Waikato Regional Council Technical Report 2013/49

Soil quality monitoring in the Waikato region 2011

www.waikatoregion.govt.nz
ISSN 2230-4355 (Print)
ISSN 2230-4363 (Online)

Prepared by:
Matthew Taylor

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

5th January 2013

Document #: 2286500

Peer reviewed by:
Haydon Jones

Date January 2013

Approved for release by:
Peter Singleton

Date October 2013

Disclaimer

This technical report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.

Table of contents

List of figures

Executive summary

This report provides baseline data and allows identification of the impacts of land use and associated key soil quality issues that have emerged over the last 8 years. There is a saying “What is on the land ends up in the water”, and soil quality has direct impacts on water quality.

Overall, soil quality in the region is declining. Results showed that in 2011 13% of sites (14% of land) meet targets, 34% of sites (32% of land) failed to meet 1 target and 53% of sites (53% of land) failed to meet 2 or more targets. The land use meeting most targets was production forestry (41% of sites). Dairy pasture and other pastoral land uses had the lowest proportion of sites meeting targets and the highest proportion of sites failing to meet 2 or more targets.

Four key issues contributing to the degradation of the quality of the soil resource in the Waikato region were identified. These issues are outlined below.

There had been a steady improvement in the effects of surface compaction between 2003 and 2009, but after 2009 it declined markedly (44% of sites). This abrupt decline could be due to the difficult wet winter/spring conditions of the last 2 years that made pasture more vulnerable to compaction. Surface compaction remains a priority issue due to the large area of land affected and potential off-site effects including flooding, erosion, transport of contaminants, and sedimentation.

Loss of soil organic matter continued to decline and average total C concentration has reduced (from 9.9% to 9.5%) since 2003 (equivalent to the loss of 7216 kt of carbon from the region). Much of this decline was from sites under annual cropping land use. Several indicators, including total C, total N, anaerobically mineralised N and aggregate stability declined with conversion of pine to pasture and point to loss of soil organic matter during the conversion process.

In all land uses where fertiliser is applied, excess nutrients, such as nitrogen and phosphorus are either trending upwards or are stable (44% of sites have excess N, 48% have excess P). Conversely, some forestry, forest to pasture conversion, and other pasture sites showed deficient nutrients, reflecting low carbon status (influencing the soil’s ability to hold nutrients) or worsening economic factors leading to lower applications of fertiliser than optimum.

Erosion of soil decreases soil quality, including damaging soil structure and lost of topsoil. Eroded soil can be transported to water where it becomes sediment, effecting water quality. A large proportion of forestry sites have high erosion risk, especially if the trees are removed, because production forests tend to be situated on steeper land. It is a management practice to leave erosion prone soils in native bush or planted in production forestry to help control erosion. In addition, some annual cropping and a few horticulture and pasture sites have a higher risk of eroding, especially between crops or at re-sowing when the land is bare and/or is sloping (> 7°).

Accumulation of contaminants, which has been part of the soil quality report in the past, is now considered under a separate report currently being written (Trace Element Monitoring in the Waikato Region 2011).

1 Introduction

Monitoring of soil properties provides important information on the overall health of the soil and any potential impacts that land use may be having on soil quality in the region. Waikato Regional Council participated in the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" from 1998–2001. The Council continues to sample new sites and resample previously sampled sites, at a rate of about 30 sites each year, to determine the extent and direction of changes in soil quality. There are now 151 soil quality sampling sites in the Waikato region. Sites were chosen to cover a representative range of land uses (including native sites to provide background levels) and soil types.

2 Objectives

- Provide an assessment of the current soil quality status of the soils of the Waikato region.
- Provide interpretation of changes in monitored soil characteristics over the last 7 years.

3 Methods

Sampling

Soil quality monitoring sites were chosen and sampled according to the methods set-out in the Land and Soil Monitoring Manual (Hill & Sparling, 2009). Soils were classified according to the New Zealand Soil Classification (Hewitt et al., 2003). The land use classes sampled were dairy pasture (pasture grazed with milking cows), other pasture (all other pasture), cropping (annual cultivation), horticulture (plants left in place), forestry (production pine forests), and native (background). An additional land use class called forest to pasture was defined to encompass sites where the land use has recently changed from production forestry to pasture. A new class was required because results would have been significantly skewed if these sites were included in the pasture categories. No trends are reported for the forest to pasture land use in this report because sites in this class have only been sampled once (in 2009) to date.

Land classified as urban/town, rock, permanent ice and snow, was not discussed as the soils in these areas are either highly modified by human occupation or are unlikely to change in the short to medium-term.

In 2011, Waikato Regional Council staff selected 29 sites (23 previously sampled sites and 6 new sites in Kiwifruit orchards) for sampling. Samples were analysed at Landcare Research and Plant and Food Research. Data from these sites were added to the Waikato Regional Council soil quality database. At present there are 151 soil quality monitoring sites distributed across the Waikato region (Figure 1).

Indicators

To be useful, a soil quality indicator must be both measureable and informative on the condition of the soil. After three years of trials (1998-2001) over many hundreds of sites, the National Land Monitoring Forum agreed on seven key indicators plus two optional environmental indicators (Hill & Sparling, 2009). Table 1 lists the soil quality indicators, the soil property measured, and why the indicator is important.

A review of soil quality indicators was carried out by the Land Monitoring Forum as part of an Envirolink Tools Project (Taylor & Mackay, 2012, Mackay et al 2013). This review resulted in a lowering of the upper limit of the Olsen P target range to 50 mg/kg for all land uses to be more in line with the recommended levels of the farming industry. It also identified that the upper limit of the anerobically mineralised N target range was unsuitable and, consequently, has been removed. In addition, the revised macroporosity targets suggested by Beare et al. (2007) and Mackay et al. (2006) were endorsed.

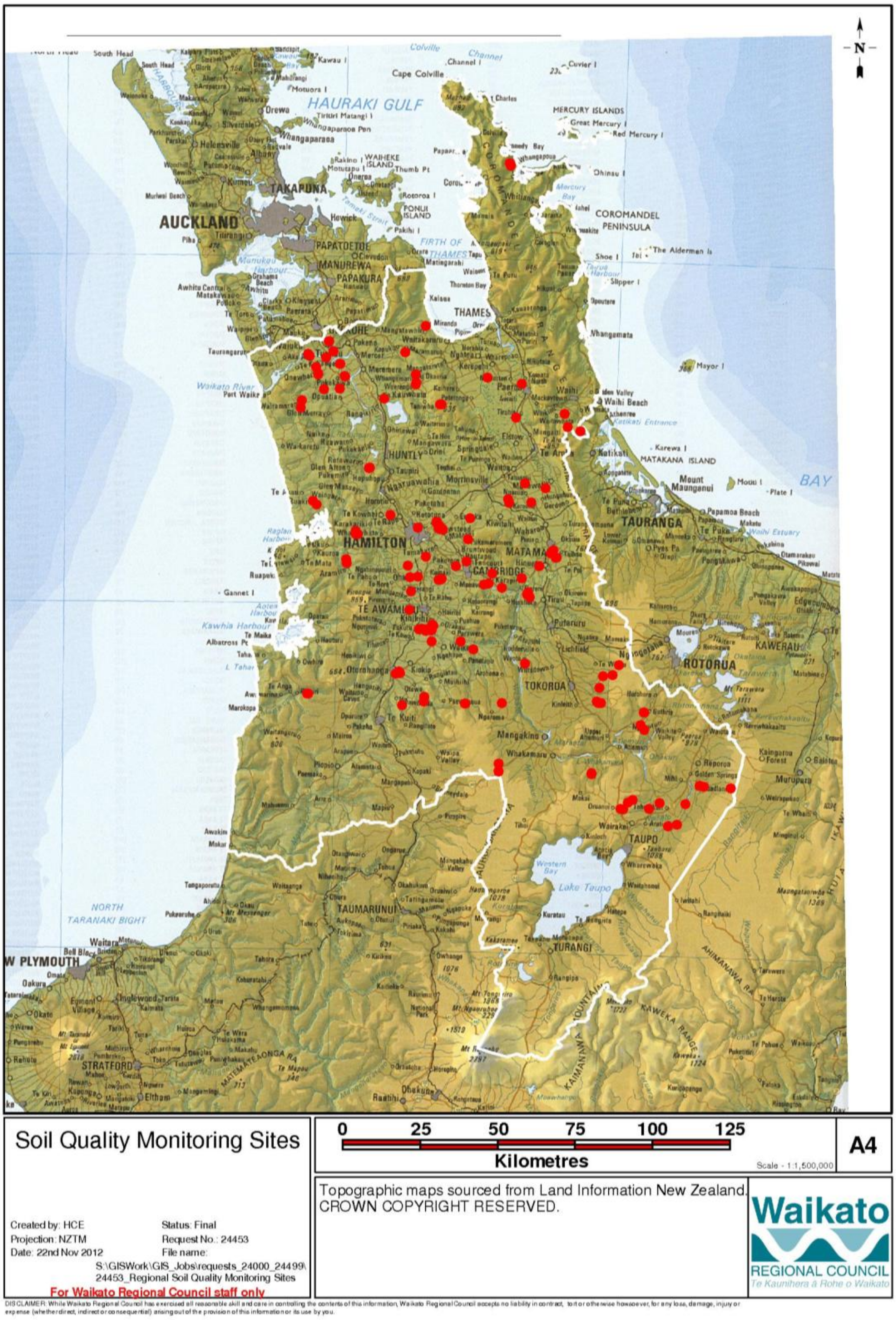


Figure 1: Map of soil quality site locations

Table 1 National Soil Quality Monitoring Indicators (from Hill & Sparling, 2009)

Soil property	Indicator	Why is this measure important	Issue addressed
Organic matter and humus	**Total C**	Organic matter helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth.	Organic matter depletion. C loss from soil.
	Total N	Nitrogen (N) is an essential nutrient for plants and animals. Most N in soil is within the organic matter fraction, and total N gives a measure of those reserves.	Organic N reserves for plant nutrition. Potential for N leaching.
	Mineralisable N (anaerobic incubation method)	Not all the organic matter N can be used by plants; soil organisms change the N to forms that plants can use. Mineralisable N gives a measure of how much organic N is available to the plants, and the activity of the organisms.	N build-up at sites Reserves of plant available N. Potential for N leaching at times of low plant demand.
Fertility and acidity	**Soil pH**	Most plants and soil animals have an optimum pH range for growth. Indigenous species are generally tolerant of acid conditions but introduced pasture and crop species require a more alkaline soil.	Remediation may be needed to grow some crops. Some heavy metals may become soluble and bioavailable.
	Olsen P	Phosphorus (P) is an essential nutrient for plants and animals. Plants get their P from phosphates in soil. Many soils in New Zealand have low available phosphorus, and P needs to be added for agricultural use. However, excessive levels can increase loss to waterways, contributing to eutrophication.	Depletion of nutrients. Indicates whether soils being “mined” and if so current land use may require maintenance applications of fertiliser. Excessive nutrients (risk to waterways).
Physical condition	**Bulk density**	Compacted soils will not allow water or air to penetrate, do not drain easily, and restrict root growth.	Adverse effects on plant growth. Potential for increased run-off and nutrient losses to surface waters.
	Macroporosity (pores that drain at -10 kPa)	Macropores are important for air penetration into soil, and are the first pores to collapse when soil is compacted.	Adverse effects on plant growth due to poor root environment, restricted air access and N-fixation by clover roots. Infers poor drainage and infiltration (see above).

Additional Environmental Indicators

	Aggregate stability	A stable “crumbly” texture lets water quickly soak into soil, doesn’t dry out too rapidly, and allows roots to spread easily.	A measure of the stable crumbs in soil that are of a desirable size, and resist compaction, slaking, and capping of seedbeds.
	C:N Ratio	Once a soil is saturated with nitrogen it can no longer hold further inputs of nitrogen.	A measure of the nitrogen saturation of the soil.

Indicator Target Ranges

Provisional soil quality target ranges were set in 2003 (Sparling et al., 2003) using expert opinion and data on production responses. Target ranges for pH, total C, total N, anaerobically mineralised nitrogen, and bulk density are based on Sparling et al.

(2003). These are presented in Appendix 1. The revised target range for macroporosity (-10kPa) is based on Beare et al. (2007) and Mackay et al. (2006). The upper limit of the target range for Olsen P was set to 50 mg/kg based on Taylor & Mackay (2012) and Mackay et al. (2013). The target for aggregate stability is based on Beare et al. (2005).

Results are compared to target ranges. Soil quality sites that meet all 7 indicator targets are described as having 'met all targets'. Those soil quality sites that met 6 indicator targets but failed to meet 1 indicator target are described as having 'failed to meet 1 target'. Sites that failed to meet 2 or more indicator targets are described as having 'failed to meet 2 or more targets'.

Laboratory Analysis

All analyses were carried out at IANZ-accredited laboratories (Landcare Research, Hill Laboratories, both of Hamilton, and Plant & Food Research, Lincoln) according to methods set-out in the Land and Soil Monitoring Manual (Hill & Sparling, 2009). All results and target ranges are presented on a gravimetric basis.

Reporting basis

Results are presented on an overall regional basis. Data is first presented as site proportion information. Some land use classes represent relatively large proportions of the land area in the Waikato region (e.g. dairy, other pasture and production forestry) whereas other classes represent a relatively small proportion of the area (e.g. annual cropping and horticulture). As the number of sample sites within each land use class is not proportional to the area of land within the region that each class represents. Therefore, the data were weighted by the area of land occupied by each land use class within the region and data subsequently presented on a land area basis.

Statistical methods

Summary statistics were calculated using Data Desk version 6 and boxplots were produced using Sigma Plot version 7. The data was log-transformed to make a normal distribution for significance testing. Pooled Student's t-tests were used to assess significance of the difference between each pair of means. As samples were taken over a 5 year rotation, 5 year floating averages were calculated for soil quality indicator concentrations and presented in graphs showing concentration by land use.

4 Status of soil quality indicators in 2011

Status of soil quality indicator sites in 2011

Only 13% of sites meet all 7 soil quality targets, 34% did not meet 1 target and 53% did not meet 2 or more targets (Figure 2).

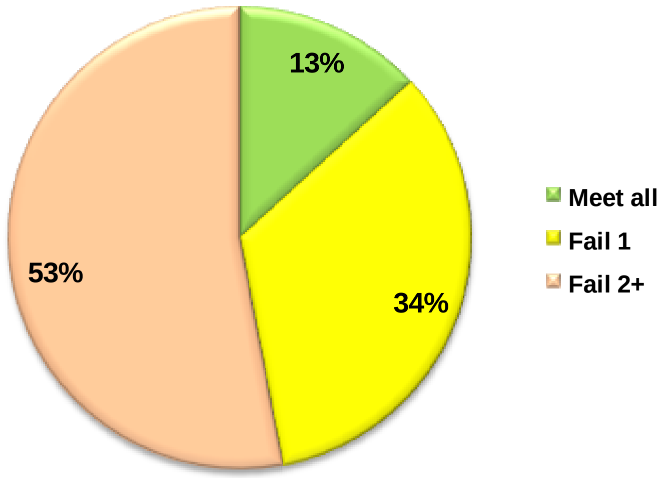


Figure 2: Proportion of soil quality sites meeting/failing to meet targets in 2011

The state of the Waikato Region's soils by land area

The number of sites in each land use class do not match the amount on land in that land use. This is because a minimum number of sites are required for statistical analysis in each land use class. The data is corrected for the amount of land in each land use class to give the current state of the Waikato region's soils (Figure 3).

In 2011 about 14% of land met all 7 soil quality indicator targets, 32% of land failed to meet 1 target, and 54% of land failed to meet 2 or more targets (Figure 3).

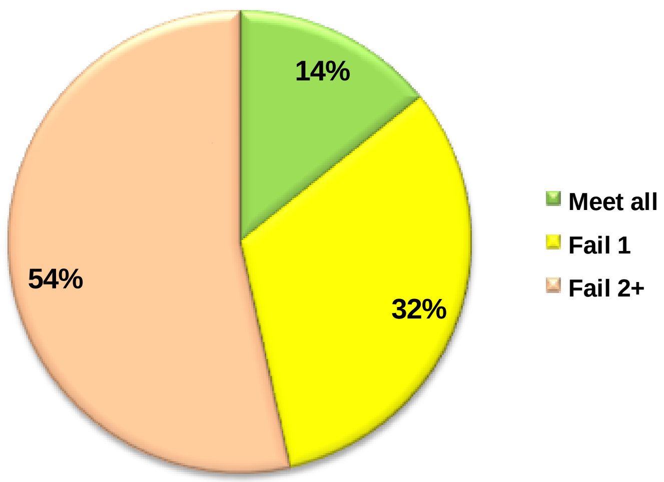


Figure 3: Proportion of soil quality sites meeting/failing to meet soil quality targets in 2011 corrected for the amount of land in each class

Results are similar to Figure 2, which implies the spread of soil quality sites is representative of the region's soils. .

High total N and Olsen P (indicators of excess fertility) and low macroporosity (indicator of compaction) were the indicators for which targets were most commonly not met (Figure 4). The target range for bulk density (indicator of compaction) was not met at 11% of sites. The interaction between land use and each indicator is discussed below.

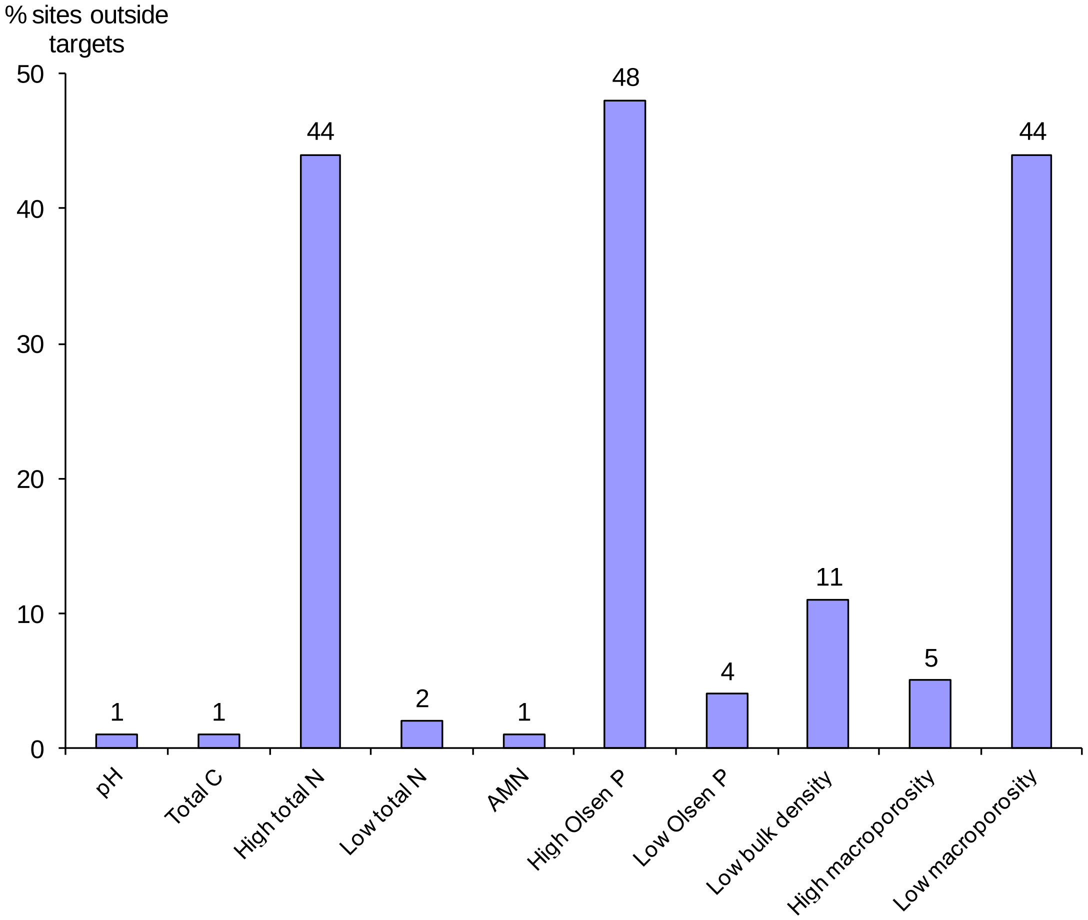


Figure 4: Proportion of soil quality sites outside soil quality targets in 2011

5 Effect of land use on soil quality indicators in 2011

Overview

The effect of land use on soil quality indicators was assessed based on the latest data for each of the 151 sites. Forestry (41%) had the largest proportion of land meeting soil quality indicator targets. Twenty-two percent of land under horticulture, 16% of land under annual cropping and 14% of land converted from forestry to pasture also met targets, while dairy (4%) and other pasture (3%) had the smallest proportion of land area meeting soil quality indicator targets (Figure 5).

Annual cropping sites failing 2 or more indicators tended to have high nutrients (total N and Olsen P), low organic matter and microbiological activity (Total C and AMN). Horticulture, dairy and other pasture sites failing 2 or more indicators tended to have high nutrients (total N and Olsen P) and surface compaction (low macroporosity). Forestry sites failing 2 or more indicators had erosion potential (low bulk density and high macroporosity).

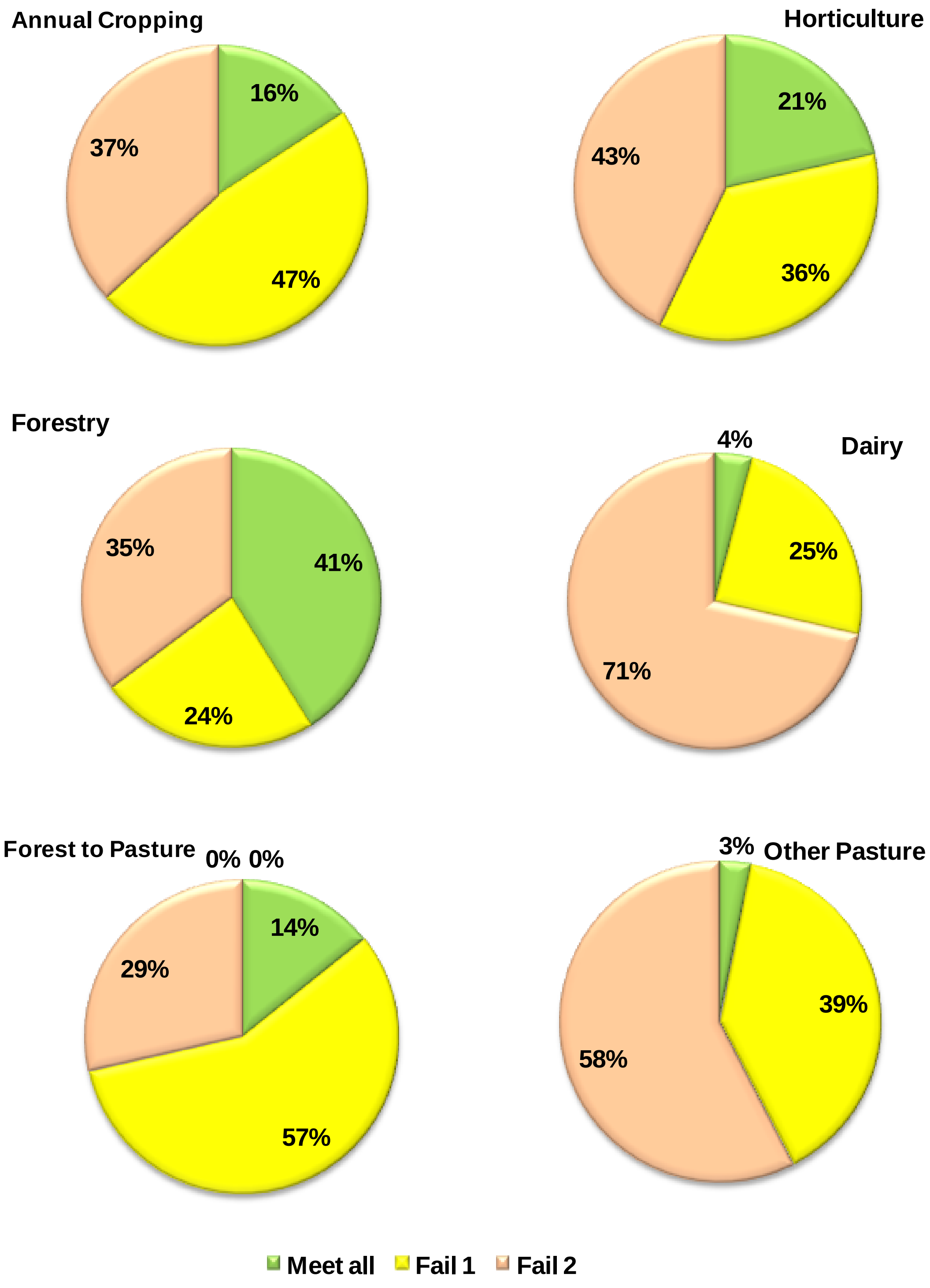
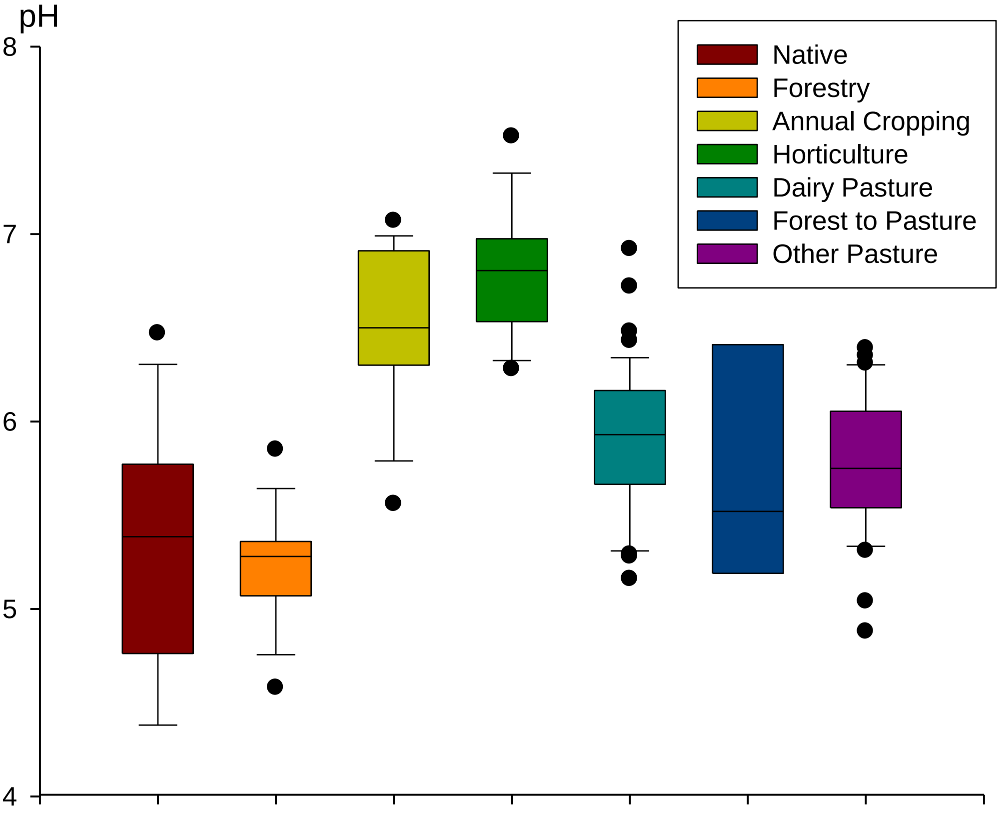


Figure 5: Proportion of soil quality sites by land use meeting/failing to meet soil quality targets in 2011

The effect of land use on soil pH

Soil pH levels were, on average, significantly higher at sites under annual cropping and horticulture, than at sites under dairy pasture and other pasture, which, in turn, were significantly higher than at sites under native and forestry (Figure 6). These results reflect farm management is meeting the pH requirements of the plants grown under the different land uses. One sheep and beef farm had pH below targets but generally, no soil quality issues associated with soil pH were identified.

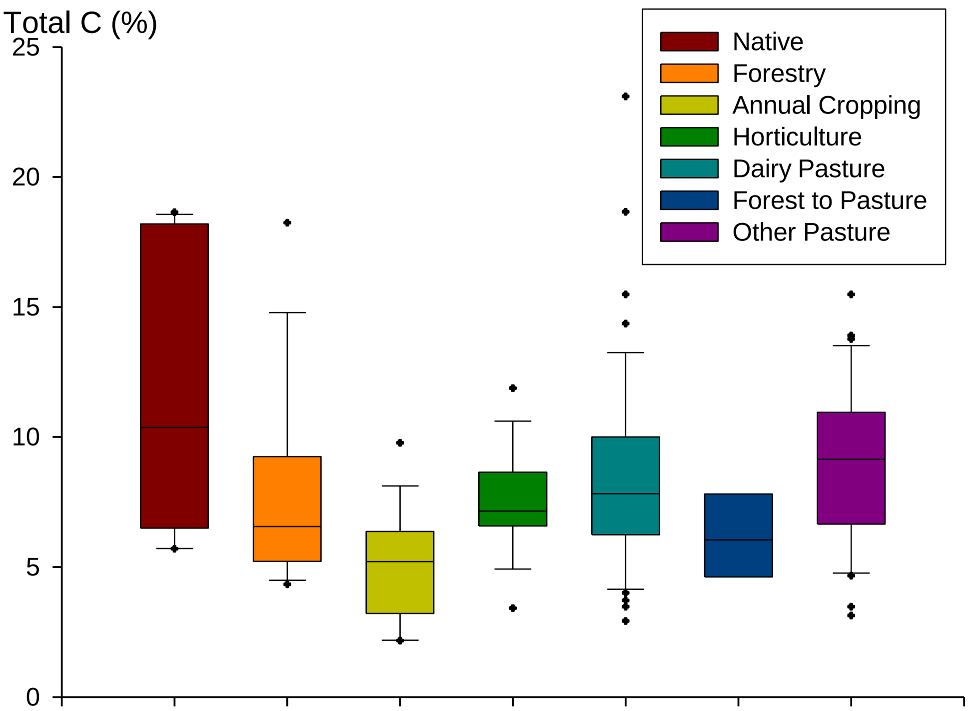


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 6: Soil pH by land use class.

The effect of land use on soil total carbon

This indicator is not suitable for analysing Organic Soils (peat). Therefore, Organic Soils were excluded from the data set when assessing total carbon (total C). Total C concentrations were, on average, significantly lower at sites under annual cropping than at sites under native, forestry, horticulture, dairy pasture, forest to pasture, and other pasture, indicating loss of soil organic matter (Figure 7). The loss of soil carbon due to disturbance events such as tillage is well known (e.g. Dick & Gregorich, 2004). Likewise, the regeneration of soil carbon due to increased return of plant material when fertility is increased and tillage decreased is also well documented (e.g. Dick & Gregorich, 2004). Long-term dairy pasture and other pasture had higher total carbon concentrations than those under forest to pasture recently converted from forest, indicating that total carbon concentrations are likely to increase at conversion sites as fertility and the return of plant material increases.

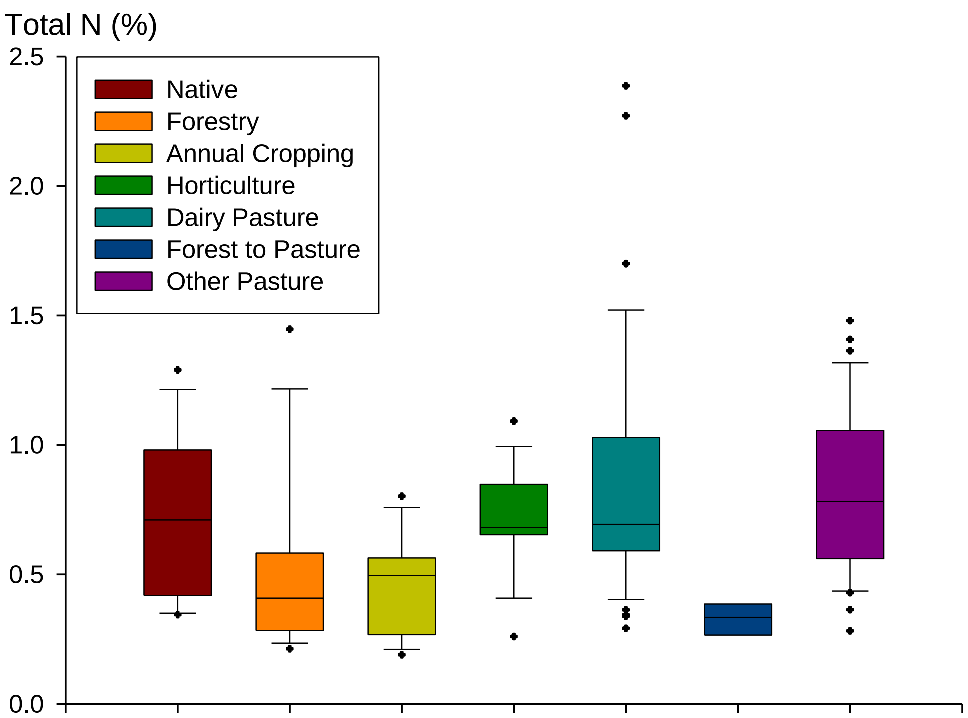


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 7: The effect of land use on soil total carbon.

The effect of land use on soil total nitrogen

Total nitrogen concentrations were, on average, significantly lower at sites under annual cropping than at sites under native, horticulture, dairy pasture, and other pasture, indicating loss of soil organic matter (Figure 8). Soils with lower soil organic matter have a lesser ability to hold on to nitrogen. However, forest to pasture had total nitrogen concentrations, significantly lower than those under cropping, consistent with the loss of soil organic matter under the conversion process.

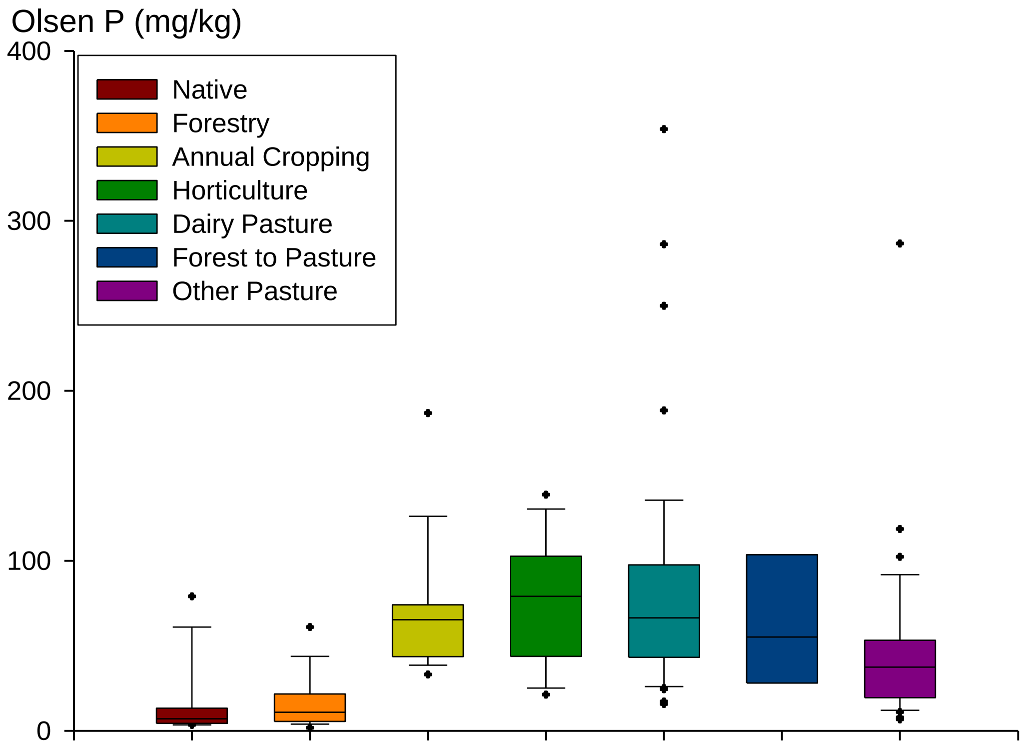


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 8: The effect of land use on soil total nitrogen.

The effect of land use on Olsen P

Olsen P measurements were, on average, significantly higher at sites under annual cropping, horticultural, dairy pasture, forest to pasture and other pasture land uses than those under native and forestry (Figure 9). The results suggest little application of phosphate fertiliser in production forests compared to the other productive land uses. There were several extremely high Olsen P concentrations under dairy pasture and occasional extreme values under other pasture and cropping, almost certainly from very high fertiliser applications. Soils with extreme Olsen P concentrations have greater risk of phosphorous being transported to ground or surface waters (McDowell 2001.

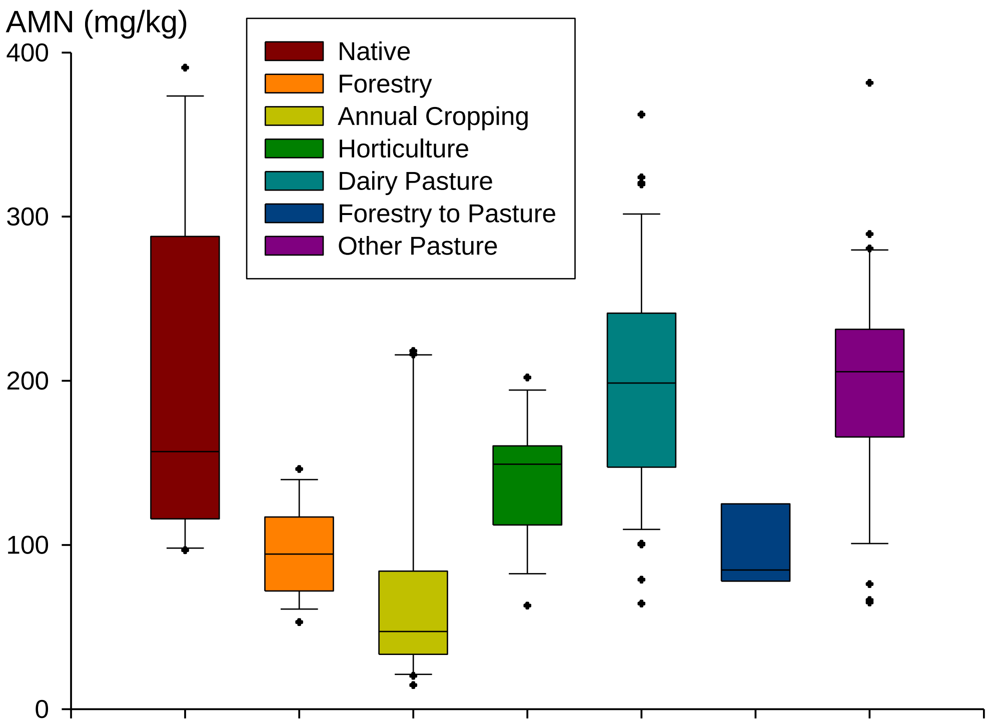


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 9: The effect of land use on Olsen P.

The effect of land use on soil Anaerobically Mineralised Nitrogen (AMN)

Annual cropping had, on average, significantly lower concentrations of AMN than forestry and forest to pasture, which had, on average, significantly lower concentrations than native, horticulture dairy pasture and other pasture (Figure 10. Annual cropping and forest to pasture occurs on soils that have lost of soil organic matter (Figures 7 & 8), which is a food source for microorganisms. The reason for the low forestry concentrations is unclear but it may be related to the ability of the micro-organisms to use pine debris as a food source and/or food sources are tied up in the organic material contained in the forest floor (L and FH horizons). Only mineral soil was sampled as part of this soil quality monitoring.

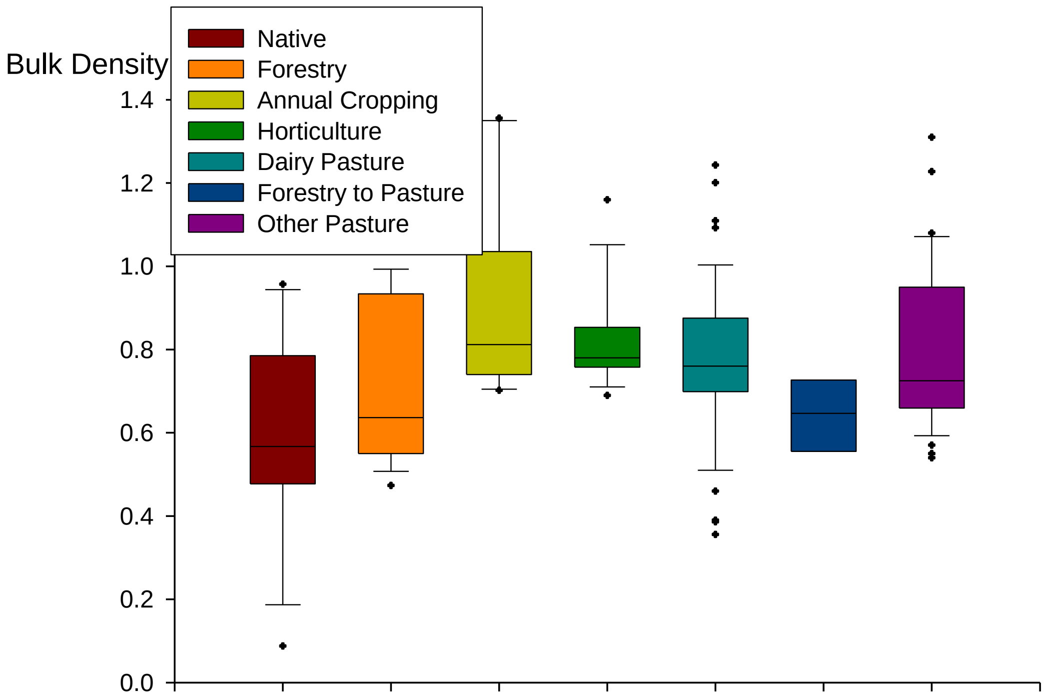


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 10: The effect of land use on soil anaerobically mineralised nitrogen.

The effect of land use on soil bulk density

Soil bulk density was, on average, significanly lower under native than under cropping, horticulture, dairy pasture and other pasture (Figure 11). Annual cropping had significantly higher bulk density than all other land uses except horticulture, consistent with compaction by machinery. Adoption of techniques such as precision agriculture would likely improve bulk density, hence soil quality under annual cropping. Bulk density values for horticulture, dairy pasture and other pasture were also significantly higher than those under native, consistent with surface compaction due to trafficking and stock treading, or both.

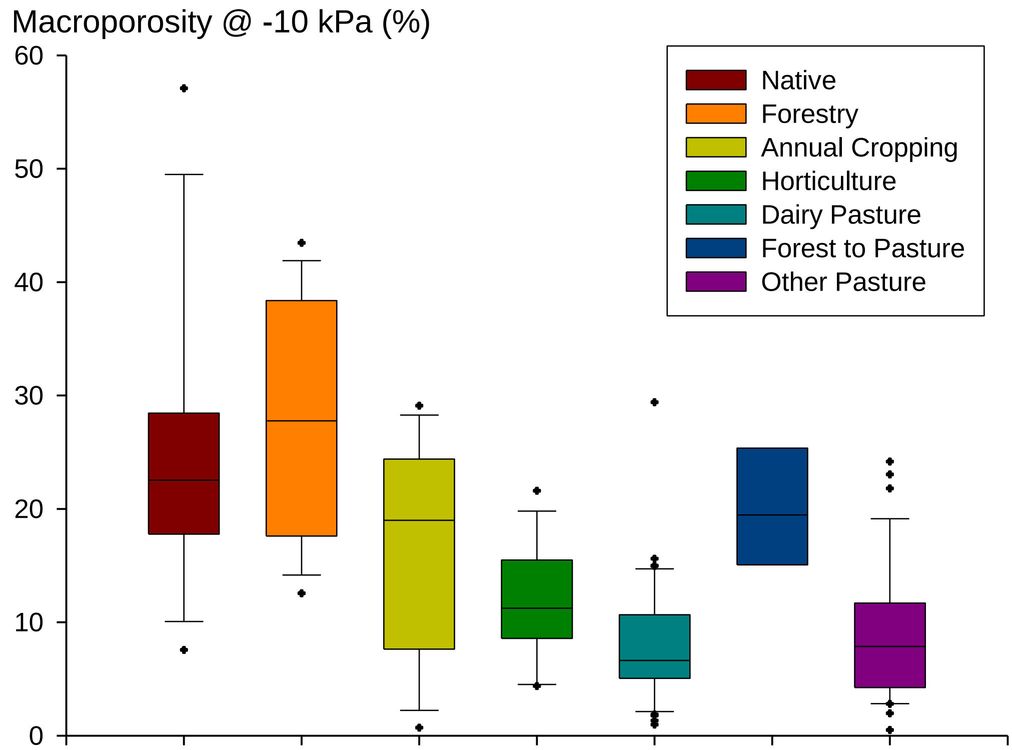


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 11: The effect of land use on soil bulk density.

The effect of land use on macroporosity

Soils under horticulture, dairy pasture and other pasture land uses had, on average, significantly lower macroporosity than those under native and forestry, consistent with surface compaction due to trafficking and stock treading, or both (Figure 12). Annual cropping and forest to pasture had intermediate macroporosity values.



Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 12: The effect of land use on macroporosity

6 Effect of land use on environmental indicators in 2011

Introduction

This section covers two indicators that are additional to the 7 key soil quality indicators described above. They are aggregate stability and the C:N ratio. They add further information to the soil quality data allowing an improved interpretation of the results.

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. Aggregate stability is a measure of the ability of soil aggregates to resist disintegration when forces associated water or wind erosion, or with tillage are applied. A greater amount of stable aggregates implies better soil quality. Aggregate stability is important for infiltration, root growth, and resistance to water and wind erosion.

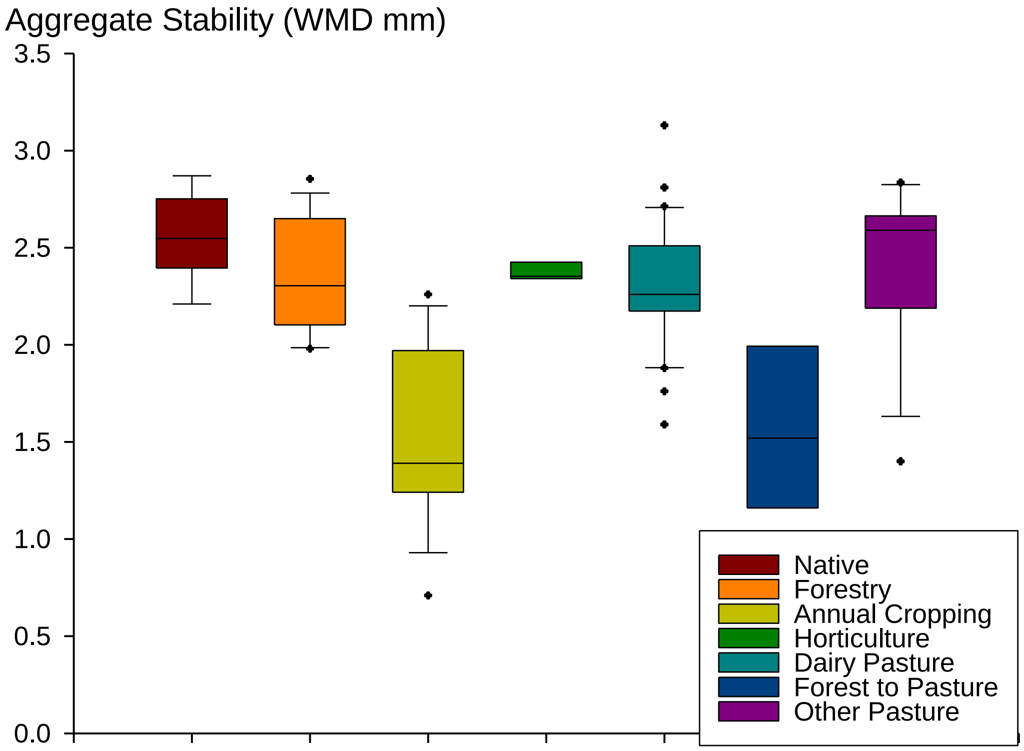
Stable aggregates allow a large amount pore space in soil, including small pores within and large pores between aggregates. Pore space is essential for air, water, nutrient, and biota movement into and within soil. Large pores associated with large, stable aggregates allow high infiltration rates and appropriate aeration for plant growth. Pore space also provides zones of weakness for root growth and penetration.

Conversely, surface crusts and filled pores occur in weakly aggregated soils. Unstable aggregates may disintegrate during rainstorms. Dispersed soil particles can fill soil pores and a hard crust can develop on the soil surface when it dries. Filled pores lower infiltration, water-holding and air-exchange capacity and increase bulk density, deteriorating the conditions for root growth. Crusting results in increased runoff, water erosion and transport of contaminants, with reduced water infiltration so less is later available for plant growth. A surface crust can also restrict seedling emergence.

The C:N ratio is the total carbon divided by the total nitrogen. It is a measure of the degree of nitrogen saturation of a soil and also influences the rate of decomposition of SOM. Decomposition of SOM results in the release (mineralisation) or immobilisation of soil nitrogen.

The effect of land use on aggregate stability

Aggregate stability measurements were, on average, significantly lower at sites that are cropped annually or under forest to pasture than at sites under other land uses, indicating a loss of soil stability cause by tillage or the conversion process (Figure 13).



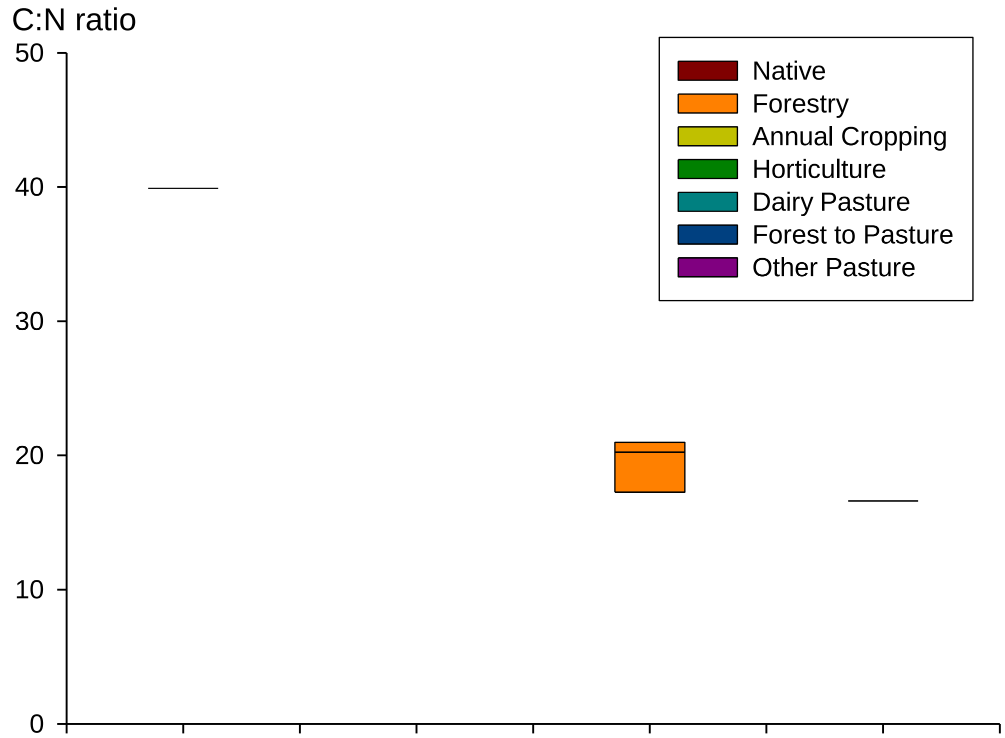
Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 13: The effect of land use on aggregate stability

The Carbon:Nitrogen ratio

Organic soils (peat) have a different carbon:nitrogen (C:N) ratio compared to mineral soils due to their very high carbon concentrations. Therefore, organic and mineral soils were analysed separately.

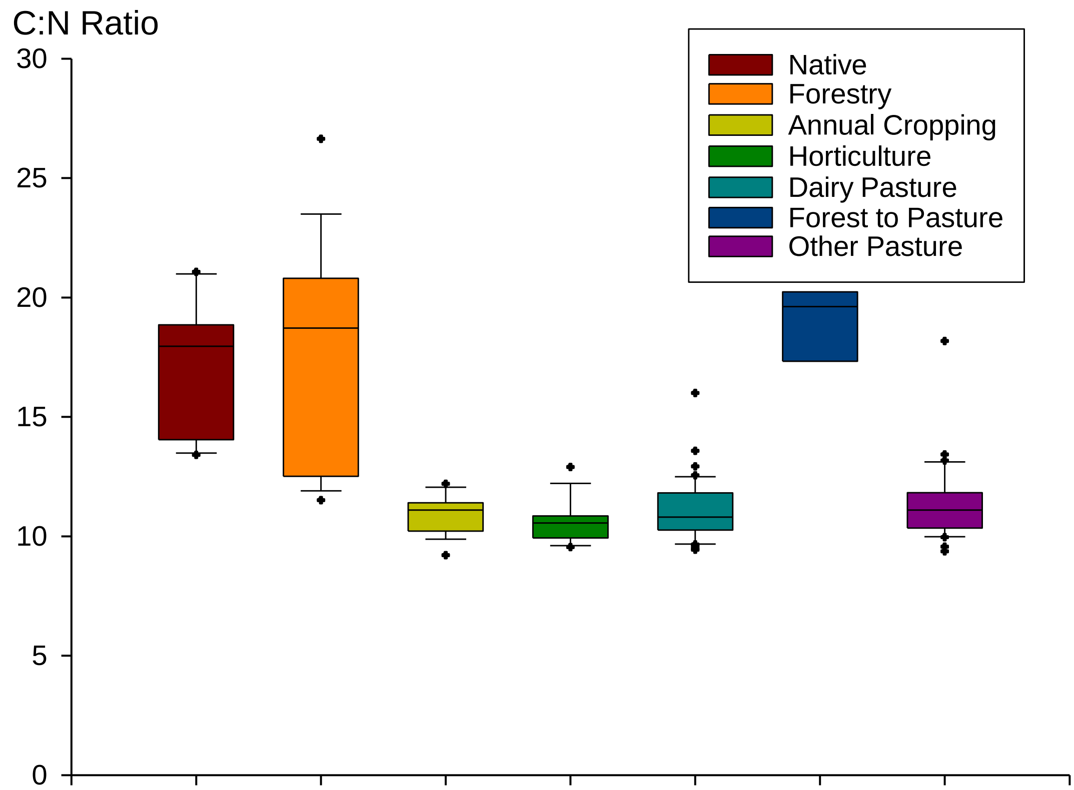
There were a total of 8 sample sites on Organic Soils covering three land uses in the Waikato Region (native, dairy pasture and other pasture). The C:N ratio for both dairy pasture and other pasture was about half that of native land use, consistent with the application of nitrogen fertiliser (Figure 14). As nitrogen accumulates in the soil the C:N ratio is lowered.



Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 14: The effect of land use on the C:N ratio for Organic soils

The C:N ratio for mineral soils was lower, on average, than that for Organic soils for all land uses measured (Figure 15, compare with Figure 14). Annual cropping, horticulture, and dairy pasture and other pasture had significantly lower C:N ratios than native, forestry and forest to pasture, consistent with the application of nitrogen fertiliser and/or the loss of soil carbon. The higher C:N ratio for forest to pasture probably reflect the short time these soils have received nitrogen fertiliser.



Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 15: The effect of land use on the C:N ratio for mineral soils

7 Trends in meeting indicator targets

Trends indicate how the soil quality results are changing over time (Figure 16). Overall, soil quality in the Waikato region is declining; the number of sites meeting all soil quality indicator targets is declining and the number of sites not meeting indicator targets is increasing.

The trend in the proportion of sites meeting all soil quality indicator targets shows an initial improvement between 2003 and 2005, followed by a decline since 2005. The number of sites not meeting 1 indicator target initially declined between 2003 and 2007, and then increased since 2007. Sites failing 1 indicator most commonly had high Olsen P or low macroporosity.

The number of sites not meeting 2 or more indicator targets has been somewhat inconsistent but has trended upwards (more sites failing to meet 2 or more indicators) between 2003 and 2011.

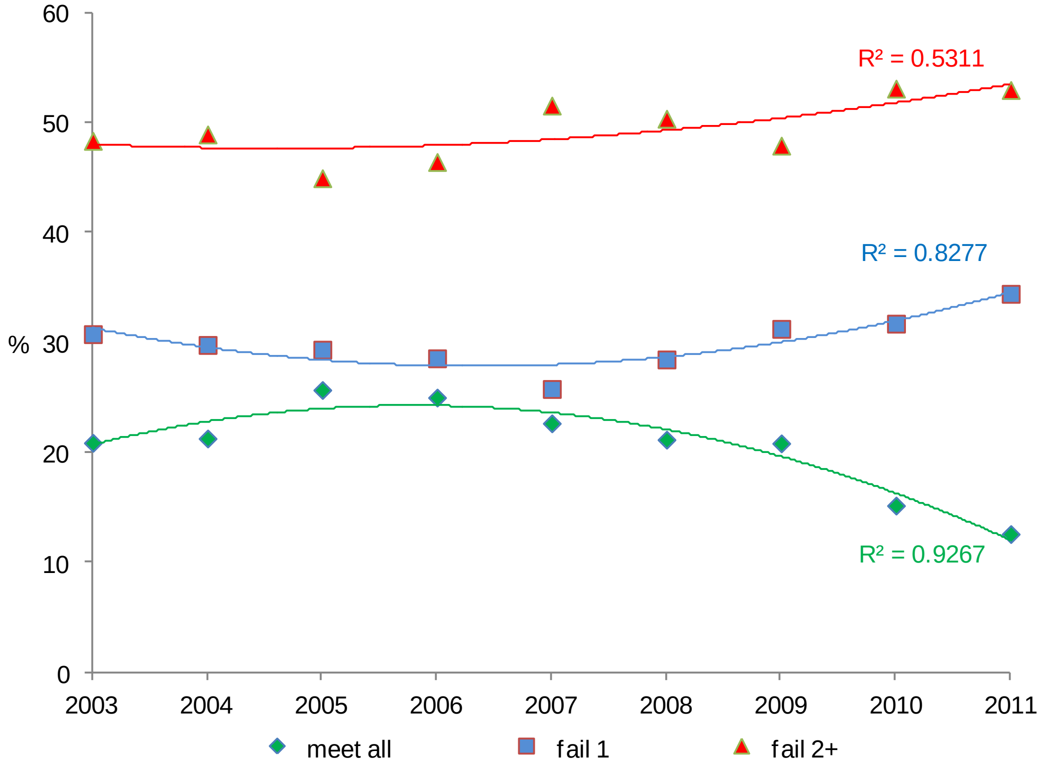


Figure 16: Trends in soil quality sites meeting/failing to meet targets

8 Key issues

Introduction

Four key issues of soil quality were identified from the monitoring. These issues are important as they impact on the soil's long-term ability to sustain production and other environmental services. These key issues are discussed in detail below. Tables of the proportion of sites meeting/not meeting the targets associated with each issue are presented in Appendix 2

Surface Compaction

Surface compaction may be the most pressing soil quality issue identified for the Waikato region due to the large proportion of land area potentially affected and its associated off-site impacts, such as flooding and nutrient run-off. All arable/pastoral land uses monitored were impacted by surface compaction; only forestry showed no compaction at all sites.

Macroporosity (-10kPa) is the soil quality indicator used for compaction. Research has shown reduced production at macroporosity (-10 kPa) <10% for pasture, arable and horticultural soils and at <5% for soils under production forestry (Mackay et al. 2006, Sparling et al. 2003).

In the Waikato region, only about one third of dairy pasture sites and less than half of the other pasture sites met the lower target in 2010 and 2011, a large decrease compared with the previous year's results (2009). This result was a reverse in the trend of improving results between 2003 and 2009 (Figure 17). The particularly wet winter/spring periods over the last two years may have increased the vulnerability of the land to compaction resulting in lower soil macroporosity values. Greater intensification, particularly on dairy farms, may also be a contributing factor.

About 80% of cropping sites met the lower target, no change from the previous year, whereas horticultural sites improved from 75% to 85% of sites meeting targets. These results are consistent with excessive vehicle trafficking (cropping and horticulture) and stocking pressure (dairy pasture and other pasture) causing soil compaction. Soil compaction may result in reduced infiltration and potential increased runoff to waterways. Runoff can carry contaminants and may result in increased peak-flows causing localised flooding and bank erosion (McDowell et al., 2001, Taylor et al., 2009).

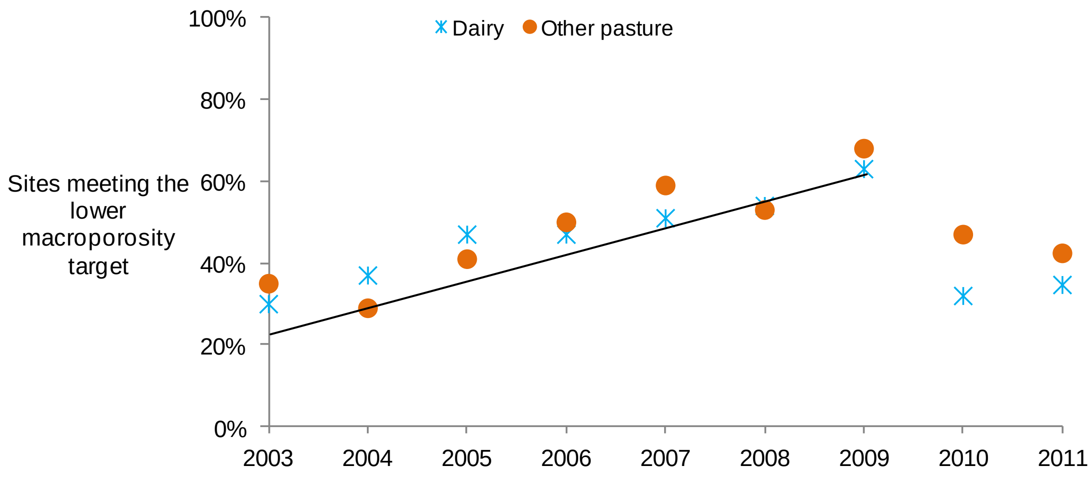


Figure 17: Trend in meeting the lower macroporosity (-10kPa) targets by pastoral land uses

Of note is that forest to pasture sites had higher macroporosity than dairy pasture and other pasture sites, with 86% of sites meeting the lower target. These sites have had stock on them for only a short time and are expected to show more compaction as time goes on.

Loss of soil organic matter

Soil organic matter (SOM) is considered a key soil attribute as it affects many physical, chemical and biological properties that control soil services such as productivity, the adsorption of water and nutrients, and resistance to degradation (Dick & Gregorich, 2004). Organic acids (e.g., oxalic acid), commonly released from decomposing organic residues and manures, prevents phosphorus fixation by clay minerals and improve its plant availability. Carbon compounds found in SOM, such as polysaccharides (sugars) bind mineral particles together into microaggregates. Glomalin, a SOM substance that may account for 20% of soil carbon, glues aggregates together and stabilises soil structure making soil more resistant to erosion, but porous enough to allow air, water and plant roots to move through the soil.

It is important to remember that SOM is essential for the viability and life-sustaining function of the soil. A direct effect of low SOC is reduced microbial biomass, activity, and nutrient mineralisation due to a shortage of energy sources and loss of habitat. In the acid soils of the Waikato region, aggregate stability, infiltration, drainage, and airflow are reduced. Scarce SOC results in less diversity in soil biota with a risk of the food chain equilibrium being disrupted, which can cause disturbance in the soil environment (e.g. plant pest and disease increase, accumulation of toxic substances etc). Of particular significance to the Waikato catchment is SOM's role in retaining nitrogen in the soil.

Total carbon (total C) is the target indicator chosen for SOM assessment. Monitoring results for the Waikato region showed about 89% of cropping sites met the target and this has stayed consistent over the period 2003-2011 (Appendix 2). However, an increasing decline in average total C concentration at sites under cropping land use between 2003 and 2011 is clearly evident (Figure 18) and is of considerable concern. Burning, harvesting, or otherwise removing residues and decreases SOM. Practices, such as no-till, may increase SOM concentrations. Other practices that increase SOM concentrations include continuous application of manure and compost, and use of cover crops.

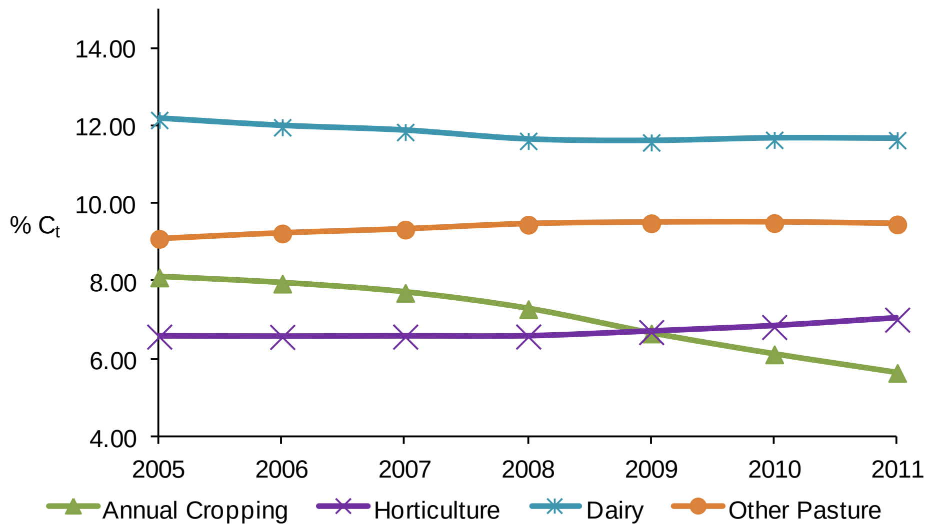


Figure 18: Floating 5 year average soil total C (%) concentrations by land uses between 2003 and 2011

A slight decline in average total C concentration is evident for sites under dairy pasture, whereas sites under other pasture remained fairly constant. The apparent slight increase of total C under horticulture was due to the addition of relatively carbon–rich kiwifruit orchards in 2009 and 2011. Research has indicated that some dairy farms on non-allophanic soils have lost large amounts of soil carbon (Schipper et al., 2007) and this is evident in the declining average total C for dairy pasture, from 12.2% in 2005 to 11.7% in 2011.

Data for the forest to pasture land use (data for 2009 only) shows average total carbon levels higher than annual cropping but below every other land use, indicating a loss of soil organic matter during the conversion process. Both dairy pasture and other pasture had significantly higher carbon concentrations than those under forest to pasture (Fig 6), indicating that carbon concentrations are likely to increase at conversion sites.

Overall, the average total C concentration for all sites has declined from 9.9% to 9.5% over the last 8 years. Using the average bulk density (0.773 t/m^3) for the 151 soil quality sites, it is possible to calculate the amount of carbon lost from the top 0.1 m of the region's 2,333,741 ha of soils. A hectare = 10,000 m^3, so

0.1 * 2,333,741 * 10000 * 0.773 = 1,803,982 kt soil in the top 0.1 m.

The amount of carbon lost is 0.4%.

0.004 * 1803982 = 7216 kt carbon lost from the region.

Aggregate stability is strongly influenced by the soil organic matter and loss of aggregate stability is often linked to loss of organic matter. The proportion of annual cropping sites meeting the aggregate stability target continues to decrease, indicating a continued decline in soil stability. Sites with aggregate stability below the target range have lower productivity (Beare et al., 2005). These sites may be at increased risk of compaction, slaking, and capping of seedbeds. This result is consistent with the observed loss of soil carbon under annual cropping.

Although forest to pasture sites didn't have significantly lower total C (Figure 6), the conversion of pine forest to pasture appears to have had a severe impact on aggregate stability. Only 57% of forest to pasture sites met the aggregate stability target while 100% of forestry sites met this target. Also forest sites had significantly higher aggregate stability compared to forest to pasture sites (Figure 13).

Excessive or deficient nutrient levels

Excessive phosphorous is assessed against the upper Olsen P target of 50 mg/kg, while production limitations due to phosphorus deficiency can be identified by the low Olsen P targets of 5 mg/kg for forestry, 15 mg/kg for pasture and 20-25 mg/kg for horticulture and cropping. Production limitations also can result in increased erosion risk due to reduced vegetative cover to protect the soil.

The upper Olsen P target was exceeded at some sites under all land uses, indicating an opportunity for more efficient fertiliser use. Between 2003 and 2011, there was a decline in meeting the upper Olsen P target by annual cropping, horticultural, dairy pasture, forest to pasture and other pasture land uses.

Assessing the average Olsen P values of the different land uses showed all productive land uses had higher values in 2011 than in previous years consistent with increased availability of phosphate (Figure 19). Sites under forestry may have been unintentionally fertilised by drift from surrounding farmland although third rotation pine forests may be fertilised if phosphorous has become depleted. Olsen P values at sites under native land use did not increase.

The increase in soil phosphorous is also associated with changes in water quality. Long-term records of river water quality in the Waikato region show phosphorous concentrations in streams are increasing by about 1% of the median value per year (Vant, 2008). Soil phosphorous concentration influences stream phosphorous concentrations (McDowell et al., 2001) and about 77% of phosphorous entering tributaries of the Waikato River is attributable to pastoral farming (Environment Waikato, 2008).

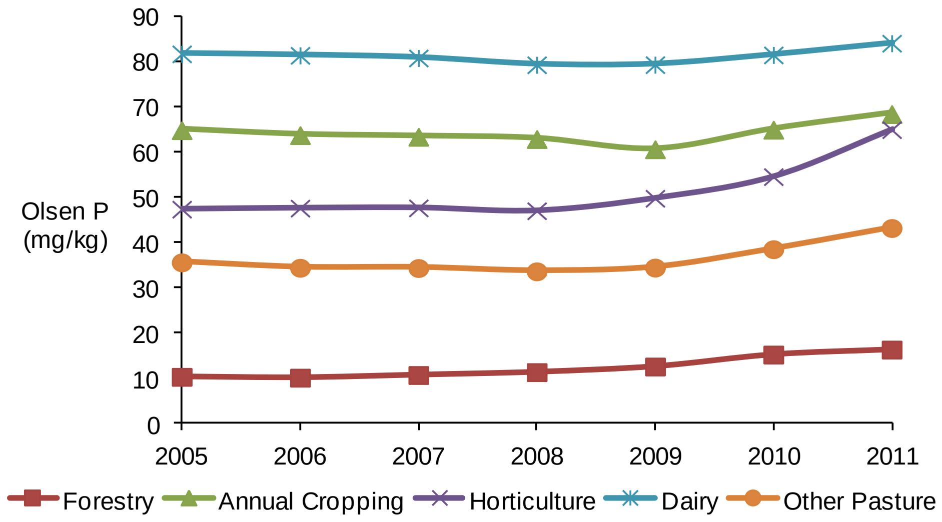


Figure 19: Floating 5 year average Olsen P concentrations by land uses between 2003 and 2011

Phosphorus deficiency is measured against the lower Olsen P target. With careful fertiliser management, sites with low Olsen P could have increased yields and increased vegetative cover to protect the soil from erosion. Several sites had Olsen P levels below the lower (production) target including 22% of other pasture and 12% of production forestry sites. However, other pasture showed a trend of improvement in meeting the targets since 2006 (Figure 20), while forestry initially improved, but then stabilised. Both these land uses tend to take place on the more marginal hilly land and the optimal fertility of these soils may reflect economic factors (e.g. transportation and spreading costs) more than production factors.

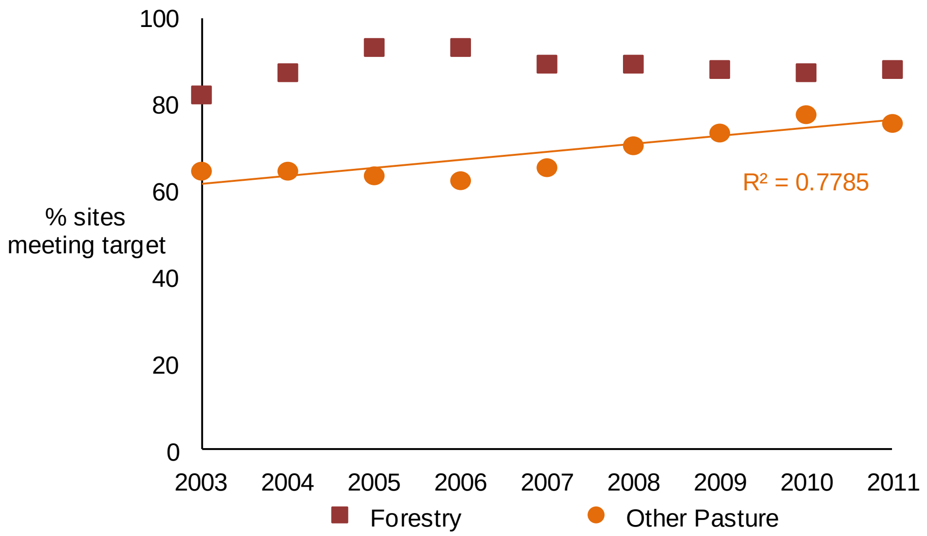


Figure 20: Trend in meeting the lower Olsen P (deficiency) target by forestry and other pasture

Excessive nitrogen is assessed against the upper total N target, while production limitations due to nitrogen deficiency can be identified by the low total N target. It is also useful to compare total N data against the C:N ratio (Figure 15) as it becomes more difficult for soil to retain nitrogen at C:N ratios of 10 or less.

There is a direct relationship between farming intensity and loss of nitrogen — losses are 5 to >100 times greater under farmed land uses than under forest land (Environment Waikato, 2008). Farming in the Waikato region, and in New Zealand generally, is intensifying with increased N fertilisation and stocking rates. The soil quality monitoring results show that the average total N concentration is trending upwards (Figure 21) and, at the same, time nitrogen in river systems has increased at nearly 2% of the median value per year (Vant, 2008).

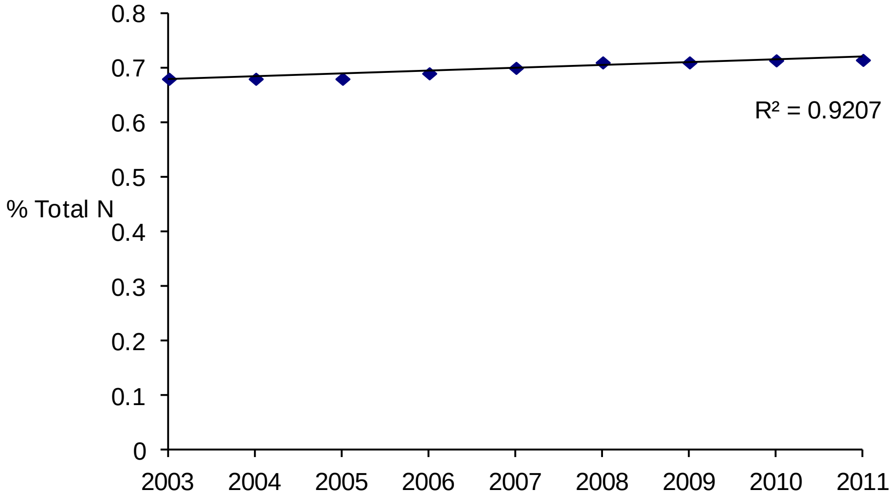


Figure 21: Average total N (%N) at soil quality sites

Both positive and negative trends in the number of sites meeting the upper total N target over the period 2003-2009 for different land uses were apparent. Of concern was the trend showing a declining proportion of other pasture sites meeting the upper total N target (Figure 22). The trend is consistent with land use intensification, including increased N-fertilisation, and is likely to result in increased nitrogen in receiving water bodies. Annual cropping has lost soil organic matter (Figure 18), which holds nitrogen. With less soil organic matter (and a lower C:N ratio) in the soil to hold nitrogen, N fertiliser tends to be washed through the soil with drainage water. Although the proportion of annual cropping sites that meet the upper total N target is increasing (Figure 22), the risk of N loss from annual cropping may be increasing due to the loss of soil organic matter under this land use.

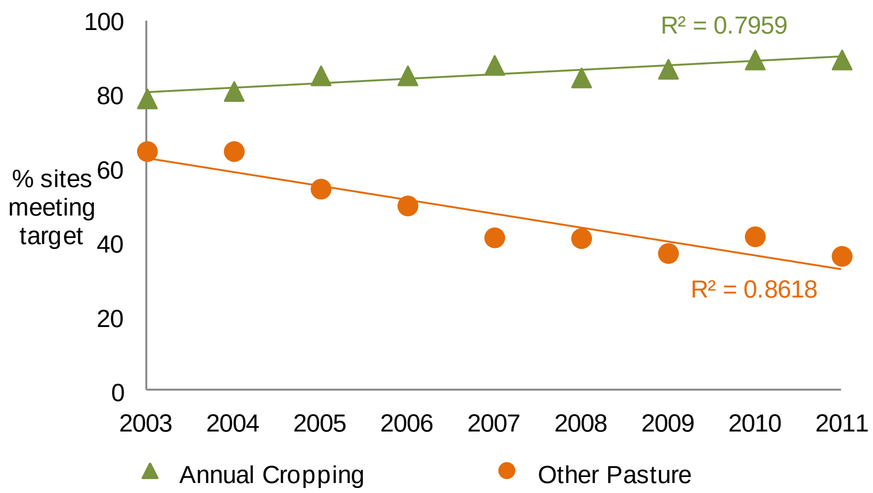


Figure 22: Trend in the proportion of other pasture and annual cropping sites meeting the upper total N target

Forestry and dairy pasture have remained fairly static, while horticulture is more variable (Figure 23). There was a genuine improvement in the proportion of horticultural sites meeting the upper nitrogen target in 2007, but this proportion has declined over 2009-2011.

Figure 23: Trend in the proportion of forestry, horticulture and dairy pasture sites meeting the upper total N target

Prior to 2009, there were no production limitations due to nitrogen shortage at any of the monitoring sites. However, in 2009, 14% of forest to pasture sites had total N values that were below the lower (deficiency) total N target, reflecting their low soil organic matter status (Figure 8). Soil organic matter is needed to help retain nitrogen. No trend in the proportion of forest to pasture conversion sites below the lower total N target is available because these sites were not sampled in 2010 or 2011.

Anaerobically mineralisable N (AMN) measures how easily nitrogen in SOM is able to be mineralised (Sparling et al., 2003). This mineralised nitrogen is a useful guide to the quantiy of the microbial population. There were 5% of annual cropping sites below the lower target (associated with low soil organic matter) and these may have sub-optimal production (Appendix 2). All other land uses meet the AMN targets.

Assessing the average AMN values of the different land uses showed most land uses are static or increasing (Figure 24). Annual cropping initially had low AMN values (in 2005) and values have declined over the period (2005 to 2011), indicating greater risk of decreased production. On the other hand, AMN values under horticulture and other pasture have increased over the period from a moderately low AMN initial value in 2005, consistent with increasing microbial activity.

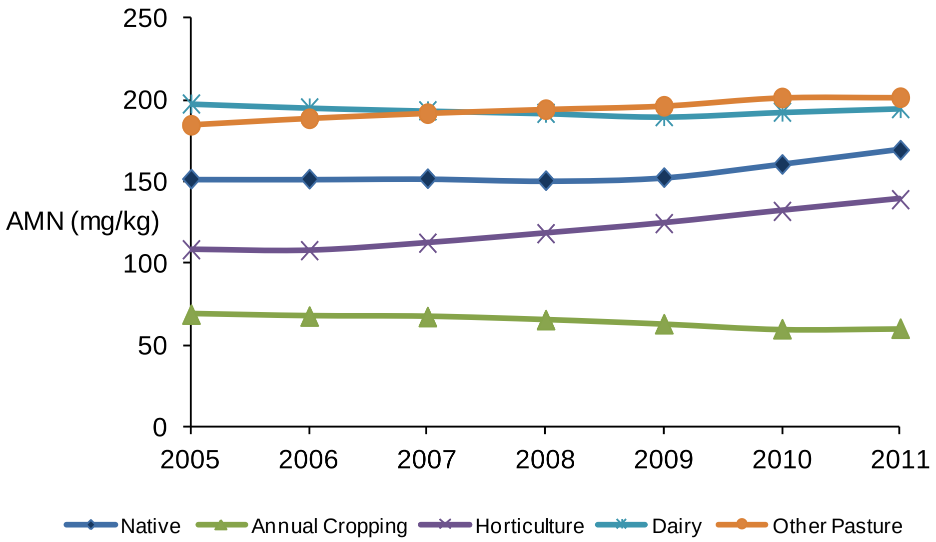


Figure 24: Floating 5 year average anaerobically mineralised N concentrations for cropping and horticultural sites between 2005 and 2010

Low pH was found on 3% of other pasture sites in 2010 and 2009. This land use tends to take place on the more marginal hilly land and the optimal fertility of these soils may reflect economic factors (e.g. transportation and spreading costs) more than production factors. Sites with low pH could be limed to increase yields and vegetative cover to protect the soil from erosion. No trends with pH were identified.

Erosion and soil stability

Many soils within the region are 'light-textured' and with an 'open' structure (e.g. Pumice and Allophanic soils), making them vulnerable to erosion. Erosion of soil decreases soil quality, including damaging soil structure and lost of topsoil. Eroded soil can be transported to water where it becomes sediment, effecting water quality.

There are two soil quality indicators assessing erosion susceptibility; macroporosity (-10 kPa) and bulk density. Macroporosity (-10 kPa) values above the upper targets and bulk density values below the lower targets implies increased erosion risk. Soils with macroporosity and bulk density outside of these targets are susceptible to erosion, may dry out quickly, and plant roots may find it difficult to obtain purchase and absorb water and nutrients (Sparling et al., 2003).

Macroporosity (-10 kPa) and bulk density results showed that about 30% of forestry sites appear to have high erosion risk. This result reflects the tendency to locate production forests on steeper land and it is a commonly accepted practice to leave erosion prone soils in native bush or planted in production forestry to help manage erosion. Care is needed at harvest or conversion of such land to another land use as trees reduce the amount of rain impacting the ground and increase the drainage time, thus reducing erosion risk, while bare ground has higher erosion risk. Environment Waikato (2008) identified increased erosion risk with increasing slope.

The proportion of forestry sites meeting targets seems to have recently increased, perhaps linked to the conversion of some erosion-vulnerable forest to dairy pasture. The conversion process often includes compaction by heavy machinery and the impact of animal hooves would also compact the soil, allowing sites to now meet the upper macroporosity target under dairy, whereas they were outside the target under forestry. The increased compaction may result in transport of contaminants and increased peak-flows causing localised flooding and bank erosion (McDowell et al., 2001, Taylor et al., 2009).

All horticulture, and most cropping, forest to pasture, dairy pasture and other pasture sites met the lower bulk density and upper macroporosity (-10 kPa) targets. Sites not meeting these targets may have a higher risk of eroding, especially between crops or at re-sowing when the land is bare and/or is on sloping ground. No consistent trends in the data were identified.

9 Conclusions

Overall, soil quality is declining. Soil quality monitoring in 2011 showed 13% of sites meet targets, 34% of sites failed to meet 1 target and 53% of sites failed to meet 2 or more targets, both on site and area basis. Dairy pasture (4%) and other pasture (3%) had the lowest proportion meeting all targets, while dairy pasture had the highest proportion failing to meet 2 or more targets (71%).

There are four key soil quality issues:

1. Surface compaction
   There had been a steady improvement in meeting the macroporosity lower targets between 2003 and 2009 with dairy pasture and other pasture farmers, as a whole, becoming more aware of compaction and taking measures to prevent its occurrence. However, particularly wet winter/spring periods over the last two years

have made land more vulnerable to compaction, resulting in low macroporosity values.

2. Loss of organic matter
   Loss of soil organic matter continues with a decline in average total C concentration from 9.9% to 9.5% between 2003 and 2011. Much of this decline was at sites under annual cropping land use and the proportion of annual cropping sites meeting the targets for this indicator have decline from 93% in 2006 to about 89% in 2011. Although all forest to pasture sites met targets, several indicators point to loss of soil organic matter during the conversion process.

3. Excessive or deficient nutrient levels
   An excess of nutrients such as nitrogen continue to trend upwards in productive soils, consistent with the increased nitrogen measured in river systems in the Waikato region. Other pasture sites showed a declining trend in meeting the upper total N target (i.e. a decreasing proportion of sites meeting the upper target) and increased nitrogen in receiving water bodies is likely.

   The upper Olsen P target was exceeded at some sites under all land uses, indicating an opportunity for more efficient fertiliser use. Between 2003 and 2011, there was a decline in the proportion of annual cropping, horticultural, dairy pasture, forest to pasture, and other pasture sites meeting the upper Olsen P target. Average Olsen P values of the different land uses showed all productive land uses had higher values in 2011 than in previous years consistent with increased availability of phosphate and/or increased application of P fertiliser.

   Prior to 2009, there were no production limitations due to nitrogen shortage at any of the monitoring sites. However, in 2009, 14% of forest to pasture sites had total N values that were below the lower (deficiency) total N target, reflecting their low carbon status. No trend in the proportion of forest to pasture sites below the lower total N target is available because these sites were not sampled in 2010 or 2011.

   Olsen P levels were below the lower target at 22% of other pasture and 12% of production forestry sites, indicative of a P deficiency and possible production limitations. Low pH was also found on 3% of other pasture sites. These land uses tend to take place on the more marginal hilly land and the optimal fertility of these soils may reflect economic factors (e.g. transportation and spreading costs) more than production factors.

4. Erosion
   Macroporosity (-10 kPa) and bulk density results showed nearly 30% of forestry sites appear to have high erosion risk, especially during the period between tree harvest and the growth of the next rotation. In addition, some annual cropping and a few horticulture and pasture sites have a higher risk of eroding, especially between crops or at sowing when the land is bare and/or is sloping.

References

Beare M, Curtin D, Ghani A, Mackay A, Parfitt R. Stevenson B 2007. Current knowledge on soil quality indicators for sustainable production and environmental protection in New Zealand: a discussion document. Lincoln, SLURI. New Zealand Institute for Crop & Food Research Ltd.

Beare MH, Lawrence EJ, Tregurtha CS, Harrison-Kirk T, Pearson A, Meenken ED 2005. Progress towards the development of the Land Management Index – 2004-05 project report. Crop & Food Research Confidential Report No. 1408. Christchurch, Crop & Food Research. http://www.maf.govt.nz/sff/about-projects/search/02-125/02125-finalreport.pdf [accessed 21st July 2009]

Dick W, Gregorich E 2004. Developing and maintaining soil organic matter levels. In: Schjonning S, Elmholt S, Christensen B eds. Managing soil quality: challenges in modern agriculture. Wallingford, UK, CABI Publishing. 103-120

Hewitt AE 2003. New Zealand Soil Classification. Landcare Research Science Series No. 1. Lincoln, Manaaki Whenua Press.

Hill RB, Sparling GP 2009. Soil quality monitoring. In: Land Monitoring Forum. Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton: Land Monitoring Forum. pp 27–88.

Mackay AD, Dominati E, Taylor MD 2013. Soil quality indicators: the next generation. Client report number: RE500/2012/05. Hamilton, AgResearch.

Mackay AD, Simcock R, Sparling GP, Vogler I, Francis G 2006. Macroporosity. Internal SLURI report. Hamilton, AgResearch.

McDowell R, Sharpley A, Brookes P, Poulton P 2001. Relationship between soil test phosphorous and phosphorus release to solution. Soil Science 166(2), 137-149.

Schipper L, Baisden W, Parfitt R, Ross C, Claydon J, Arnold G 2007. Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years Global Change Biology 13(4), 1138-1144.

Sparling GP, Lilburne L, Vojvodic-Vukovic M 2003. Provisional targets for soil quality indicators in New Zealand. Lincoln, Landcare Research.

Taylor MD, Mackay AD 2012. Towards developing targets for soil quality indicators in New Zealand: Final report (Findings of a Review of Soil Quality indicators Workshop, 6th May 2011 and response from the Land Monitoring Forum). Unpublished report to the Land Monitoring Forum. Waikato Regional Council DOC Number 2286500.

Taylor MD, Mulholland M, Thornburrow D 2008. Infiltration characteristics of soils under forestry and agriculture in the Upper Waikato Catchment. Environment Waikato Technical Report 2009/18. Hamilton, Waikato Regional Council (Environment Waikato).

Vant B 2008. Trends in river water quality in the Waikato Region, 1987-2007. Environment Waikato Technical Report 2008/33. Hamilton, Waikato Regional Council (Environment Waikato).

Waikato Regional Council (Environment Waikato) 2008. The condition of rural water and soil in the Waikato Region; risks and opportunities. Hamilton, Waikato Regional Council (Environment Waikato).

Appendix 1: Target ranges for soil quality indicators

Total Carbon (% w/w)

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

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

Total Nitrogen (% w/w)

Pasture	0	**0.25**	0.35	0.65	**0.7**	1.0
Forestry	0	**0.10**	0.2	0.6	**0.7**	1.0
Cropping and Horticulture	exclusion					
	Very depleted	Depleted	Adequate	Ample	Excessive	

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

Anaerobic N (ug/g)

Pasture	25	**50**	100	200	200	250	300
Forestry	5	**20**	40	120	150	175	200
Cropping and Horticulture	5	**20**	100	150	150	200	225
	Very Low	Low	Adequate	Ample			

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

pH

Pastures on all soils except Organic	4	**5**	5.5	6.3	**6.6**	8.5
Pastures on Organic soils	4	**4.5**	5	6	**7.0**	
Cropping & horticulture on all soils except Organic	4	**5**	5.5	7.2	**7.6**	8.5
Cropping & horticulture on Organic soils	4	**4.5**	5	7	**7.6**	
Forestry on all soils except Organic		**3.5**	4	7	**7.6**	
Forestry on Organic soils	exclusion					
	Very Acid	Slightly Acid	Optimal	Sub-optimal	Very alkaline	

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

Olsen P (µg/g)

Pasture on Sedimentary and Allophanic soils	0	**15**	20		**50**	
Pasture on Pumice and Organic soils	0	**15**	35		**50**	
Cropping and horticulture on Sedimentary and Allophanic soils	0	**20**	50		**50**	
Cropping and horticulture on Pumice and Organic soils	0	**25**	50		**50**	
Forestry on all soil orders	0	**5**	10		**50**	
	Very Low	Low	Adequate	Ample	Excessive	

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

Bulk Density (t/m^3) or Mg/m^3

Semiarid, Pallic and Recent soils	0.3	**0.4**	0.9	1.25	**1.4**	1.6
Allophanic soils		**0.3**	0.6	0.9	**1.3**	
Organic soils		**0.2**	0.4	0.6	**1.0**	
All other soils	0.3	**0.7**	0.8	1.2	**1.4**	1.6
	Very Loose	Loose	Adequate	Compact	Very compact	

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

Macroporosity (%)

Pastures, cropping and horticulture	0	**10**	20	**30**	40
Forestry	0	**10**	20	**30**	40
	Very Low	Low	Adequate	High	

<u>Notes</u>: Applicable to all soil orders. Target ranges for cropping and horticulture are poorly defined. Targets from Mackay et al. 2006

Aggregate Stability
Target > 1.5 mm MWD

Appendix 2: Data on land uses meeting indicator targets

Table 2: Percent of soil quality sites meeting pH targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	97	97	97	100	100	100	100	100	100

n.s. = sites not sampled

Table 3: Percent of soil quality sites meeting total C targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	89	89	91	92	92	93	93	90	89
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	100	100	100	100	100	100

n.s. = sites not sampled

Table 4: Percent of soil quality sites meeting the lower Total N target by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	100	100	100	100	100	100

n.s. = sites not sampled

Table 5: Percent of soil quality sites meeting the upper Total N targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	89	89	87	85	88	85	85	81	79
Horticulture	86	75	78	83	83	67	67	71	67
Forestry	82	81	82	79	84	80	80	81	82
Dairy Pasture	53	51	53	46	49	50	50	46	48
Forest to pasture	n.s.	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	36	42	37	41	41	50	55	65	65

n.s. = sites not sampled

Table 6: Percent of soil quality sites meeting the Lower Olsen P targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	96	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	88	88	88	89	89	93	93	88	82
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	76	78	74	71	66	63	64	65	65

n.s. = sites not sampled

Table 7: Percent of soil quality sites meeting the upper Olsen P target by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	26	32	52	54	60	63	67	52	58
Horticulture	29	50	56	67	67	50	50	57	50
Forestry	94	94	94	95	95	100	100	100	100
Dairy Pasture	35	34	37	49	44	50	53	50	52
Forest to pasture	n.s.	n.s.	43	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	70	75	74	76	72	75	73	71	71

n.s. = sites not sampled

Table 8: Percent of soil quality sites meeting the anerobically mineralised N targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	95	95	96	96	96	96	96	90	95
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	100	100	100	100	100	100

n.s. = sites not sampled

Table 9: Percent of soil quality sites meeting the lower bulk density targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	96	96	96	95	89
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	65	63	59	53	53	60	60	63	59
Dairy Pasture	96	96	95	95	95	93	93	92	96
Forest to pasture	n.s.	n.s.	71	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	100	100	100	100	100	100

n.s. = sites not sampled

Table 10: Percent of soil quality sites meeting the upper bulk density targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	100	100	100	100	100	100

n.s. = sites not sampled

Table 11: Percent of soil quality sites meeting the lower macroporosity (-10kPa) targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	79	79	87	81	84	85	89	86	79
Horticulture	86	75	78	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	35	32	63	54	51	47	47	38	30
Forest to pasture	n.s	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	42	47	68	53	59	50	41	29	35

n.s. = sites not sampled

Table 19: Percent of soil quality sites meeting the upper macroporosity (-10kPa) targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	95	79	87	81	84	85	89	86	79
Horticulture	100	75	78	100	100	100	100	100	100
Forestry	71	100	100	100	100	100	100	100	100
Dairy Pasture	100	32	63	54	51	47	47	38	30
Forest to pasture	n.s.	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	47	68	53	59	50	41	29	35

n.s. = sites not sampled

Table 13: Percent of soil quality sites meeting the aggregate stability target by land use over 7 years.

	2011	2010	2009	2008	2007	2006	2005
Annual Cropping	47	47	70	77	76	78	78
Horticulture	93	88	100	100	100	100	100
Forestry	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100
Forest to pasture	n.s.	n.s.	57	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	97	100	100	100	100

n.s. = sites not sampled

Table 14: Percent of soil quality sites meeting the C:N ratio targets by land use over 9 years.

	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	84	84	83	85	88	89	89	100	100
Horticulture	100	100	89	83	83	83	83	86	83
Forestry	100	100	100	100	100	100	100	100	100
Dairy Pasture	96	96	96	93	95	93	93	92	91
Forest to pasture	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	100	100	94	100	100	100	100	100

n.s. = sites not sampled