry	5.25	9.06	0.48	19.04	5.1	2.5	106	5
SOL 000081	Allophanic	Dairy	5.89	13.76	1.30	10.59	53.9	1.1	262	31
SOL 000087	Allophanic	Drystock	4.83	9.13	0.88	10.41	84.3	1.6	187	58
SOL 000093	Allophanic	Dairy	5.43	10.12	0.98	10.37	82.4	1.1	261	58
SOL 000094	Allophanic	Dairy	5.68	8.71	0.93	9.39	65.6	0.8	174	108
SOL 000095	Allophanic	Dairy	5.80	8.95	0.87	10.26	35.1	1.1	164	42
SOL 000110	Brown	Dairy	5.07	8.23	0.71	11.58	54.5	1.5	161	50
SOL 000123	Allophanic	Drystock	5.54	13.14	1.03	12.73	13.2	2.1	288	23
SOL 000128	Gley	Drystock	5.23	5.01	0.48	10.42	24.9	1.9	158	49
SOL 000133	Allophanic	Crop/Hort	6.50	7.53	0.73	10.37	57.7	0.3	50	79
SOL 000146	Allophanic	Crop/Hort	5.70	8.75	0.86	10.13	53.5	0.5	117	36
SOL 000147	Gley	Dairy	5.63	15.06	1.05	14.37	39.8	0.7	191	58
SOL 000150	Brown	Dairy	5.70	5.27	0.48	10.94	36.3	1.8	107	47
SOL 000191	Gley	Drystock	5.04	5.23	0.49	10.61	11.9	1.7	170	32
SOL 000192	Allophanic	Drystock	5.25	6.20	0.57	10.94	27.3	2.0	132	134
SOL 000148	Allophanic	Indigenous	5.75	10.89	0.87	12.57	29.3	1.2	266	14
SOL 000149	Allophanic	Indigenous	5.04	18.65	1.35	13.80	36.2	47.4	424	5

* Items in orange are below the target range, and blue above the target range (note: indigenous sites are not included in target value assessment).

Table 4 Key soil quality chemical and biochemical characteristics (Volumetric basis) of TRC soils sampled in 2017 (includes managed land uses only)

TRC Code	Soil Order	Land use	Total C (mg cm^{-3})	Total N (mg cm^{-3})	AMN (µg cm^{-3})	Olsen P (µg cm^{-3})
SOL 000067	Allophanic	Drystock	59.2	5.38	128	168
SOL 000076	Allophanic	Forestry	66.5	4.46	94	2
SOL 000077	Allophanic	Forestry	70.9	4.97	70	3
SOL 000078	Recent	Forestry	52.3	2.75	61	3
SOL 000081	Allophanic	Dairy	72.5	6.85	138	16
SOL 000087	Allophanic	Drystock	66.0	6.34	135	42
SOL 000093	Allophanic	Dairy	65.1	6.28	168	37
SOL 000094	Allophanic	Dairy	75.2	8.01	150	93
SOL 000095	Allophanic	Dairy	73.4	7.16	134	35
SOL 000110	Brown	Dairy	70.2	6.06	137	43
SOL 000123	Allophanic	Drystock	71.8	5.64	157	12
SOL 000128	Gley	Drystock	36.3	3.48	114	36
SOL 000133	Allophanic	Crop/Hort	71.8	6.92	47	75
SOL 000146	Allophanic	Crop/Hort	77.9	7.68	104	32
SOL 000147	Gley	Dairy	101.9	7.09	129	40
SOL 000150	Brown	Dairy	60.2	5.50	122	54
SOL 000191	Gley	Drystock	38.7	3.65	126	24
SOL 000192	Allophanic	Drystock	51.7	4.72	110	112

* Items in orange are below the target range, and blue above the target range.

Table 5 Key soil quality physical characteristics of TRC soils sampled in 2017

TRC Code	Land use	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Total porosity (%) (v/v)	Macroporosity (−10kPa) (%)(v/v)
SOL 000067	Drystock	1.02	2.65	61.3	5.1
SOL 000076	Forestry	0.57	2.39	76.1	27.6
SOL 000077	Forestry	0.51	2.23	77.2	17.1
SOL 000078	Forestry	0.58	2.46	76.5	33.2
SOL 000081	Dairy	0.53	2.32	77.3	6.3
SOL 000087	Drystock	0.72	2.43	70.3	5.5
SOL 000093	Dairy	0.64	2.47	73.9	7.7
SOL 000094	Dairy	0.86	2.47	65.1	2.1
SOL 000095	Dairy	0.82	2.46	66.7	8.8
SOL 000110	Dairy	0.85	2.48	65.8	10.9
SOL 000123	Drystock	0.55	2.31	76.5	4.0
SOL 000128	Drystock	0.72	2.50	71.0	7.5
SOL 000133	Crop/Hort	0.95	2.56	62.7	5.2
SOL 000146	Crop/Hort	0.89	2.51	64.5	3.9
SOL 000147	Dairy	0.68	2.36	71.4	10.3
SOL 000150	Dairy	1.14	2.91	60.7	21.3
SOL 000191	Drystock	0.74	2.60	71.5	11.1
SOL 000192	Drystock	0.83	2.46	66.3	8.0
SOL 000148	Indigenous	0.55	2.44	77.3	20.7
SOL 000149	Indigenous	0.32	2.38	86.3	31.2

* Items in orange are below the target range, and blue above the target range (note: indigenous sites are not included in target value assessment).

Table 6 Soil respiration and microbial biomass on a gravimetric and volumetric basis for TRC soils sampled in 2017

TRC code	Land Use	Microbial biomass C (mg kg^{-1})	Basal respiration (μgC g^{-1} h^{-1})	Microbial biomass C (μgC cm^{-3})	Basal respiration (μgC cm^{-3} h^{-1})
SOL 000067	Drystock	668	0.78	684	0.79
SOL 000076	Forestry	1480	1.44	849	0.82
SOL 000077	Forestry	1350	1.32	684	0.67
SOL 000078	Forestry	983	1.38	567	0.80
SOL 000081	Dairy	3030	1.73	1596	0.91
SOL 000087	Drystock	1580	1.25	1143	0.90
SOL 000093	Dairy	2140	1.19	1377	0.76
SOL 000094	Dairy	1660	1.33	1433	1.15
SOL 000095	Dairy	1300	0.17	1066	0.14
SOL 000110	Dairy	1470	1.11	1254	0.94
SOL 000123	Drystock	2810	1.54	1536	0.84
SOL 000128	Drystock	1630	1.44	1179	1.04
SOL 000133	Crop/Hort	216	0.17	206	0.16
SOL 000146	Crop/Hort	762	0.85	678	0.76
SOL 000147	Dairy	1330	1.65	900	1.12
SOL 000150	Dairy	843	0.09	963	0.10
SOL 000191	Drystock	1640	0.71	1214	0.53
SOL 000192	Drystock	1360	1.38	1133	1.15
SOL 000148	Indigenous	1750	1.42	968	0.79
SOL 000149	Indigenous	3050	1.69	986	0.55

Table 7 Total and bioavailable cadmium (Cd) from TRC topsoils sampled in 2012 and 2017, and change between sampling dates

TRC Code	Land use	Total Cd (mg kg^{-1})			Bio-available Cd (mg kg^{-1})		
		2012	2017	Change	2012	2017	Change
SOL000067	Drystock	0.330	0.350	0.02	0.016	0.016	0.000
SOL000076	Forestry	0.160	0.076	-0.08	0.015	0.007	-0.008
SOL000077	Forestry	0.090	0.073	-0.02	0.008	<0.007	-0.004[1]
SOL000078	Forestry	0.070	0.047	-0.02	0.003	0.007	0.004
SOL000081	Dairy	1.150	1.140	-0.01	0.021	0.009	-0.012
SOL000087	Drystock	0.310	0.290	-0.02	0.019	0.021	0.002
SOL000093	Dairy	0.850	0.620	-0.23	0.010	0.016	0.006
SOL000094	Dairy	0.560	0.660	0.10	0.021	0.009	-0.012
SOL000095	Dairy	0.460	0.680	0.22	0.005	<0.007	-0.001[1]
SOL000110	Dairy	0.740	0.570	-0.17	0.035	0.037	0.002
SOL000123	Drystock	0.300	0.570	0.27	0.012	0.019	0.007
SOL000128	Drystock	0.320	0.220	-0.10	0.013	0.016	0.003
SOL000133	Crop/Hort	0.710	0.650	-0.06	0.002	<0.007	0.002[1]
SOL000146	Crop/Hort	0.550	0.124	-0.43	0.017	<0.007	-0.013[1]
SOL000147	Dairy	0.470	0.141	-0.33	0.008	<0.007	-0.004[1]
SOL000150	Dairy	0.120	0.370	0.25	0.002	0.013	0.011
SOL000191	Drystock		0.140	-		0.012	-
SOL000192	Drystock		0.370	-		0.013	-
SOL000148	Indigenous	0.130	0.158	0.03	0.002	<0.007	0.002[1]
SOL000149	Indigenous	0.220	0.140	-0.08	0.006	0.012	0.006

[1]For calculation of change where 2017 samples were below detection limit, change was calculated using half the detection limit.

Cropping sites

Two cropping sites were measured, both on Allophanic Soil (SOL000133, SOL000146). Because of the small number of sites it is not possible to generalize about effects of this land use in Taranaki. Site SOL000133 had particularly low microbial biomass and basal respiration suggesting depleted labile C availability; SOL000146 was still below most other sites but not nearly as low as SOL000133. SOL133 also had Olsen P values above target values.

Both sites had low macroporosity, which can be associated with compaction from mechanical harvesting equipment. Macroporosity needs to be interpreted cautiously for arable sites as this can change significantly throughout the year and point in the cropping cycle from factors such as cultivation and mechanical harvesting (Tables 5, 6).

Drystock pastures

Six drystock sites were sampled. The original sites (SOL00067, 87 123, 128) include three Allophanic and one Gley Soils. Two new sites (SOL000191 and 192) replaced sites SOL 000144 and 145. One site SOL 000191 met all targets.

Site SOL000087 had a low pH value for pasture (Table 3). Four of the six drystock sites were over the new target range for Olsen P (sites SOL000123 and SOL000191 met the target range). Sites SOL000067 and SOL000192 had very high (>100) Olsen P levels. All sites met targets for AMN. On a gravimetric basis, one drystock site (with a C:N ratio of 12.7) was over the target range for total N, but on a volumetric basis it was not.

Five of the six sites showed a high level of topsoil compaction and low air capacity (macroporosity) (Table 5).

Biological indicators were generally average to above average compared with most other sites, though SOL000067 continues to have relatively low microbial biomass (Table 6).

Dairy pastures

Seven dairy pastures were sampled. Only two (SOL000081 and SOL000095) of the seven dairy sites met the new target range for Olsen P (Table 3). All sites met targets for AMN. On a gravimetric basis, six of the seven sites were over the target range for TN, while on a volumetric basis three sites were over (Table 4). The average C:N ratio of dairy sites (excluding SOL000147, which had an unusually high C:N ratio for a dairy site), however, was approximately 10.5, indicating these sites may be nearing saturation.

Similar to dry stock, macroporosity is the indicator of major concern for dairy pastures with four out of seven sites below 10% air capacity (Table 5).

Biological indicators were average to high compared with the average for all sites, except for site SOL000150 which had relatively low microbial biomass and respiration (Table 6).

Plantation forest

Apart from Olsen P, the soil chemical/biochemical and physical characteristics of the plantation forest sites were generally within ranges expected for that land use and soil type.

Two of the three forestry sites, however, had Olsen P values below the minimum target value of five (Table 3). It is not normal practice to fertilise plantation forests in New Zealand (apart from occasional side dressing at establishment) for economic reasons, therefore P status of these sites is unlikely to change under this land use, and is not of great concern for mature forest. Two of the three sites were over total N targets on a gravimetric basis but these sites were not over targets on a volumetric basis (Tables 3 and 4) and also had relatively high C:N ratios suggesting the threat of N leaching is minimal.

One site (SOL000078) did have low bulk density, which is a risk factor for erosion (Table 5). The low bulk density does pose a slight risk of erosion under forest land use, but would be of greater concern should these sites be converted to pasture.

Indigenous forest

As previously noted, we have discontinued the practice of comparing indigenous sites to target values as they can be highly variable in soil quality indicators and there is generally little that can be done to manage indicators that are outside target values. Nevertheless, we still encourage sampling of indigenous sites as they form a baseline for rate of change in other land uses.

It is interesting to note that both microbial biomass and basal respiration were generally higher in the indigenous sites than in the managed sites including pasture (particularly so for SOL000149).

One note of caution in sampling both exotic and indigenous forest sites is that the sampling procedure calls for removal of the organic litter layer prior to taking a sample of the mineral soil. Samples that contain excessive litter often can have a low bulk density and higher C (and N) content than is normal and contributes to greater variability between samples.

3.2 Overall soil quality

General soil quality statistics

Samples from the 18 managed land use sites were analysed for the seven primary soil quality indicators and compared against target values developed during the 500 Soils Project (Sparling et al. (2008), with revisions suggested by Mackay et al. (2013); see Appendix 3). Of the 126 total soil quality characteristics measured, 90 (71%) were within target ranges. On a site basis, one site (5.5%) met all target ranges, three sites (17%) did not meet the target range for one characteristic, ten sites (56%) did not meet the target ranges for two characteristics, and four sites (22 %) did not meet target ranges for three or more characteristics (Figure 2).

On a volumetric basis for comparison with the previous sampling, 99 total indicators (79%) met targets compared with 102 (80%) in the previous sampling (Fig. 3), but it should also be noted that there have been changes to target values that affect the target statistics both positively and negatively. In the previous report, two sites (10%) met all target ranges, ten sites (50%) did not meet target values for one indicator, seven sites (35%) did not meet target values for two indicators, and one site (5%) did not meet target values for three or more indicators. In the 2007 sampling (Sparling & Stevenson 2008), 78% of total indicators were within target values, 10% of sites had all indicators within target values, 35% of sites had one indicator outside target values, 50% of sites two indicators outside target values, and 5% of sites had three indicators outside target values.

The soil quality characteristic most often out of range (Fig. 4) was macroporosity (67% of all managed land use sites). All forestry sites had macroporosity within target range, but only three other sites (two dairy and one drystock) did not have macroporosity below the target range. Other indicators outside target ranges included Olsen P on 33% of all sites (five of 18 managed land use sites had low Olsen P values, one of 18 sites had high Olsen P values), total N on 17% of all sites (three of 18 sites, all dairy or drystock, had high total N values), 11% for bulk density, and 6% for AMN. The indicators of most concern for dairy, drystock and forestry are shown in Figures 4–6 respectively.

Comparison with volumetric data

The major difference in comparing the soil chemistry data (total C and N, Olsen P, mineralisable N) with targets expressed on a gravimetric basis with that expressed on a volumetric basis is that many more sites are out of target range for total N (Fig. 5). On a gravimetric basis, 10 out of 18 managed land use sites (56%) were outside target values for total N versus only three sites (17%, all dairy sites) outside target ranges for total N on a volumetric basis.

The EMaR (Environmental Monitoring and Reporting) has recommended the use of gravimetric reporting so as to remain consistent with published values. The published upper target value for total N, however, is not well suited for high C soils (particularly for Allophanic soils, which make up a large proportion of the TRC sites) where significant N can be immobilised. The soil C:N ratio should also be considered to suggest whether high N soils are nearing N saturation (Schipper et al. 2004). Several of the drystock and forestry sites that were over the target limit for total N had relatively high C:N ratios and probably do not pose a risk of N leaching. On the other hand, apart from one dairy site where the C:N was relatively high, the average C:N ratio of remaining dairy soils was approximately 10.5, indicating they may be near N saturation.

Soil physical characteristics (bulk density, particle density and porosity measures) are by definition given in volumetric measurements so the same trends for these measures apply, as previously discussed.

Soil biological health

Three sites had soil basal respiration significantly below other sites: site SOL000067, SOL000133 and SOL146). Four sites had microbial biomass significantly below the average: the three with low respiration already mentioned, and site SOL000144, a Gley Soil under pasture that generally had low fertility, TC, and respiration combined with very low macroporosity, which would explain the low microbial biomass.

SOL00067, a drystock site, has had low microbial biomass and respiration rate for several successive samplings. SOL000133 and SOL146 are cropping sites and have been discussed in section 3.2. Microbial biomass at one other site was intermediate (SOL000150); this site was the only Sandy Recent Soil sampled and as this soil has naturally low TC due to lack of profile age/development, it therefore would be expected to have correspondingly low microbial activity.

Soil cadmium

Values for total extractable Cd and bioavailable Cd for both the current sampling and the previous sampling in 2012 are shown in Table 7. Because of previous changes in equipment and methodology, it was decided in consultation with TRC to use the more widely accepted US EPA extraction method, the nitric/hydrochloric acid digestion.

In the past, the guidelines in the New Zealand Water and Wastes Association for the application of biosolids to land (NZWWA 2003) were used to define maximum limits for total Cd in soil. The recommended maximum for total Cd in soil is 1 mg kg^{-1}. The new tiered fertiliser management system (TFMS) from the Cd working group (Cadmium working group, 2011) has more specific criteria, but the trigger to Tier 3 is the same as the NZWWA limit of 1 mg kg^{-1}.

The TFMS has four tiers. At:

> Tier 1, there are no limits on the application of phosphate fertiliser other than a 5-yearly screening soil test for cadmium status. The trigger value to move to tier 2 is 0.6 mg Cd kg^{-1} soil.
>
> Tier 2, application rates are restricted to a set of products and application rates to manage accumulation, so that cadmium does not exceed the acceptable threshold within the next 100 years. Landholders are required to test for cadmium every 5 years using approved programmes. The trigger value to move to tier 3 is 1.0 mg Cd kg^{-1} soil.
>
> Tier 3, application rates are further managed by use of a cadmium balance programme to ensure that cadmium does not exceed an acceptable threshold within 100 years. The trigger value to move to tier 4 is 1.4 mg Cd kg^{-1} soil.
>
> Tier 4, above 1.8 mg Cd kg^{-1} soil no further accumulation of cadmium is allowed.

SOL000084 has been in the 1.1–1.2 mg kg^{-1} in the past two samplings and did not change appreciably in this sampling. This site would be classified as a Tier 3 in the current tier system. All other sites were below the tier 3 threshold level of 1.00 mg kg^{-1}.

As in past measurement, cadmium concentrations were generally highest on the dairy farm soils. Cadmium levels in indigenous forest soils were low, suggesting the elevated levels in intensively managed soils originated from an unwanted contaminant in phosphate fertiliser.

We are not aware of any specific limits defined for the bioavailable fraction, but the fact that a proportion (albeit a small one) of the total metal content was extracted by calcium nitrate suggests a portion of the total amount is mobile. The mobile fraction (which generally increases with cadmium containing P application or municipal biosolids application) may be taken up by plants or soil biota, or be susceptible to leaching through the soil column (McLaren et al. 2005). Leaching will have the effect of reducing surface concentrations, but ultimately may lead to trace metals appearing lower in the soil profile, or into water bodies depending upon the chemical characteristics of the soil.

The relationship between total Cd for the 2012 and 2017 sampling dates can be seen in Figure 9. While there is some variation in some sites, there were no significant changes in total Cd levels. There was some variation in several samples that could potentially be due to sample variability. To better detect changes over time it may be worth considering reanalysing a few of the 2012 samples (SOL000093, SOL000097, SOL000147), where there was large variation in relation to the 2017 sampling, but we do not think this is a high priority, as all these samples were less than the 1 mg kg^{-1} threshold.

Both McDowell (2012) and Schipper et al. (2011) noted plateauing or possible declines in total Cd in soils receiving relatively low levels of P fertiliser in fertiliser trials at Winchmore and Whatawhata respectively. This does suggest that with careful fertiliser management, Cd levels may remain stable or even decline. There are, however, some land-use management practices that could explain lower Cd values on individual sites (e.g. SOL000146), for instance tilling, which would dilute near surface soil with deeper soil. Continued monitoring is needed to confirm any decline in Cd values.

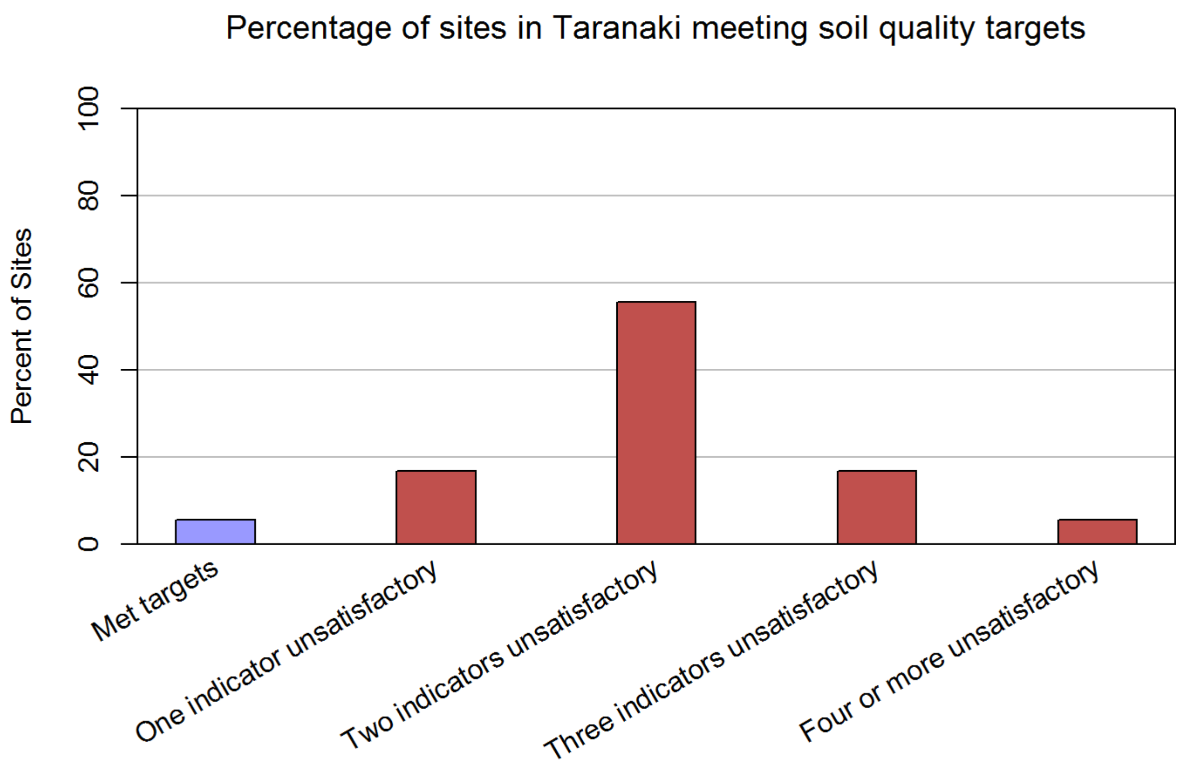

Figure 2 Proportions of the 18 managed land-use sites meeting targets for soil quality indicators on a gravimetric basis.

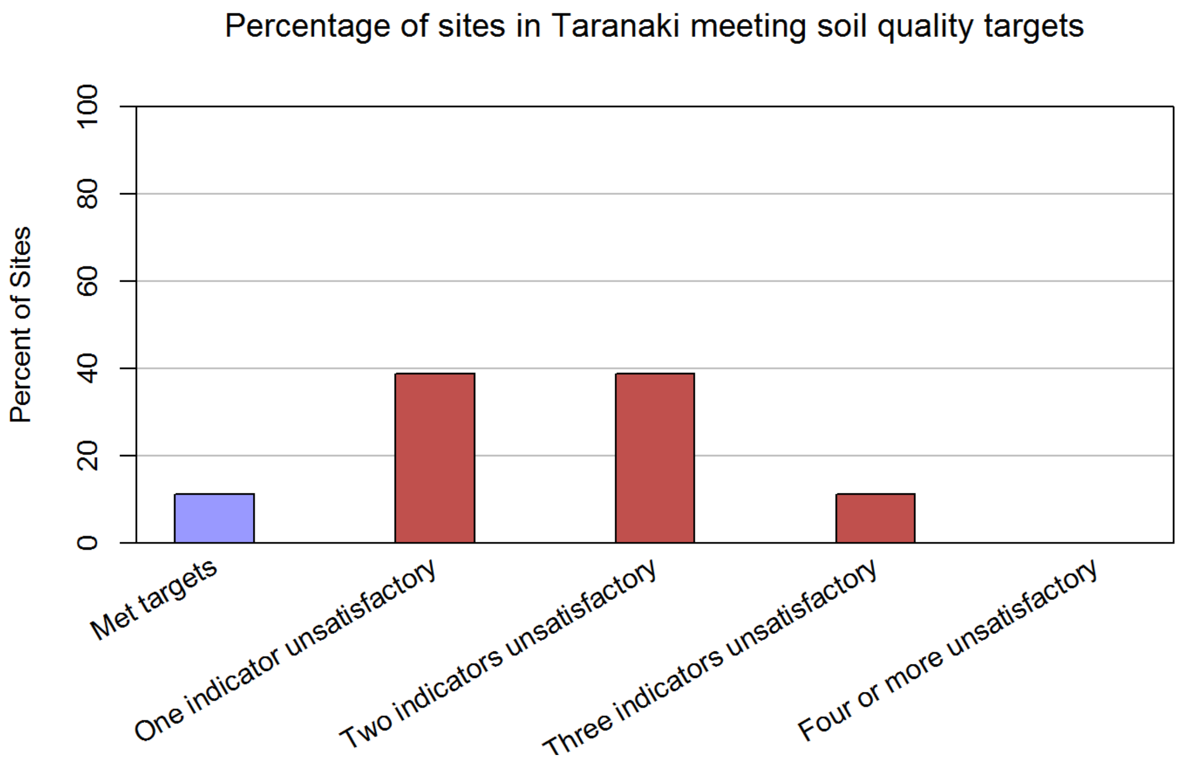

Figure 3 Proportions of the 18 managed land-use sites meeting targets for soil quality indicators on a volumetric basis.

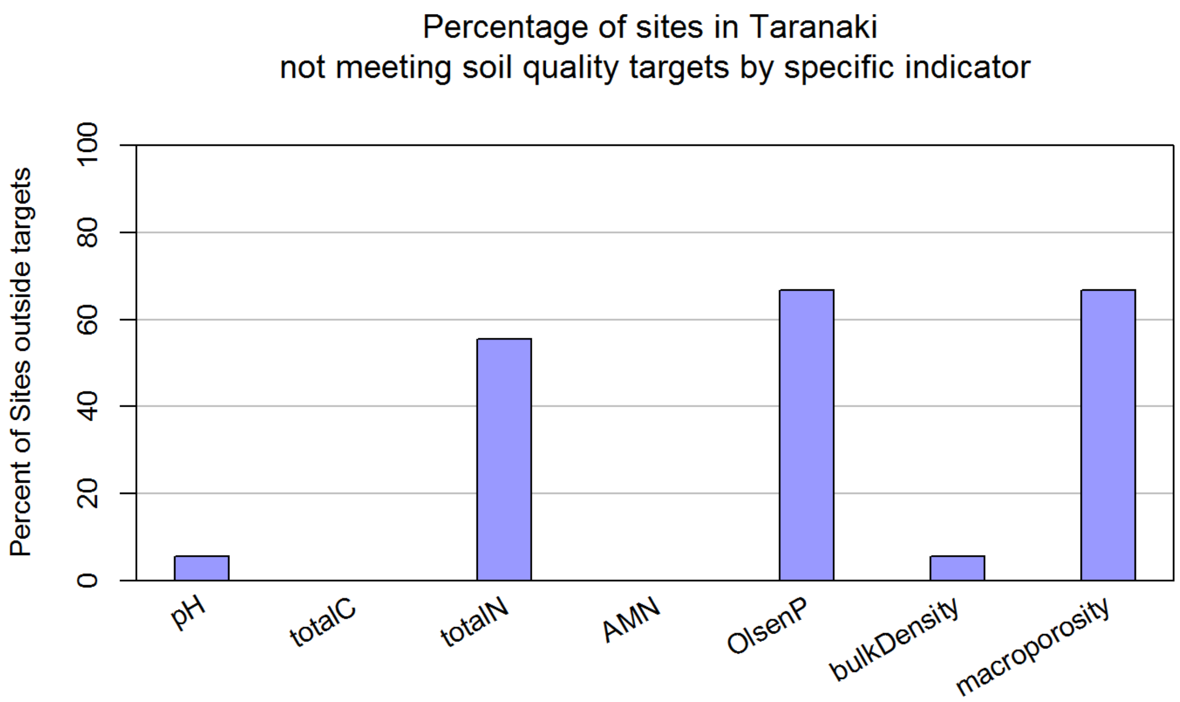

Figure 4 Proportions of the 18 managed land-use sites failing to meet target ranges for specific indicators on a gravimetric basis.

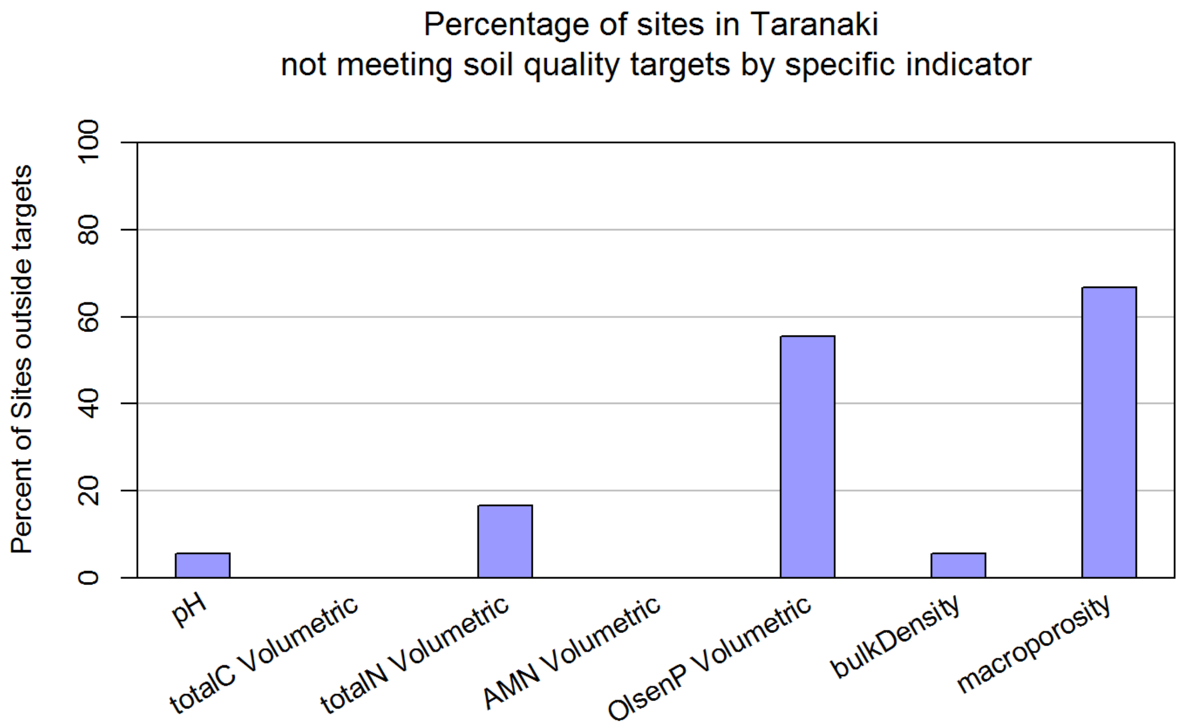

Figure 5 Proportions of the 18 managed land-use sites failing to meet target ranges for specific indicators on a volumetric basis.

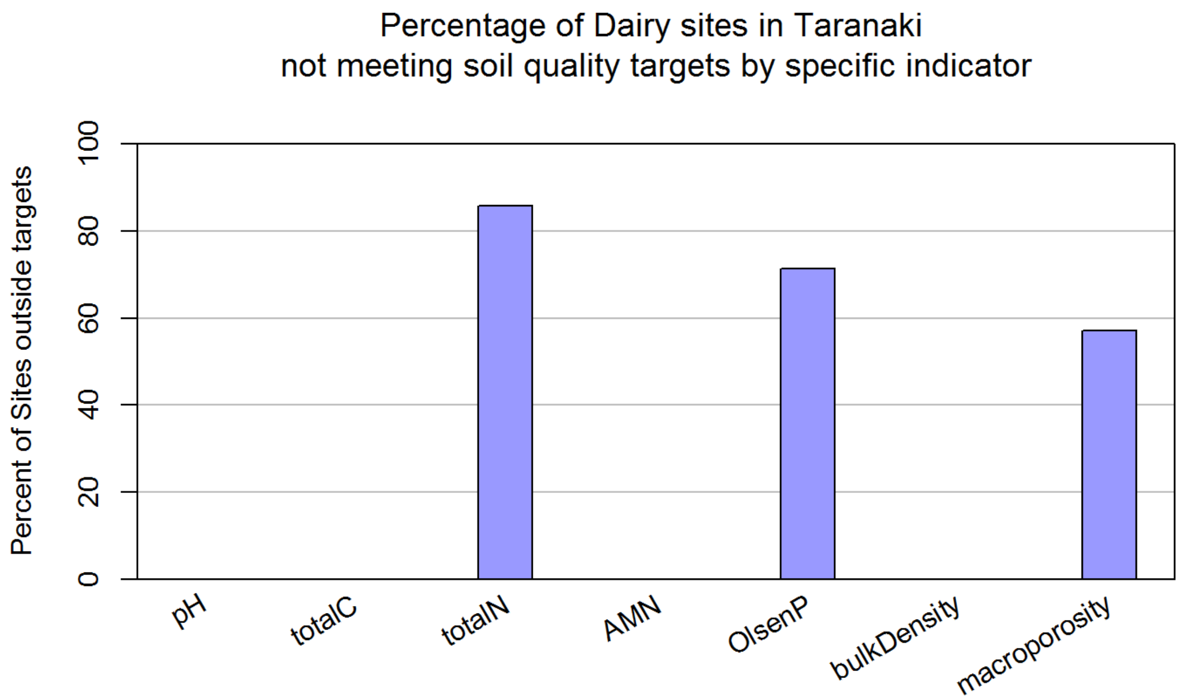

Figure 6 Proportion of the seven dairy sites failing to meet target ranges for specific indicators (on a gravimetric basis where applicable). For total N on a volumetric basis, 42% of sites did not meet targets.

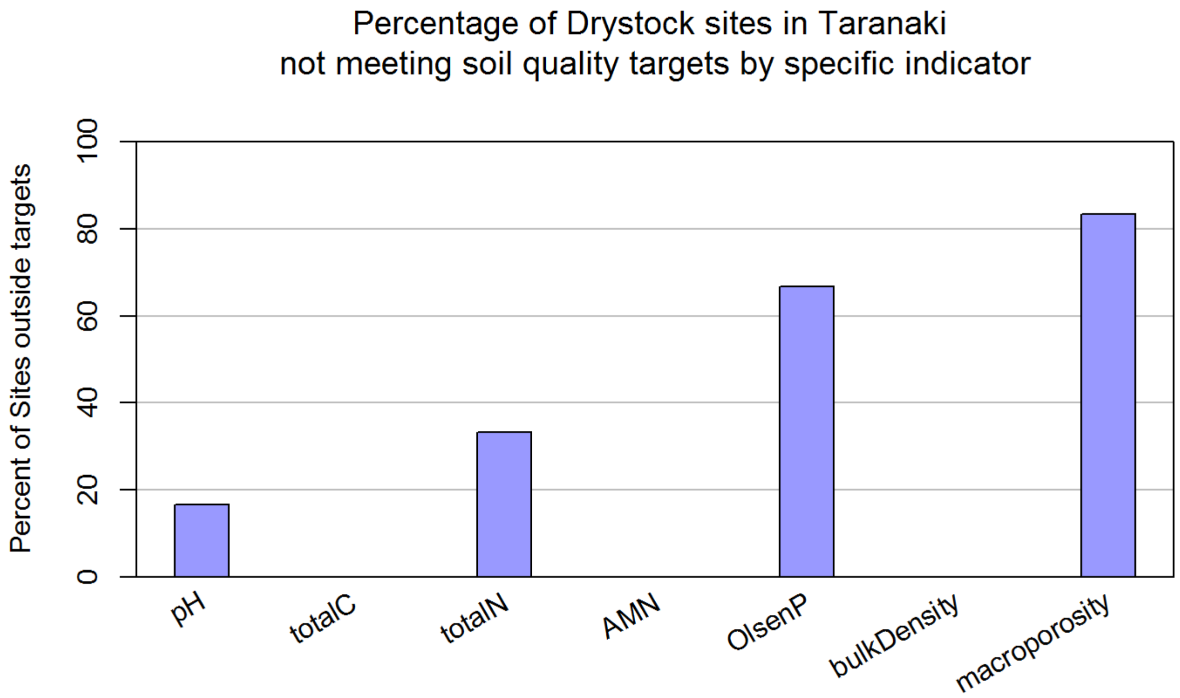

Figure 7 Proportion of the six drystock sites failing to meet target ranges for specific indicators (on a gravimetric basis where applicable). For total N on a volumetric basis, all sites met targets.

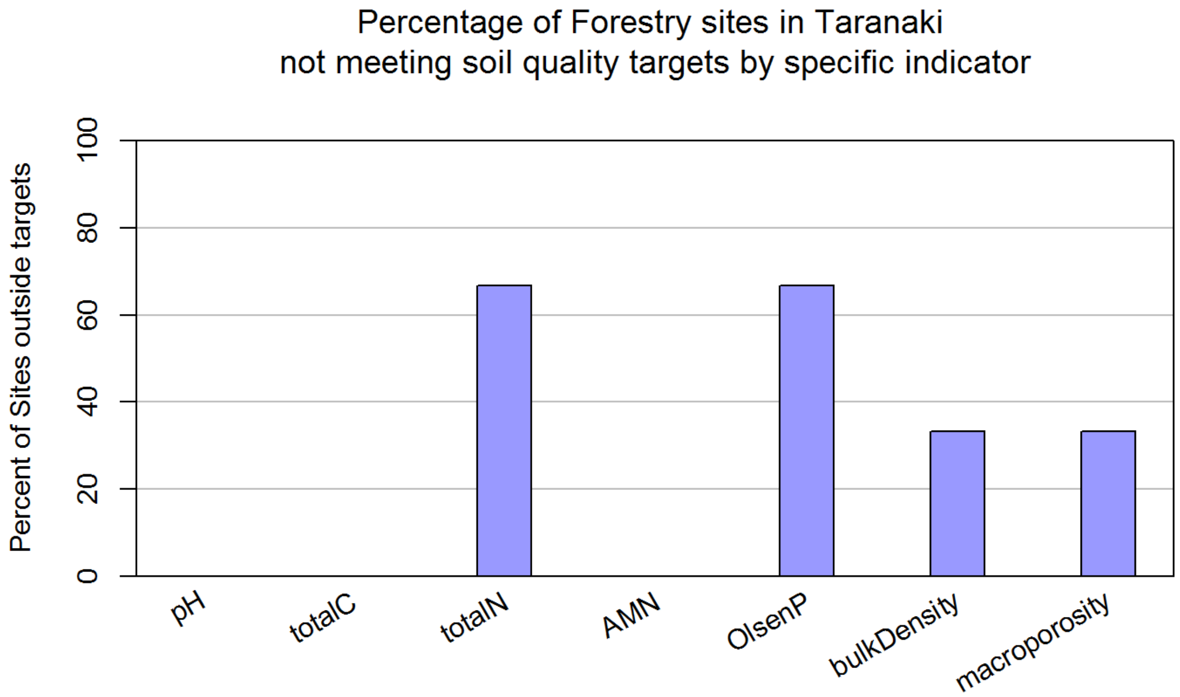

Figure 8 Proportion of three plantation forestry sites failing to meet target ranges for specific indicators (on a gravimetric basis where applicable). For total N on a volumetric basis, all sites met targets.

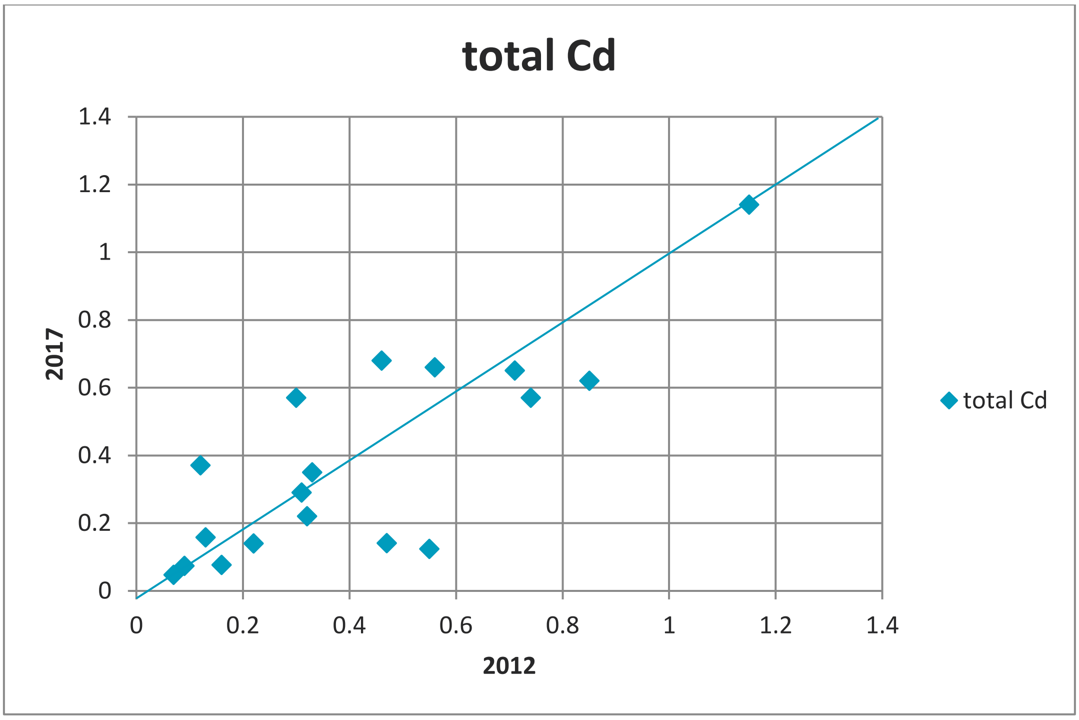

Figure 9 Total soil cadmium (mg kg^{-1}) in 2012 versus 2017. The solid line represents a 1:1 ratio (i.e. no change), with values above the line indicating an increase in soil Cd and those below the line a decrease in soil Cd.

3.3 Changes in soil quality over time

Changes in soil quality characteristics since 2012

Few statistically significant trends were observed in the resampled sites. For plantation forestry sites (Tables 8 and 9; Figs 8, 9, and 10) there was an overall decrease in mineralisable N and microbial biomass. Although there are several possible explanations for these trends, they would generally be consistent with a maturing exotic forest

For dairy sites (for which there is more statistical power by virtue of greater sample size), there was a significant decreases in the C:N ratio and basal respiration. The average C:N ratio for all dairy sites was 11.1, but one site has a relatively high C:N (SOL000147, with a C:N ratio of 14.37) and if that site is excluded the average C:N ratio of the six other dairy sites is 10.5.

There were no significant changes in drystock sites. As there were only two each of resampled crop and indigenous sites, statistical analysis was not performed on these data.

Some individual sites experienced changes larger than would normally be expected for stable land uses. Caution is advised in interpreting these changes until further data are obtained as they could be due to a variety of factors such as changes in management practices or slight variation in sampling location or procedure (thus our continued reminders that sampling procedures be consistently followed and sampling location marked as accurately as possible).

Soil quality characteristics for those sites that have been sample four times

Nine of the 20 sites (three forestry, two drystock and four dairy sites) have been monitored four times, beginning in 1998–2000 (Table 10). As previously reported, the most notable trend was decreases in macroporosity. Decline in macroporosity has been a major concern in dairy and drystock landuses across all regions. Declines in macroporosity over time are most evident in SOL000095 and SOL000133), whereas the other sites have been low since the initial sampling.

There were few definitive trends in other indicators across sites within each land use. If, however, these same sites continue to be monitored in the next sampling, the five sampling dates should give reasonable power to statistically determine if there are directional changes in the data.

Table 8 Change in soil quality characteristic from current sampling (volumetric basis) in comparison to 2012 soil quality data. Where three or more sites of a particular land use were monitored, asterisks indicate significant level of change (p* < 0.05, ** *p* < 0.01, *** *p* < 0.001)**

	pH	Total C (%)	Total N (%)	C:N (ratio)	AMN (μg g^{-1})	Olsen P (μg g^{-1})	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Air capacity (%)(v/v)	MBC (μgC g^{-1})	Basal resp (μgC g^{-1} h^{-1})
					Forestry						
SOL 000076	0.02	–2.78	–0.33	1.98	–111.36	–4.59	0.05	0.05	5.20	–665	–0.68
SOL 000077	–0.12	–4.75	–0.42	0.86	–117.91	–2.35	0.02	0.10	–5.37	–757	–1.00
SOL 000078	–0.40	–0.27	–0.02	0.14	–65.23	–0.73	–0.03	0.05	3.67	–256	–0.89
Sum	**–0.50**	**–7.80**	**–0.77**	**2.99**	**–294.50**	**–7.66**	**0.04**	**0.20**	**3.50**	**–1678**	**–2.56**
Sd	**0.21**	**2.25**	**0.21**	**0.93**	**28.71**	**1.93**	**0.04**	**0.03**	**5.71**	**267**	**0.16**
Mean	**–0.17**	**–2.60**	**–0.26**	**1.00**	**–98.17****	**–2.55**	**0.01**	**0.07**	**1.17**	**–559***	**–0.85**
					Drystock						
SOL 000067	–0.22	0.82	0.10	–0.54	29.82	–52.18	–0.11	–0.01	–2.53	290	–0.13
SOL 000087	–0.20	–0.19	–0.01	–0.05	–21.44	15.48	0.02	0.00	1.97	–27	–0.33
SOL 000123	–0.06	2.96	0.20	0.49	115.05	7.70	–0.13	–0.14	–6.10	1417	–0.03
SOL 000128	–0.37	–0.60	–0.06	0.13	–17.15	20.69	–0.08	–0.06	4.83	–359	–0.91
Sum	**–0.85**	**2.98**	**0.22**	**0.03**	**106.29**	**–8.30**	**–0.18**	**–0.19**	**0.70**	**1321**	**–1.40**
Sd	**0.13**	**1.59**	**0.12**	**0.43**	**63.39**	**33.82**	**0.08**	**0.07**	**5.67**	**772**	**0.40**
Mean	**–0.21**	**0.75**	**0.05**	**0.01**	**26.57**	**–2.07**	**–0.06**	**–0.06**	**0.23**	**330**	**–0.35**
					Dairy						
SOL 000081	0.19	–0.14	0.00	–0.09	–60.68	–4.60	0.01	0.00	0.77	9	–1.16
SOL 000093	–0.12	–2.38	–0.16	–0.59	–17.17	15.51	0.05	0.10	0.00	–265	–1.17
SOL 000094	0.09	–0.02	–0.01	0.04	-26.68	54.18	0.07	–0.01	–0.93	501	–0.09
SOL 000095	–0.25	-0.42	–0.03	–0.17	–64.49	–2.00	–0.05	–0.04	2.93	–27	–1.17

SOL 000110	–0.44	–1.30	–0.09	–0.34	-38.30	–13.79	0.00	–0.01	–1.40	170	–0.41
SOL 000147	–0.12	3.76	0.30	–0.68	7.88	7.49	–0.04	0.10	9.53	258	–0.36
SOL 000150	–0.27	1.37	0.14	–0.33	23.28	12.47	–0.12	–0.06	–1.90	–48	–1.33
Sum	**–0.92**	**0.87**	**0.15**	**–2.16**	**–176.17**	**69.28**	**–0.08**	**0.09**	**9.00**	**599**	**–5.69**
Sd	**0.22**	**1.98**	**0.15**	**0.26**	**32.88**	**22.05**	**0.07**	**0.06**	**3.98**	**248**	**0.50**
Mean	**–0.13**	**0.12**	**0.02**	**–0.31***	**–25.17**	**9.90**	**–0.01**	**0.01**	**1.29**	**85**	**–0.81***
Cropping											
SOL 000133	–0.35	–0.41	–0.01	–0.41	3.74	22.55	0.06	0.01	–2.20	–74	–0.28
SOL 000146	–0.10	0.47	0.05	–0.10	19.39	6.98	0.03	–0.01	–0.23	276	0.14
Indigenous											
SOL 000148	–0.20	4.89	0.34	1.14	56.89	-5.62	–0.22	-0.13	7.57	310	–0.15
SOL 000149	0.12	2.75	0.25	–0.63	144.35	-38.49	–0.02	0.35	–0.73	1297	–1.32

Table 9 Soil quality characteristics (gravimetric basis where applicable) for sites that have been sample three times. Note: the −5 kPa macroporosity measurements were used here as the −10 kPa aircapacity measurements were not taken in 1998–2000

Site	Land use	Date	pH	Tot C (%)	Tot N (%)	C/N (ratio)	AMN (mg kg^{-1})	Olsen P (mg kg^{-1})	Bd (Mg m^{-3})	Pd (Mg m^{-3})	Macroporosity (–5 kPa) (%) (v/v)
SOL 000076	Forestry	2017	5.35	11.6	0.78	14.9	164	4	1.02	2.65	2.8
		2012	5.52	14.4	1.11	12.9	275	2.0	0.53	2.27	17.4
		2007	5.33	15.4	1.25	12.5	246	1.5	0.56	2.27	17.4
		1998–2000	5.32	15.5	1.07	14.5	259	0.8	0.48	2.29	33.5
SOL 000077	Forestry	2017	4.96	14.0	0.98	14.3	139	6	0.51	2.23	13.9
		2012	5.08	18.7	1.40	13.4	257	1.9	0.48	2.09	18.3
		2007	5.08	17.3	1.37	13.4	222	1.4	0.51	2.09	18.3
		1998–2000	5.16	16.7	1.37	12.2	308	1.4	0.44	1.99	22.2
SOL 000078	Forestry	2017	5.25	9.06	0.48	19.0	106	5	0.58	2.46	29.2
		2012	5.57	9.3	0.49	18.9	171	1.4	0.61	2.41	20.9
		2007	5.65	9.2	0.46	19.2	121	1.0	0.65	2.42	20.9
		1998–2000	5.75	7.2	0.36	20.3	92	0.6	0.79	2.53	22.9
SOL 000087	Dry Stock	2017	4.83	9.13	0.88	10.4	187	58	0.72	2.43	2.7
		2012	5.39	9.3	0.89	10.5	208	12.3	0.70	2.43	1.1
		2007	5.03	7.8	0.70	10.8	141	11.1	0.71	2.37	3.3
		1998–2000	5.56	9.2	0.90	10.0	202	11.9	0.72	2.39	7.5
SOL 000128	Dry Stock	2017	5.23	5.01	0.48	10.4	158	49	0.72	2.50	3.87
		2012	5.65	5.6	0.55	10.3	175	8.9	0.80	2.56	1.0
		2007	5.60	5.4	0.55	10.5	151	10.6	0.73	2.53	2.9
		1998–2000	5.15	5.7	0.57	10.0	191	12.2	0.88	2.45	3.7

SOL 000093	Dairy	2017	5.43	10.1	0.98	10.4	261	58	0.64	2.47	4.5
		2012	5.83	12.5	1.14	11.0	278	10.6	0.60	2.37	3.4
		2007	5.55	9.9	0.92	10.5	176	16.4	0.76	2.44	4.3
		1998–2000	5.82	8.2	0.79	10.0	255	16.8	0.62	2.35	0.7
SOL 000094	Dairy	2017	5.68	8.71	0.93	9.4	174	108	0.86	2.47	0.7
		2012	5.69	8.7	0.93	9.4	201	17.0	0.79	2.47	0.7
		2007	5.59	9.3	1.00	9.3	201	15.9	0.80	2.42	3.1
		1998–2000	6.06	8.7	0.94	9.0	282	10.3	0.81	2.39	3.0
SOL 000095	Dairy	2017	5.80	8.95	0.87	10.3	164	42	0.82	2.46	5.7
		2012	6.02	9.4	0.90	10.4	228	15.4	0.87	2.50	2.5
		2007	6.05	9.4	0.89	10.3	208	15.9	0.79	2.45	4.4
		1998–2000	5.71	7.3	0.69	11.0	203	18.4	0.84	2.49	12.4
SOL 000133	Dairy	2017	6.50	7.53	0.73	10.4	50	79	0.95	2.56	3.6
		2012	5.79	7.9	0.74	10.8	46	19.8	0.90	2.55	3.3
		2007	6.85	7.7	0.65	10.8	69	23.2	0.77	2.50	16.2
		1998–2000	6.28	8.7	0.80	11.0	84	17.4	0.68	2.47	29.7

4 Discussion

While the trend toward dairy conversion of land and rapid intensification may have slowed, national trends still point toward soil issues around macroporosity and high levels of phosphorus and/or nitrogen (MfE 2018). This is reflected in the current set of land-use and soil quality characteristics for the Taranaki Region. Low macroporosity continues to be the indicator of most concern affecting the majority of dairy and drystock sites. In Taranaki, fewer drystock sites than dairy met the target range for macroporosity. While drystock is often thought of as being less intensive than dairy, patterns in flatland dairy and drystock in both the Waikato and Taranaki regions, suggest that drystock can be just as intensive as dairy.

The spring sampling period is arguably the time when compaction will be at its greatest, but several sites have shown extremely low macroporosity values over three to four sampling periods.

High nutrient levels are also a problem nationally. High N levels may lead to leaching or runoff losses to surface or groundwater that will impact on water quality. The gravimetric target values currently recommended are not well suited to high C soils, and on a volumetric basis substantially fewer sites are over targets. However, the average C:N ratio of dairy sites (excluding one dairy site, SOL000147, which had a very high C:N ratio), was approximately 10.5, indicating the soils are nearing N saturation (Schipper et al. 2004). It should also be noted that as the C:N ratio declines, the rate of N immobilisation also declines (Sparling et al. 2003), so even if the soils are not at saturation, their capacity to immobilise N is likely to be decreasing.

The lowering of the Olsen P upper target range did increase the number of sites outside the target range; however, the new range is more in line with industry recommendations for pastoral land uses. Several sites (SOL000067, SOL000094 and SOL000192), had very high Olsen P levels, even considering the previous ranges. Unlike the previous report, however, low Olsen P levels were not observed on drystock sites.

Examples of possible management options are on-farm nutrient budgeting; greater use of run-off pads on dairy farms; rapid movement of cattle from susceptible paddocks to minimise pugging and/or compaction; subsoiling to relieve soil compaction; direct drilling for pasture renewal; disposal of effluents only onto suitable land and at rates that allow adequate treatment; greater return of crop residues; and use of minimum and zero tillage in arable farming. Education of landowners and land managers must be an integral part of this strategy. We recommend that activities in this area continue to be expanded. Most of the soil quality characteristics reported here can be modified (or reversed) by suitable management; trace element accumulation remains a longer term concern.

As in the past sampling, selection of indicators for soil biological health remains problematic. The analyses selected for this sampling (respiration and microbial biomass) are among the most utilised techniques currently available. Although they do provide useful information in general comparisons of land use and can determine soils that are drastically compromised, they are difficult to interpret in the soil/land use context used to describe the standard soil quality indicators. Comparison of these indicators over time may provide some suggestion of microbial functioning but changes, particularly in microbial biomass and respiration, are difficult to interpret as they are somewhat dependent on climatic conditions at the time of sampling and increases and decreases in these indicators do not necessarily correlate to positive and negative effects on soil health.

5 Conclusions

- Overall, there has been a decrease in soil quality statistics of sites monitored, but this is related to the more realistic Olsen P target range values (i.e. more sites are outside the new ranges than the old) rather than a trend in indicator values themselves. It is important to note, however, that Olsen P levels at several sites were still exceptionally high (in excess of 100 µg g^{-1}).
- The general patterns in soil quality are similar to those found in other regions.
- Primary concerns are (1) compaction of soils on dairy and drystock sites; and (2) generally high Olsen P and/or N levels on dairy and flatland drystock sites (where intensity of grazing often approaches that of dairy farms).
- Although target value statistics for total N were similar to the last reporting period when considered on a volumetric basis (and total sites meeting the mineralisable N targets improved), the downward movement of the C:N ratio for dairy does suggest these soils may be nearing N saturation.
- The low macroporosity values on dairy and drystock sites mirror results from other regions of the country where land use has intensified and soil compaction from intensive grazing remains a concern. The Allophanic Soils of the Taranaki region are generally more resilient than non-Allophanic Soils; however, even the Allophanic Soils are showing evidence of adverse compaction, indicated by low air capacity values. High N and/or Olsen P values on dairy sites are also of concern because of the risk to water quality.
- There was no overall significant change in Cd concentrations from the previous sampling suggesting soil Cd levels may be plateauing, but further monitoring is required to confirm this trend. One site, however, has consistently been over the 1 mg kg^{-1} level.
- The lack of a distinct trend in Cd values between the current and previous sampling also suggests that the change in the analytical methodology for Cd analysis did not adversely affect the results.
- The majority of instances of poor soil quality could be reversed by appropriate management.
- The microbial health analyses (basal respiration, microbial biomass), showed differences between sites; however, due to difficulty in defining target ranges it is not possible to provide a clear statement on functional and biodiversity status of Taranaki soils. Comparison of these parameters over time may still provide useful indicators of microbial functioning.

6 Recommendations

- A soil-quality monitoring programme of resampling existing sites continues in order to determine the extent and direction of any changes since originally sampled.
- With the advent of national reporting (e.g. the recent MfE 2018 Land report), sampling protocols, indicators and target values are currently being reviewed by the Environmental Monitoring and Reporting (EMaR) group to achieve a more unified sampling and reporting regime across regions. There are likely to be further changes in soil quality monitoring, and it is recommended that TRC have a voice in these changes through the Land Management Forum.
- Since the change in method for Cd analysis did not adversely affect results, we would recommend that TRC continue to use the US EPA nitric/hydrochloric acid digest. There was some variation in individual site Cd values, and while it may be worthwhile to consider having some of those samples rerun in the future, we do not consider this to be a pressing need at present.
- Taranaki Regional Council considers activities to educate land managers on strategies to protect the environment while achieving an economic return from the land. In particular, awareness of the current recommendations on Olsen P levels and the general benefits of nutrient budgeting are recommended.
- After the next sampling, a number of sites will have been sampled five times. Although the number of sites is relatively small (on a statistical basis), TRC should consider formal statistical analysis of temporal trends for the next report.

7 Acknowledgements

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

8 References

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

Cadmium Working Group. 2011. Cadmium and New Zealand agriculture and horticulture: a strategy for long term risks management. MfE technical report. ISBN online: 978–0–478–37546–6 (accessed 25 July 2013).

Hill RB, Sparling G, Frampton C, Cuff J 2003. National soil quality review and programme design: environmental reporting – signposts for sustainability. Ministry for the Environment Technical Paper No 75: Land. 34 p.

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

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

Kovacs B, Prokisch J, Gyori Z, Kovacs AB, Palencsar A 2000. Studies on soil sample preparation for inductively coupled plasma atomic emission spectrometry analysis. Communications in Soil and Plant Analysis 31: 1949–1963.

Mackay, A, Dominati E, Taylor M. 2013. Soil quality indicators: the next generation. AgResearch Client Report RE500/2012/025 prepared for the Land Management Forum.

McDowell RW. 2012. The rate of accumulation of cadmium and uranium in a long-term grazed pasture: implications for soil quality. New Zealand Journal of Agricultural Research 55: 133–146.

McLaren RG, Clucas LM, Taylor MD 2005. Leaching of macronutrients and metals from undisturbed soils treated with metal-spiked sewage sludge. 3: Distribution of residual metals. Australian Journal of Soil Research 43: 159–170.

Ministry for the Environment & Stats NZ (2018). New Zealand's Environmental Reporting Series: Our land 2018. Retrieved from www.mfe.govt.nz and www.stats.govt.nz. 134 p.

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

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

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

Schipper LA, Percival HJ, Sparling GP 2004. An approach for estimating when soils will reach maximum nitrogen storage. Soil Use and Management 20: 281–286.

Schipper LA, Sparling GP, Fisk LM, Dodd, MB, Power IL, Littler RA 2011. Rates of accumulation of cadmium and uranium in a New Zealand hill farm soil as a result of long-term use of phosphate. Agriculture, Ecosystems & Environment 144: 95–101.

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

Sparling GP 2003. Implementing soil quality indicators for land: Waikato region 2003-2004. Landcare Research Contract Report LC0304/121. Hamilton, Landcare Research.

Sparling G, Ross D, Trustrum N, Arnold G, West A, Speir T, Schipper 2003. Recovery of topsoil characteristics after landslip erosion in dry hill country of New Zealand, and a test of the space-for-time hypothesis. Soil Biology & Biochemistry 35(12): 1575–1586.

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

Sparling GP, Zhu C 1993. Evaluation and calibration of methods to measure microbial biomass C and N in soils from Western Australia. Soil Biology and Biochemistry 25: 1793–1801.

Sparling GP, Rijkse W, Wilde RH, van der Weerden T, Beare MH, Francis GS 2001a. Implementing soil quality indicators for land: Research report for 1999/2000. Landcare Research Contract Report LC0001/059.

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

Sparling GP, Stevenson BA 2008. Soil quality in Taranaki Region: Characteristics of new sites, and current status of previously sampled sites. Landcare Research Contract Report LC0708/096.

Vance ED, Brookes PC, Jenkinson DS 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry 19: 703–707.

Wu J, Joergensen RG, Pommeraning B, Chaussod R, Brookes PC 1990. Measurements of soil microbial biomass C by fumigation-extraction: an automated procedure. Soil Biology and Biochemistry 22: 1167–1169.

Appendix 1 – Soil Chemistry and Biochemistry Data

Landcare Research
Manaaki Whenua

Environmental Chemistry Laboratory
Analytical Report - Soils

Private Bag 11052
Palmerston North 4442

Phone: +64 6 353 4800
Fax: +64 6 353 4801

Job Number: LJ17047
Customer: Bryan Stevenson, Landcare Research Ltd
Private Bag 3127, Hamilton 3240

Date Received: 17th November 2017
Date Reported: 26th March 2018

Client ID	Sample No.	Water Content (method 104(II)) (% dry wt)	pH (2:5 Water) (method 106(I))	Organic C (method 114) (%)	Total N (method 114) (%)	KCl-extractable (method 118) (mg/kg)		Anaerobic Mineralisable-N (method 120) (mg/kg)
						NO_3-N	NH_4-N	
SOL00067	M17/2134	50	5.69	5.79	0.53	8	1	125
SOL00076	M17/2135	95	5.35	11.6	0.78	10	2	164
SOL00077	M17/2136	88	4.96	14.0	0.98	19	2	139
SOL00078	M17/2137	49	5.25	9.06	0.48	5	2	106
SOL00081	M17/2138	119	5.89	13.8	1.30	54	1	262
SOL00087	M17/2139	81	4.83	9.13	0.88	84	2	187
SOL00093	M17/2140	68	5.43	10.1	0.98	82	1	261
SOL00094	M17/2141	53	5.68	8.71	0.93	66	1	174
SOL00095	M17/2142	55	5.80	8.95	0.87	35	1	164
SOL00110	M17/2143	70	5.07	8.23	0.71	54	1	161
SOL00123	M17/2144	135	5.54	13.1	1.03	13	2	288
SOL00128	M17/2145	71	5.23	5.01	0.48	25	2	158
SOL00133	M17/2146	58	6.50	7.53	0.73	58	0	50
SOL00146	M17/2147	61	5.70	8.75	0.86	53	0	117
SOL00147	M17/2148	72	5.63	15.1	1.05	40	1	191
SOL00148	M17/2149	86	5.75	10.9	0.87	29	1	266
SOL00149	M17/2150	165	5.04	18.7	1.35	36	47	424
SOL00150	M17/2151	28	5.70	5.27	0.48	36	2	107
SOL00191	M17/2152	87	5.04	5.23	0.49	12	2	170
SOL00192	M17/2153	41	5.25	6.20	0.57	27	2	132

N Foster

Ngaire Foster, Lab Manager

Page 1 of 2

IANZ
ACCREDITED LABORATORY

Job Number: LJ17047

Date Reported: 26th March 2018

Landcare Manaaki

Client ID	Sample No.	Olsen P (method 124) (mg/kg)	Microbial Biomass Carbon (method 174) (mg/kg)	Basal Respiration (method 172)* µgC/g/h	$Ca(NO_3)_2$-extractable Cadmium (method 154)* mg/kg	Total Cadmium (subcontract) mg/kg
				*	*	
SOL00067	M17/2134	164	668	0.78	0.016	0.350
SOL00076	M17/2135	4	1480	1.44	0.007	0.076
SOL00077	M17/2136	6	1350	1.32	<0.007	0.073
SOL00078	M17/2137	5	983	1.38	<0.007	0.047
SOL00081	M17/2138	31	3030	1.73	0.009	1.14
SOL00087	M17/2139	58	1580	1.25	0.021	0.290
SOL00093	M17/2140	58	2140	1.19	0.016	0.620
SOL00094	M17/2141	108	1660	1.33	0.009	0.660
SOL00095	M17/2142	42	1300	0.17	<0.007	0.680
SOL00110	M17/2143	50	1470	1.11	0.037	0.570
SOL00123	M17/2144	23	2810	1.54	0.019	0.570
SOL00128	M17/2145	49	1630	1.44	0.016	0.220
SOL00133	M17/2146	79	216	0.17	<0.007	0.650
SOL00146	M17/2147	36	762	0.85	0.016	0.510
SOL00147	M17/2148	58	1330	1.65	0.010	0.650
SOL00148	M17/2149	14	1750	1.42	<0.007	0.124
SOL00149	M17/2150	5	3050	1.69	<0.007	0.141
SOL00150	M17/2151	47	843	0.09	<0.007	0.158
SOL00191	M17/2152	32	1640	0.71	0.012	0.140
SOL00192	M17/2153	134	1360	1.38	0.013	0.370

Appendix 2 – Soil Physics Data

Moisture Release & Solid/Void Characterisation

Project Name: Taranaki Regional Council Soil Quality Monitoring 2017

Contact Name: Bryan Stevenson

Job Number: 682202-0245

Date: 12 April 2018

Lab Number	Client ID	Sampled Liner Number	Lab Liner Number	Initial Water Content (%, w/w)	Dry Bulk Density (t/m^3)	Particle Density (t/m^3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)
HP7356a	SOL000067 15 m	1637	844	52.6	1.05	2.63	60.0	0.9	3.0	59.1	56.9
HP7356b	SOL000067 30 m	1627	843	61.1	0.98	2.67	63.2	2.5	4.6	60.7	58.6
HP7356c	SOL000067 45 m	1592	959	48.6	1.04	2.65	60.7	5.1	7.8	55.6	53.0
HP7357a	SOL000076 15 m	1091	961	82.6	0.52	2.41	78.3	26.3	30.7	52.0	47.6
HP7357b	SOL000076 30 m	1278	969	71.6	0.65	2.47	73.8	18.3	21.5	55.5	52.3
HP7357c	SOL000076 45 m	1725	971	68.9	0.55	2.29	76.2	24.2	30.6	51.9	45.6
HP7358a	SOL000077 15 m	1379	812	98.2	0.59	2.29	74.1	8.5	11.4	65.6	62.7
HP7358b	SOL000077 30 m	1300	964	116.3	0.45	2.23	79.8	18.8	22.1	61.0	57.7
HP7358c	SOL000077 45 m	1234	965	112.9	0.48	2.17	77.7	14.5	17.8	63.2	59.8
HP7359a	SOL000078 15 m	1279	956	83.8	0.55	2.43	77.2	22.9	27.9	54.4	49.3
HP7359b	SOL000078 30 m	1707	977	40.2	0.65	2.54	74.3	33.6	36.6	40.7	37.7
HP7359c	SOL000078 45 m	1048	946	69.3	0.53	2.41	78.0	31.0	35.2	47.0	42.8

Lab Number	Client ID	Sampled Liner Number	Lab Liner Number	Initial Water Content (%, w/w)	Dry Bulk Density (t/m^3)	Particle Density (t/m^3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)
HP7360a	SOL000081 15 m	1649	945	138.9	0.51	2.32	77.8	6.0	9.3	71.8	68.5
HP7360b	SOL000081 30 m	1395	938	130.1	0.56	2.33	76.0	1.0	2.9	75.0	73.1
HP7360c	SOL000081 45 m	1504	983	148.0	0.51	2.30	78.0	3.5	6.8	74.4	71.2
HP7361a	SOL000087 15 m	1354	952	78.7	0.79	2.49	68.4	1.2	3.1	67.1	65.2
HP7361b	SOL000087 30 m	1721	944	100.1	0.65	2.36	72.3	4.2	7.5	68.2	64.8
HP7361c	SOL000087 45 m	1064	986	84.5	0.73	2.44	70.2	2.7	5.9	67.5	64.3
HP7362a	SOL000093 15 m	1293	957	89.0	0.63	2.52	74.9	7.2	10.8	67.7	64.1
HP7362b	SOL000093 30 m	1348	958	98.9	0.68	2.39	71.6	0.9	2.6	70.7	69.0
HP7362c	SOL000093 45 m	1195	967	97.7	0.62	2.51	75.2	5.4	9.6	69.8	65.6
HP7363a	SOL000094 15 m	1162	980	71.7	0.77	2.41	68.2	0.3	3.4	67.9	64.8
HP7363b	SOL000094 30 m	1264	963	58.9	0.91	2.50	63.6	0.9	2.9	62.7	60.6
HP7363c	SOL000094 45 m	1737	979	60.4	0.91	2.49	63.5	<1	0.0	65.8	63.5
HP7364a	SOL000095 15 m	1352	996	52.3	0.86	2.49	65.5	7.7	10.6	57.8	54.9
HP7364b	SOL000095 30 m	1716	517	60.4	0.83	2.46	66.4	3.2	6.8	63.2	59.6
HP7364c	SOL000095 45 m	1638	927	62.7	0.77	2.44	68.3	6.1	9.0	62.2	59.3
HP7365a	SOL000110 15 m	1561	988	59.6	0.93	2.51	63.1	5.0	7.9	58.1	55.3
HP7365b	SOL000110 30 m	1604	998	66.2	0.80	2.49	67.9	11.6	15.3	56.3	52.7
HP7365c	SOL000110 45 m	1615	999	71.0	0.83	2.45	66.3	5.7	9.4	60.6	56.9
HP7366a	SOL000123 15 m	1191	997	148.0	0.51	2.25	77.5	1.5	3.7	76.0	73.8
HP7366b	SOL000123 30 m	1316	990	130.0	0.57	2.32	75.4	0.9	2.3	74.5	73.2
HP7366c	SOL000123 45 m	1240	934	131.1	0.56	2.37	76.5	3.7	5.9	72.8	70.6

Lab Number	Client ID	Sampled Liner Number	Lab Liner Number	Initial Water Content (%, w/w)	Dry Bulk Density (t/m^3)	Particle Density (t/m^3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)
HP7367a	SOL000128 15 m	1041	921	104.7	0.65	2.37	72.4	3.6	7.6	68.8	64.9
HP7367b	SOL000128 30 m	1280	978	78.1	0.81	2.58	68.6	3.8	6.0	64.8	62.6
HP7367c	SOL000128 45 m	1260	970	97.8	0.71	2.54	72.0	4.2	8.8	67.8	63.3
HP7368a	SOL000133 15 m	1736	975	56.1	0.96	2.56	62.4	3.4	4.4	59.0	58.0
HP7368b	SOL000133 30 m	1363	924	56.1	0.98	2.54	61.5	2.1	3.3	59.4	58.2
HP7368c	SOL000133 45 m	1243	995	55.5	0.92	2.57	64.3	5.3	7.8	59.1	56.5
HP7369a	SOL000146 15 m	925	992	65.4	0.87	2.51	65.3	2.8	4.2	62.5	61.1
HP7369b	SOL000146 30 m	1140	989	64.2	0.89	2.50	64.3	1.5	2.9	62.8	61.5
HP7369c	SOL000146 45 m	1378	931	59.1	0.91	2.51	63.9	2.7	4.5	61.3	59.4
HP7370a	SOL000147 15 m	1317	920	102.1	0.59	2.24	73.8	3.6	6.6	70.2	67.2
HP7370b	SOL000147 30 m	1238	929	83.1	0.70	2.36	70.4	7.9	9.9	62.6	60.5
HP7370c	SOL000147 45 m	1072	680	68.0	0.74	2.48	70.0	10.3	14.4	59.6	55.6
HP7371a	SOL000148 15 m	1734	502	80.5	0.59	2.45	75.8	14.6	20.9	61.1	54.9
HP7371b	SOL000148 30 m	1065	930	90.9	0.51	2.43	79.0	22.0	26.1	57.0	52.9
HP7371c	SOL000148 45 m	1022	994	105.7	0.56	2.44	77.1	11.3	15.2	65.8	61.9
HP7372a	SOL000149 15 m	1170	932	160.7	0.36	2.54	85.7	25.8	30.4	59.9	55.3
HP7372b	SOL000149 30 m	1534	993	142.3	0.40	2.30	82.5	24.2	28.9	58.3	53.6
HP7372c	SOL000149 45 m	1389	925	286.8	0.21	2.28	90.6	29.3	34.2	61.3	56.4
HP7373a	SOL000150 15 m	1360	928	20.7	1.33	2.93	54.6	11.2	22.2	43.3	32.3
HP7373b	SOL000150 30 m	1232	510	37.4	0.97	2.91	66.8	15.8	24.0	51.0	42.8
HP7373c	SOL000150 45 m	1202	981	35.8	1.13	2.89	60.8	7.3	17.6	53.6	43.3

Lab Number	Client ID	Sampled Liner Number	Lab Liner Number	Initial Water Content (%, w/w)	Dry Bulk Density (t/m^3)	Particle Density (t/m^3)	Total Porosity (%, v/v)	Macro Porosity (%, v/v)	Air Filled Porosity (%, v/v)	Vol. WC 5kPa (%, v/v)	Vol. WC 10kPa (%, v/v)
HP7374a	SOL000191 15 m	1718	987	91.8	0.73	2.59	71.8	5.8	10.5	66.0	61.3
HP7374b	SOL000191 30 m	1230	665	78.9	0.83	2.61	68.1	2.9	7.4	65.2	60.7
HP7374c	SOL000191 45 m	1250	650	105.8	0.66	2.60	74.6	10.0	15.5	64.5	59.1
HP7375a	SOL000192 15 m	1002	852	51.7	0.77	2.38	67.8	3.6	6.7	64.2	61.1
HP7375b	SOL000192 30 m	1045	891	45.9	0.86	2.51	65.6	4.2	6.7	61.4	58.9
HP7375c	SOL000192 45 m	1732	854	34.4	0.87	2.48	65.1	7.5	10.4	57.6	54.7

Notes:

Macro-porosity cited here is determined between total porosity and tension of –5 kPa, for consistency with the National Soils Database of New Zealand (NSD).

Air-filled porosity cited here is determined between total porosity and tension of –10 kPa. This can be referred to as Macro-porosity.

It is important to be aware what tension has been used, particularly when data is compared with historical or NSD data.

Macro-porosity (and Air-filled porosity) figures marked as <1 indicate instances where the samples were right on the limit of the methodology capability.

These samples have extremely low Macro-porosity and have presented as negative numbers following calculation of the raw data.

In reality it is impossible for Macro-porosity to exceed Total Porosity hence the Macro-porosity data has been adjusted to simply indicate samples with extremely low figures.

Analyst DT

Checked by: John Claydon, Laboratory Manager

Date: 13 April 2018

Appendix 3 – Target Values used in generating soil quality statistics on a gravimetric basis, for volumetric reporting, total C and total N targets are multiplied by 10

		Target Values (gravimetric basis where applicable)													
		pH		**bulkDensity**		**macroporosity**		**totalC**		**totalN**		**AMN**		**OlsenP**	
Landuse	**Soil Order**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
Crop/Hort	Allophanic	5.0	7.6	0.5	1.3	8	30	3.0	NA	NA	NA	20	NA	20	50
Crop/Hort	Brown	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Crop/Hort	Gley	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Crop/Hort	Granular	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Crop/Hort	Melanic	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Crop/Hort	Organic	4.5	7.0	0.2	1.0	8	30	NA	NA	NA	NA	20	NA	20	40
Crop/Hort	Oxidic	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Crop/Hort	Pallic	5.0	7.6	0.7	1.4	8	30	2.0	NA	NA	NA	20	NA	20	45
Crop/Hort	Podzol	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	50
Crop/Hort	Pumice	5.0	7.6	0.6	1.4	8	30	2.0	NA	NA	NA	20	NA	20	50
Crop/Hort	Raw	5.0	7.6	0.6	1.4	8	30	2.0	NA	NA	NA	20	NA	5	25
Crop/Hort	Recent	5.0	7.6	0.7	1.4	8	30	2.0	NA	NA	NA	20	NA	20	45
Crop/Hort	SemiArid	5.0	7.6	0.7	1.4	8	30	2.0	NA	NA	NA	20	NA	20	45
Crop/Hort	Ultic	5.0	7.6	0.6	1.4	8	30	2.5	NA	NA	NA	20	NA	20	45
Dairy	Allophanic	5.0	6.6	0.5	1.3	10	30	3.0	NA	0.25	0.7	50	NA	20	50
Dairy	Brown	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
Dairy	Gley	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
Dairy	Granular	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45

		Target Values (gravimetric basis where applicable)													
		pH		bulkDensity		macroporosity		totalC		totalN		AMN		OlsenP	
Landuse	**Soil Order**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
Dairy	Melanic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Organic	4.5	7.0	0.2	1.0	10	30	NA	NA	0.25	0.7	50	NA	20	40
	Oxidic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Pallic	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	Podzol	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	5	25
	Pumice	5.0	6.6	0.6	1.4	10	30	2.0	NA	0.25	0.7	50	NA	20	50
	Raw	5.0	6.6	0.6	1.4	10	30	2.0	NA	0.25	0.7	50	NA	5	25
	Recent	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	SemiArid	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	Ultic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
Drystock	Allophanic	5.0	6.6	0.5	1.3	10	30	3.0	NA	0.25	0.7	50	NA	20	50
	Brown	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Gley	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Granular	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Melanic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Organic	4.5	7.0	0.2	1.0	10	30	NA	NA	0.25	0.7	50	NA	20	40
	Oxidic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
	Pallic	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	Podzol	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	5	25
	Pumice	5.0	6.6	0.6	1.4	10	30	2.0	NA	0.25	0.7	50	NA	20	50
	Raw	5.0	6.6	0.6	1.4	10	30	2.0	NA	0.25	0.7	50	NA	5	25

		Target Values (gravimetric basis where applicable)													
		pH		bulkDensity		macroporosity		totalC		totalN		AMN		OlsenP	
Landuse	**Soil Order**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
	Recent	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	SemiArid	5.0	6.6	0.7	1.4	10	30	2.0	NA	0.25	0.7	50	NA	15	45
	Ultic	5.0	6.6	0.6	1.4	10	30	2.5	NA	0.25	0.7	50	NA	15	45
Forestry	Allophanic	3.5	7.6	0.5	1.3	8	30	3.0	NA	0.10	0.7	20	NA	5	30
	Brown	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Gley	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Granular	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Melanic	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Organic	3.5	7.0	0.2	1.0	8	30	NA	NA	0.10	0.7	20	NA	5	30
	Oxidic	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Pallic	3.5	7.6	0.7	1.4	8	30	2.0	NA	0.10	0.7	20	NA	5	30
	Podzol	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30
	Pumice	3.5	7.6	0.6	1.4	8	30	2.0	NA	0.10	0.7	20	NA	5	30
	Raw	3.5	7.6	0.6	1.4	8	30	2.0	NA	0.10	0.7	20	NA	5	30
	Recent	3.5	7.6	0.7	1.4	8	30	2.0	NA	0.10	0.7	20	NA	5	30
	SemiArid	3.5	7.6	0.7	1.4	8	30	2.0	NA	0.10	0.7	20	NA	5	30
	Ultic	3.5	7.6	0.6	1.4	8	30	2.5	NA	0.10	0.7	20	NA	5	30