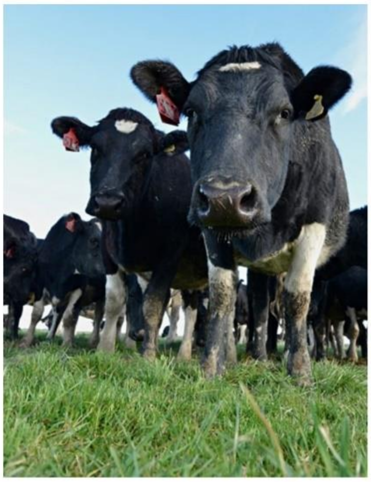


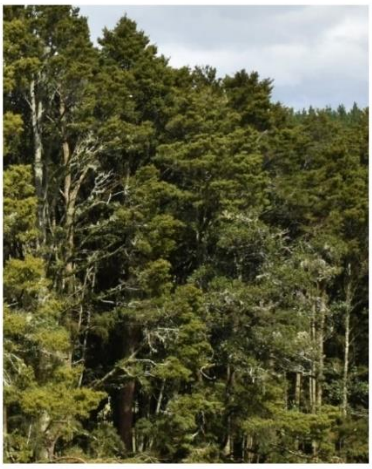


Soil quality in Northland

State of the Environment monitoring programme, 2001-2016

Date: November 2020

Author: John Ballinger and Andrew Macdonald

Northland
REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau

Executive Summary

This report presents soil quality data from 29 sites chosen to represent the major soil orders and land uses within the Northland Region. The sites were first sampled in 2001 as part of the nationwide 500 Soils Project, and subsequently every 5 years as part of council's State of the Environment (SOE) monitoring programme. The purpose of the programme is to monitor soil quality and trace element concentrations across different land uses and soil orders to examine the state and trends of soil throughout Northland.

Our soil monitoring data indicates that soil compaction and nutrient issues are a localised problem in Northland. Since 2001, soils have become compacted on a third of tested dairy and drystock sites. Furthermore, a proportion of dairy and drystock sites have elevated soil nitrogen levels, while others have low Olsen P levels. Some dairy and drystock sites, in addition to the orchard site, exhibited soil cadmium levels above the Tier 1 trigger value. However, the 2016 results were slightly lower than earlier years. These sites will be monitored closely following the next round of sampling. Soil pH levels were optimum at all sites except one drystock site while soil carbon levels were normal to elevated at all sites.

Many instances of degrading soil quality can be modified (reversed) by suitable management. Such on-farm management options include the use of run-off pads on dairy farms, rapid movement of cattle to minimize pugging, on-farm nutrient budgeting, disposal of effluent onto suitable land and at rates that allow for adequate treatment, greater return of crop residues, and the use of minimum and zero tillage in arable farming (Stevenson, 2007). Those sites with elevated cadmium levels should implement the actions defined in the Tiered Fertiliser Management System. Techniques that improve soil function through increasing the biological health of soil such as regenerative farming, are also gaining momentum in New Zealand and internationally.

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Introduction

Soil provides a wide range of services that are essential to life on earth. It is the part of the planet's natural capital that supports our food, feed, fibre and fuel production. Soils also provide a regulating service by cleaning our water, recycling nutrients and storing carbon (Collins et al., 2014), while hosting a quarter of our planet's biodiversity (FAO, 2015). For these reasons, the quality and quantity of soil is crucial to Northland's economy and the overall health of our land and water.

Soils and land use

Northland has over 200 described soil types occurring over undulating to moderately steep hill country that has been weathered by the subtropical climate over a long period of time. As a result, most of Northland's soils have clay-rich profiles over deeply weathered rock. Several factors have contributed to the high levels of physical and chemical weathering of the rocks including (Molloy, 1988; Harmsworth, 1996):

- A warm humid environment;
- strong influence of vegetation on soil formation;
- old topography with little rejuvenation from glaciation; and
- a scarcity of tephra.

"While only scattered remnants of pre-European forest remain, their influence on pedogenesis was considerable. Kauri produced deep layers of highly acidic litter, which is implicated in the podzolisation and gleying processes that have contributed to the poor physical properties of many of the region's soils." (Molloy, 1988)

"On the flatter areas which were originally covered in kauri, gumland soils developed. These were mined for kauri gum in the late 19th and early 20th centuries. Superphosphate was applied to gumland soils used for forestry, and potassium fertiliser has been used on podzolised sands. Pine forest grown near coastal sand dunes also needed nitrogen fertiliser, or associated plantings of lupins which 'fix' nitrogen in the soil so it can be used by the trees." (Gillingham, 2008)

"Gley podzol soils are generally used for sheep and beef farming, and dairying, but need lots of initial fertilisation. Derived from sedimentary parent rocks, gley podzols have brown clay topsoils, and are wet in winter and spring. They cannot support large numbers of cattle at those times, unless the soil is well drained. The other Northland soils are mostly a mix of brown soils, free-draining soils from basalt, and poorly drained hill and steepland soils from old andesitic volcanic action. The best free-draining (oxidic) soils, from more recent basaltic volcanism, are used for dairying and a range of horticultural crops.

"All Northland's soils are acidic and low in natural phosphorus and sulfur, so lime and superphosphate fertiliser have been applied for pasture growth. Other nutrients such as potassium, molybdenum and copper may also be required." (Gillingham, 2008)

Soil monitoring programme

This report presents soil quality data from 29 individual sites chosen to represent the major soil orders and land uses within the Northland Region. The sites were first sampled in 2001 as part of the nationwide 500 Soils Project and subsequently every 5 years as part of State of the Environment monitoring programme (Sparling et al., 2001; Stevenson, 2007; Ballinger, 2012). The purpose of the programme is to monitor soil quality across different land uses and soil orders to examine the state and trends of soil quality and trace elements throughout Northland.

Objectives

- Provide information on the physical, chemical and biological properties of soils;
- Identify the effects of primary land uses on soil productivity and the environment;
- Track specific, identified issues relating to the effects of land use on long-term soil productivity;
- Assist in the detection of spatial and temporal changes in soil quality and trace elements; and
- Provide information required to determine the effectiveness of regional policies and plans.

Monitoring network

Northland Regional Council's (NRC) soil quality monitoring programme comprises 29 individual sites chosen to represent the major soil orders and land uses within Northland. These included seven dairy sites, ten Drystock, five plantation forest, five native forest, and one horticultural. The frequency of sampling is every five years. A range of soil orders were sampled. Details of the soil order, group, soil type, and land use are presented in Table 3. As recommended by Stevenson (2011), the number of sites were increased from 24 to 29 for the 2016 sampling round.

Sampling and analysis methodology

Soil samples were collected by NRC staff and the chemical, physical and biological characteristics analysed by Manaaki Whenua–Landcare Research. The samples were collected using the protocols established in the 500 Soils Project and now adapted through the Land Monitoring Forum (2009) manual. Where appropriate, soils were chilled before analyses. Analyses were carried out as detailed in Stevenson (2007).

Soil quality indicators and interpretation

Inherent in soil quality assessment is the understanding that we can't measure soil quality directly, thus physical, chemical, and biological indicators are used as proxies for soil quality. Soil quality as defined by Doran and Parkin (1994) is "the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." Seven primary soil indicators were measured to assess soil quality in Northland (Table 1).

To assist with the interpretation of soil quality data collected during the sampling period, data were input into Manaaki Whenua–Landcare Research's 'Soil Quality Indicators (SINDI)' model. This interpretive framework houses empirically-derived land use-specific target ranges or thresholds for each of the seven soil quality indicators. The following information on the chosen indicators is sourced directly from the SINDI website (Manaaki Whenua–Landcare Research, 2012):

The indicators selected to assess soil quality in SINDI reflect the idea that soil quality is not a single concept but one that encompasses aspects of the soil physical structure, chemical fertility, nutrient storage, organic matter resources, and biological activity in the soil. There are potentially many indicators that can be used, but for any extensive national or regional monitoring scheme it is not practical to have more than a small core number.

Table 1 Indicators used for soil quality assessment (Manaaki Whenua–Landcare Research, 2012)

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

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

Group 1 - Olsen P

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

Group 2 – pH

One property makes up the second group representing the acidity status of the soil. Soil pH is the degree of acidity or alkalinity of a soil, which controls the availability of many nutrients to plants. The acidity of soil is greatly influenced by the application of lime and fertilisers. In their natural state, most soils in New Zealand are acidic (pH 5-7).

Group 3 – Mineralisable nitrogen, Total carbon, Total nitrogen

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

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

Group 4 — Bulk density, Macroporosity

These properties formed the fourth group representing the physical status of soil. Bulk density is a surrogate for soil compaction. Total porosity is a measure of the holes or voids within the soil matrix. Voids are important to allow air to penetrate the soil, but also to give the soil an open structure to enable it to retain water. The larger pores or macropores are of particular importance for infiltration and drainage but are easily lost when soil becomes compacted. The physical characteristics and the susceptibility to compaction are heavily influenced by soil mineralogy and soil texture (the relative amounts of sand, silt and clay sized particles that make up the mineral fraction of soils).

Trace element targets, draft eco-soil guidelines and trigger values

Indicators for trace element monitoring include arsenic, boron, cadmium, chromium, copper, lead, mercury, and zinc. The environment is sensitive to concentrations of these elements. Eco-soil guideline values (Eco-SGVs) were developed to protect soil and terrestrial biota namely soil microbes, invertebrates, plants, wildlife and livestock (Cavanagh 2016, 2019). Eco-SGVs are intended to provide a benchmark for assessing soil quality over time in relation to regional council State of the Environment (SOE) monitoring. The Eco-SGVs are presented in Table 2.

Soil mercury levels have been compared to the soil targets presented in the New Zealand Water and Wastes Association's *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (NZWWA, 2003). While guidelines for soil contaminant values have been written for a specific activity (e.g., biosolids application), the values are generally transferable to other activities that share similar hazardous substances. The biosolids guideline values for selected trace elements are presented in Table 2.

Cadmium results can also be compared against the trigger values in the Tiered Fertiliser Management System (FA, 2019) from the New Zealand Cadmium Management Strategy (CMG, 2019). This strategy, developed in response to concerns about the accumulation of cadmium in soils from phosphate fertiliser usage, recommends different management actions at certain trigger values. Trace element trigger values from these sources are also presented in Table 2.

Table 2 Trace element targets, draft eco-soil guidelines and trigger values

Eco-soil guideline values for trace element concentrations in soil from Cavanagh (2016) and Cavanagh et al., (2019).	**Upper soil limit (in mg metal concentration per kg dry weight soil).**
Arsenic (As)	Agricultural land - 20 mg/kg
Boron (B)	Agricultural land - 6 mg/kg
Chromium (Cr)	Agricultural land - 300 mg/kg
Lead (Pb)	Agricultural land - 530 mg/kg
Copper (Cu)	Typical soil (Brown) - 220 mg/kg Sensitive soil (Recent) - 150 mg/kg Tolerant soil (Allophanic) - 340 mg/kg
Zinc (Zn)	Typical soil (Brown) - 190 mg/kg Sensitive soil (Recent) - 130 mg/kg Tolerant soil (Allophanic) - 265 mg/kg
Tiered Fertiliser Management System (FANZ, 2019) Cadmium (Cd)	0.6 mg/kg (Tier 1 trigger value) 1.0 mg/kg (Tier 2 trigger value) 1.4 mg/kg (Tier 3 trigger value) 1.8 mg/kg (Tier 4 trigger value)
Guideline values for heavy metal concentrations in soils (NZWWA 2003) Mercury (M)	1 mg/kg

Table 3 Site codes, soil series, soil classification (Hewitt, 1998) and land uses resampled in 2016-17

Site code	Soil subgroup, group, order	Soil type	Land use, farm system or vegetation at time of sampling (2016-17)
NRC00_1	Typic Orthic Granular	Marua clay	Drystock for 12 yrs, (previously dairy)
NRC00_2	Typic Orthic Granular	Marua clay	Drystock
NRC00_3	Typic Orthic Granular	Marua clay	Drystock for 12 yrs (previously dairy)
NRC00_4	Mottled Acid Brown	Waiotira clay	Dairy, non-irrigated
NRC00_5	Mottled Acid Brown	Waiotira clay	Dairy, irrigated
NRC00_6	Mottled Acid Brown	Waiotira clay	Indigenous forest (formally some stock browsing but now fenced)
NRC00_7	Mottled Acid Brown	Waiotira clay loam	Drystock
NRC00_8	Mottled Acid Brown	Waiotira clay loam	Plantation forestry (second rotation)
NRC00_9	Mottled Acid Brown	Waiotira clay	Drystock
NRC00_10	Typic Allophanic Brown	Red Hill sandy loam	Drystock for 13 yrs (previously mixed cropping)
NRC00_11	Typic Allophanic Brown	Red Hill sandy loam	Plantation forestry (second rotation)
NRC00_12	Typic Allophanic Brown	Red Hill loamy sand	Dairy, non-irrigated
NRC00_13	Typic Allophanic Brown	Red Hill loamy sand	Drystock
NRC00_14	Perch-gleyed Densipan Ultic	Wharekohe silt loam	Dairy - less intensive (previously Drystock)
NRC00_15	Perch-gleyed Densipan Ultic	Wharekohe silt loam	Dairy - intensive, non-irrigated
NRC00_16	Perch-gleyed Densipan Ultic	Wharekohe silt loam	Plantation forestry (first rotation after pasture)
NRC00_17	Typic Orthic Brown	Marua clay loam	Plantation forestry (first rotation after pasture)
NRC00_18	Typic Orthic Brown	Marua clay loam	Indigenous forest (bush on previous pasture)
NRC00_19	Acidic Oxidic Granular	Awarua clay loam	Dairy, non-irrigated
NRC00_20	Acidic Oxidic Granular	Awarua clay loam	Indigenous forest (formally some stock browsing but now fenced)
NRC00_21	Acidic Oxidic Granular	Awarua clay loam	Dairy, irrigated
NRC00_22	Acidic Oxidic Granular	Awarua clay loam	Plantation forestry (first rotation after pasture)
NRC00_23	Typic Orthic Allophanic	Kiripaka bouldery clay loam	Urban park space (previously Drystock now a school yard – not sampled in 2010-11)
NRC00_24	Typic Orthic Allophanic	Kiripaka bouldery clay loam	Indigenous forest
NRC00_25	Typic Orthic Allophanic	Kiripaka bouldery clay loam	Horticulture (Citrus orchard)
NRC00_26	Albic Ultic	Waiotu Friable Clay	Indigenous forest
NRC00_27	Typic Nodular Oxidic	Okaihau gravelly friable clay	Dairy
NRC00_28	Typic Nodular Oxidic	Okaihau gravelly friable clay	Drystock
NRC00_29	Typic Orthic Allophanic	C1 Complex / Otao silt loam	Drystock

Results

Soil quality indicators

While there are 29 sites within Northland Regional Council's soil quality monitoring programme, the results below focus on the 23 sites located on productive land use and exclude five indigenous forest sites and one urban open space site located within a school ground. These six sites are used for comparison purposes only and were not input into the SINDI model.

Fertility - Olsen P

The Olsen P results show that 52% of tested sites have soil phosphorus levels that are either too high (4%) or too low (48%). Soils with phosphorus levels below the target range have too little phosphorus for optimum plant growth. This essential element is necessary to support plant growth in productive systems. Some New Zealand soils have naturally low levels of soil phosphorus, while other soils can be depleted by continuous intensive growing of crops. In 'pasture' and 'cropping and horticulture' land uses, this may lead to reduced yields.

Soils with phosphorus levels higher than the target range present a higher risk of phosphorus reaching waterbodies through run-off, leaching and erosion. If conditions in the waterbody are right, the excess phosphorus can trigger weed growth and reduce water quality. High levels of soil phosphorus can result from excessive phosphate fertiliser or manure applications over the long term.

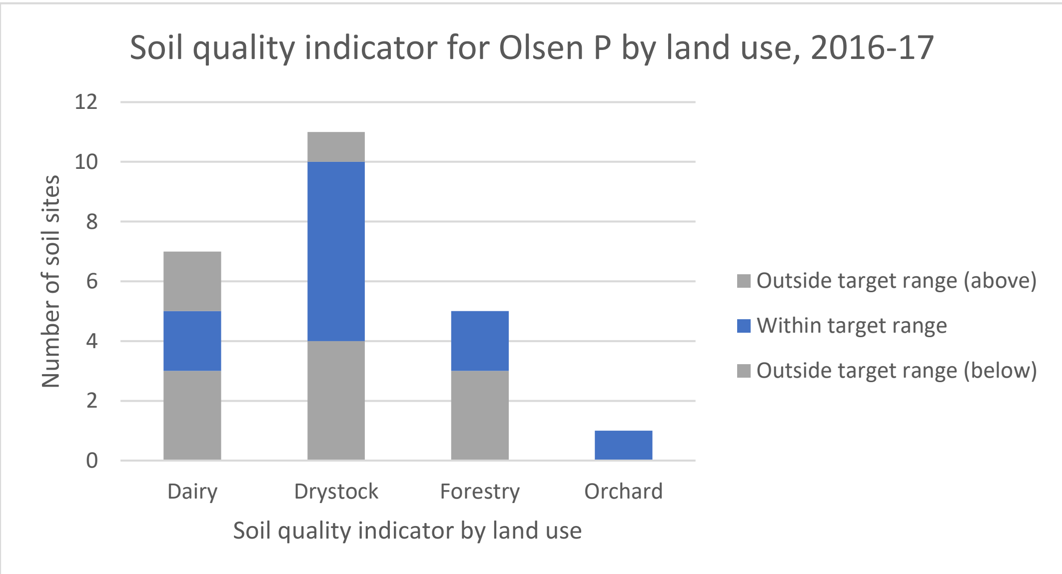

Figure 1 Soil quality indicator for Olsen P by land use, 2016-17. Note that target ranges are land-use specific.

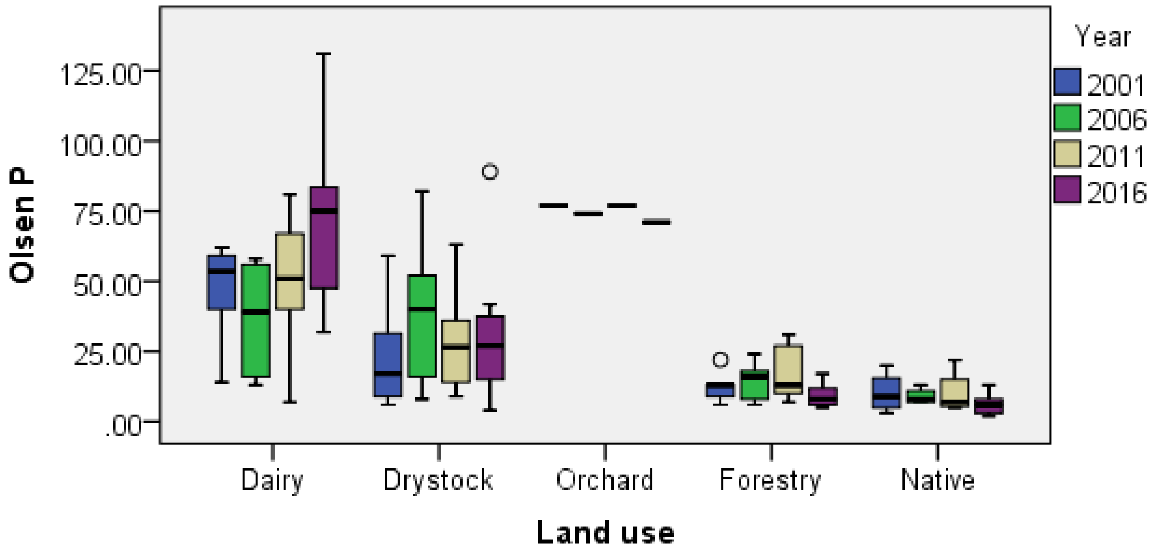

Figure 2 Olsen P (µg/cm3) displayed by land use for each sampling year

Acidity – pH

Soil pH can affect plant and crop growth and the availability of nutrients. Farmers and growers add lime or other compounds to acidic soils to raise pH in order to maintain adequate pH levels. Soil pH was within target ranges at all but one site (96%), that being a drystock farm with near neutral (slightly alkaline) pH.

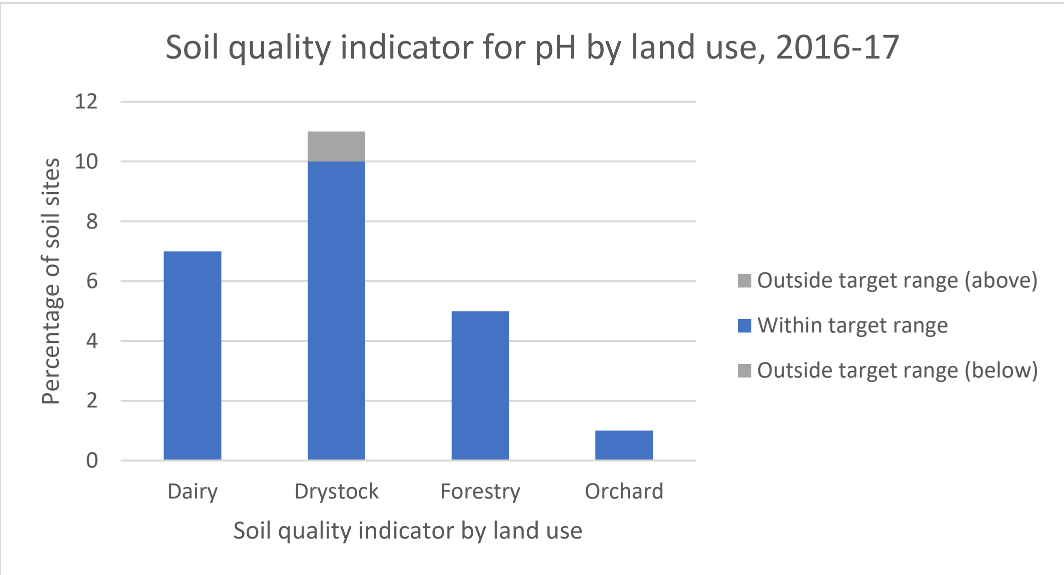

Figure 3 Soil quality indicator for pH by land use, 2016-17.

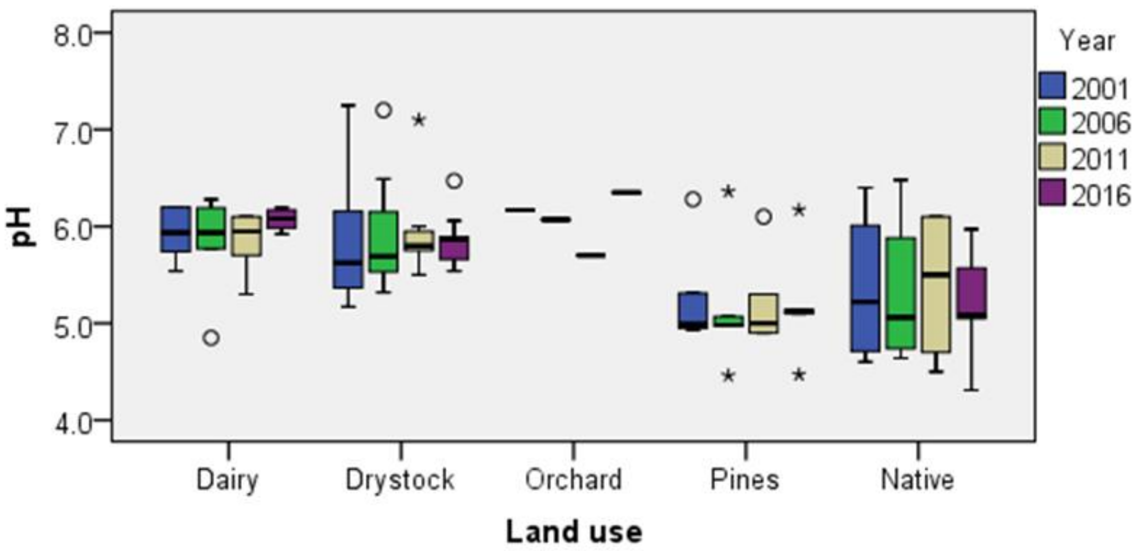

Figure 4 pH displayed by land use for each sampling year

Organic resources - Mineralisable nitrogen, Total carbon, Total nitrogen

The organic reserves within the soil are estimated through total carbon (C), total nitrogen (N), and mineralisable nitrogen. Collectively these measures indicate how much organic material is available in the soil, providing key functions such as provision of nutrients and physical functions that hold soil together allowing air and water movement.

Mineralisable nitrogen is a measure of the organic nitrogen reserves that are potentially mineralised by microorganisms into plant available nitrogen. As such, it is an indicator of the biological status of the soil, and can be heavily influenced by land use. Of the 23 sites located on productive land uses, 18 (78%) were within target ranges, with two drystock sites exhibiting high levels, two dairy sites exhibiting excessive levels, and the one horticulture site presenting a high level of mineralizable N.

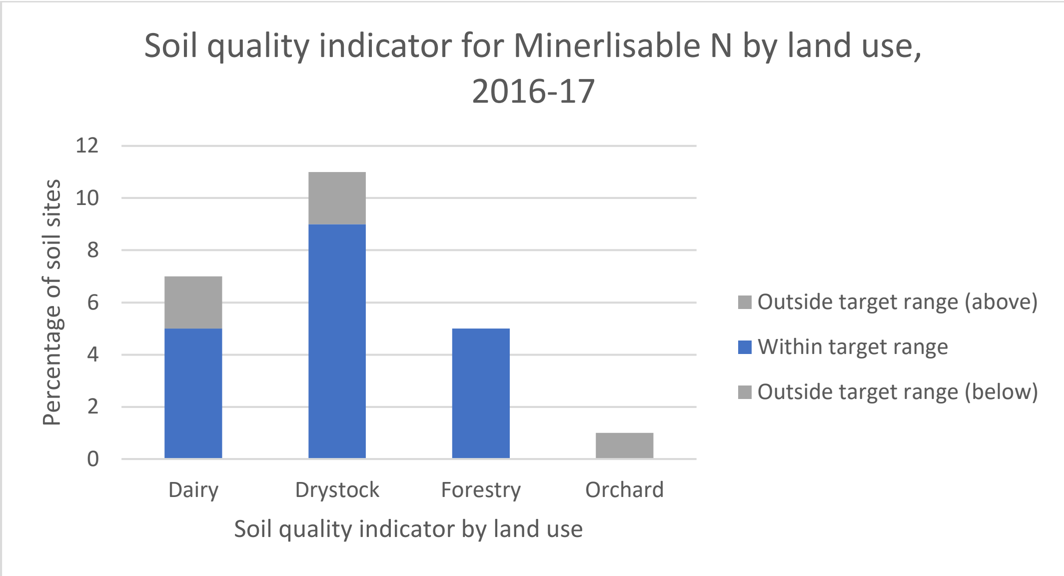

Figure 5 Soil quality indicator for Minerlisable N by land use, 2016-17.

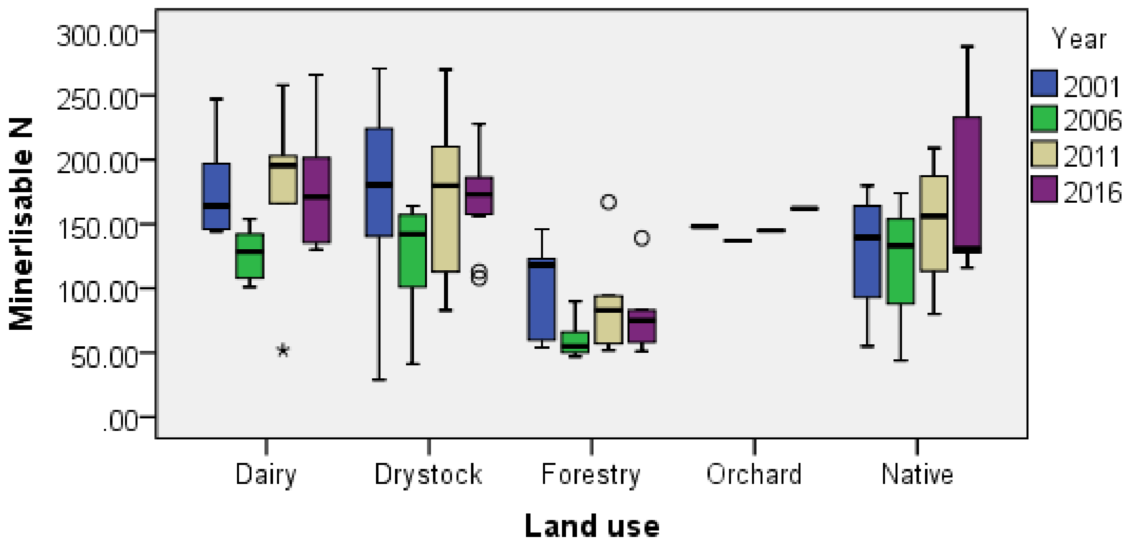

Figure 6 Mineralisable N (µg/cm3) displayed by land use for each sampling year

Unsurprisingly, the sites with elevated Minerlisable N also had elevated total N levels, except for the orchard site which was within the target range for total N. One drystock site exhibited high total N, whereas its mineralisable N was within the target range.

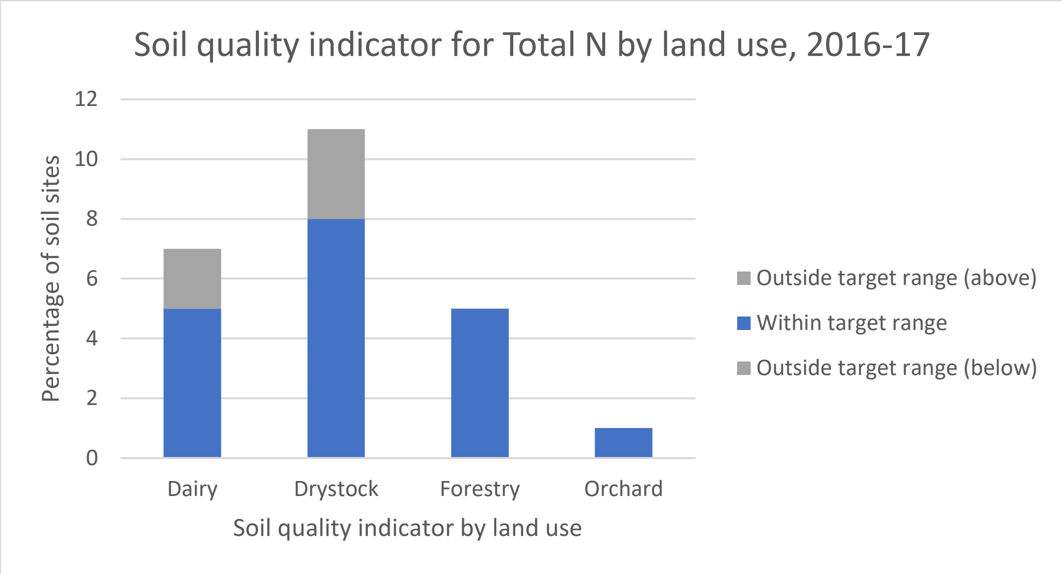

Figure 7 Soil quality indicator for Total N by land use, 2016-17

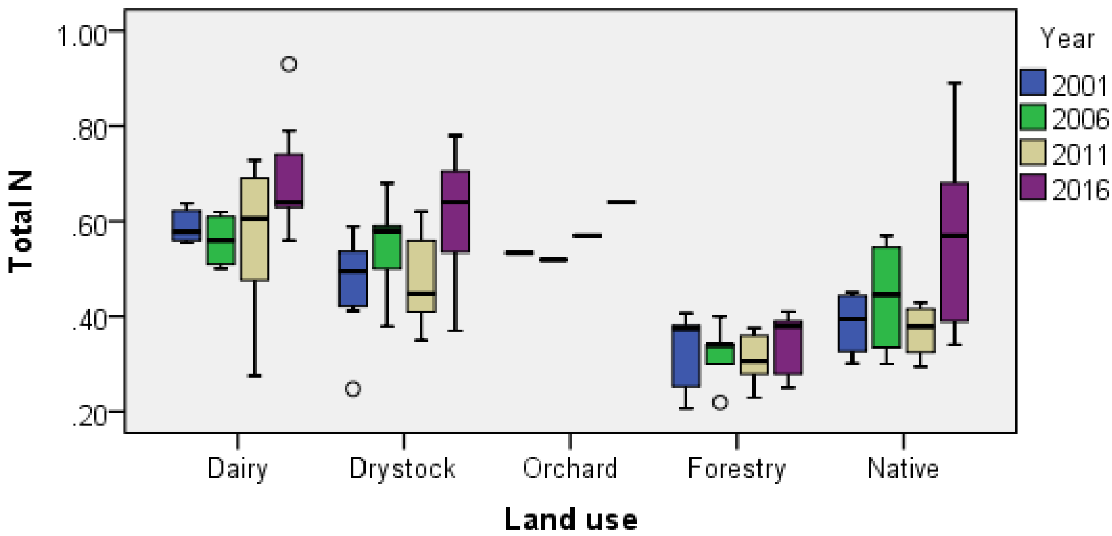

Figure 8 Total Nitrogen (µg/cm3) displayed by land use for each sampling year

Soil carbon is important for soil nutrient release and uptake, and helps to maintain soil structure and water storage. It can help to reduce soil erosion and is an indicator of soil organic matter. Soil total carbon was within target ranges at 100% of tested sites.

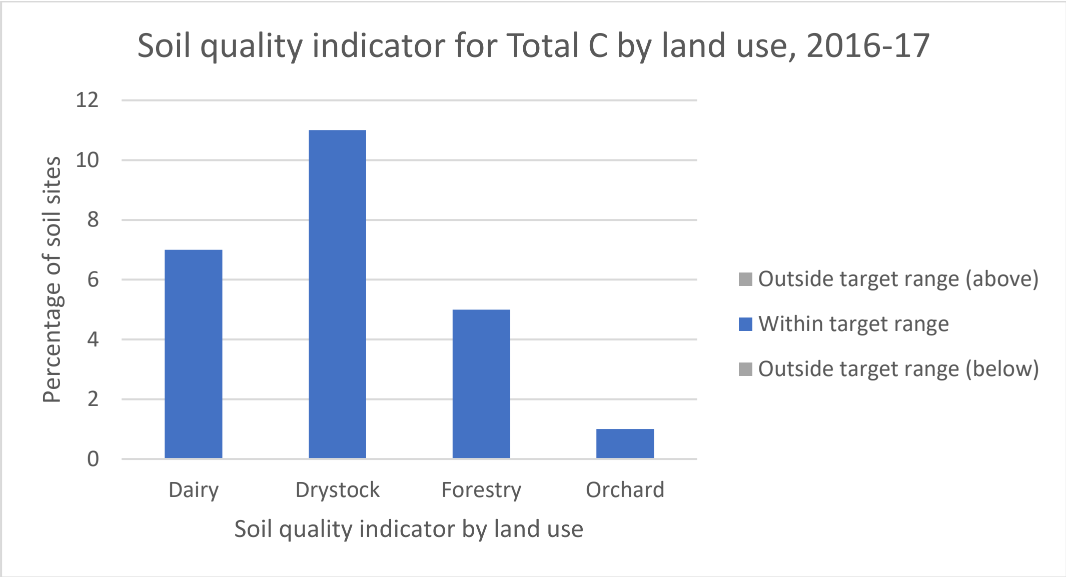

Figure 9 Soil quality indicator for Total C by land use, 2016-17

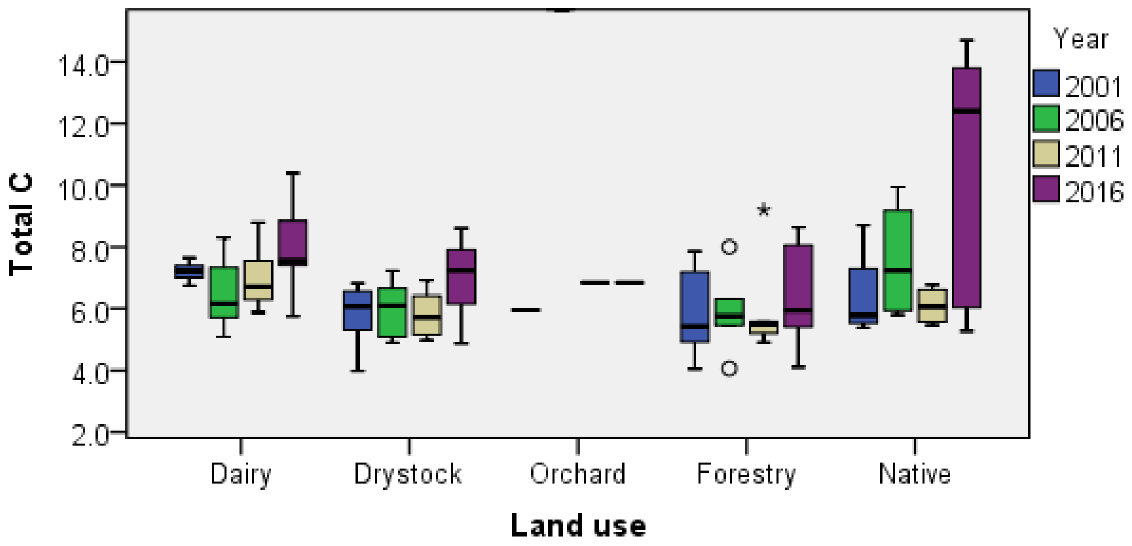

Figure 10 Total Carbon (µg/cm3) displayed by land use for each sampling year

Physical properties – bulk density and macroporosity

Bulk density is the weight of the soil in a given volume. Measuring bulk density provides an indication of compaction in that bulk density increases with compaction. The bulk density results show that approximately 35 percent of the sites were either lower than optimum (50%) or higher than optimum (50%) for supporting each of the four land uses with respect to bulk density.

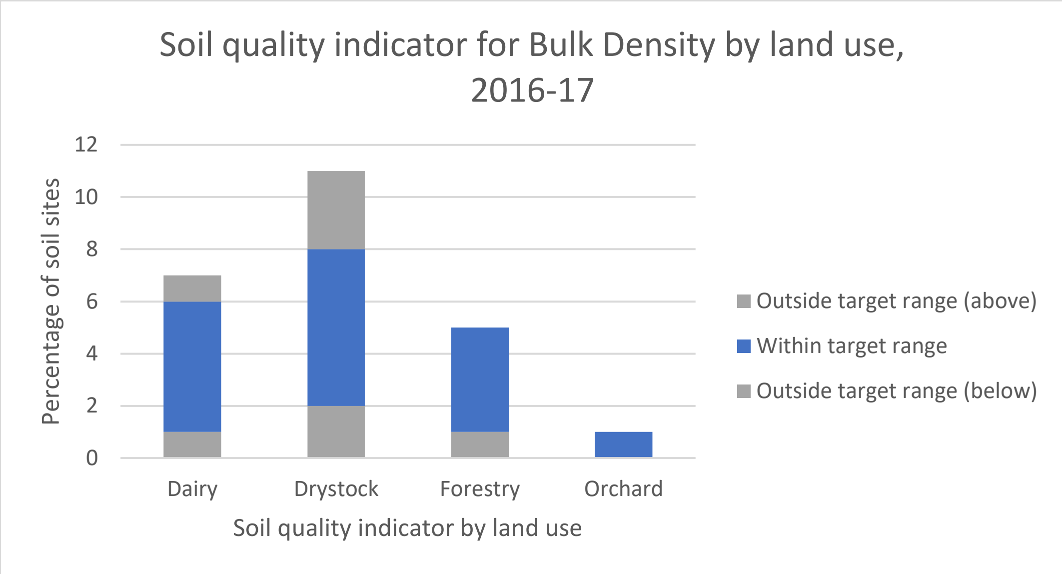

Figure 11 Soil quality indicator for Bulk Density by land use, 2016-17

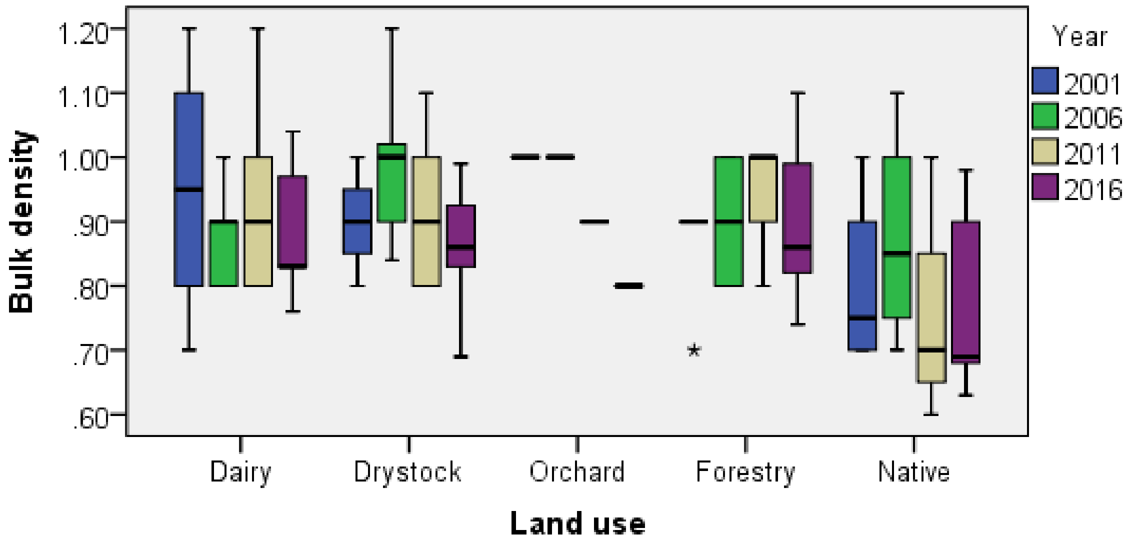

Figure 12 Bulk Density (Mg/m3) displayed by land use for each sampling year

The macroporosity results show that approximately 35 percent of the sites measured have macroporosity levels that are either too low (91%) or too high (9%). Macroporosity is a measure of how many pore spaces there are in soil. Low macroporosity levels indicate soil compaction, particularly when the soil is wet (Drewry et al, 2008) and is undesirable from a water drainage and aeration standpoint. High microporosity implies the soil is very loose, leading to susceptibility to erosion and poor water capillarity (Sparling et al., 2008).

Soil compaction can decrease soil infiltration rates impeding its capacity to drain. This generates more surface runoff which can increases surficial erosion, gullying and flooding. Soil compaction makes the soil less productive (Drewry, et al, 2004) by reducing soil biodiversity and lowering plant uptake of N and P due to shallower rooting and reduced available N concentrations (Taylor et al., 2017). This can result in increased greenhouse gas emissions from urine on soils (van der Weerden, 2017) and an increased amount of phosphorus and eroded soil reaching freshwater and marine environments (Curran-Courane et al, 2011).

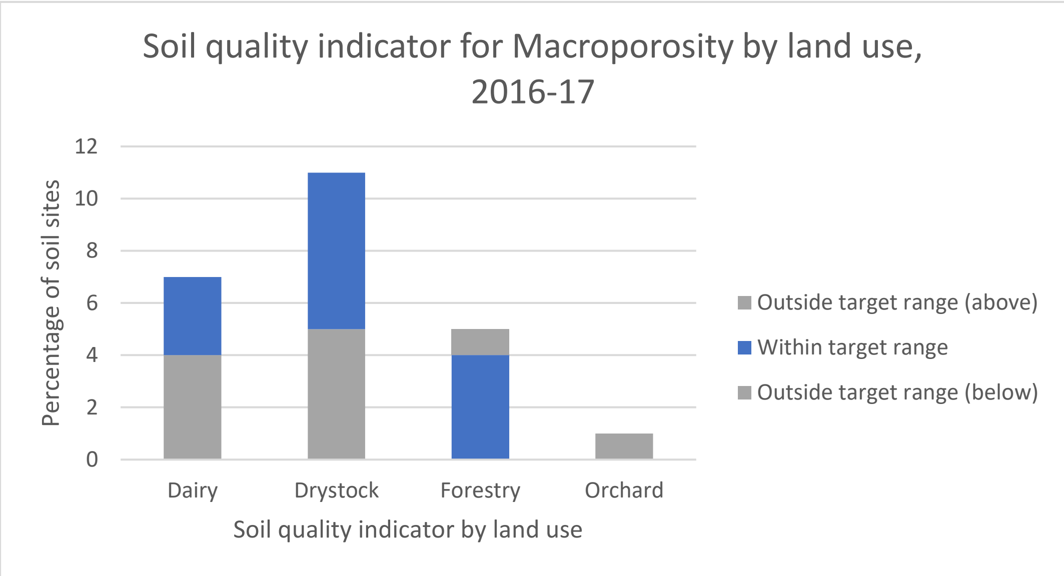

Figure 13 Soil quality indicator for Macroporosity by land use, 2016-17.

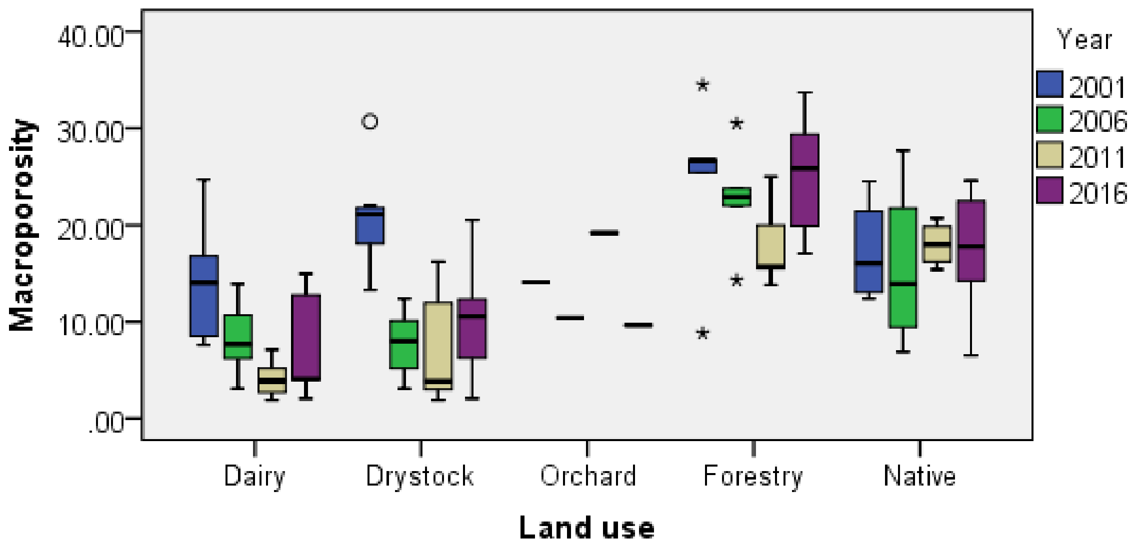

Figure 14 Macroporosity (Mg/m3) displayed by land use for each sampling year.

Summary of soil indicators

Across all productive land uses, none of the 23 sites were in the optimum range for every soil quality indicator. Sites under more intensive land uses, such as dairy and drystock, were more frequently outside the target ranges for soil quality indicators. For example, 29% of dairy sites and 9% of drystock had excess soil phosphorus (they were above target range for Olsen P). However, 43% of dairy and 36% of drystock had low soil phosphorus levels which indicate that pasture production is suboptimal and could contribute to poor pasture persistence/growth and overgrazing. Sixty percent of forestry sites also had suboptimal soil phosphorus levels.

Compaction on dairy and drystock farms remains a concern, with 57% of dairy sites and 83% of drystock sites below the target range for macroporosity. Like many other regions, high total soil N levels are an issue, with 29% of dairy and 27% of drystock sites with levels above target ranges. The solitary horticultural site had mineralisable N above target levels. The sites with levels of excess nutrient and low macroporosity present a greater risk to soil health and water quality in those areas.

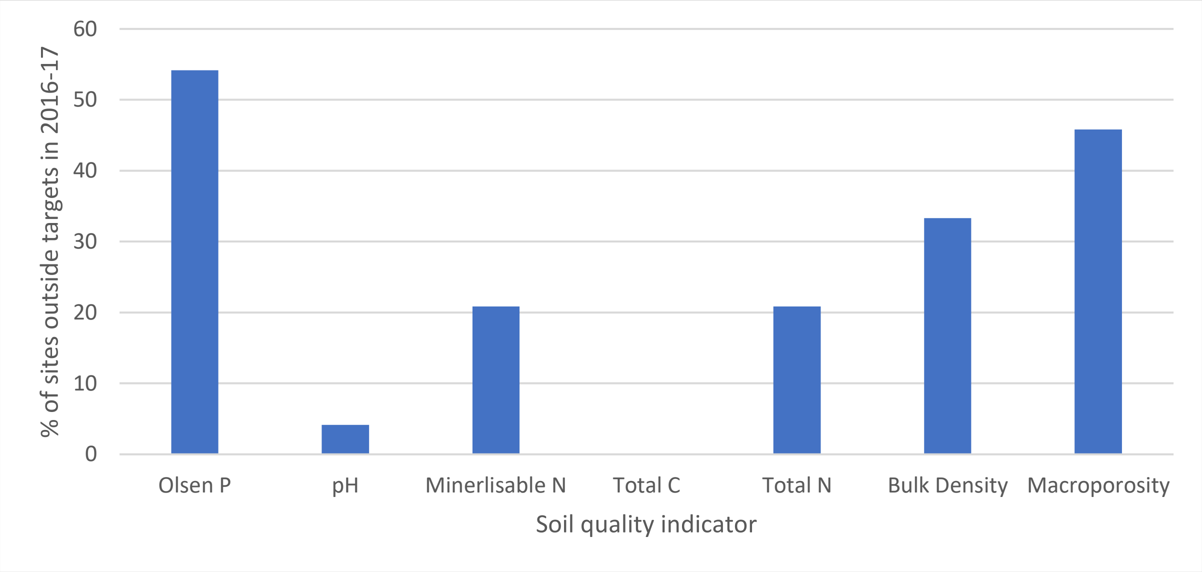

Figure 15 Proportion of sites not meeting targets for soil quality indicators in 2016-17.

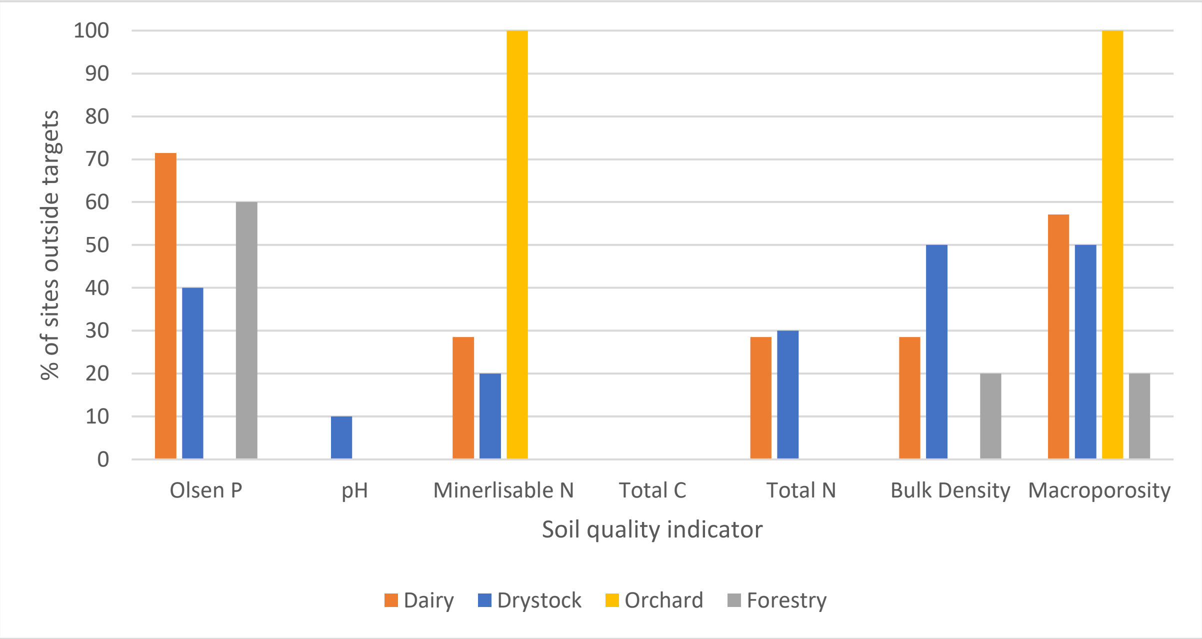

Figure 16 Proportion of sites by land use not meeting targets for soil quality indicators. (Dairy n = 8, Drystock n = 9, Orchard n = 1, Forestry n = 5)

Trace elements

Cadmium

Cadmium is a naturally occurring heavy metal in soil. Phosphate fertiliser is the primary source of cadmium accumulation in agricultural soils, with implications for plant uptake and bioaccumulation within the food chain. Cadmium is acutely toxic at high levels of intake but can also accumulate in kidneys and livers over long time periods which can lead to chronic toxicity problems (Cadmium Management Group, 2019).

The Tiered Fertiliser Management System (TFMS) is an approach developed by the fertiliser industry and endorsed by the Cadmium Working Group as an appropriate response to the accumulation of soil cadmium in agricultural production land. Management of soil cadmium is required because there is currently no commercially viable mechanism to entirely remove cadmium from phosphate fertiliser (FANZ, 2019).

The system is a voluntary approach for identifying the soil cadmium concentration through soil testing and responding with the best available choice and rate of phosphate fertiliser application. The soil cadmium tiers (Table 2) represent soil cadmium levels ranging from natural background levels (Tier 0) up to an agreed maximum threshold (Tier 4). The TFMS seeks to ensure that cadmium in soils do not progress from Tier 0 to Tier 4 within 100 years. This is achieved by increasing the restrictions on choice and rate of phosphate fertiliser as soil cadmium increases. At the Tier 4 threshold of 1.8 mg Cd/kg soil, no net accumulation of cadmium in soils is allowed unless there is a detailed site-specific investigation to identify risks and pathways for potential harm.

In 2010-11, 3 dairy and 2 drystock sites had cadmium levels above the Tier 1 trigger value of ≥0.6 mg Cd/kg soil, with 1 dairy and the orchard site at or above the Tier 2 trigger value of 1 mg/Cd/kg soil. In 2016, the levels of cadmium had decreased slightly with only 2 dairy, 1 drystock and the orchard site with levels above the tier 1 trigger value. Two of the dairy sites and 1 drystock site that were above Tier 1 in 2010-11, were below Tier 1 in 2016. The orchard and dairy site had decreased from Tier 2 to Tier 1. The monitoring results will be passed onto the landowners to assist them in implementing the TFMS should they wish to comply with the programme.

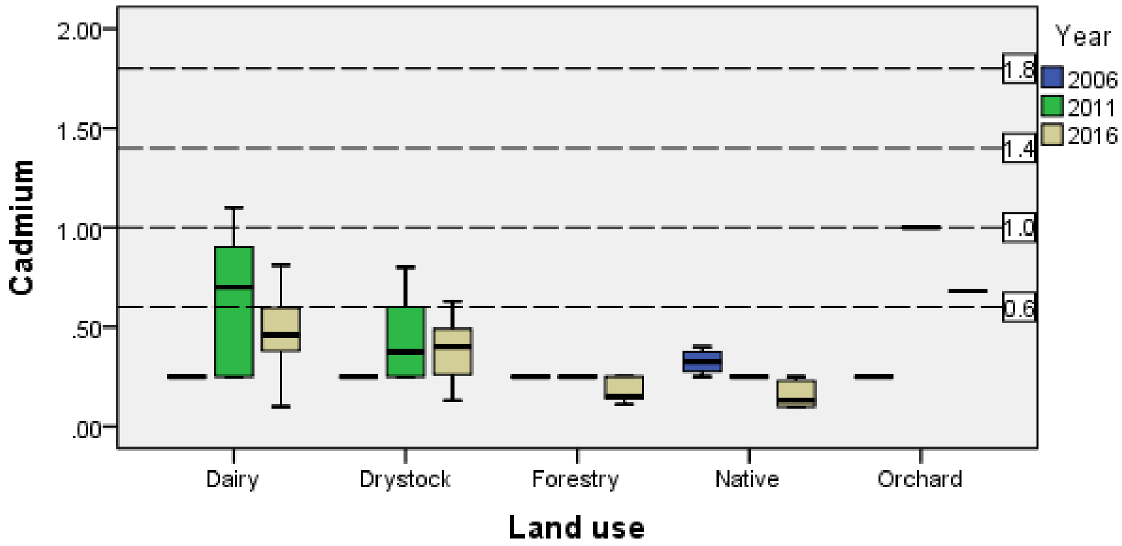

Figure 17 Cadmium accumulation (mg/kg) displayed by land use for each sampling year. The dashed lines display the four tier trigger values as defined in the Tiered Fertiliser Management System (FANZ, 2019).

Zinc

No samples exceeded the trigger values for zinc accumulation in soil (Table 2). The site with the highest zinc concentrations was a dairy site that recorded 133mg/kg in 2006, 138 mg/kg in 2010-11, and 78 mg/kg in 2016. While the results for 2006 and 2010-11 exceed the trigger value for recent soils (130 mg/kg), the soil is classified as granular (a clayey soil formed from material derived by strong weathering of ancient volcanic rocks or ash), which is closer to an allophanic soil which has a higher trigger value of 265 mg/kg.

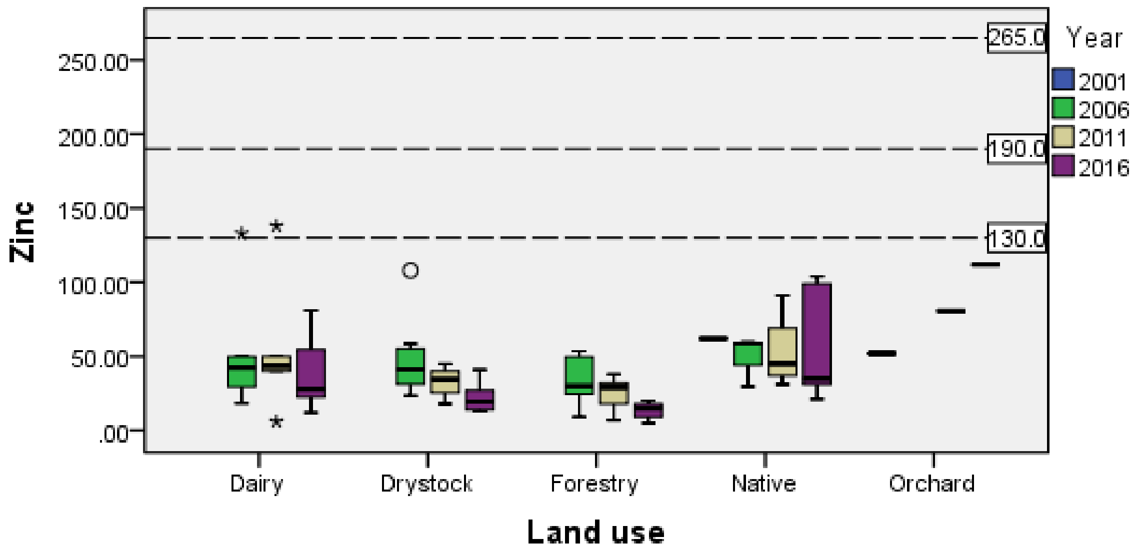

Figure 18 Zinc accumulation (mg/kg) displayed by land use for each sampling year. The dashed lines display the varying trigger values as defined by soil type in the eco-soil guideline values (Cavanagh, 2019).

Arsenic, boron, chromium, lead, copper and mercury

Trace element concentrations for arsenic, boron, chromium, lead, copper and mercury at all sites were well below the trigger values defined in the eco-soil guideline values (Cavanagh, 2019). Note that laboratory results for boron at all sites was <20 mg/kg (due to the detection limit of the methods used for analysis), whereas the trigger value is 6 mg/kg. Future laboratory testing will need to be able to measure to this level to be useful for SOE reporting purposes.

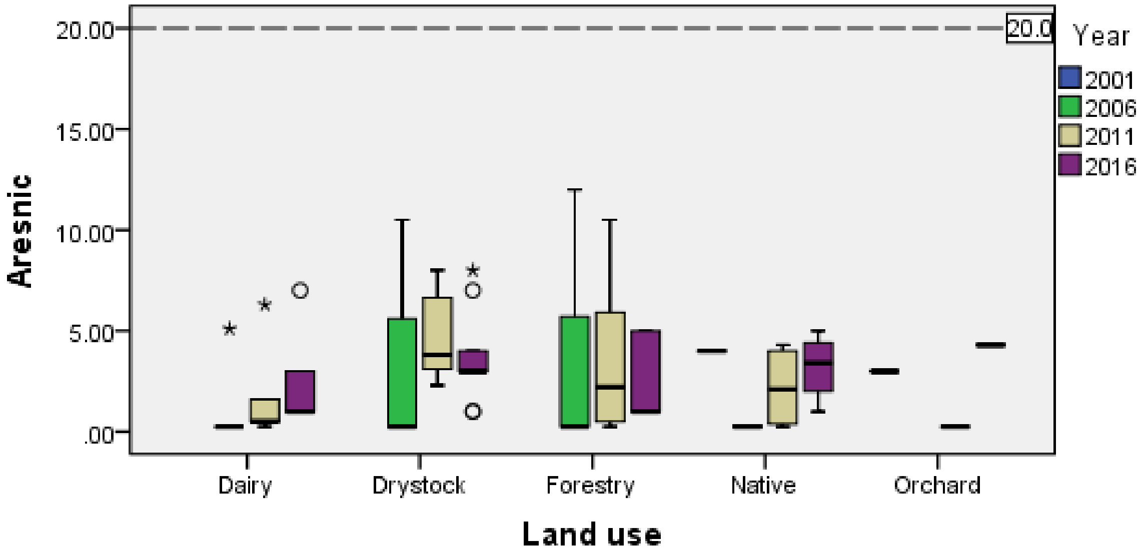

Figure 19 Arsenic accumulation (mg/kg) displayed by land use for each sampling year. The dashed line displays the trigger value as defined in the eco-soil guideline values (Cavanagh, 2019).

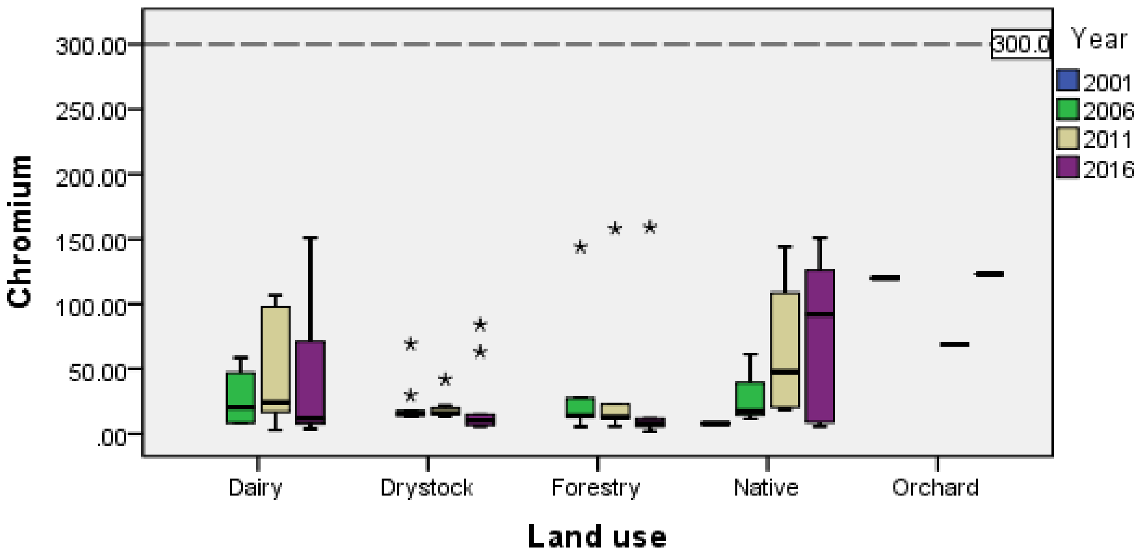

Figure 20 Chromium accumulation (mg/kg) displayed by land use for each sampling year. The dashed line displays the trigger value as defined in the eco-soil guideline values (Cavanagh 2019).

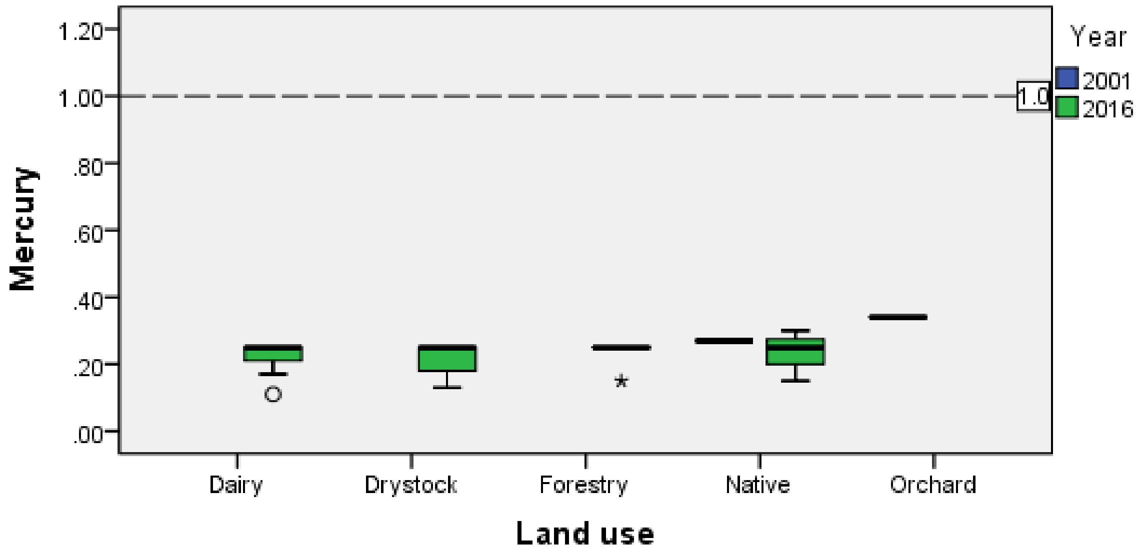

Figure 21 Mercury accumulation (mg/kg) displayed by land use for each sampling year. The dashed line displays the trigger value as defined in NZWWA (2003).

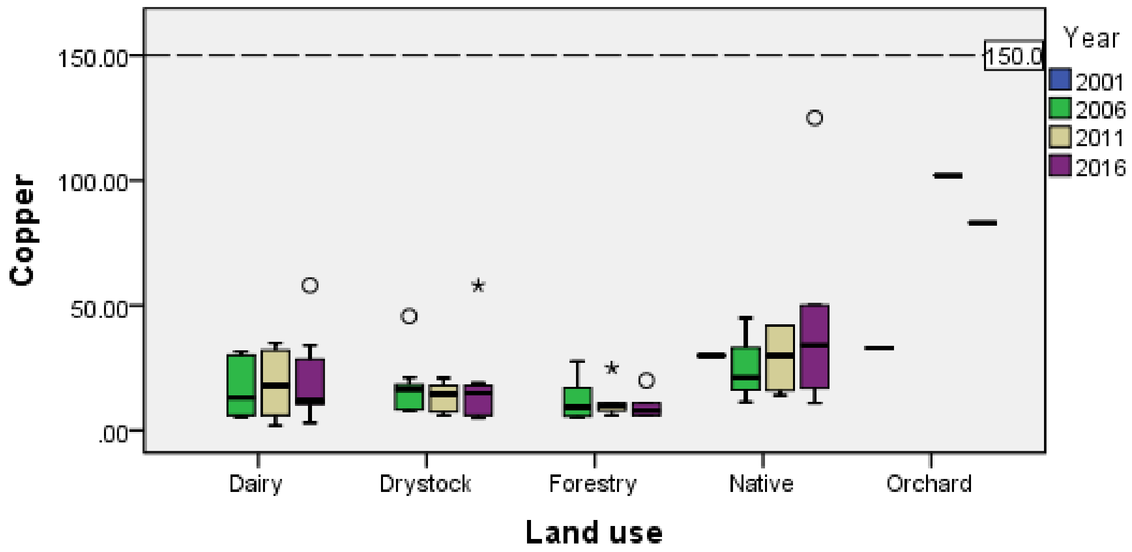

Figure 22 Copper accumulation (mg/kg) displayed by land use for each sampling year. The dashed line displays the trigger value as defined in the eco-soil guideline values (Cavanagh 2019).

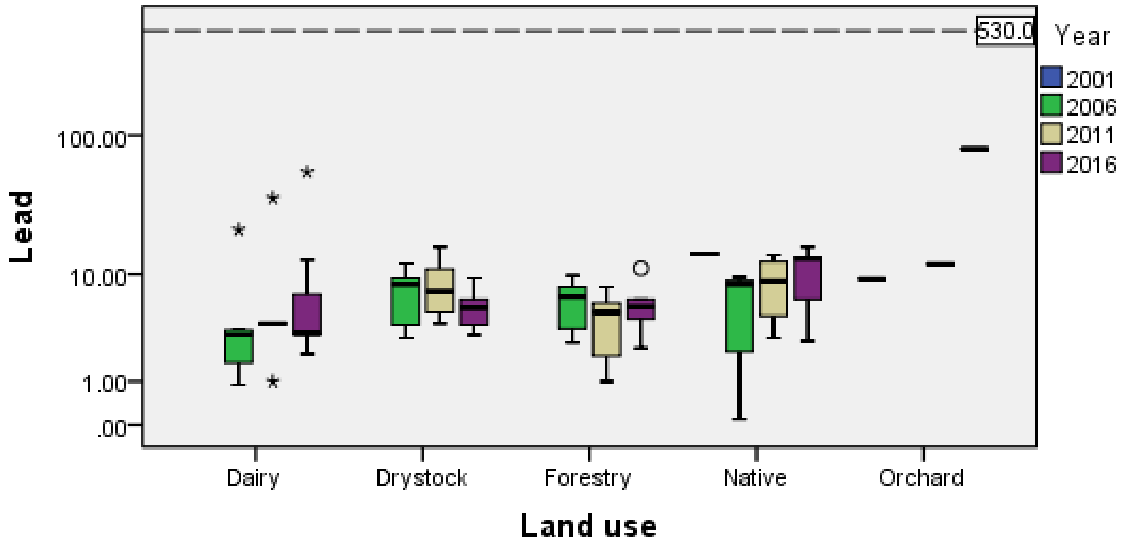

Figure 23 Lead accumulation (mg/kg) displayed by land use for each sampling year. The dashed line displays the trigger value as defined in the eco-soil guideline values (Cavanagh 2016).

Changes in soil quality since previous sampling

The mean values from every sampling year (2001, 2006, 2011, 2016), for each soil indicator grouped by landuse were tested to determine statistically significant changes between sampling years, i.e., has there been a change in soil quality through time?

The statistical tests included ANOVA, which tested whether all means are equal (grouped by landuse and soil indicator). Because there is only one 'Orchard' site, the yearly data itself rather than the mean was tested using the Mann-Kendall trend test to determine statistically significant differences between sampling years (Table 4). Where significant differences were determined (coloured red), Bonferroni post hoc tests were used to determine which means are not equal i.e. between what years was the difference significant (Table 5).

Results from dairy and drystock sites show that mean macroporosity in 2001 is statistically different to the mean macroporosity in all later sample years. This suggests that mean macroporosity at dairy and drystock sites has declined since 2001 and remains in a reasonably stable, more compacted state (see Figure 11). This can probably be attributed to the nationwide trend of increasing stock densities on dairy and drystock farms.

Mean Total Nitrogen (TN) for drystock in 2016 is significantly different to mean TN in all other sampling years. However, when looking at all TN data across all years, it appears that TN levels in 2016 were elevated across all land uses, although the mean drystock results were the only ones that were statistically significant. Nitrogen levels can vary depending on time of year, with Nitrate-N levels increasing as the soil warms up after winter, and can accumulate in the soil during summer drought conditions. New Zealand experienced it's hottest ever recorded year in 2016, and this may explain the difference between TN results in 2016 compared to previous sampling years.

It should be noted that due to the small sample size the standard deviation (variation) is high for a lot of indicators which makes it difficult to make generalisations about the results. In addition, the climate variability between sampling years may have contributed to several soil indicators changing greatly between years. Adding more sites to the programme and sampling at the same time of year will help to minimise this variation and obtain a more representative understanding of soil quality indicators across land uses and soil types.

Table 4 Statistical tests to determine significant differences between sampling years by land use. Red numbers in bold indicate the difference is significant at the 0.05 level.

Land use	Dairy	Drystock	Orchard	Forestry	Native
Statistical test	ANOVA	ANOVA	Mann-Kendall trend test	ANOVA	ANOVA
Olsen P	.122	.562	.279	.429	.727
pH	.540	.937	1.00	.989	.980
Total Carbon	.132	.441	.718	.953	.118
Minerlisable N	.206	.250	.497	.409	.511
Total Nitrogen	.107	**.028**	.174	.917	.181
Bulk density	.808	.082	.071	.714	.714
Macroporosity	**.010**	**.000**	.497	.378	.960

Table 5 Post hoc test (Bonferroni) of macroporosity at dairy sites. Red numbers in bold indicate the difference is significant at the 0.05 level.

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2001	2006	12.7500*	2.32110	**.000**	6.2223	19.2777
	2011	13.7875*	2.38839	**.000**	7.0705	20.5045
	2016	11.0982*	2.21958	**.000**	4.8560	17.3404
2006	2001	-12.7500*	2.32110	**.000**	-19.2777	-6.2223
	2011	1.0375	2.32110	1.000	-5.4902	7.5652
	2016	-1.6518	2.14700	1.000	-7.6899	4.3863
2011	2001	-13.7875*	2.38839	**.000**	-20.5045	-7.0705
	2006	-1.0375	2.32110	1.000	-7.5652	5.4902
	2016	-2.6893	2.21958	1.000	-8.9315	3.5529
2016	2001	-11.0982*	2.21958	**.000**	-17.3404	-4.8560
	2006	1.6518	2.14700	1.000	-4.3863	7.6899
	2011	2.6893	2.21958	1.000	-3.5529	8.9315
Based on observed means. The error term is Mean Square(Error) = 22.818.						

Table 6 Post hoc test (Bonferroni) of macroporosity at drystock sites. Red numbers in bold indicate the difference is significant at the 0.05 level.

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2001	2006	12.7500*	2.32110	**.000**	6.2223	19.2777
	2011	13.7875*	2.38839	**.000**	7.0705	20.5045
	2016	11.0982*	2.21958	**.000**	4.8560	17.3404
2006	2001	-12.7500*	2.32110	**.000**	-19.2777	-6.2223
	2011	1.0375	2.32110	1.000	-5.4902	7.5652
	2016	-1.6518	2.14700	1.000	-7.6899	4.3863
2011	2001	-13.7875*	2.38839	**.000**	-20.5045	-7.0705
	2006	-1.0375	2.32110	1.000	-7.5652	5.4902
	2016	-2.6893	2.21958	1.000	-8.9315	3.5529

2016	2001	-11.0982*	2.21958	**.000**	-17.3404	-4.8560
	2006	1.6518	2.14700	1.000	-4.3863	7.6899
	2011	2.6893	2.21958	1.000	-3.5529	8.9315
Based on observed means. The error term is Mean Square(Error) = 22.818.						

Table 7 Post hoc test (Bonferroni) of Total Nitrogen at drystock sites. Red numbers in bold indicate the difference is significant at the 0.05 level.

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2001	2006	-.0656	.05335	1.000	-.2156	.0845
	2011	-.0076	.05490	1.000	-.1620	.1468
	2016	-.1423	.05102	**.053**	-.2857	.0012
2006	2001	.0656	.05335	1.000	-.0845	.2156
	2011	.0580	.05335	1.000	-.0921	.2080
	2016	-.0767	.04935	.781	-.2155	.0621
2011	2001	.0076	.05490	1.000	-.1468	.1620
	2006	-.0580	.05335	1.000	-.2080	.0921
	2016	-.1346	.05102	.077	-.2781	.0089
2016	2001	.1423	.05102	**.053**	-.0012	.2857
	2006	.0767	.04935	.781	-.0621	.2155
	2011	.1346	.05102	.077	-.0089	.2781
Based on observed means. The error term is Mean Square(Error) = .012						

Conclusions

The current national trend is for greater land intensification. Consequently, monitoring from around New Zealand has highlighted issues such as loss of macroporosity (indicating soil compaction) and excessive levels of soil phosphorus (MfE and Stats NZ, 2018). Our soil monitoring data indicates that soil compaction and nutrient issues are a localised problem in Northland. Since 2001, soil has become compacted on a third of tested dairy and drystock sites. Furthermore, a proportion of dairy and drystock sites have elevated soil nitrogen levels, while others have low Olsen P levels. Some dairy and drystock sites, in addition to the orchard site, exhibited soil cadmium levels above the Tier 1 trigger value. However, the 2016 results were slightly lower than earlier years and cadmium will need to be monitored closely following the next round of sampling. Soil pH levels were optimum at all sites except at one drystock site, and soil carbon levels were normal to ample at all sites.

In general, all instances of degrading soil quality can be modified (reversed) by suitable management. Such on farm management options include the use of run-off pads on dairy farms, rapid movement of cattle to minimize pugging, on-farm nutrient budgeting, disposal of effluent onto suitable land and at rates that allow adequate treatment, greater return of crop residues, and the use of minimum and zero tillage in arable farming (Stevenson, 2007). Those sites with elevated cadmium levels should implement the actions defined in the Tiered Fertiliser Management System. Regenerative farming techniques that improve soil function through increasing the biological health of soil are also gaining momentum in New Zealand and internationally and may benefit some of the soil quality indicators discussed in this report.

Acknowledgements

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Appendix 1. Soil quality tables

SOIL CHEMISTRY AND PHYSICAL RESULTS 2016-17

Zero figures for NO3-N indicate the value is below our reporting limit, but not genuinely zero. 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.

Client ID	Water Content (% dry wt)	pH (2:5 Water)	Organic C (%)	Total N (%)	C/N ratio	KCl-extractable (mg/kg)		Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/kg)	Dry Bulk Density (t/m3)	Macro Porosity (%, v/v)
						NO_3-N	NH_4-N				
NRC 1	72	5.76	8.09	0.75	11	93	2	228	35	0.69	10.57
NRC 2	60	6.06	7.53	0.64	12	31	5	173	14	0.74	12.07
NRC 3	57	5.88	6.11	0.52	12	35	14	159	40	0.86	7.00
NRC 4	53	5.57	6.88	0.57	12	48	5	177	89	0.90	7.00
NRC 5	53	5.94	7.46	0.64	12	49	1	171	59	0.83	12.57
NRC 6	39	5.57	6.03	0.39	16	23	7	131	13	0.98	14.23
NRC 7	46	5.72	7.72	0.65	12	23	8	195	10	0.83	20.53
NRC 8	27	5.10	8.64	0.41	21	1	11	75	17	0.74	33.70
NRC 9	43	5.88	4.87	0.37	13	16	10	108	4	0.99	12.63
NRC 10	40	6.47	5.89	0.47	12	85	9	113	16	0.98	12.67
NRC 11	18	6.17	5.40	0.28	19	0	2	58	8	0.86	29.37
NRC 12	36	6.08	5.76	0.56	10	99	1	133	88	0.92	14.97
NRC 13	46	5.86	8.16	0.78	10	83	1	201	25	0.91	11.13
NRC 14	58	6.03	7.37	0.63	12	64	1	192	79	0.76	12.97
NRC 15	53	6.19	7.79	0.69	11	84	2	130	131	1.04	4.00
NRC 16	30	4.47	5.94	0.39	15	1	13	51	12	0.99	25.87
NRC 17	39	5.14	4.11	0.25	16	2	12	83	6	1.10	17.07
NRC 18	75	5.08	5.27	0.34	16	11	6	128	3	0.90	6.50
NRC 19	73	6.19	9.90	0.79	12	38	1	211	32	0.83	3.97
NRC 20	90	5.05	12.4	0.68	18	23	10	233	8	0.63	22.47
NRC 21	74	6.15	10.4	0.93	11	86	1	266	75	0.83	4.07
NRC 22	75	5.12	8.06	0.38	21	5	30	139	5	0.82	16.90
NRC 23	57	5.60	7.23	0.68	11	35	1	173	27	0.94	5.53
NRC 24	89	5.97	13.8	0.89	15	77	1	288	6	0.68	17.80

NRC 25	59	6.35	6.85	0.64	11	57	1	162	71	0.80	9.67
NRC 26	126	4.31	14.7	0.57	26	0	1	116	2	0.69	24.60
NRC 27	57	5.92	7.55	0.63	12	49	5	138	36	1.02	2.07
NRC 28	65	5.54	8.61	0.73	12	40	1	167	42	0.83	6.57
NRC 29	62	5.90	6.19	0.55	11	24	3	156	27	0.86	4.97

DAIRY – TRACE ELEMENTS

Site code	Land use and soil Class	As mg/kg			Cd mg/kg			Cr mg/kg			Co mg/kg		
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17
NRC 5	Dairy, Brown	0.25	1.6	3	0.25	0.8	0.51	25.6	31	12	4.7	3	1.9
NRC 12	Dairy, Allophanic	5.1	6.3	7	0.25	0.25	0.43	15.2	17	11	4.6	3	2.8
NRC 14	Dairy, Ultic	0.25	0.25	1	0.25	0.25	0.33	8.6	3	4	0.2	1	0.2
NRC 15	Dairy, Ultic	0.25	0.5	1	0.25	1.1	0.81	8.5	18	5	1.1	1	0.7
NRC 19	Dairy, Granular	0.25	0.5	1	0.25	0.6	0.46	58.8	107	75	11.2	5	3.9
NRC 21	Dairy, Granular	0.25	0.5	1	0.25	0.9	0.68	47.1	98	67	11.2	6	3.7
NRC 27	Dairy, Allophanic	-	-	1	-	-	0.4	-	-	84	-	-	2.2
	Mean*	**1.06**	**1.61**	**2.33**	**0.25**	**0.65**	**0.54**	**27.3**	**45.67**	**29**	**5.5**	**3.17**	**2.2**
	SD	1.98	2.35	2.27	0	0.35	0.17	21.15	45	36.44	4.77	2.04	1.4

Site code	Land use and soil Class	Cu mg/kg			Pb mg/kg			Zn mg/kg			B mg/kg	M mg/kg
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2016-17	2016-17
NRC 5	Dairy, Brown	15.6	23	12	3.2	4	3.2	41	50	23	10	0.25
NRC 12	Dairy, Allophanic	6.1	6	9	3.5	4	3.6	49.9	40	81	10	0.25
NRC 14	Dairy, Ultic	5.4	2	3	3.2	1	2.1	18.3	6	12	10	0.25
NRC 15	Dairy, Ultic	10.6	13	12	21.4	36	55	29.4	41	31	10	0.25
NRC 19	Dairy, Granular	30.1	32	23	0.9	4	3.3	43.9	46	28	10	0.11
NRC 21	Dairy, Granular	31.6	35	34	1.7	4	3.3	133	138	78	10	0.25
NRC 27	Dairy, Allophanic	-	-	58	-	-	7.2	-	-	14	10	0.18
	Mean*	**16.57**	**18.5**	**15.5**	**5.65**	**8.83**	**11.75**	**52.58**	**53.5**	**42.17**	**10**	**0.23**
	SD	11.66	13.66	19.02	7.78	13.36	19.42	40.98	44.28	29.08	0	0.06

DRYSTOCK – TRACE ELEMENTS

Site code	Land use and soil Class	As mg/kg			Cd mg/kg			Cr mg/kg			Co mg/kg		
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17
NRC 1	Drystock, Granular	10.5	4.1	4	0.25	0.8	0.63	13.1	15	9	6.4	6	2.6
NRC 2	Drystock, Granular	0.25	5.5	4	0.25	0.25	0.26	17	18	7	7.6	6	1.9
NRC 3	Drystock, Brown	0.25	3.5	3	0.25	0.7	0.38	14	14	6	5.5	4	2.5
NRC 4	Drystock, Brown	0.25	3.2	3	0.25	0.25	0.49	29.7	42	14	6.1	2	1
NRC 7	Drystock, Brown	0.25	2.3	3	0.25	0.5	0.4	17.5	17	8	9.2	5	1
NRC 9	Drystock, Brown	0.25	3	3	0.25	0.25	0.13	14.1	15	7	2.6	4	0.8
NRC 10	Drystock, Allophanic	5.6	8	8	0.25	0.25	0.25	16	22	15	5.1	3	1.8
NRC 13	Drystock, Allophanic	10.5	7.8	7	0.25	0.5	0.42	14	15	12	4.4	6	2.5
NRC 28	Drystock, Allophanic	-	-	1	-	-	0.59	-	-	63	-	-	2
NRC 29	Drystock, Allophanic	-	-	2	-	-	0.42	-	-	12	-	-	4.4
	Mean	**3.48**	**4.68**	**3.8**	**0.25**	**0.44**	**0.4**	**16.93**	**19.75**	**15.3**	**5.86**	**4.5**	**2.05**
	SD	4.71	2.2	2.15	0	0.22	0.15	5.4	9.35	17.05	2	1.51	1.06

* For means and standard deviations, values below detection limit were assumed to be half that of detection limit

Site code	Land use and soil Class	Cu mg/kg			Pb mg/kg			Zn mg/kg			B mg/kg	M mg/kg
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2016-17	2016-17
NRC 1	Drystock, Granular	16.4	18	18	9.3	10	4.5	45.8	43	41	10	0.25
NRC 2	Drystock, Granular	18.3	18	14	12.1	12	3.2	55.1	45	33	10	0.25
NRC 3	Drystock, Brown	8.4	8	6	9.3	9	6.4	28.8	24	18	10	0.25
NRC 4	Drystock, Brown	17.6	21	16	3	16	9.3	41.2	37	27	10	0.25
NRC 7	Drystock, Brown	21.2	18	18	8.4	5	3.6	58.6	32	21	10	0.25
NRC 9	Drystock, Brown	8.1	7	5	5	5	5.6	23.5	18	14	10	0.25
NRC 10	Drystock, Allophanic	7.9	6	5	3.9	6	5.3	31.2	27	15	10	0.13
NRC 13	Drystock, Allophanic	9.5	11	9	3.6	4	3.9	37.7	37	25	10	0.25
NRC 28	Drystock, Allophanic	-	-	19	-	-	5.8	-	-	13	10	0.16
NRC 29	Drystock, Allophanic	-	-	8	-	-	6.7	-	-	20	10	0.25
	Mean	**13.43**	**13.38**	**11.8**	**6.83**	**8.38**	**5.43**	**40.24**	**32.88**	**22.7**	**10**	**0.23**
	SD	5.48	6	5.77	3.37	4.17	1.8	12.47	9.4	8.98	0	0.04

Plantation forest – trace elements

Site code	Land use and soil Class	As mg/kg			Cd mg/kg			Cr mg/kg			Co mg/kg		
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17
NRC 8	Plantation forest, Brown	0.25	2.2	1	0.25	0.25	0.14	14.2	12	6	3.2	6	1.1
NRC 11	Plantation forest, Allophanic	5.7	5.9	5	0.25	0.25	0.15	13	13	8	17.1	6	1.7
NRC 16	Plantation forest, Ultic	0.25	0.25	1	0.25	0.25	0.11	5.7	6	2	5.3	2	0.2
NRC 17	Plantation forest, Brown	12	10.5	5	0.25	0.25	0.25	27.6	23	12	5.7	5	1.5
NRC 22	Plantation forest, Granular	0.25	<0.5	1	0.25	0.25	0.25	144	158	159	13.4	12	3.1
	Mean*	**3.69**	**4.71**	**2.6**	**0.25**	**0.25**	**0.18**	**40.9**	**42.4**	**37.4**	**8.94**	**6.2**	**1.52**
	sd	5.21	4.51	2.19	0	0	0.07	58.17	64.91	68.07	5.98	3.63	1.05

Site code	Land use and soil Class	Cu mg/kg			Pb mg/kg			Zn mg/kg			B mg/kg	M mg/kg
		2006	2010-11	2016-17	2006	2010-11	2016-17	2006	2010-11	2016-17	2016-17	2016-17
NRC 8	Plantation forest, Brown	9.4	11	8	6.7	6	6.4	30	29	18	10	0.25
NRC 11	Plantation forest, Allophanic	17.1	10	6	8	5	4.4	53.5	32	15	10	0.25
NRC 16	Plantation forest, Ultic	5.3	8	6	3.6	1	2.4	9.2	7	5	10	0.25
NRC 17	Plantation forest, Brown	5.7	6	11	9.8	8	11.1	24.5	18	9	10	0.25
NRC 22	Plantation forest, Granular	27.6	25	20	2.7	2	5.6	49.7	38	20	10	0.15
	Mean*	**13.02**	**12**	**10.2**	**6.16**	**4.4**	**5.98**	**33.38**	**24.8**	**13.4**	**10**	**0.23**
	sd	9.43	7.52	5.85	2.98	2.88	3.23	18.34	12.32	6.27	0	0.04

NATIVE FOREST AND ORCHARD – TRACE ELEMENTS

Site code	Land use and soil Class	As mg/kg			Cd mg/kg			Cr mg/kg			Co mg/kg		
		2006	**2010-11**	**2016-17**	**2006**	**2010-11**	**2016-17**	**2006**	**2010-11**	**2016-17**	**2006**	**2010-11**	**2016-17**
NRC 6	Native, Brown	0.25	3.7	3	0.25	0.25	0.1	17.5	19	6	9.2	2	2.5
NRC 18	Native, Brown	0.25	4.3	5	0.3	0.25	0.25	11.8	22	9	5	6	4.9
NRC 20	Native, Granular	0.25	0.5	1	0.35	0.25	0.23	61.1	144	92	25.5	10	10.8
NRC 24	Native, Allophanic	0.25	3.8	3	0.4	0.25	0.13	73.2	151	120	27.3	25	19.7
NRC 26	Native, Allophanic	-	-	3	-	-	0.1	-	-	151	-	-	2.8
	Mean*	**0.25**	**3.08**	**3**	**0.33**	**0.25**	**0.16**	**40.9**	**84**	**75.6**	**16.75**	**10.75**	**8.14**
	SD	0	1.74	1.41	0.06	0	0.07	30.8	73.39	65.58	11.3	10.05	7.27
NRC00_25	Citrus orchard, Allophanic	0.25	4.3	5	<0.5	1	0.68	68.8	123	126	27.9	123	105

* For means and standard deviations, values below detection limit were assumed to be half that of detection limit

Site code	Land use and soil Class	Cu mg/kg			Pb mg/kg			Zn mg/kg			B mg/kg	M mg/kg
		2006	**2010-11**	**2016-17**	**2006**	**2010-11**	**2016-17**	**2006**	**2010-11**	**2016-17**	**2016-17**	**2016-17**
NRC 6	Native, Brown	21.2	14	11	8.4	7	6.4	58.6	43	31	10	0.25
NRC 18	Native, Brown	11.3	18	17	9.5	14	13.1	29.5	31	21	10	0.25
NRC 20	Native, Granular	45	42	34	0.1	3	2.8	59.7	47	35	10	0.15
NRC 24	Native, Allophanic	41.9	50	33	11.1	16	9.2	91.2	104	52	10	0.34
NRC 26	Native, Allophanic	-	-	58	-	-	12.8	-	-	22	10	0.17
	Mean*	**29.85**	**31**	**30.6**	**7.28**	**10**	**8.86**	**59.75**	**56.25**	**32.2**	**10**	**0.23**
	SD	16.26	17.7	18.28	4.91	6.06	4.37	25.2	32.55	12.56	0	0.08
NRC 25	Citrus orchard, Allophanic	102	83	125	11.9	80	13.5	80.5	112	99	10	0.3