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Soil quality monitoring in the Waikato region 2012

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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 10 years in the Waikato region. Waikato Regional Council monitors a variety of indicators to assess soil quality in the region to provide information about how particular land uses are affecting soils in the long-term as required by the Resource Management Act 1991 Section 35. Indicators are measurements of soil physical, chemical and biological properties that assess the ability of soil to perform the functions necessary for its intended and foreseeable uses. If these measurements fall within the range of values that is desirable for the soil to function, the soil is meeting targets. There are seven soil quality indicators, which are: pH, total carbon, total nitrogen, mineralisable N, Olsen P, bulk density and macroporosity. In addition there are two environmental indicators, aggregate stability and C:N ratio, that provide information to improve interpretation of the results but are not counted as soil quality indicators.

The land use classes sampled were dairy pasture (pasture grazed with milking cows), other pasture (pasture used for cut and carry or grazed with animals other than milking cows), cropping (annual cultivation), horticulture (plants left in place), forestry (production pine forests), and native (indigenous vegetation). 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 dairy or other pasture.

Overall, soil quality in the region is declining for the 151 monitored sites. Results in 2012 showed that 13% of sites (14% of sites corrected for the amount of land) meet targets, 33% of sites (30% of sites corrected for the amount of land) failed to meet one target and 54% of sites (56% of sites corrected for the amount of land) failed to meet two or more targets. The land use meeting most targets was production forestry (53% of sites). Dairy pasture and other pastoral land uses had the lowest proportion of sites meeting targets (2 and 0% of sites) and the highest proportion of sites failing to meet two or more targets (73 and 67% of sites).

Four key issues contributing to the degradation of the quality of the soil resource in the Waikato region were identified. These issues are surface compaction, loss of soil organic matter, excessive nutrients (above the needs of production), and erosion.

Overall, there had been a steady reduction (improvement) in surface compaction between 2003 and 2009, but it declined markedly after 2009, and the rate of decline is increasing. This may be attributed to greater intensification, and the wet winter/spring periods over the last three years increasing the vulnerability of the land 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, and the continued decline in meeting targets.

However, soils recently converted from forest to dairy or other pasture, which were compacted by vehicles and thus damaged during the conversion process, have improved from 86% to 100% meeting the target. This improvement can be attributed to improved pasture growth, with root expansion opening up the soil, while vegetation cover protects the surface from rain impact and reduces the pressure from animal hooves. These results show that these soils can be farmed without compaction being an issue.

Overall, loss of soil organic matter continued with a decline in average total C concentration from 9.9% to 9.5% since 2003 (equivalent to the loss of 7.2 Mt of carbon from the region). Much of this decline was from sites under annual cropping land use. In comparison, soil organic matter is increasing in soils recently converted from forest to dairy or other pasture. In 2009, these soils had total C and N concentrations significantly lower than those under other land uses. This is no longer the case as both total C and N concentrations have increased in the converted soils. If left undisturbed

organic matter is expected to continue to increase in these soils to levels found under permanent dairy or other pasture.

In all land uses where fertiliser is applied, levels of nutrients, such as nitrogen and phosphorus are stable or trending upwards. Other pasture sites showed deficient nutrients.

A large proportion of forestry sites have high erosion risk because production forests tend to be situated on steeper land, especially if the trees are removed. The proportion of forestry sites meeting targets has recently increased with the conversion of some erosion-vulnerable forest sites to dairy pasture. However, the increased compaction may result in increased transport of contaminants and peak-flows causing localised flooding and bank erosion. In addition, some of the forest to dairy pasture sites still had bulk density measurements below targets, which indicates the soils are light and are easily eroded by wind or water. As a result, these sites 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.

1 Introduction

Monitoring of soil properties provides important information on the overall health of the soil and any potential impacts of land use 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 magnitude 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 sites under native forest to provide background levels) and soil types.

2 Objectives

The objectives of this report are as follows:

- 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 10 years.

3 Methods

3.1 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 (pasture used for cut and carry or grazed with animals other than milking cows), cropping (annual cultivation), horticulture (plants left in place), forestry (production pine forests), and native (indigenous vegetation) (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 one of 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 previously (in 2009) or were in pine forest before conversion about 2008.

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 2012, Waikato Regional Council staff selected 39 sites 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).

3.2 Indicators

Indicators are measurements of soil physical, chemical and biological properties that assess the ability of soil to perform the functions necessary for its intended and foreseeable uses. If these measurements fall within the range of values that is desirable for the soil to function, the soil is meeting targets. There are seven soil quality indicators, which are: pH, total carbon, total nitrogen, mineralisable N, Olsen P, bulk density and macroporosity. In addition there are two environmental indicators, aggregate stability and C:N ratio, that provide information to improve interpretation of the results but are not counted as soil quality indicators

Table 1 lists the soil quality indicators monitored and why the indicator is important.

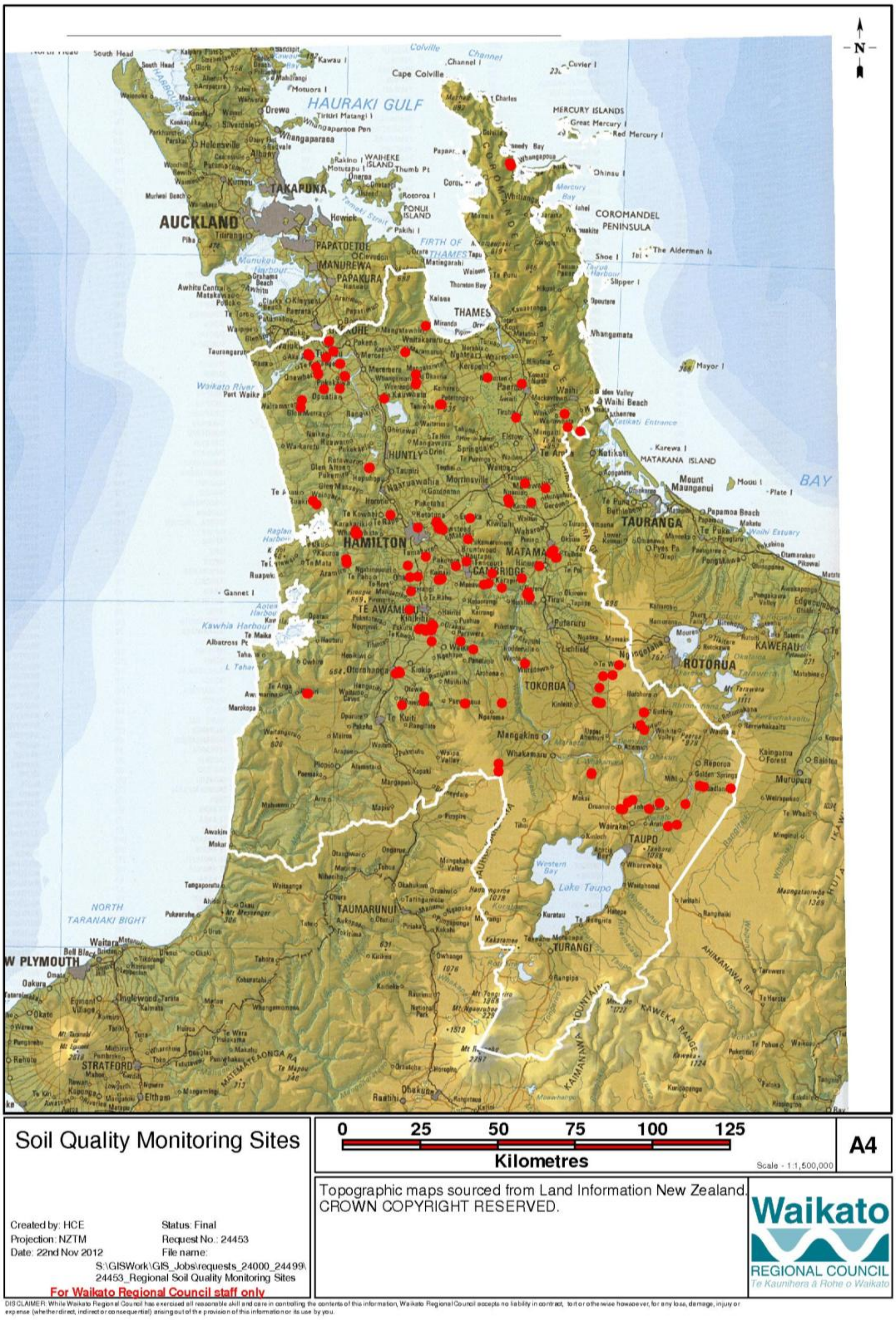


Figure 1: Map of soil quality site locations

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.

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 bio-available.
	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.	Indicates P status, if current land use requires maintenance applications of fertiliser or if levels are above those needed for production. Depletion of nutrients 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.

(Mackay et al. 2013). The review also identified that the upper limit of the anerobically mineralised N target range was unsuitable and, as a consequence, it has been removed. In addition, the revised macroporosity targets suggested by Beare et al. (2007) and Mackay et al. (2006) were endorsed.

12.1 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).

Soil quality monitoring results are compared to target ranges. Monitoring sites that meet all seven indicator targets are described as having ‘met all targets’. Those soil quality sites that met six indicator targets but failed to meet 1 indicator target are described as having ‘failed to meet one target’. Sites that failed to meet 2 or more indicator targets are described as having ‘failed to meet two or more targets’.

12.2 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.

12.3 Reporting basis

Results are presented on an overall regional basis. Data are 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.

12.4 Statistical methods

Summary statistics were calculated using Data Desk version 6 and boxplots were produced using Sigma Plot version 7. The data were 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 five-year rotation, five-year floating averages were calculated for soil quality indicator values and presented in graphs showing value by land use.

13 Results: Status of soil quality indicators in 2012

13.1 Status of soil quality indicator sites in 2012

Only 13% of sites meet all seven soil quality targets, 33% did not meet 1 target and 54% did not meet 2 or more targets (Figure 2).

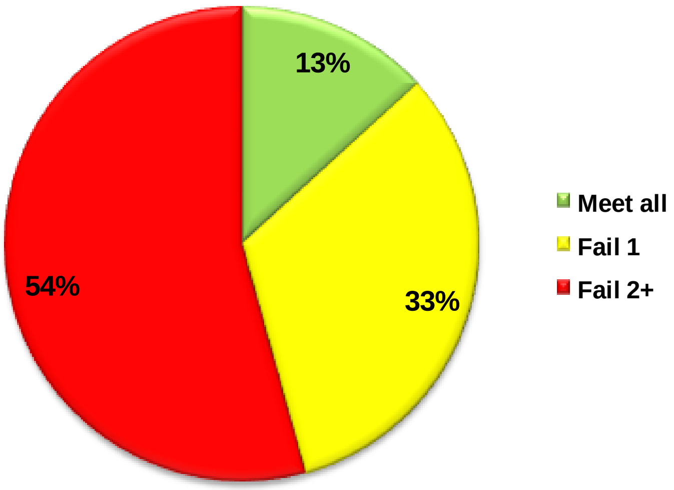


Figure 2: Proportion of soil quality sites meeting/failing to meet targets in 2012

13.2 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 are corrected (weighted) for the area of land in each land use class within the Waikato region to give the current state of the region’s soils (Figure 3).

In 2012, about 14% of sites corrected for the amount of land (the weighted proportion of the sits) met all seven soil quality indicator targets, 30% failed to meet one target, and 56% failed to meet two or more targets (Figure 3).

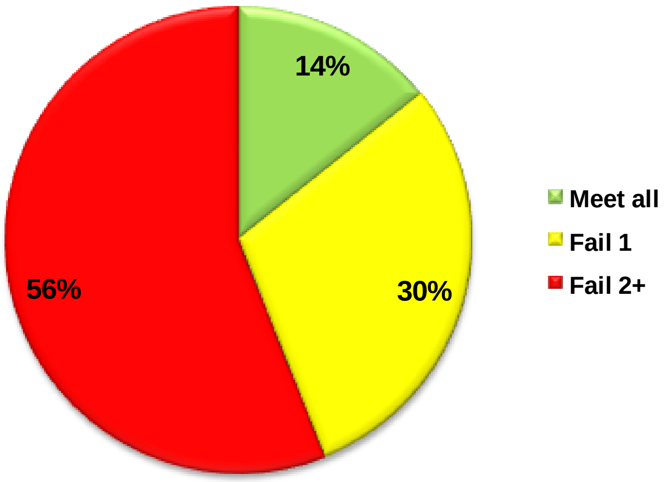


Figure 3: Proportion of soil quality sites meeting/failing to meet soil quality targets in 2012 corrected for the amount of land in each land use class

The land area corrected results in Figure 3 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 nutrients) and low macroporosity (indicator of compaction) were the indicators for which targets were most commonly not met (Figure 4). The interaction between land use and each indicator is discussed below.

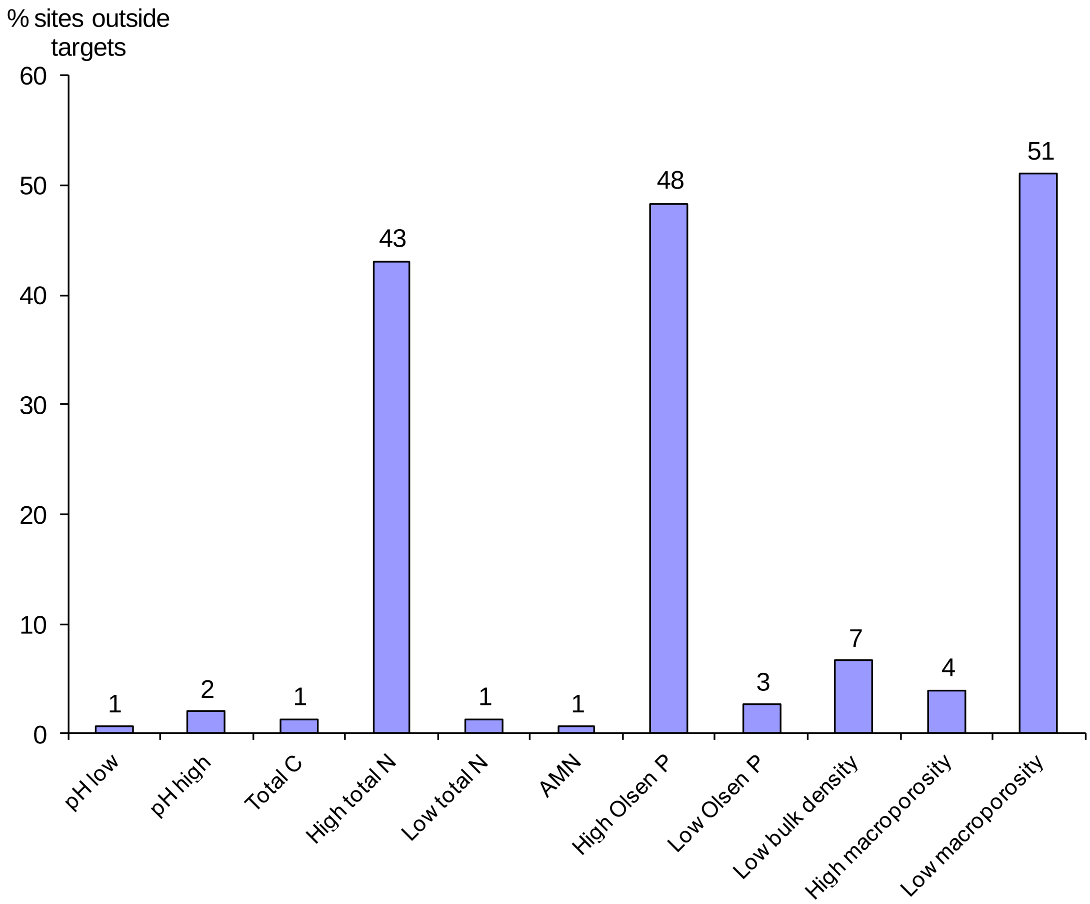


Figure 4: Proportion of soil quality sites outside soil quality targets in 2012

14 Effect of land use on soil quality indicators in 2012

14.1 Overview

The effect of land use on soil quality indicators was assessed based on the latest data for each of the 151 sites. Forestry (53%) had the largest proportion of sites corrected for land area meeting all soil quality indicator targets. Twenty-nine percent of land converted from forestry to pasture, 16% of land under annual cropping and 14% of land under horticulture also met all targets, while dairy (2%) and other pasture (0%) had the smallest proportion of land area meeting all soil quality indicator targets (Figure 5). Dairy pasture had the highest proportion failing to meet two or more indicator targets (73%).

Annual cropping sites failing to meet two 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 two or more indicators tended to have high nutrients (total N and Olsen P) and surface compaction (low macroporosity). Forestry sites failing two or more indicators had erosion potential (low bulk density and high macroporosity).

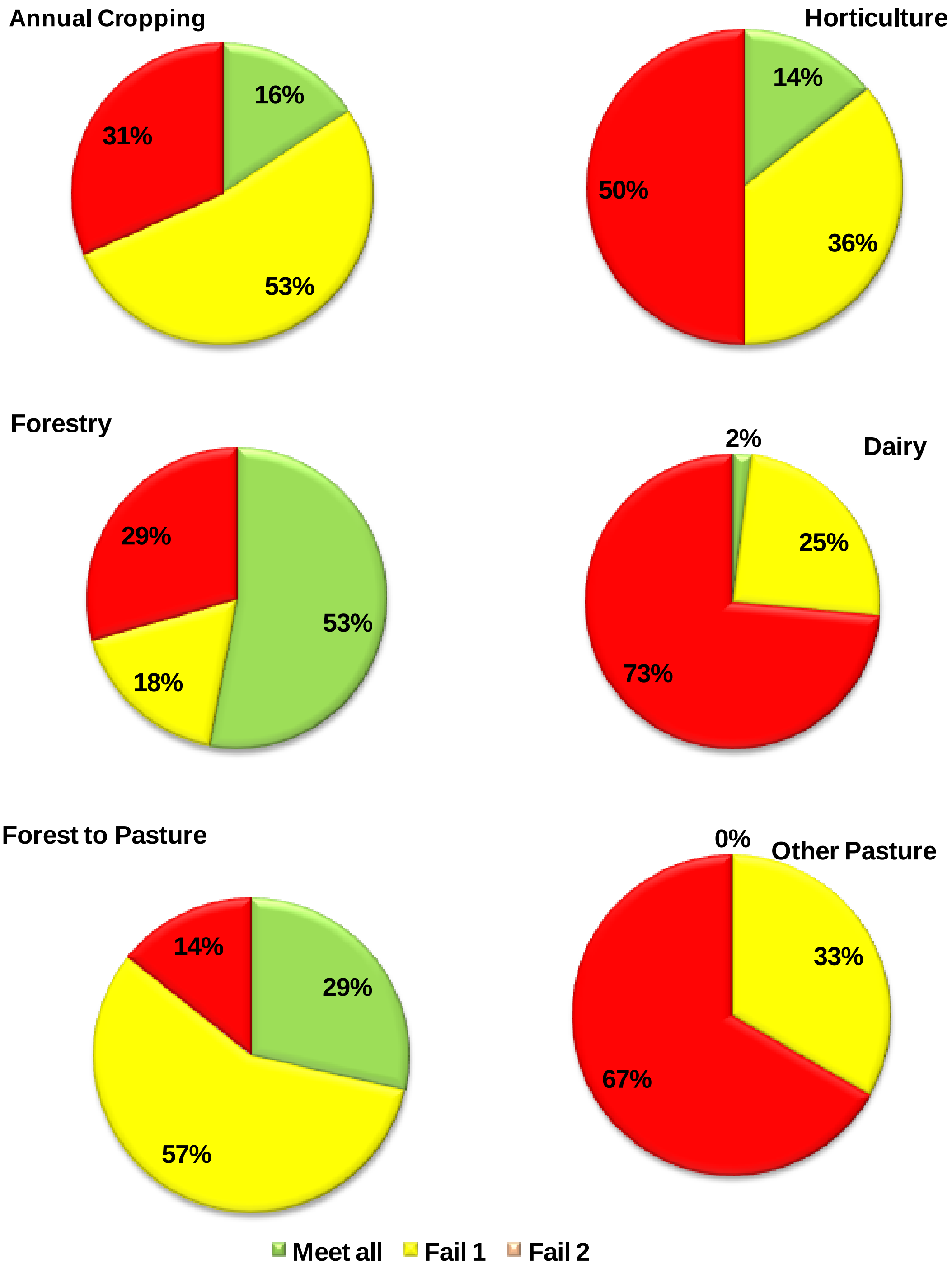
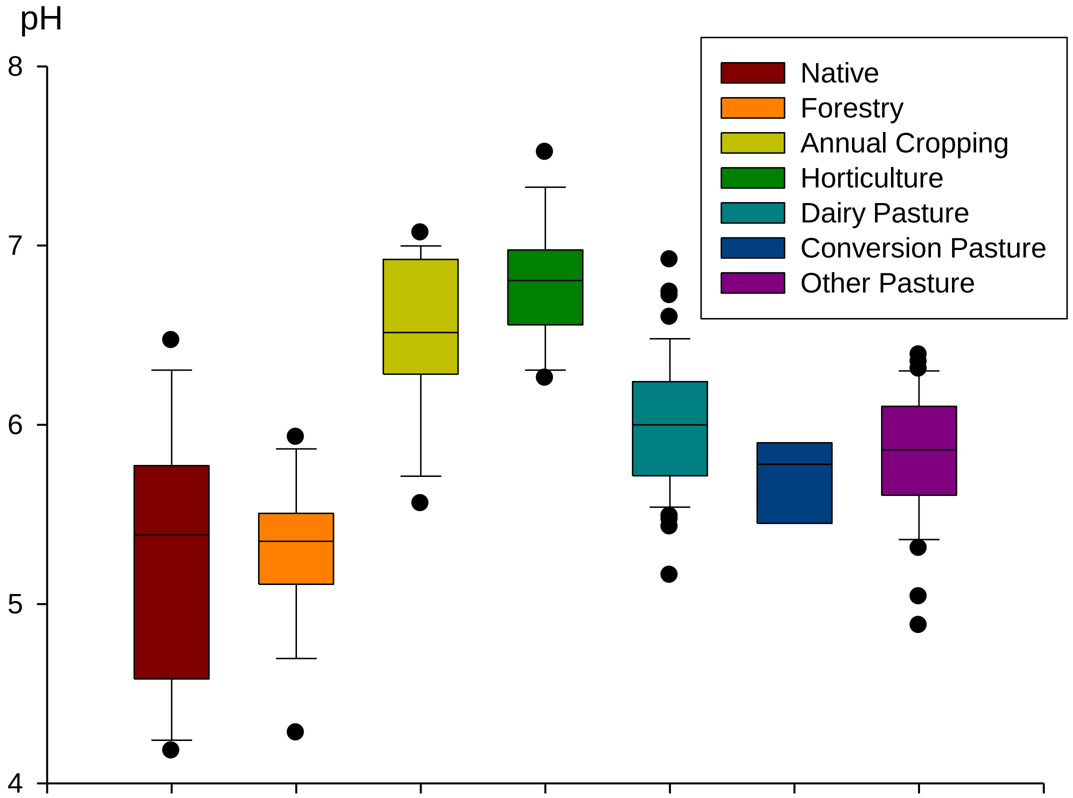


Figure 5: **Proportion of soil quality sites weighted by land use meeting/failing to meet soil quality targets in 2012**

14.2 The effect of land use on soil pH

Median soil pH levels were 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 indicate that 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.

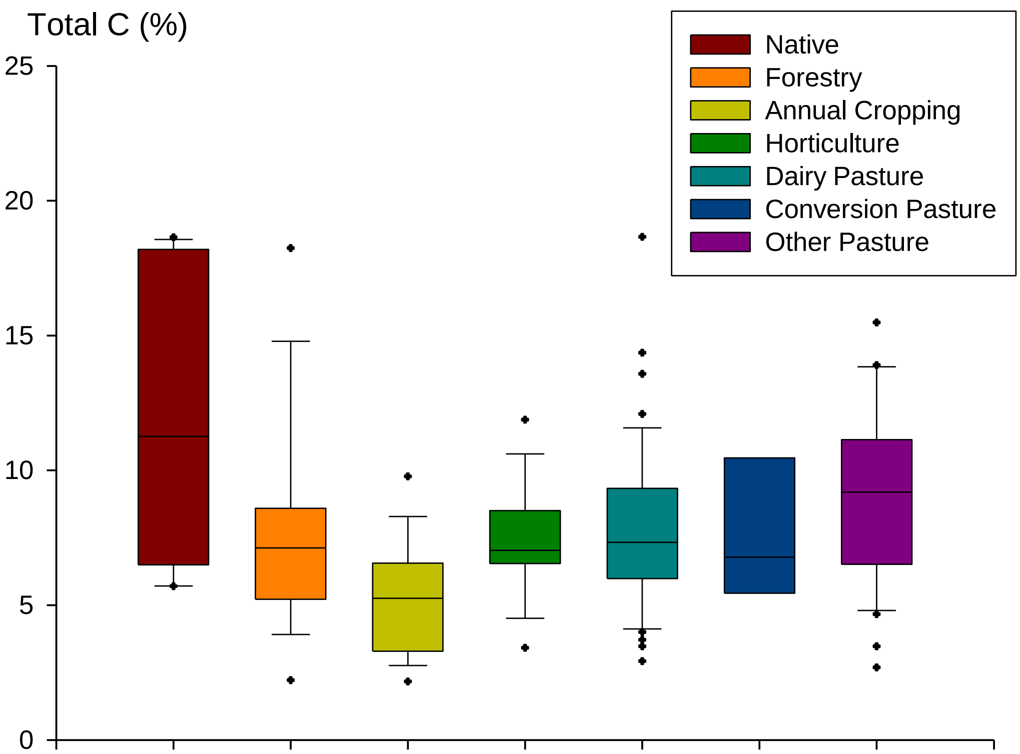


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 6: Soil pH by land use class.

14.3 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). Median total C concentrations were 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). In 2009, long-term dairy pasture and other pasture had higher total carbon concentrations than those recently converted from forest-to-pasture. After three years, increased plant production has resulted in the return of plant material to the soil and increasing carbon stocks. So, the difference in carbon concentrations between the sites recently converted from forest-to-pasture and sites in long-term dairy pasture and other pasture has decreased.

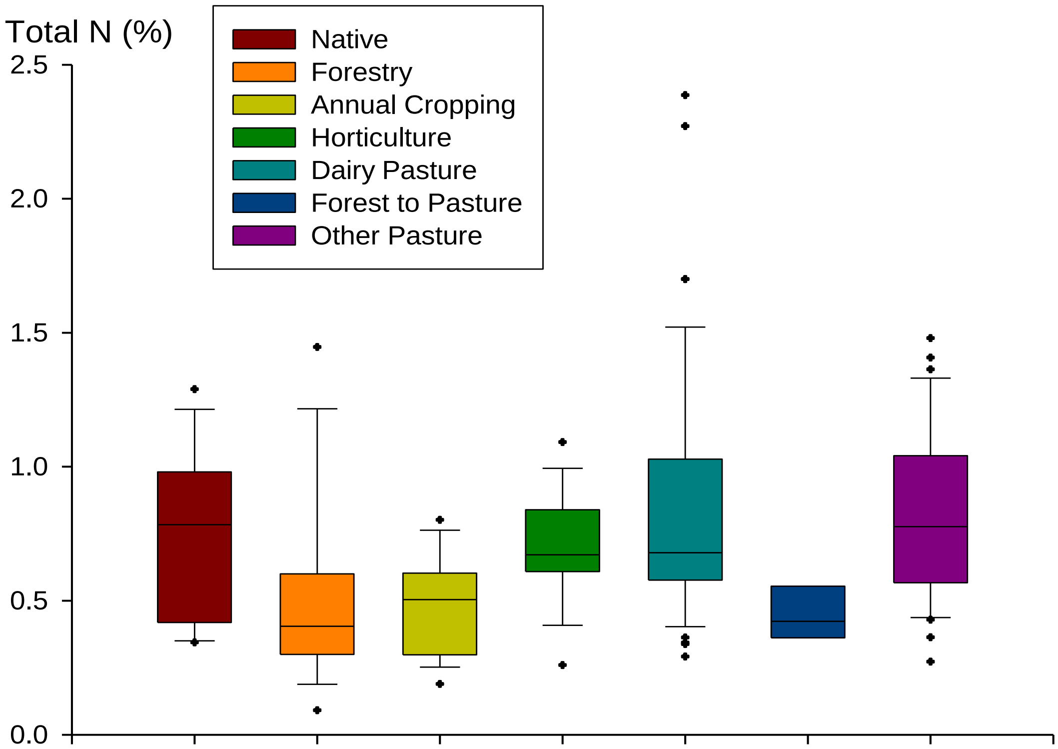


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

14.4 The effect of land use on soil total nitrogen

Median total nitrogen concentrations were 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. In 2009, soils recently converted from forest to pasture had total nitrogen concentrations, significantly lower than those under cropping, but this is no longer the case as soil organic matter has increased in these soils.

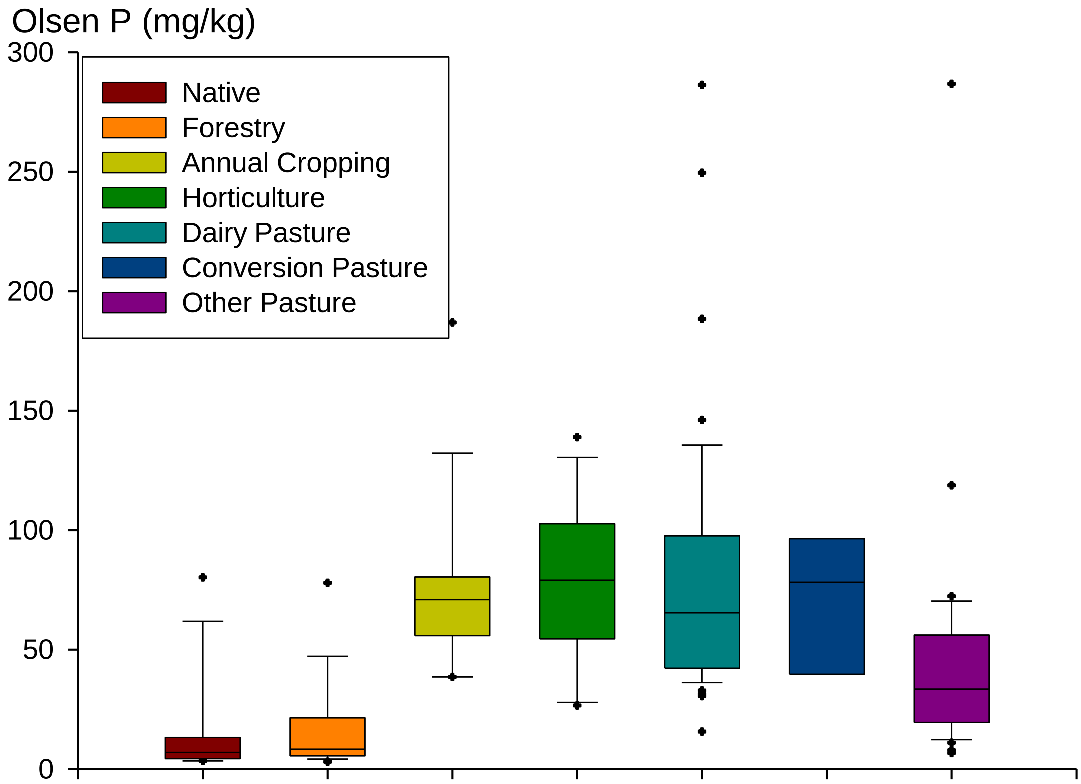


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

14.5 The effect of land use on Olsen P

Median Olsen P measurements were 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. The number of sites with very high Olsen P concentrations, over 100 mg/kg, associated with very high fertiliser applications under dairy pasture, have decreased over five years. There are lesser numbers of very high values under other pasture and cropping, but these have not changed over time. Soils with high or very high Olsen P concentrations have greater risk of phosphorous being transported to ground or surface waters than soils with optimum Olsen P concentrations for production (McDowell 2001).

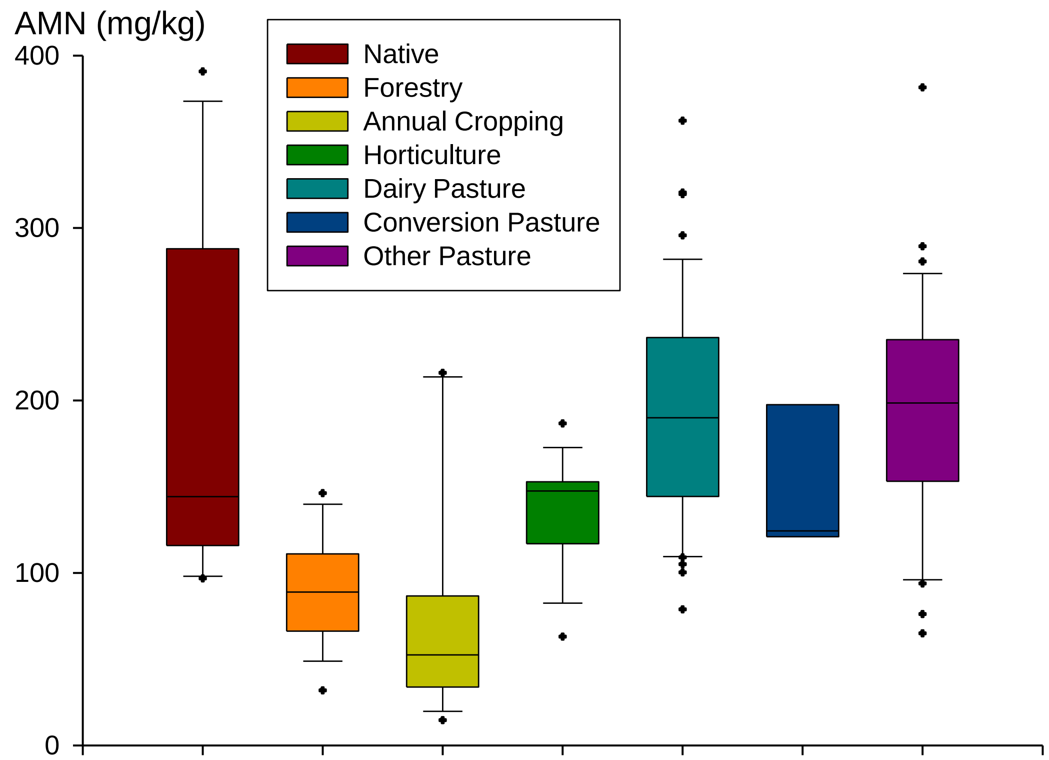


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

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

Annual cropping sites had significantly lower median concentrations of AMN than forestry, which had significantly lower median concentrations than native, horticulture dairy pasture, forest-to-pasture and other pasture (Figure 10) sites. Annual cropping has resulted in the loss soil organic matter (Figures 7 & 8), which is a food source for microorganisms. Soils recently converted from forest-to-pasture have gained soil organic matter since 2009. This has lead to almost a doubling of AMN. The reason for the low forestry concentrations is unclear but food sources are tied up in the organic material contained in the forest floor (L and FH horizons) and only mineral soil was sampled as part of this soil quality monitoring (Melilo et al. 1989). Also, pine debris are acidic and acidity has been shown to reduce microorganism numbers and activity (Baath et al. 1980).

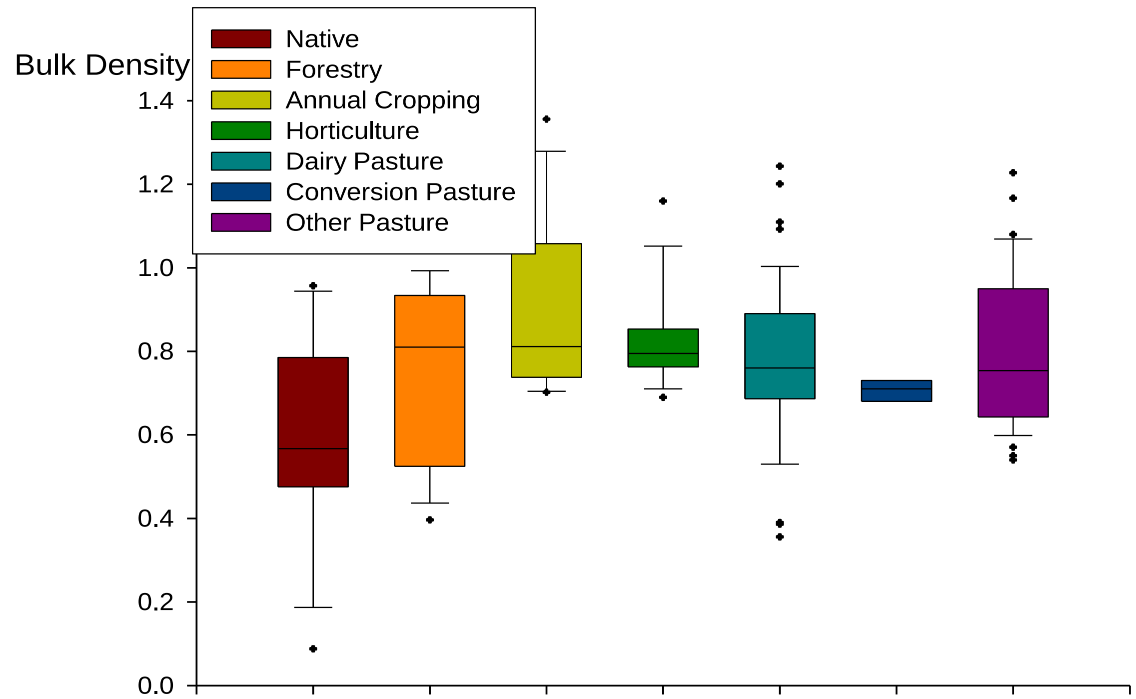


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

14.7 The effect of land use on soil bulk density

Median soil bulk density was significantly lower under native than under cropping, horticulture, dairy pasture and other pasture (Figure 11). Annual cropping sites had significantly higher bulk density than all other land uses except horticulture, consistent with compaction by machinery. Compaction can be minimised with the adoption of techniques such as precision agriculture and not driving on the soil when it is wet (Raper 2005). Bulk density values for horticulture, dairy pasture and other pasture sites were also significantly higher than those under native vegetation, consistent with surface compaction due to agricultural traffic and stock treading, or both.

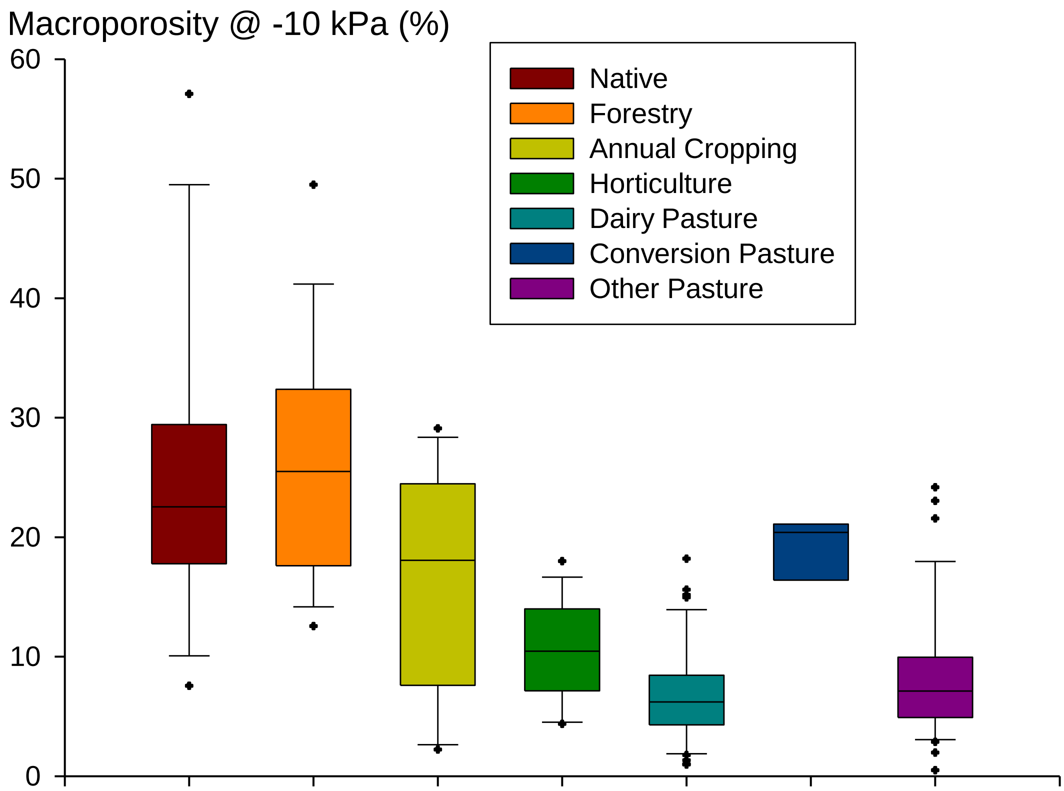


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

14.8 The effect of land use on macroporosity

Soils under horticulture, dairy pasture and other pasture land uses had significantly lower median macroporosity measurements than those under native and pine forestry, consistent with surface compaction due to agricultural traffic and stock treading, or both (Figure 12). Annual cropping and forest-to-pasture land uses 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

15 Effect of land use on environmental indicators in 2012

15.1 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.

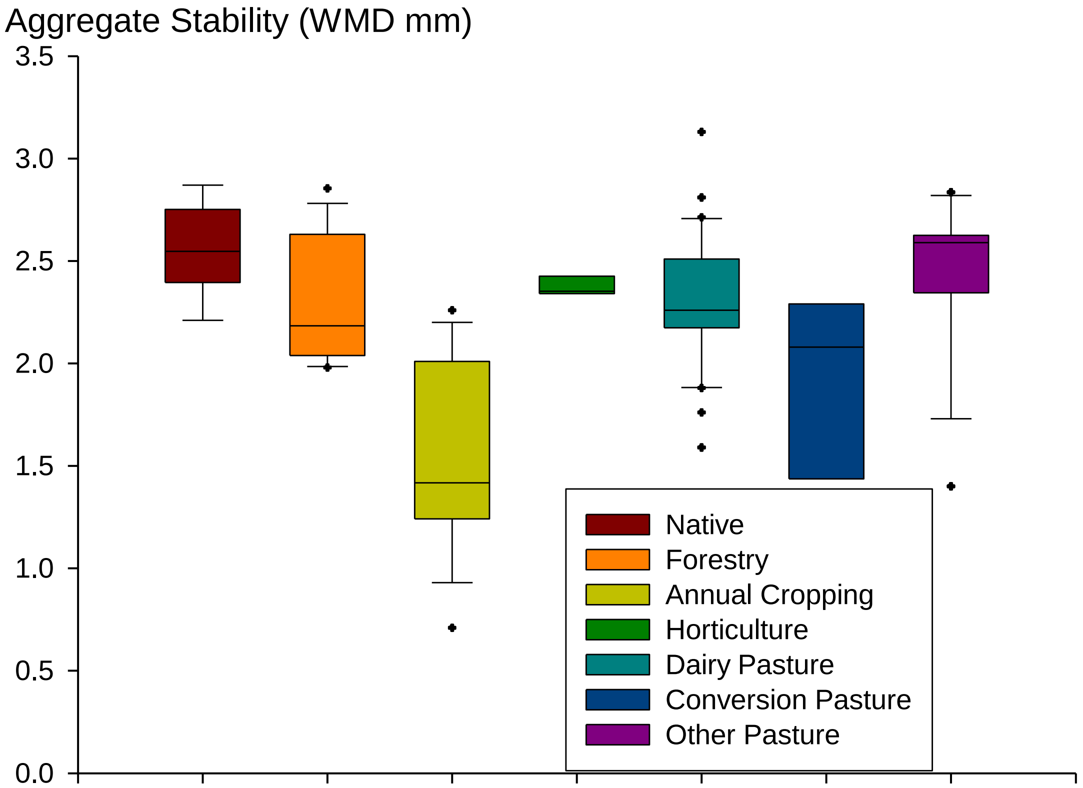
Stable aggregates allow a large amount pore space in soil, including small pores within and large pores between aggregates. Pore space is essential for air, water, nutrient, and biota movement into and within soil. Large pores associated with large, stable aggregates allow high infiltration rates and 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.

15.2 The effect of land use on aggregate stability

Median aggregate stability measurements were significantly lower at sites that are cropped annually and those recently than converted from forest to pasture than sites under other land uses, indicating a loss of soil stability cause by tillage or the conversion process (Figure 13).



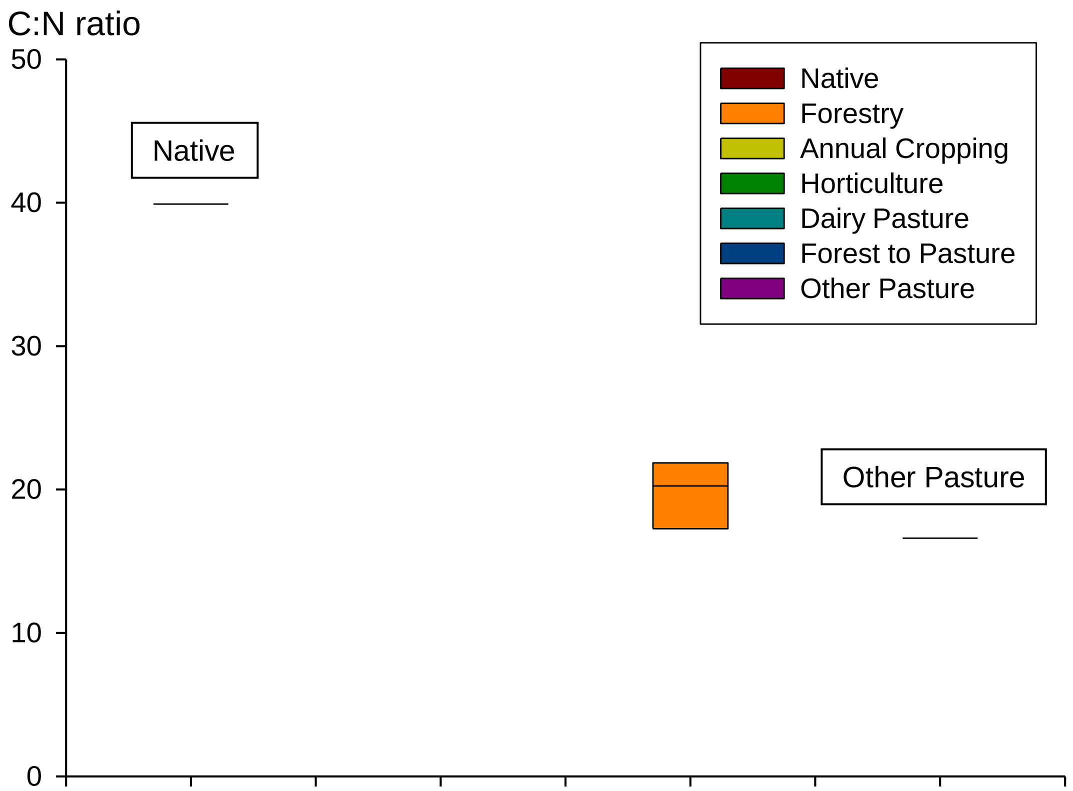
Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

Figure 13: The effect of land use on aggregate stability

15.3 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.

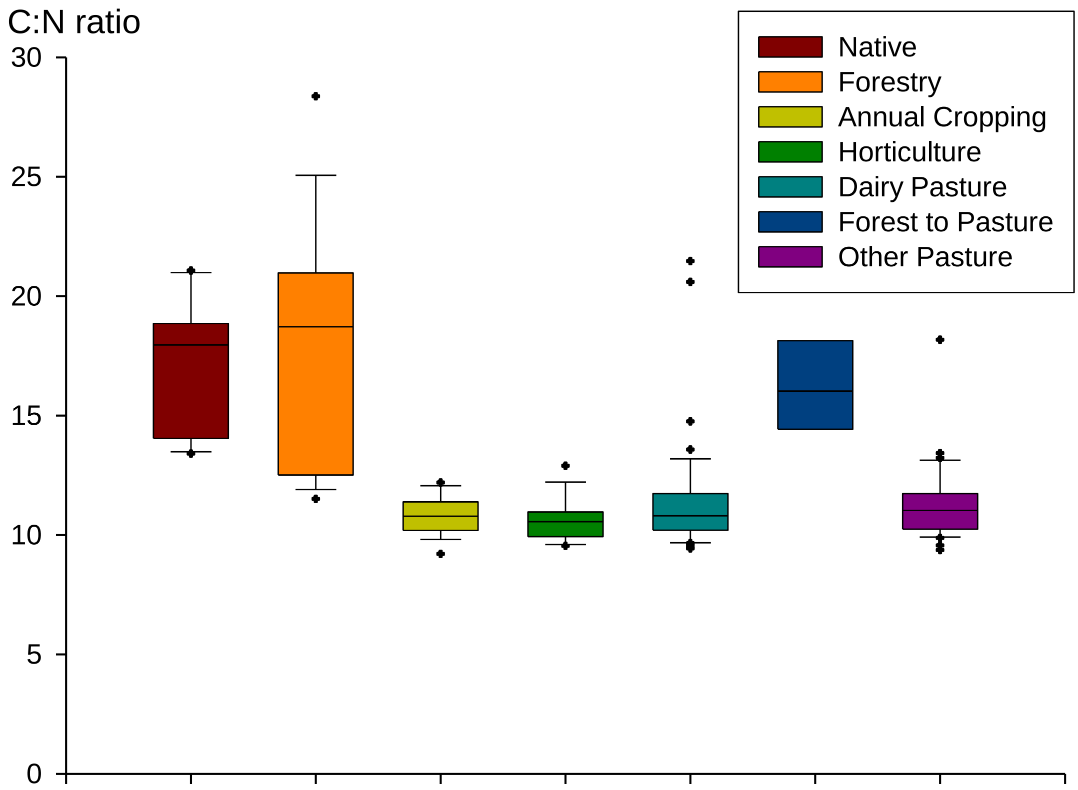
There were a total of eight sample sites on Organic Soils covering three land uses in the Waikato Region (native dairy pasture and other pasture). The C:N ratio for soil under native vegetation was about 40 but that for both dairy pasture and other pasture was about 20, half that of native land use (Figure 14). These results are consistent with the application of nitrogen fertiliser. 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

16 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 may be declining; the proportion of sites meeting all soil quality indicator targets appears to have decreased, while the number of sites not meeting oneindicator and not meeting two or more indicators appears to have increased.

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 until stabilising in 2011. The numbers of sites not meeting one indicator target appear to be a mirror image of sites meeting all indicator targets; an initial improvement between 2003 and 2007, followed by a decline until stabilising in 2012. Sites failing one indicator most commonly had high Olsen P or low macroporosity.

The number of sites not meeting two or more indicator targets has been somewhat inconsistent but has trended upwards (more sites failing to meet two or more indicators) between 2003 and 2012.

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

17 Key issues

17.1 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

17.2 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, a large decrease in average macroporosity was observed compared with the previous results, most evident in cropping, horticulture, dairy and other pasture land uses (Figure 17). This result was a continuing of the trend since 2009 and a reverse in the trend of improving results for pasture between 2003 and 2009 (Figure 18). Only about one fifth of dairy pasture sites and other pasture sites met the lower target in 2012. Greater intensification, particularly on dairy farms, may be a contributing factor (Houlbrooke et al. 2010). Another factor may be climate change with wet winter/spring periods over the last three years increasing the vulnerability of the land to compaction (Drewry et al. 2008).

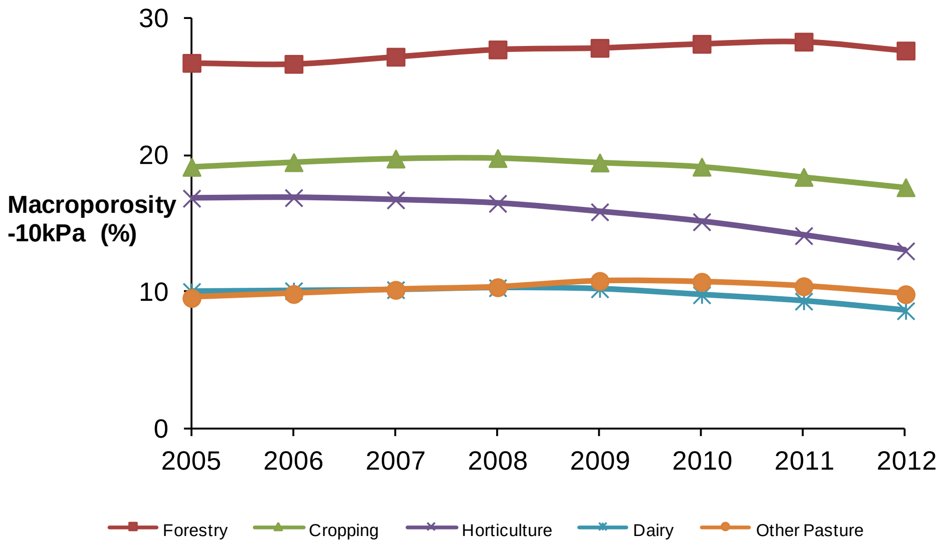


Figure 17: Floating 5 year average soil macroporosity at -10kPa (%) concentrations by land uses between 2003 and 2012

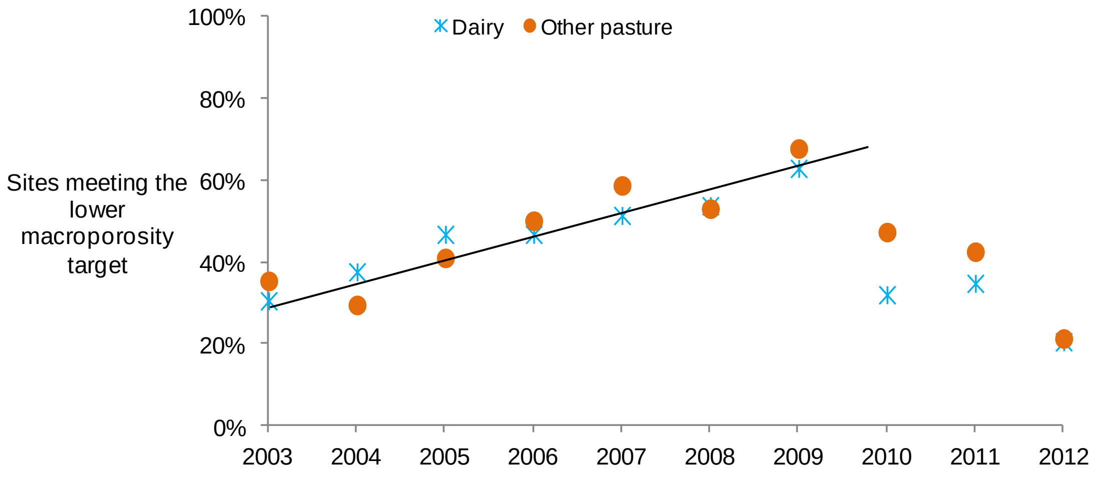


Figure 18: Trend in meeting the lower macroporosity (-10kPa) targets by pastoral land uses

About 74% of cropping sites met the lower target, down from 80% in 2011, while the number of horticultural sites also declined from 85% to 57% 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).

However, soils recently converted from forest to dairy or other pasture, which were compacted by vehicles, thus damaged during the conversion process, have improved from 86% to 100% meeting the target. This improvement can be attributed to improved pasture growth, with root expansion opening up the soil, while vegetation cover protects the surface from rain impact and reduces the pressure from animal hooves. (Drewry et al. 2008, Betteridge et al. 1999). These sites have had stock on them for only a short time and are expected to show more compaction as time goes on if they are intensively farmed. However, the results show that these soils can be farmed without compaction being an issue.

17.3 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.

SOM is essential for the viability and life-sustaining function of the soil (Dick & Gregorich 2004). A direct effect of low SOM 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 SOM 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 95% of cropping sites now met the total C target due to the conversion of "exhausted" cropping land to pasture (Appendix 2). However, a decline in average total C concentration at sites remaining in cropping land use is clearly evident between 2003 and 2012 (Figure 19), and is of concern. Burning, harvesting, or otherwise removing residues 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 (Dick & Gregorich 2004).

Harvesting of trees from forestry sites can disturb the soil resulting in loss of organic matter. Three sites had been harvested since the previous round of soil quality sampling and one site had total C below targets (Appendix 2). Changes in soil C in forest soils are largely influenced by how the forest floor is managed during the harvest operation (Nave et al. 2010).

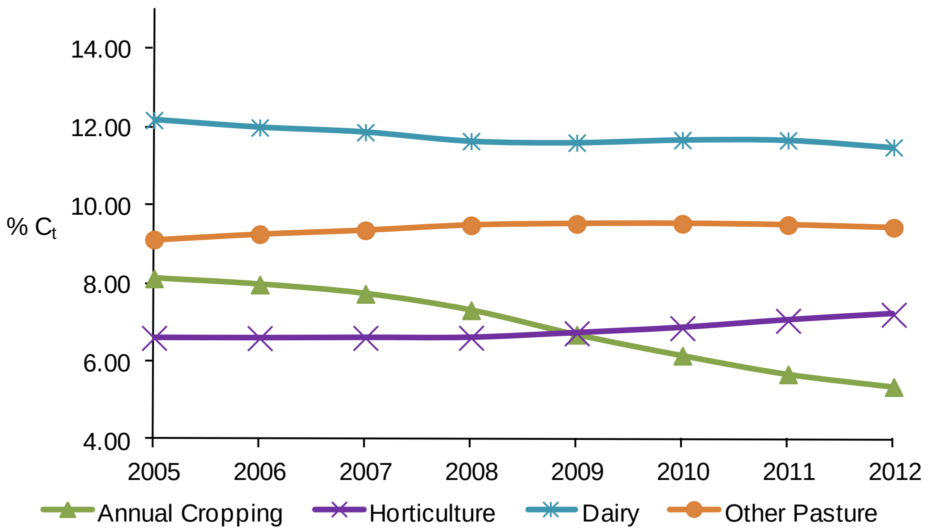


Figure 19: Floating 5 year average soil total C (%) concentrations by land uses between 2003 and 2012

A slight decline in average total C concentration is evident for sites under dairy pasture, whereas sites under other pasture remained fairly constant. 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 11.5% in 2012. The apparent slight increase of total C under horticulture was due to the addition of kiwifruit orchards in 2009 and 2011 that were on carbon–rich Allophanic soils.

Data for the forest to pasture land use (data for 2009 and 2012 only) show average soil total carbon levels have increased from 6.5% to 7.9%, similar to forestry, but below dairy and other pasture, and native land uses. Carbon concentrations are likely to continue to increase at conversion sites until they reach similar levels to dairy and other pasture.

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

0.1 * 2,333,741 * 10000 * 0.773 = 1,804 Mt soil in the top 0.1 m.

The amount of carbon lost is 0.4%.

0.004 * 1803982 = 7.2 Mt carbon lost from the region over the last 10 years.

Aggregate stability is strongly influenced by the amount and type of soil organic matter (Blanco-Canqui & Schliegel 2012). The fraction of soil organic matter available as food for soil microorganisms (such as measured by hot water extractable carbon) is strongly correlated with aggregate stability (Taylor & Ghani *in press*, Hot water carbon as a soil quality indicator, Waikato Regional Council document 2316350). Decrease of soil organic matter, in general, and hot water extractable carbon, in particular, are associated with decreases in soil structure and stability.

The proportion of annual cropping sites meeting the aggregate stability target of 1.5 mm continues to decrease, indicating a continued decline in soil stability (Figure 20). 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.

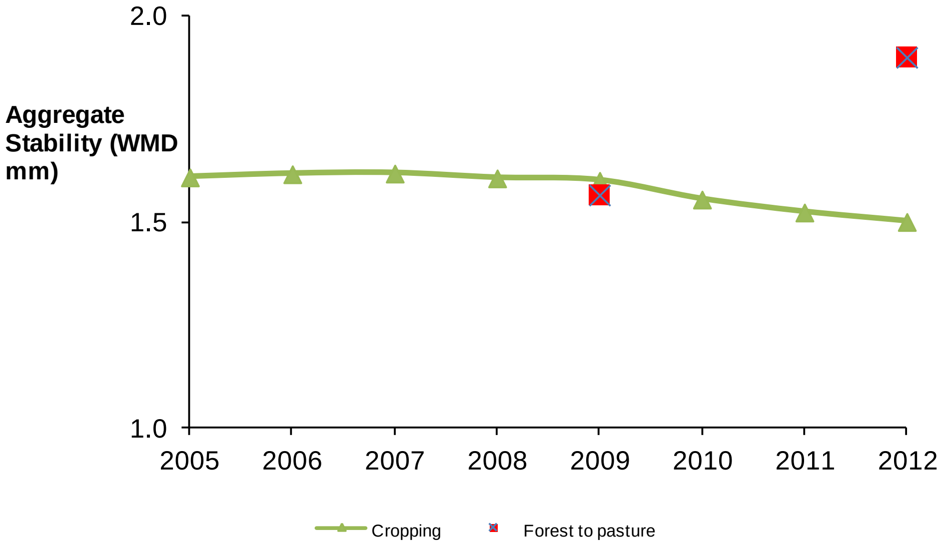


Figure 20: Floating 5 year average aggregate stability for cropping and forest to pasture land uses

Although forest to pasture sites did not have significantly lower total C (Figure 6), the conversion of pine forest to pasture resulted in a reduction of about 40% for aggregate stability, but this reduction appears probably temporary. This recovery is reflected in the number of sites meeting the aggregate stability target. In 2009, only 57% of forest to pasture sites met the target but this has increased to 71% in 2012 (Figure 20).

17.4 High or low nutrient levels

Soil phosphorous above the upper Olsen P target of 50 mg/kg is in excess of production needs for nearly all plant systems and considered high. Conversely, soil phosphorous below 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 may result is deficiency symptoms, reduced productivity, and can be considered low. Production limitations also can result in increased erosion risk due to reduced vegetative cover to protect the soil (Gillingham & Thorroid 2000, Wilmshurst 1997).

The upper Olsen P target was exceeded at some sites under all productive land uses, indicating an opportunity for more efficient fertiliser use. Between 2003 and 2012, there was a decline in meeting the upper Olsen P target by all productive land uses and the average regional Olsen P increased from 47 mg/kg in 2003 to 60 in 2012. Also, the average Olsen P values had increased in 2012 compared to previous years, consistent with increased availability of phosphate (Figure 21). 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 during the same period.

Soil phosphorous is migrating from soil and entering water where it influences stream phosphorous concentrations (McDowell et al. 2001), e.g. about 45% of phosphorous discharged to the sea between 2003 and 2012 by the Waikato River is attributable to pastoral farming (Vant, 2014).

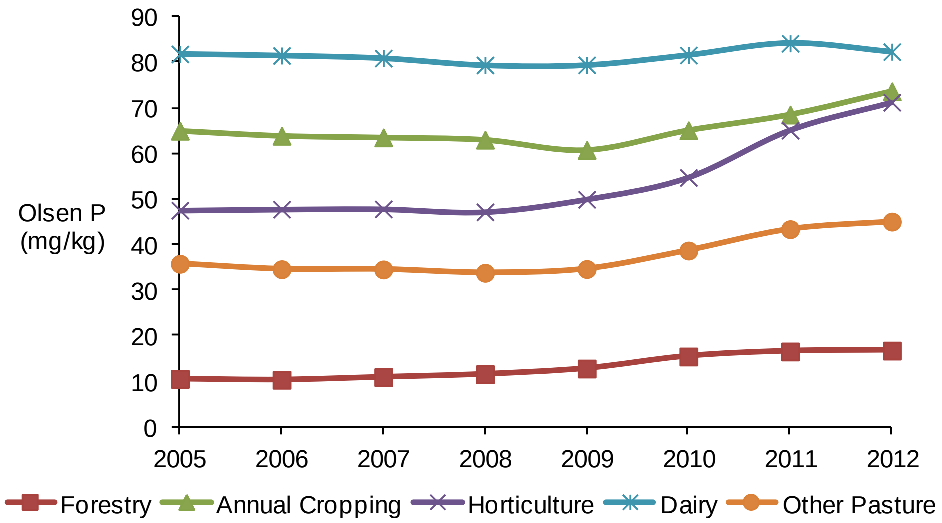


Figure 21: Floating 5 year average Olsen P concentrations by land uses between 2003 and 2012

Phosphorus deficiency is measured against the lower Olsen P target. Sites with low Olsen P could have increased yields and increased vegetative cover to protect the soil from erosion with application of P fertilisers but care should be taken to not apply in excess of agronomic requirements. Twelve percent of other pasture sites and 0% of forestry sites had Olsen P levels below the lower (production) target. This has continued a trend since 2006 of improvement in meeting the lower Olsen P target by other pasture and forestry land uses (Figure 22). Both these land uses tend to take place on the more marginal hilly land.

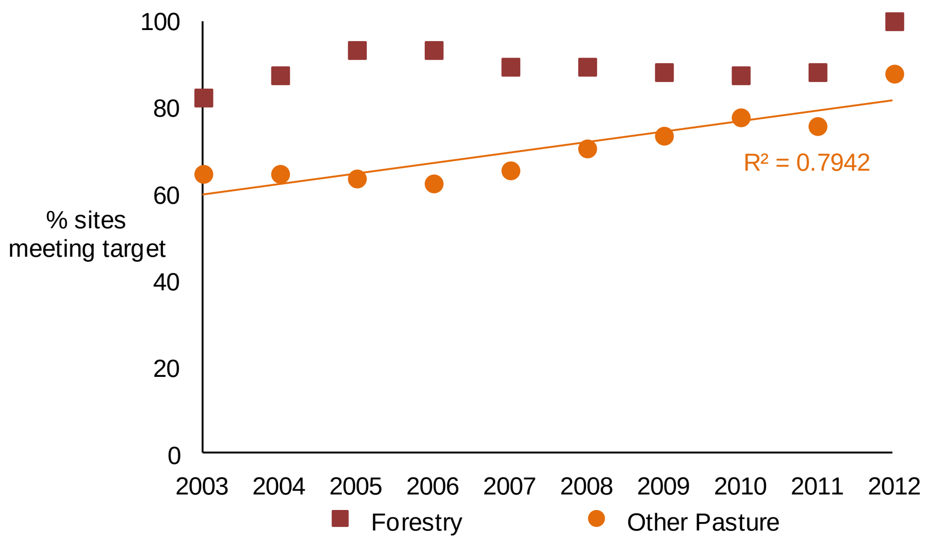


Figure 22: Trend in meeting the lower Olsen P (deficiency) target by forestry and other pasture

High nitrogen is assessed against the upper total N target, while production limitations due to nitrogen deficiency, described as low nitrogen, 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 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. Typically, pastoral agriculture has a much higher nutrient yield than forestry (Vant 2014), while yields of nitrogen correlated strongly (r = 0.83) with the average stocking rate of dairy cows (Vant 1999) — losses are five to over100 times greater under farmed land uses than under forest land (Environment Waikato, 2008).

Diffuse agricultural sources contribute about 61% of the mass flow of nitrogen discharged to the sea by the Waikato River between 2003 and 2012 (Vant 2014). Surplus nitrogen is reported to leach to downstream systems (Carpenter et al. 1998), e.g. Monaghan et al. (2005) reported nitrogen fertilisation significantly increased losses of nitrate-N in drainage, while Heathwaite & Johnes (1996) reported high loads of ammonium-N in runoff from grazed land and organic-N was important in subsurface flow. Nitrogen in river systems is regarded as an important contributor to the deterioration in water quality and concentrations are increasing (Vant, 2012).

The soil quality monitoring results show that the average soil total N concentration is trending upwards (Figure 23). Farming in the Waikato region, and in New Zealand generally, is intensifying with increased N fertilisation and stocking rates. Intensive use of N fertilisers in modern agriculture may promote the decomposition of plant residues and soil organic matter (Khan et al 2007), reducing carbon and nitrogen storage in the soil, decreasing soil structure and stability, and restricting the ability of the soil to retain nitrogen. So, these soils become less likely to hold the extra nitrogen required by increased intensification of farming.

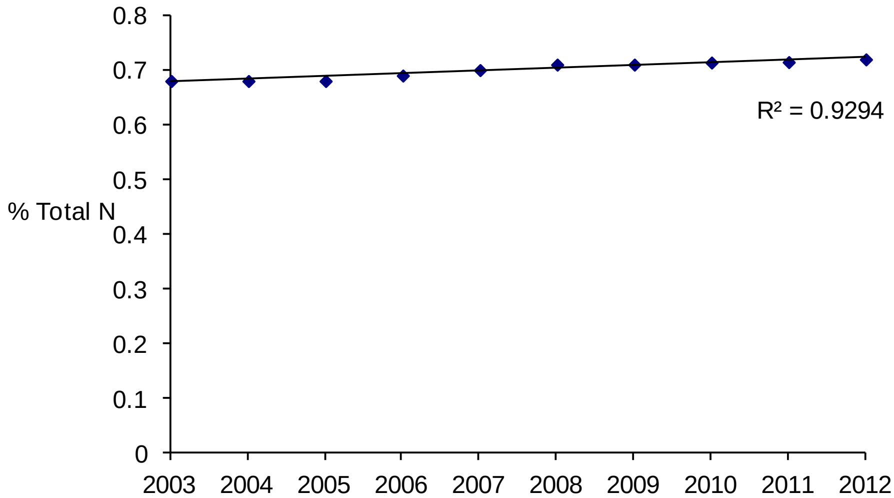


Figure 23: Average total N (%N) at soil quality sites

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 24). The trend is consistent with land use intensification, including increased N-fertilisation. Annual cropping has lost soil organic matter (Figure 19), 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 static (Figure 24), the risk of N loss from annual cropping may be increasing due to the loss of soil organic matter under this land use.

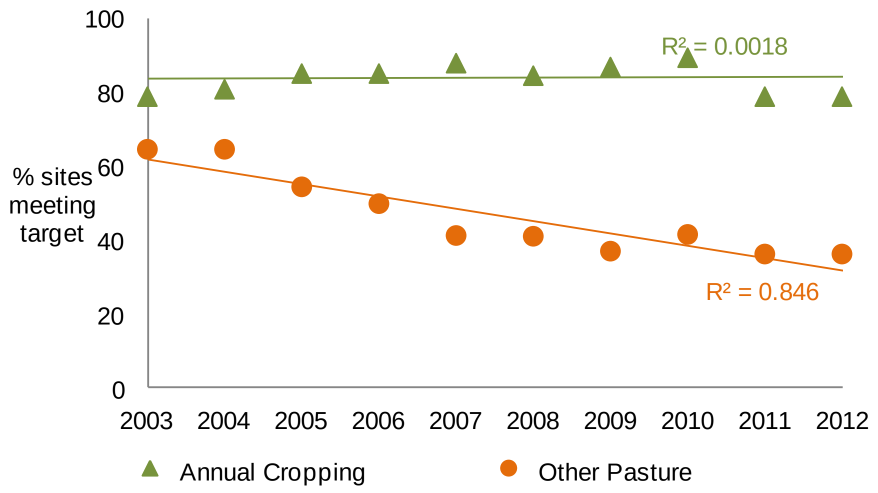


Figure 24: Trend in the proportion of other pasture and annual cropping sites meeting the upper total N target

Forestry land use has remained static, while dairy shows improvement in meeting the total N target. However, horticulture is more variable (Figure 25). There was an improvement in the proportion of horticultural sites meeting the upper nitrogen target in 2007, but this proportion has declined over 2009-2012.

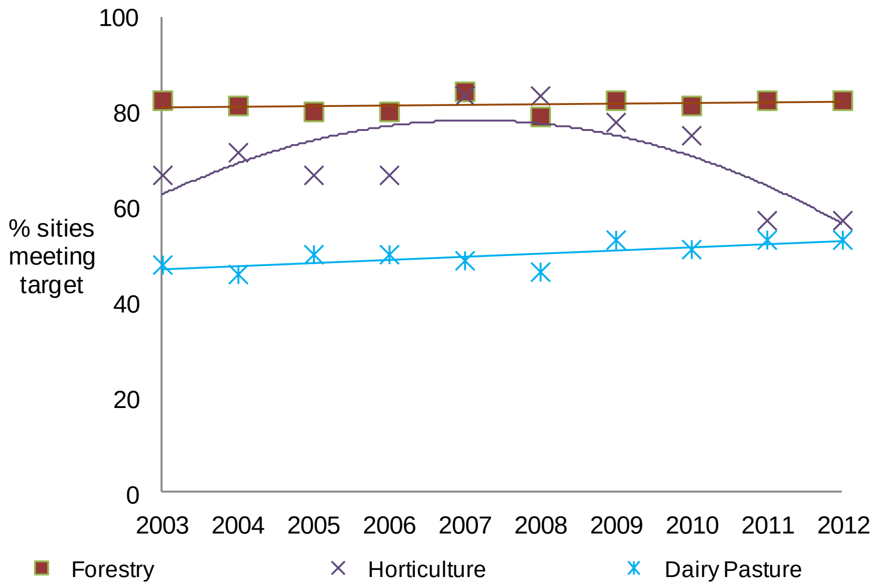


Figure 25: Trend in the proportion of forestry, horticulture and dairy pasture sites meeting the upper total N target

Prior to 2009, there were no production limitations due to nitrogen shortage at any of the monitoring sites. However, in 2009, 14% of sites recently converted from forest to pasture had total N values that were below the lower (deficiency) target, reflecting their low soil organic matter status. Soil organic matter has accumulated in these soils over the years and now 100% of sites recently converted from forest to pasture now meet the low nitrogen target.

In 2012, one cropping site and one forestry site had total N values that were below the lower (deficiency) target (Appendix 2). The forestry site had recently been harvested, which disturbed the soil and resulted in the loss of soil organic matter. The cropping site also had total C values below the total C target, thus had little organic matter. Organic matter is needed to retain nitrogen in the soil.
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 quantity 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 26). 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 108 mg/kg in 2005 to 140 mg/kg in 2013, consistent with increasing microbial activity.

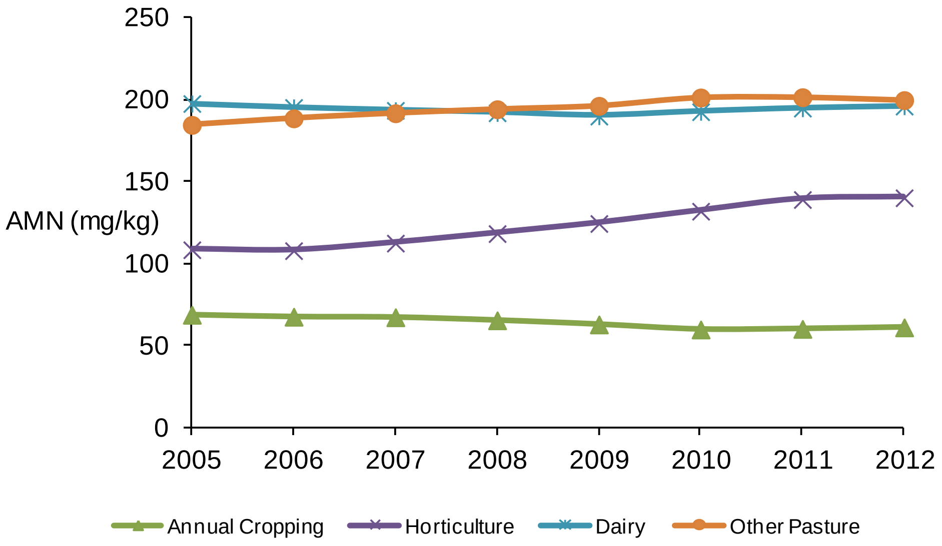


Figure 26: Floating 5-year average anaerobically mineralised N concentrations for cropping and horticultural sites between 2005 and 2012

Low pH was found on 3% of other pasture sites from 2009 to the present. This land use tends to take place on the more marginal hilly land. Sites with low pH could be limed to increase yields and vegetative cover to protect the soil from erosion. Alternatively, if productivity of this land is low, it may be less costly to return the land to native bush than to try to farm it. No trends with pH were identified.

17.5 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. There are two soil quality indicators assessing erosion susceptibility; macroporosity (-10 kPa) and bulk density. There are also two quite separate types of erosion indicated by macroporosity and bulk density measurements.

1. Soils with macroporosity (-10 kPa) values below the lower targets and bulk density values above the upper targets are compacted at the surface and have less infiltration and more surface run-off, leading to a greater risk of surface erosion. See also the discussion on surface compaction above.
2. Soils with macroporosity (-10 kPa) values above the upper targets and bulk density values below the lower targets are very loose and light, so are easily transported by wind or water if not protected by vegetation. In addition, they may dry out quickly, and plant roots may find it difficult to obtain purchase and absorb water and nutrients (Sparling et al., 2003).

Only about one fifth of dairy pasture sites and other pasture sites met the lower macroporosity (-10 kPa) target in 2012, therefore about 80% of pastoral sites are surface compacted (Figure 18). Land that is sloping in addition to being surface compacted is at greater risk of surface erosion than flat land (Environment Waikato 2008).

About 75-80% of forestry sites met the upper macroporosity (-10 kPa) and lower bulk density targets, therefore about 20-25% of forestry sites are on very light loose soils. This is close to the natural state of these soils. It is a commonly accepted practice to leave light, loose 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. As with surface erosion, erosion risk increased with increasing slope (Environment Waikato 2008).

The proportion of forestry sites meeting targets has recently increased with the conversion of some erosion-vulnerable forest to dairy pasture, removing them from the forestry category. 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. However, 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). Adding to the complexities surrounding this issue, some of the forest to dairy pasture sites still had bulk density measurements below targets, so 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.

All horticulture, and cropping, dairy pasture and other pasture sites met the lower bulk density and upper macroporosity (-10 kPa) targets in 2012.

18 Conclusions

Overall, soil quality in the Waikato region is declining. Soil quality monitoring in 2012 showed 13% of sites meet targets, 33% of sites failed to meet one target and 54% of sites failed to meet two or more targets. Dairy pasture (2%) and other pasture (0%) had the lowest proportion of sites meeting all targets, while dairy pasture had the highest proportion failing to meet two or more targets (73%).

There are four key soil quality issues:

1. Surface compaction
   There was a large decrease in the proportion of sites meeting the macroporosity targets compared with the previous year's results, indicating surface compaction is increasing. This trend has been consistent since 2009. Farmed land uses showed the greatest decline in meeting the macroporosity targets. Greater intensification, particularly relating to the dairy industry, may be a contributing factor. Another factor may be climate change with wet winter/spring periods over the last three years increasing the vulnerability of the land to compaction.

   However, soils recently converted from forest to dairy or other pasture, which were compacted by vehicles, thus damaged during the conversion process, have improved from 86% to 100% meeting the target. This improvement can be attributed to improved pasture growth, with root expansion opening up the soil, while vegetation cover protects the surface from rain impact and reduces the pressure from animal hooves. These results imply that these soils can be farmed without compaction being an issue.

2. Loss of organic matter
   Loss of soil organic matter continues with a decline in regional average total C concentration from 9.9% to 9.5% between 2003 and 2012. The amount of carbon lost from the regions soils over this time is estimated to be 7.2 Mt. Loss of organic matter is associated with increased surface compaction, slaking of aggregates and capping of seedbeds.

A clear decline in average total C is evident in cropping land and the proportion of sites meeting the aggregate stability indicator continues to decrease. Also, a slight decline in average total C concentration is evident for sites under dairy pasture.

Harvesting of trees from forestry sites can disturb the soil resulting in loss of organic matter. Three sites had been harvested since the previous round of soil quality sampling and one site had total C below targets (Appendix 2), probably reflecting forest floor management during the harvest.

Sites recently converted from forest to pasture are continuing to recover after the loss of organic matter during the conversion process. Average soil total carbon levels have increased from 6.5% to 7.9%, consistent with increased organic matter production from the increased fertility at these sites. Carbon concentrations are likely to continue to increase at conversion sites until they reach similar levels to dairy and other pasture.

3. High or low nutrient levels

Nitrogen continues to trend upwards in productive soils,, which increased the risk of nitrogen leaching into the waterways. 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. Although the proportion of annual cropping sites that meet the upper total N target is static, the risk of nitrogen loss from annual cropping may be increasing due to the loss of soil organic matter under this land use.

The average regional Olsen P concentration increased from 47 mg/kg in 2003 to 60 mg/kg in 2012 and the upper Olsen P target was exceeded at some sites under all productive land uses. Also, the proportion of sites meeting the upper Olsen P target declined between 2003 and 2012. Average Olsen P values in dairy sites have increased more slowly than the other productive land uses and there was a small improvement in the proportion of dairy sites meeting this indicator in 2012 compared to 2011. However, horticulture, sites recently converted from forest to pasture, and other pasture sites had a decrease in the proportion of sites meeting the upper Olsen P 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 carbon status. Soil organic matter has accumulated in these soils over the years and now 100% of sites recently converted from forest to pasture now meet the low nitrogen target.

Production limitations may occur if there is too little phosphorous. Olsen P levels were below the lower target at 12% of other pasture and 0% of production forestry sites. Low pH was also found on 3% of other pasture sites. These land uses tend to take place on the more marginal hilly.

4. Erosion

Macroporosity (-10 kPa) and bulk density results showed about 25% of forestry sites appear to have high erosion risk, especially during the period between tree harvest and the growth of the next rotation when the land is bare and/or is sloping. The proportion of forestry sites meeting targets has recently increased with 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. However, the increased compaction may result in increased transport of contaminants and peak-flows causing localised flooding and bank erosion. Adding to the complexities surrounding this issue, some of the forest to dairy pasture sites still had bulk density measurements below targets, so 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.

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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	300
Forestry	5	**20**	40	120	200
Cropping and Horticulture	5	**20**	100	150	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

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

Olsen P (µg/g)

Pasture on Sedimentary and Allophanic soils	0	**15**	20		**50**	**>50**
Pasture on Pumice and Organic soils	0	**15**	35		**50**	**>50**
Cropping and horticulture on Sedimentary and Allophanic soils	0	**20**	50		**50**	**>50**
Cropping and horticulture on Pumice and Organic soils	0	**25**	50		**50**	**>50**
Forestry on all soil orders	0	**5**	10		**50**	**>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 system).

Bulk Density (t/m³) 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

Notes: 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

Notes: 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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	97	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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	95	89	89	91	92	92	93	93	90	89
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	94	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	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	100

n.s. = sites not sampled

Table 4: Percent of soil quality sites meeting the lower Total N target by land use over 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	95	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	94	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	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	100

n.s. = sites not sampled

Table 5: Percent of soil quality sites meeting the upper Total N targets by land use over 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	79	89	89	87	85	88	85	85	81	79
Horticulture	57	86	75	78	83	83	67	67	71	67
Forestry	82	82	81	82	79	84	80	80	81	82
Dairy Pasture	53	53	51	53	46	49	50	50	46	48
Forest to pasture	86	n.s.	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	36	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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	96	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	100	88	88	88	89	89	93	93	88	82
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	88	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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	26	26	32	52	54	60	63	67	52	58
Horticulture	21	29	50	56	67	67	50	50	57	50
Forestry	94	94	94	94	95	95	100	100	100	100
Dairy Pasture	39	35	34	37	49	44	50	53	50	52
Forest to pasture	29	n.s.	n.s.	43	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	67	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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	95	95	95	96	96	96	96	96	90	95
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	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	100

n.s. = sites not sampled

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

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	96	96	96	95	89
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	82	65	63	59	53	53	60	60	63	59
Dairy Pasture	100	96	96	95	95	95	93	93	92	96
Forest to pasture	86	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	100

n.s. = sites not sampled

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

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	100	100	100	100	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100	100	100
Forest to pasture	100	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	100

n.s. = sites not sampled

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

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	74	79	79	87	81	84	85	89	86	79
Horticulture	57	86	75	78	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100	100	100
Dairy Pasture	20	35	32	63	54	51	47	47	38	30

Forest to pasture	100	n.s	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	21	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 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	95	79	87	81	84	85	89	86	79
Horticulture	100	100	75	78	100	100	100	100	100	100
Forestry	76	71	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	32	63	54	51	47	47	38	30
Forest to pasture	100	n.s.	n.s.	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	100	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 8 years.

	2012	2011	2010	2009	2008	2007	2006	2005
Annual Cropping	42	47	47	70	77	76	78	78
Horticulture	100	93	88	100	100	100	100	100
Forestry	100	100	100	100	100	100	100	100
Dairy Pasture	100	100	100	100	100	100	100	100
Forest to pasture	71	n.s.	n.s.	57	n.s.	n.s.	n.s.	n.s.
Other Pasture	97	100	100	97	100	100	100	100

n.s. = sites not sampled

Table 14: Percent of soil quality sites meeting the C:N ratio target by land use over 10 years.

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	84	84	84	83	85	88	89	89	100	100
Horticulture	79	100	100	89	83	83	83	83	86	83
Forestry	100	100	100	100	100	100	100	100	100	100
Dairy Pasture	86	96	96	96	93	95	93	93	92	91
Forest to pasture	100	n.s.	n.s.	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	88	100	100	100	94	100	100	100	100	100

n.s. = sites not sampled