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Soil Quality and Trace Element Monitoring in the Waikato Region 2009

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Prepared by:
Matthew Taylor

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

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Peer reviewed by:
Reece Hill Date June 2011

Approved for release by:
Peter Singleton Date July 2011

Disclaimer

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Abstract

An ongoing programme of soil quality assessment in the Waikato region of New Zealand is providing baseline data and allowing identification of the impacts of land use and associated key soil quality issues. This report provides an assessment of the current soil quality status of the soils of the Waikato region and interpretation of changes in soil characteristics over the last 7 years. In addition, trace element indicators that provide measures of defuse contamination were trialled. The trace element indicators meeting or not meeting targets are considered separately from the assessment of soil quality indicators.

Results showed in 2009 26% of sites meet soil quality targets. Of the rest, 34% failed to meet 1 target and 40% failed to meet 2 or more targets. The land use meeting most targets was horticulture, followed by forestry and cropping. Dairy and other pasture had the lowest proportion meeting targets and the highest proportion failing to meet 2 or more targets, both as a proportion of sites and as land area. There has been some improvement in meeting macroporosity targets by pasture and in meeting lower (deficient) Olsen P targets by pasture and forestry over the last 7 years. Conversely, the proportion of sites not meeting nitrogen targets is increasing. While the proportion of sites meeting all existing indicator targets has increased over the last 7 years and the proportion of sites not meeting 1 indicator has decreased, the proportion of sites not meeting 2 or more indicator targets is static or increasing slightly.

This soil quality report distinguishes five key issues that cause loss of soil resource. These are soil surface compaction, loss of soil organic matter, excessively high fertility levels, erosion risk, and accumulation of contaminants. One of these issues, soil compaction, shows a steady improvement in meeting targets. 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.

Similar improvements in the other issues have yet to be seen:
Loss of soil organic matter continues with a decline in average total C concentration from 9.9% to 9.4% over the last 7 years. Much of this decline was from sites under annual cropping land use and only about 90% of cropping sites now meet the target. However, cropping only takes place on a small proportion of land area in the Waikato region. Although all conversion pasture sites met targets, several indicators point to loss of soil organic matter during the conversion process.

In farmed land uses, excess nutrients, such as nitrogen and phosphorus are trending upwards or are stable at best. Conversely, some forestry, conversion pasture and other pasture sites showed deficient nutrients, reflecting low carbon status (to hold nutrients) or worsening economic factors.

A large proportion of forestry sites have high erosion risk, especially if the tress are removed. It is a management practice to leave erosion prone soils in native bush or planted in production forestry to manage erosion. In addition, some annual cropping and a few horticulture and pasture sites have a higher risk of eroding, especially between crops or at resowing when the land is bare and/or is sloping (> 7°).

Trialling of indicators for trace element monitoring clearly identified accumulation of diffuse soil contaminants and land use impacts on soil concentrations, e.g. cadmium (under horticulture, dairying and other pasture) and zinc (under dairying and other pasture) exceeded targets and the proportion doing so was increasing. An unexpected observation was the significantly higher and upwards trending concentrations of chromium, mercury and nickel in soil under annual cropping. These 3 elements remain well below targets but the cause of the accumulation needs to be identified before targets are exceeded. Other diffuse contaminates, such as arsenic, copper and fluoride exceeded targets under annual cropping, horticulture, dairy pasture and other

pasture land uses but trends are not yet clear due to insufficient data. These diffuse contaminants are linked to fertiliser and agricultural chemical use.

Lead had concentrations that were not of concern and levels are static or declining.

The soil quality status of soil in the Waikato region has improved in relation to the issue of compaction, although compaction remains a priority issue due the the amount of land affected and its off-site impacts. Similar improvements in relation to loss of soil organic matter, excessively high fertility levels, erosion risk, and accumulation of contaminants was not observed, and continuing efforts in education and enforcement are needed.

Executive Summary

This report provides an assessment of the current soil quality status of the soils of the Waikato region and interpretation of changes in soil characteristics over the last 7 years and reports on the trial of trace element indicators of defuse contamination. The soil quality indicators meeting or not meeting targets are considered separately from the assessment of trace element indicators.

Results showed in 2009 26% of sites meet soil quality targets. Of the rest, 34% failed to meet 1 target and 40% failed to meet 2 or more targets. The land use meeting most targets was horticulture, followed by forestry and cropping. Dairy and other pasture had the lowest proportion meeting targets and the highest proportion failing to meet 2 or more targets, both as a proportion of sites and as land area.

There has been some improvement in meeting macroporosity (surface compaction) targets by pasture and in meeting lower (deficient in phosphorous) Olsen P targets by pasture and forestry over the last 7 years. Conversely, the proportion of sites not meeting nitrogen targets is increasing. While the proportion of sites meeting all existing indicator targets has increased over the last 7 years and the proportion of sites not meeting 1 indicator has decreased, the proportion of sites not meeting 2 or more indicator targets is static or increasing slightly.

Five key issues that cause loss of soil resource were distinguished. One of these issues, soil compaction, shows a steady improvement in meeting targets but 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 continues with a decline in average total C concentration from 9.9% to 9.4% over the last 7 years. Much of this decline was from sites under annual cropping land use while, several indicators point to loss of soil organic matter from pine forest to pasture conversion during the conversion process. Excess nutrients, such as nitrogen and phosphorus are trending upwards or are stable at best under cropping, horticulture and most pasture sites. Conversely, some forestry, conversion pasture and other pasture sites showed deficient nutrients, reflecting low carbon status (to hold nutrients) or worsening economic factors. A large proportion of forestry sites have high erosion risk, especially if the trees are removed. It is a management practice to leave erosion prone soils in native bush or planted in production forestry to manage erosion. In addition, some annual cropping and a few horticulture and pasture sites have a higher risk of eroding, especially between crops or at resowing when the land is bare and/or is sloping (> 7°).

Trialling of indicators for trace element monitoring clearly identified accumulation of diffuse soil contaminants. Cadmium (under horticulture, dairying and other pasture) and zinc (under dairying and other pasture) exceeded targets and the proportion doing so was increasing. An unexpected observation was the significantly higher and upwards trending concentrations of chromium, mercury and nickel in soil under annual cropping. These 3 elements remain well below targets but the cause of the accumulation needs to be identified before targets are exceeded. Other diffuse contaminates, inked to fertiliser and agricultural chemical use, such as arsenic, copper and fluoride exceeded targets under annual cropping, horticulture, dairy pasture and other pasture land uses but trends are not yet clear due to insufficient data. Lead had concentrations that were not of concern and levels are static or declining.

The soil quality status of soil in the Waikato region has improved in relation to the issue of compaction, although compaction remains a priority issue due the amount of land affected and its off-site impacts. Similar improvements in relation to loss of soil organic matter, excessively high fertility levels, erosion risk, and accumulation of contaminants was not observed, and continuing efforts in education and enforcement are needed.

1 Introduction

Environment Waikato (EW) participated in the Sustainable Management Fund project "Implementing Soil Quality Indicators for Land" from 1998–2001. EW has continued 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 includes 144 soil quality sites in the Waikato region. Sampling sites were chosen to cover a representative range of land uses and Soil Orders including background and different farming systems.

2 Objectives

- Provide an assessment of the current soil quality status of the soils of the Waikato region.
- Provide interpretation of changes in soil characteristics over the last 7 years.
- Trial trace element monitoring indicators that measure defuse contamination

3 Methods

Sampling
Soil quality monitoring sites were chosen and sampled according to Land and Soil Monitoring: A guide for SoE and regional council reporting (Hill & Sparling 2009, Kim & Taylor 2009). Soils were classified according to the New Zealand Soil Classification (Hewitt et al 2003). Land use classes used were dairy (pasture grazed with milking cows), drystock (all other animal grazed pasture), arable (annual cultivation), horticulture (plants left in place), production forestry and background (native).

In 2009, EW staff selected 29 sites (22 previously sampled sites and 7 new ones) for sampling. Samples were analysed at Landcare Research, Plant and Food Research and at Hill Laboratories for soil quality parameters and diffuse contaminates such as arsenic, cadmium, copper, fluoride and zinc. Data from these samples were added to the EW soil quality database.

Indicators
An indicator needs to be measureable and to inform about the soils condition to be useful. After three years of trials (1998-2001) over many hundreds of sites, the National Land Monitoring Forum has agreed on seven key indicators plus 2 optional indicators (Hill & Sparling 2009). Table 1 lists the soil quality indicators, the soil property measured and why this indicator is important.

Indicators for trace element monitoring were arsenic, cadmium, chromium, copper, fluoride, lead, mercury, nickel, uranium and zinc. These elements are considered environmentally sensitive.

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)
	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.

Analysis

All analyses were carried out at IANZ-accredited laboratories (Landcare Research, Hill Laboratories, both of Hamilton, and Plant & Food Research, Lincoln) according to the Land and Soil Monitoring Manual (Hill & Sparling 2009, Kim & Taylor 2009). In addition, total fluorine was analysed using the alkali-fusion/ion-selective electrode method (McQuaker & Gurney 1977). A subset of samples have been analysed twice, and/or at different laboratories, as a check on precision and accuracy of the results. In-house quality control standards and a standard reference river sediment (AGAL-10) were also analysed. All results and target ranges are presented on a gravimetric basis.

Target Ranges

Provisional soil quality target ranges were set in 2003 (Sparling et al 2003) using expert opinion and data on production responses. Revision of these target ranges were intended as further information became available. Target ranges for pH, total C, total N, anaerobically mineralised nitrogen and bulk density were from Sparling et al (2003), while those for macroporosity (-10kPa) were from the reviews of Sparling et al (2003) by Beare et al (2007) and Mackay (2006). The target for aggregate stability is from Beare (2005).

Trace element monitoring indicators are trialled in this year's report including total fluorine, acid extractable arsenic, cadmium, copper and zinc. These indicators provide measures of defuse contamination. The target ranges for these indicators are from Taylor (2009) and Biosolids Guidelines (NZWWA 2003). As there is no accepted target or guideline for uranium, these results are presented as part of a "watching brief".

Results are compared to target ranges. Soil quality sites that meet all 7 indicator targets are described as meeting all targets. Those soil quality sites that meet 6 indicator targets but failed to meet 1 are described as failed 1. Similarly for those that failed 2, 3 or 4 indicator targets. Trace element indicators are looked at on an individual element basis; Sites either met or did not meet the target range for each element.

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. For trace element indicator concentrations a 3 year floating average was used as data had been collected for a shorter period.

Land Use Classes

Results are presented on an overall regional basis. Land uses that may be influenced by council policy, including indicative trends where there are sufficient data, are then discussed further. These land uses include annual cropping (annual or more often) harvest, horticulture (crop stays in place every year), production forestry, dairy pasture and other pastoral farming (deer, sheep, beef, cut and carry pasture). Land classified as urban and town, rock, permanent ice and snow, and in native vegetation are not discussed as their soils are either modified by man beyond recognition or not likely to change.

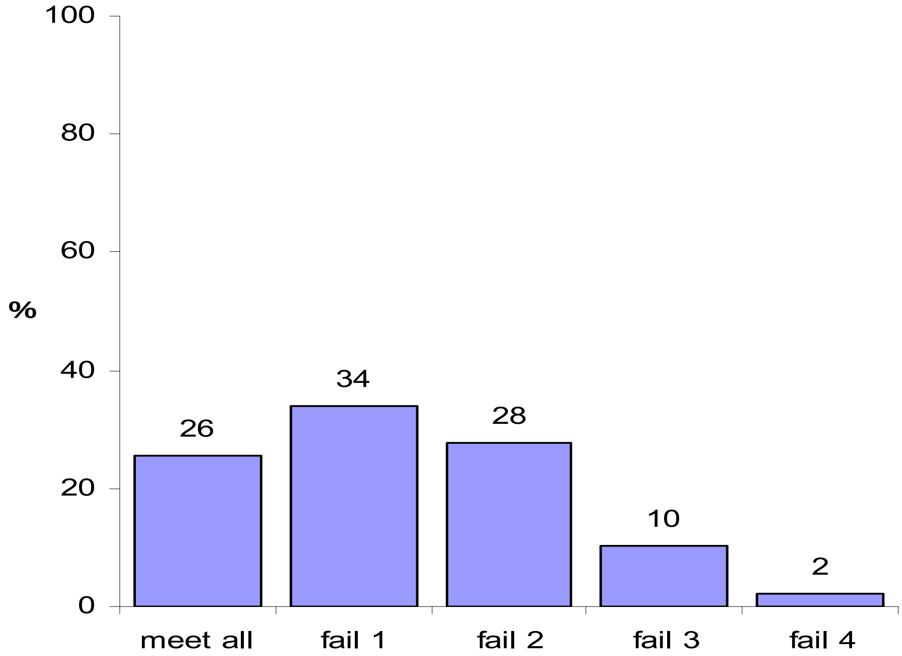
A separate land use category "conversion pasture" was developed to include a cluster of outliers that had been converted from production forestry to pasture since last sampled. Results were significantly skewed if these sites were included in the pasture categories. This land use includes 7 sites sampled in 2009. No trends are reported for this land use as there is only 1 year's data.

4 Results

Data from 2009 for Existing Indicators

Only 26% of sites meet all targets, 34% failed to meet 1 target and 40% failed to meet 2 or more targets (Figure 1). Results are similar compared to those from previous years. Trends in the results are discussed in the next section.

Figure 1: Percent of soil quality sites meeting/failing to meet targets in 2009



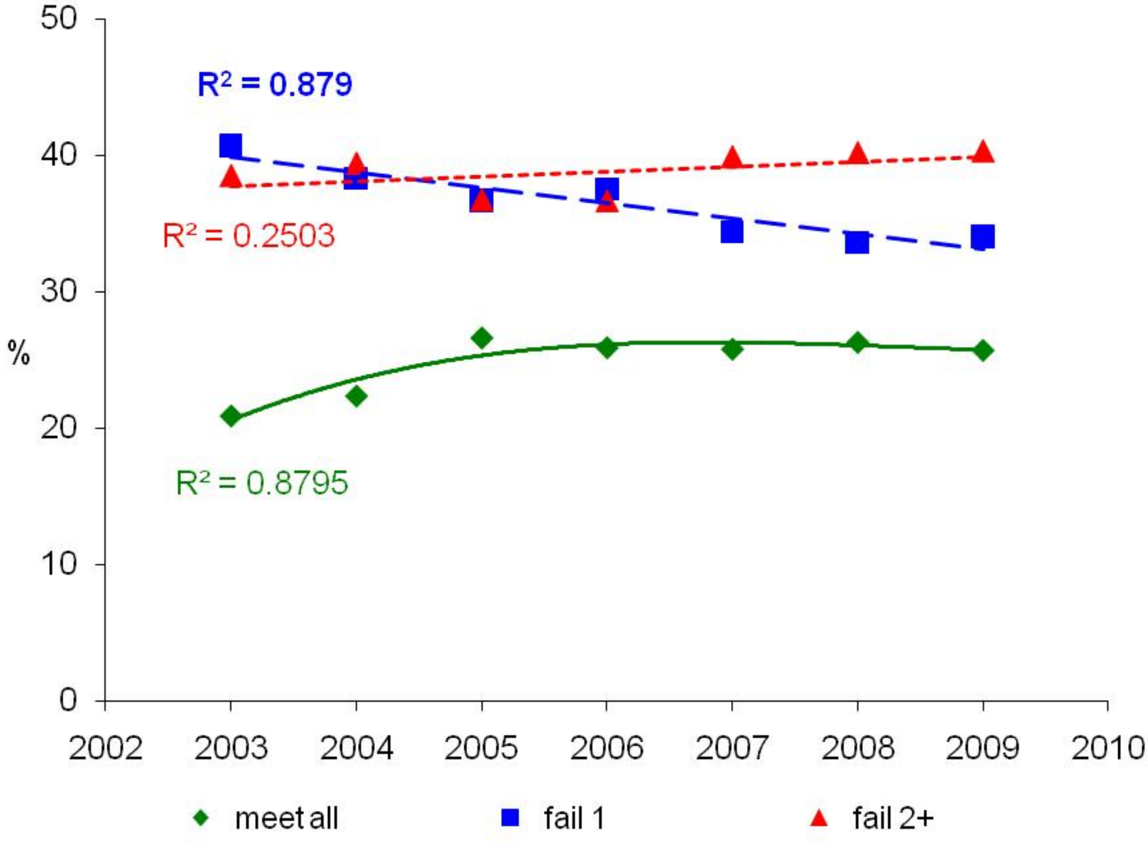
Trends in Meeting Existing Soil Quality Indicator Targets

Overall, after an initial improvement, soil quality in the region static over the last 4 years as the proportion of sites meeting all existing indicator targets over the last 7 years has remained static since 2005. However, the proportion of sites not meeting 1 indicator is decreasing (Figure 2) and sites appear to be going one of two ways:

1. Improvement in meeting macroporosity targets by pasture and in meeting Olsen P targets by formerly deficient pasture and forestry means more sites are meeting all indicators.
2. Conversely, the proportion of sites failing to meet nitrogen targets is increasing and more sites are failing to meet 2 indicators or more.

The proportion of sites not meeting 2 or more indicator targets is increasing but this trend is much weaker than the improvement in meeting all or the decrease in failing 1 indicator target.

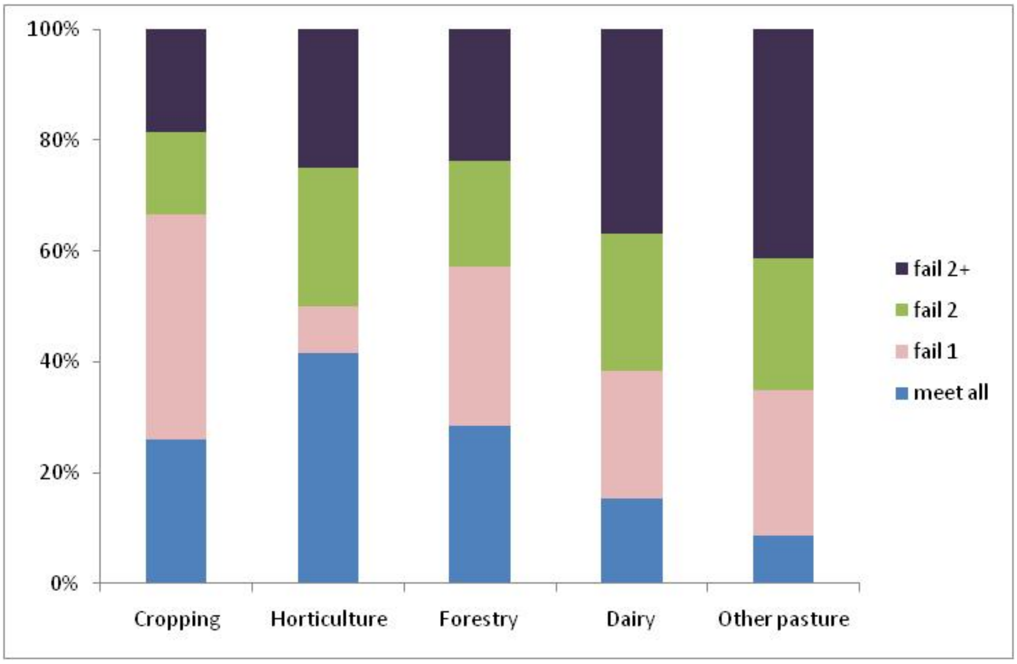
Figure 2: Trends in soil quality sites meeting/failing to meet targets



Land Use and Meeting Existing Soil Quality Targets

The land use meeting most targets was horticulture, followed by forestry and annual cropping (Figure 3). Dairy pasture and other pasture had the lowest proportion meeting all targets, while dairy pasture had the highest proportion failing to meet 2 or more targets.

Figure 3: Soil quality sites meeting/failing to meet targets in 2009 by land use



The State of the Waikato Region's Soils According to Land Use

The data is corrected for the amount of land in each land use to give the current state of the Waikato region's soils (Figure 4). Results are very similar to Figure 1, which implies the spread of soil quality sites is representative of the region's soils. About 25% of land in the Waikato region meet targets, 35% failed to meet 1 target and 39% failed to meet 2 or more targets. Dairy, other pasture and forestry land uses make up a large proportion of the region and have a large impact, either for good or for bad. Annual cropping or horticulture have little impact on the overall state of the regions soils as the proportion of land in these land uses is very small (Figure 5).

Figure 4: Amount of land meeting/failing to meet soil quality targets in 2009

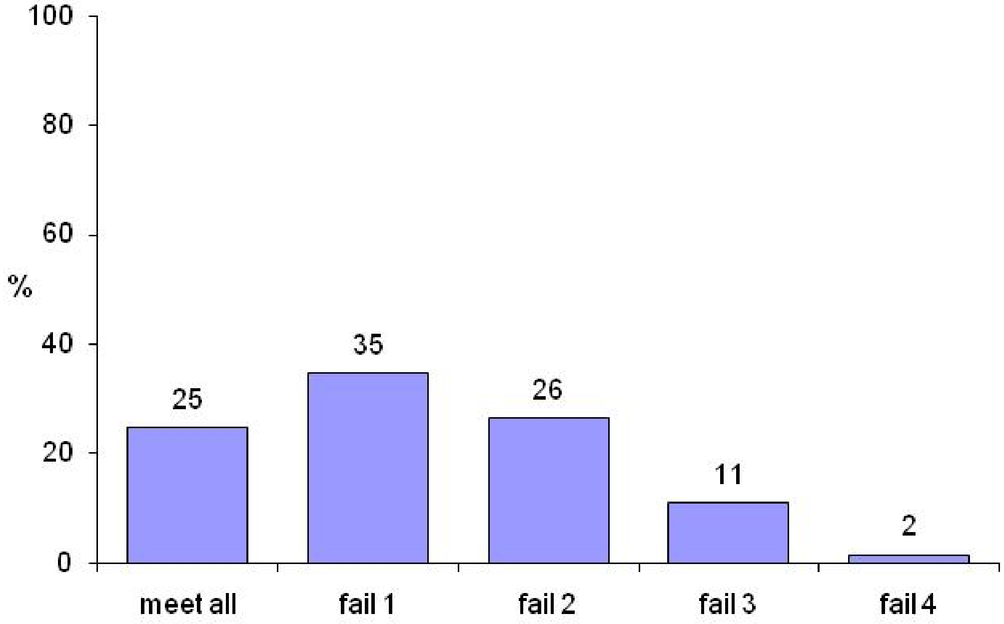
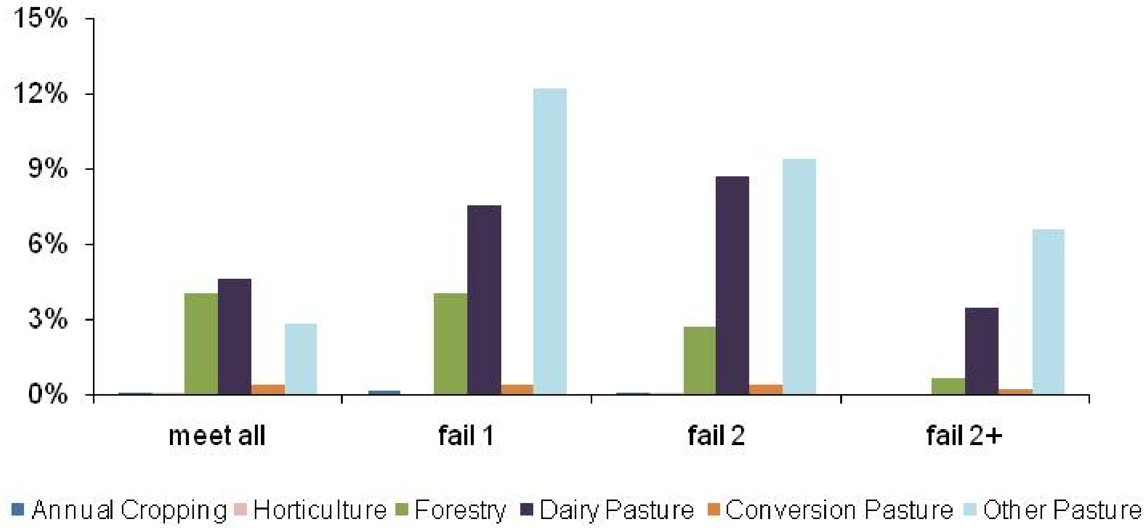


Figure 5: Amount of land as % of regional area meeting/failing to meet soil quality targets in 2009 by land use

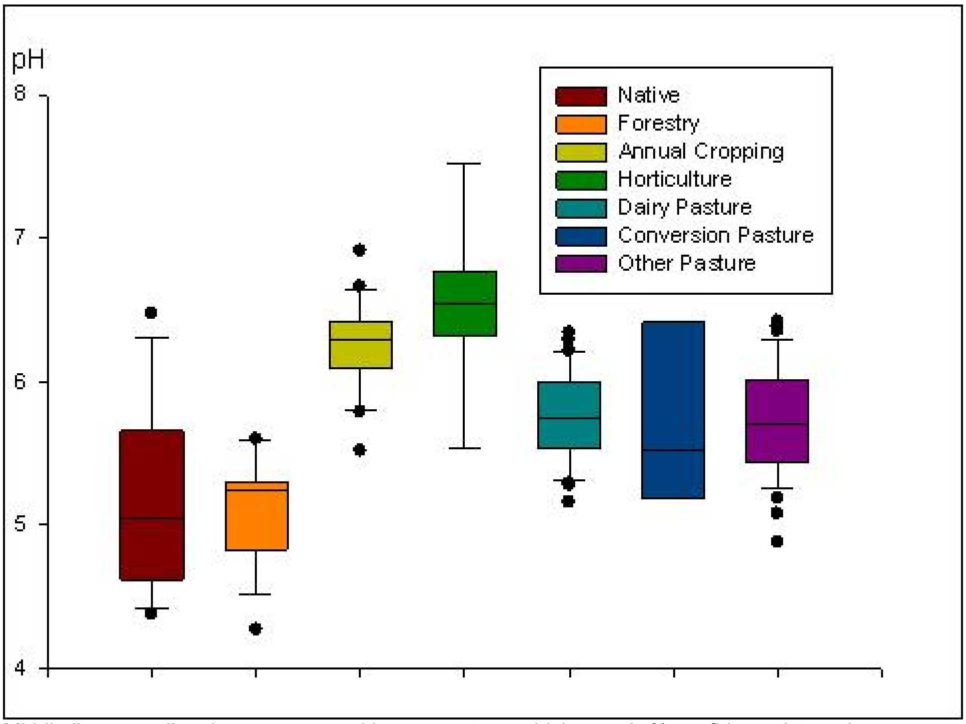


The Effect of Land Use on Soil Quality Monitoring Indicators

The effect of land use on soil pH

As a general rule, soil pHs were significantly higher at sites under annual cropping, horticultural, dairy pasture, conversion pasture and other pasture land uses than those under native and forestry (Figure 6). These 2 groups represent sites that receive or do not receive lime.

Figure 6: The effect of land use on soil pH.

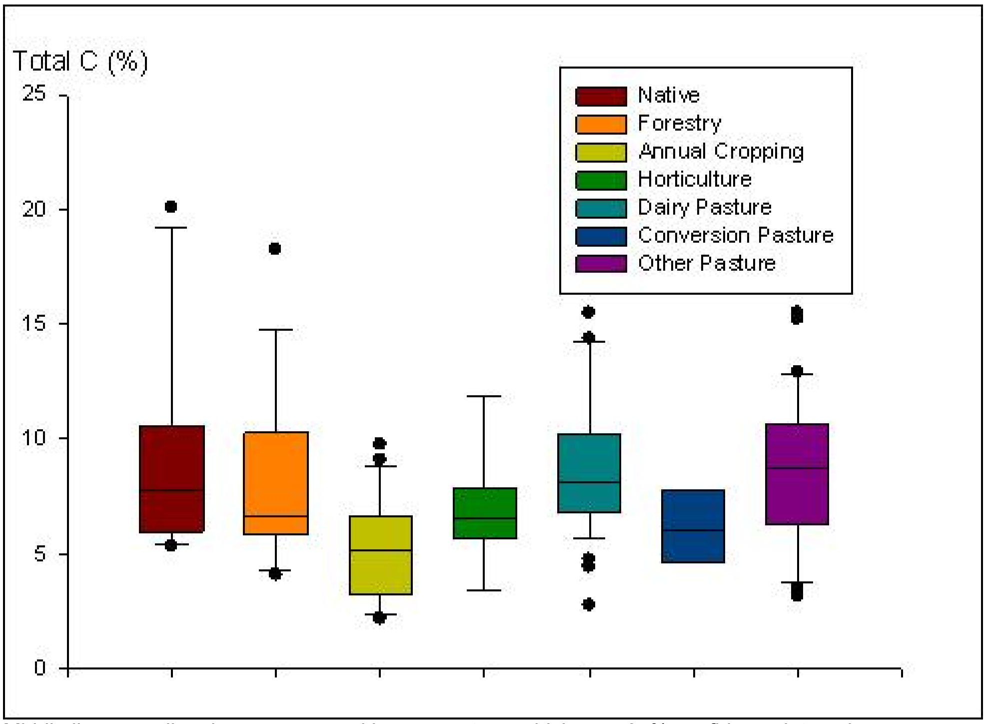


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on soil total carbon

Total carbon concentrations were significantly lower at sites under annual cropping than at sites under native, forestry, horticulture, dairy pasture, and other pasture, indicating loss of soil organic matter (Figure 7). Conversion pasture had total carbon concentrations that were lower than those under forestry, which was their land use before conversion, and higher concentrations than those under annual cropping but these were not statistically significant. However, both dairy pasture and other pasture had significantly higher total carbon concentrations than those under conversion pasture, indicating that total carbon concentrations are likely to increase at conversion sites.

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

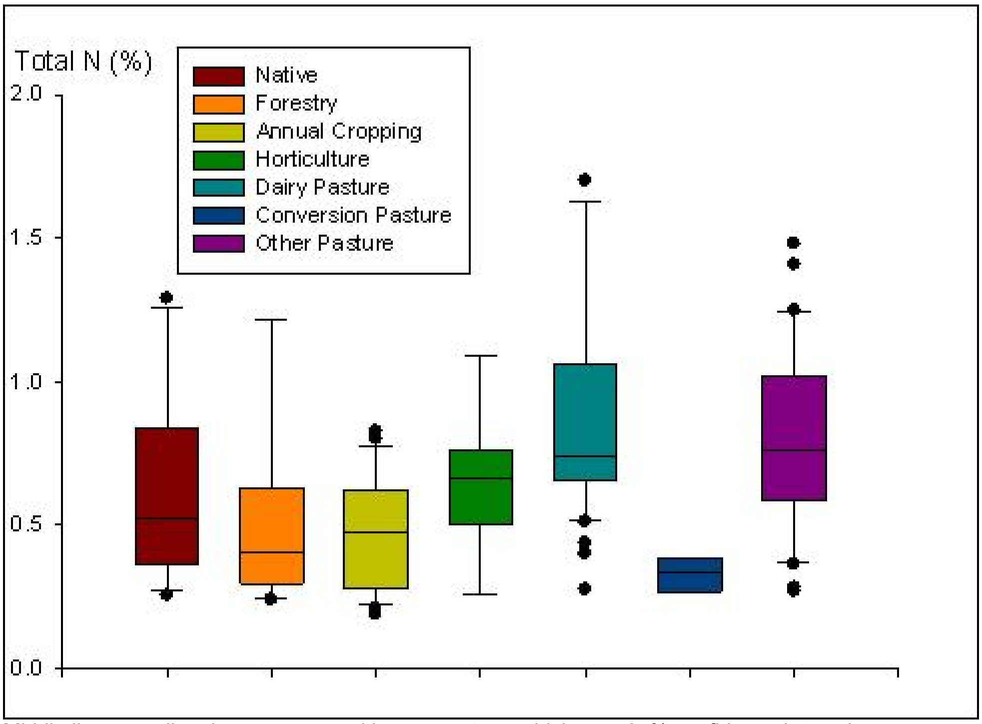


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on soil total nitrogen

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. However, conversion pasture had even lower total nitrogen concentrations, significantly lower than those under cropping, consistent with the loss of soil organic matter under the conversion process.

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

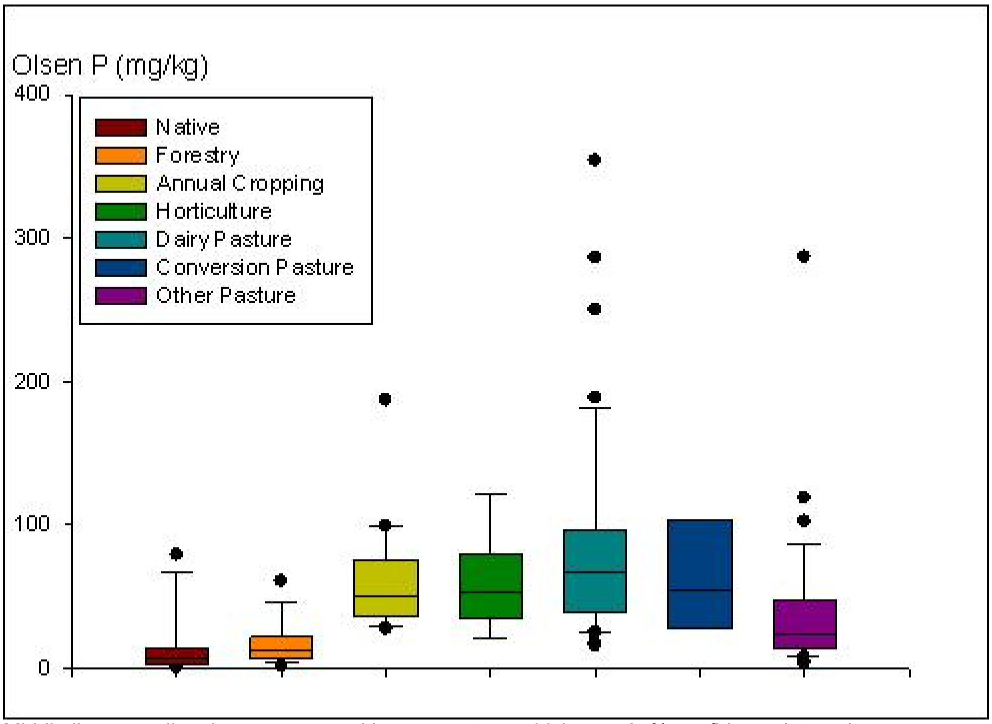


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on Olsen P

Olsen P measurements were significantly higher at sites under annual cropping, horticultural, dairy pasture, conversion pasture and other pasture land uses than those under native and forestry (Figure 9). These two groups represent soils that receive or do not receive phosphate fertiliser, respectively. There were several extremely high Olsen P concentrations under dairy and occasional extreme values under other pasture and cropping.

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

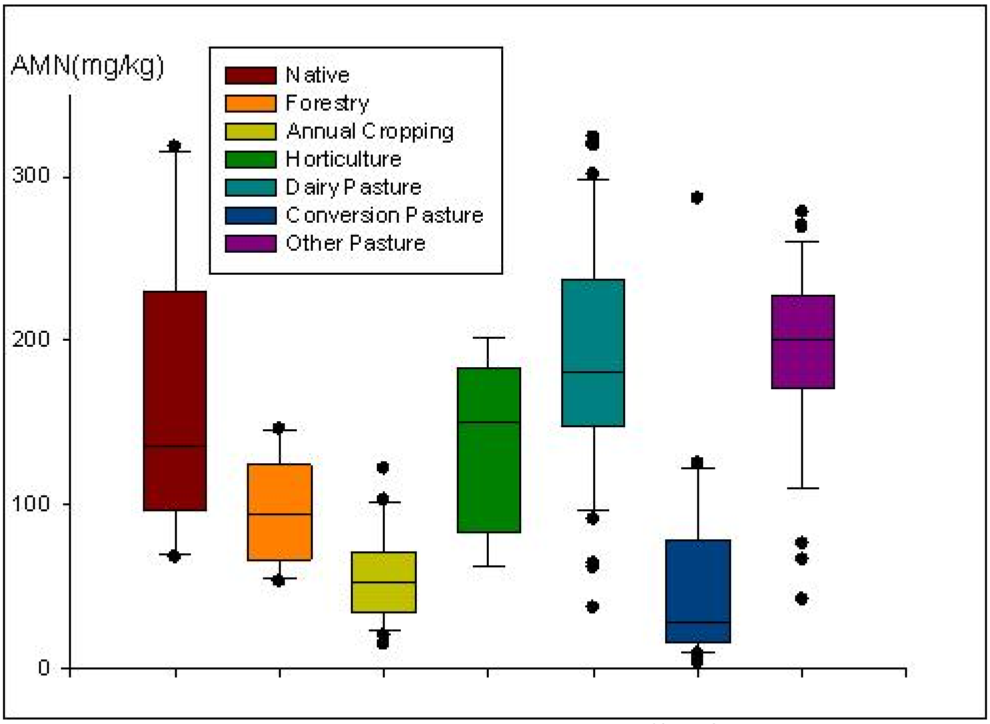


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

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

As a general rule, native and horticulture had similar concentrations of AMN, while dairy and other pasture had higher concentrations, although not significant (Figure 10). In comparison, forestry, annual cropping and conversion pasture had significantly lower concentrations. Annual cropping and conversion pasture occurs of 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.

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

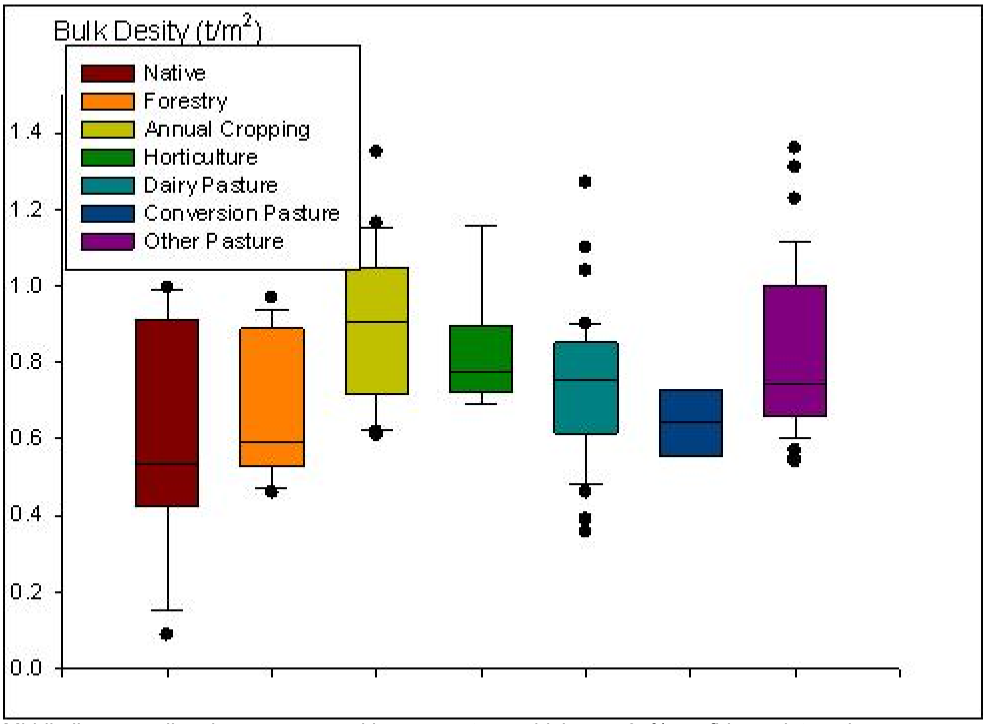


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on soil bulk density

Soil bulk densities were significantly higher in soil under annual cropping, horticulture and other pasture, than those under native, forestry and conversion pasture, with dairy pasture in between (Figure 11).

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

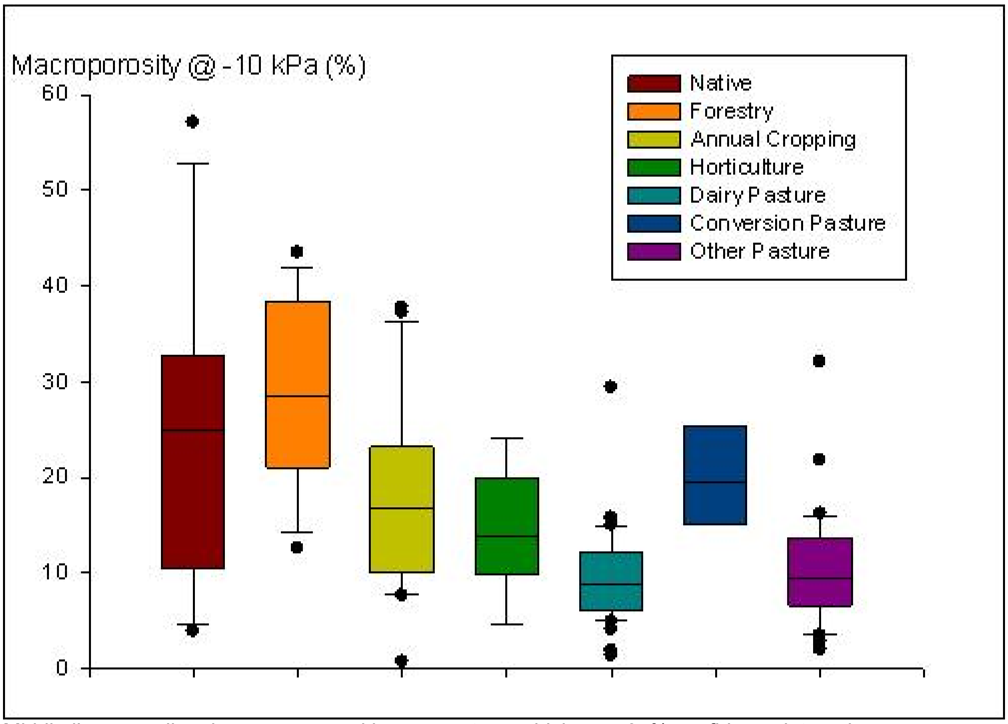


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on macroporosity

Soils under horticulture, dairy pasture and other pasture land uses had significantly lower macroporosity than those under native and forestry. Annual cropping and conversion pasture had macroporosity values in between (Figure 12).

Figure 12: The effect of land use on macroporosity

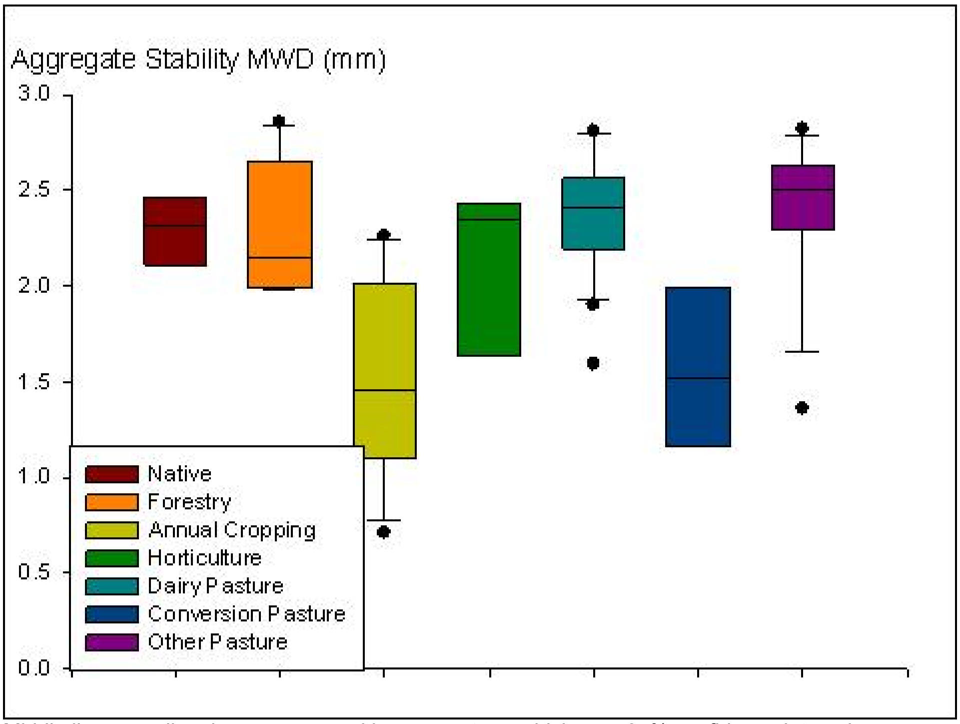


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on aggregate stability

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

Figure 13: The effect of land use on aggregate stability



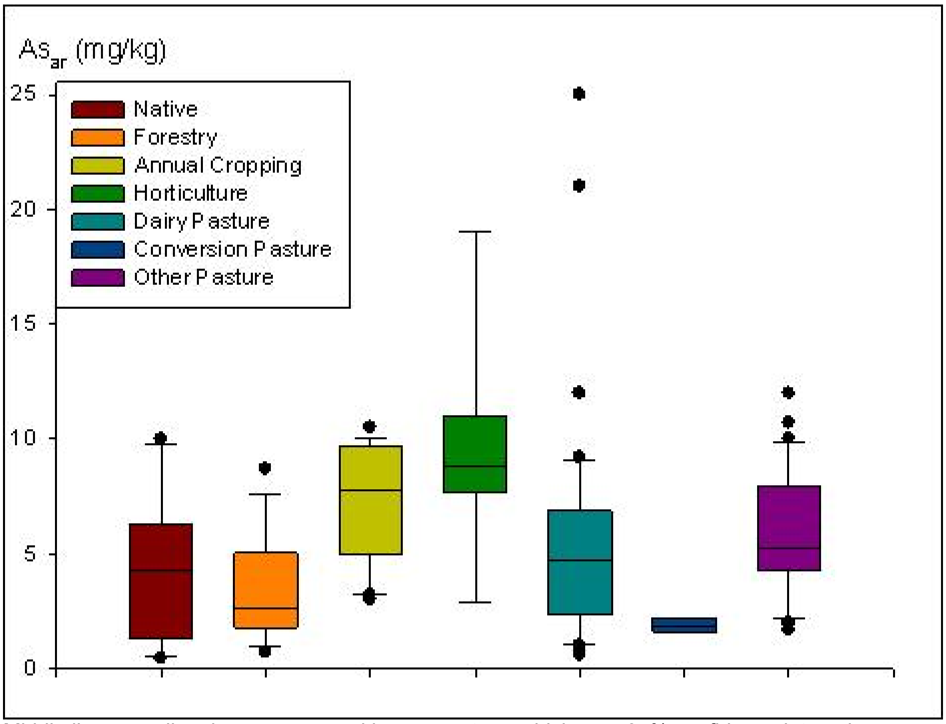
Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The Effect of Land Use on Trace Element Monitoring Indicators

The effect of land use on arsenic

Arsenic measurements were significantly higher in horticultural and annual cropping soils than at sites under other land uses, indicating accumulation, probably from arsenic-based pesticides (Figure 14). The highest measurements were under dairy pasture and may be from natural geothermal features.

Figure 14: The effect of land use on arsenic

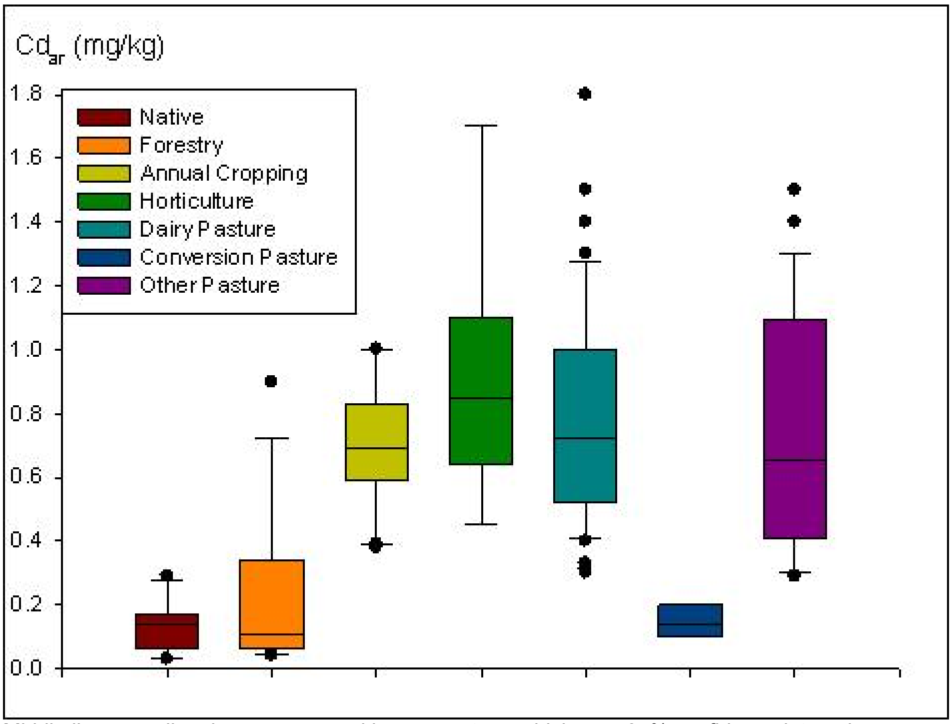


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on cadmium

Cadmium concentrations were significantly higher at sites under annual cropping, horticultural, dairy pasture and other pasture land uses than at sites under native, forestry and conversion pasture (Figure 15). Annual cropping, horticultural, dairy pasture and other pasture receive annual applications of phosphate fertiliser, while conversion pasture has only been fertilised for the 2-3 years since conversion from forest. Native sites are not (intentionally) fertilised and forestry only rarely (perhaps after the third rotation).

Figure 15: The effect of land use on cadmium

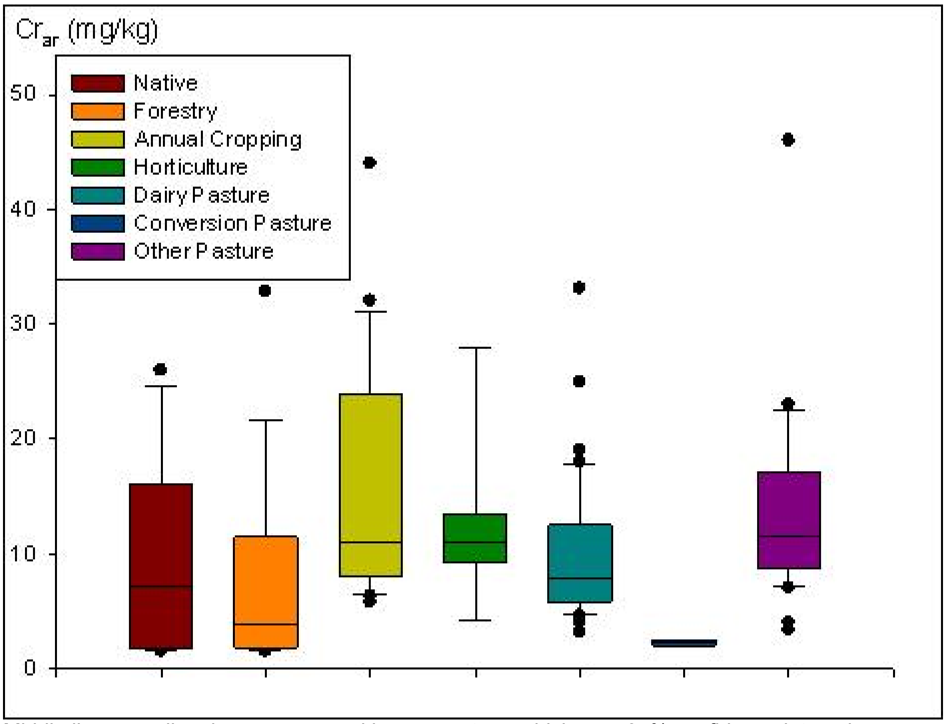


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on chromium

Chromium was significantly higher at sites under annual cropping than in those under other land uses, indicating accumulation, although the source of this accumulation is not clear (Figure 16). As similar behaviour was seen for mercury, it is speculated that the fungicide, mercuric chromate, may have been used in the past.

Figure 16: The effect of land use on chromium

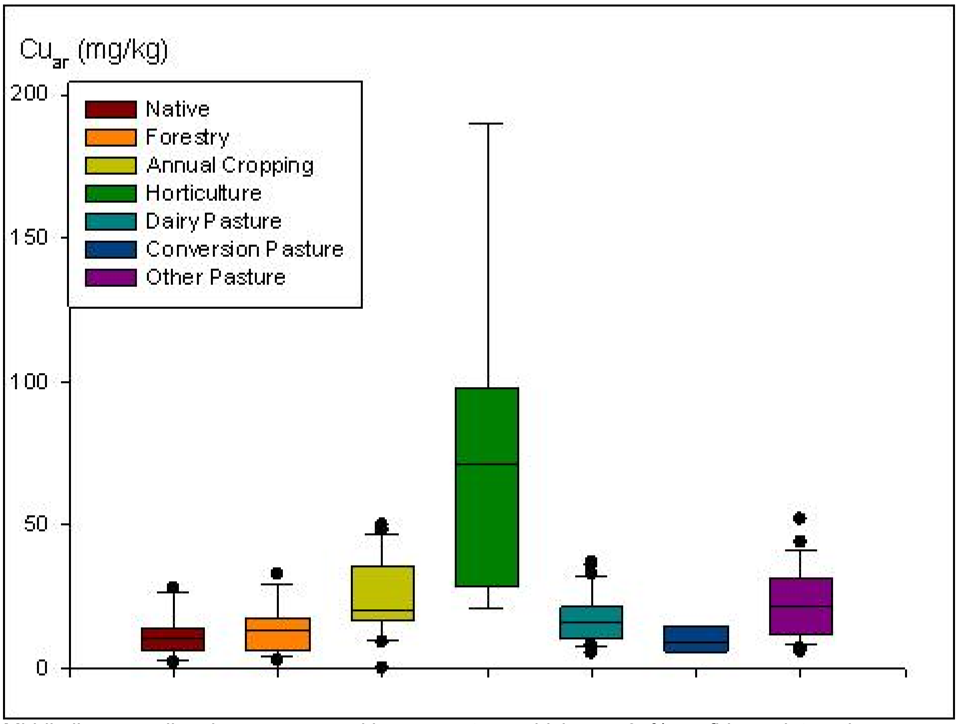


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on copper

Copper measurements were significantly higher at sites under annual cropping, horticulture, dairy pasture and other pasture land uses than at sites under native, forestry and conversion pasture (Figure 17). The horticultural sites had by far the highest copper concentrations, consistent with the use of copper-based fungicides.

Figure 17: The effect of land use on copper

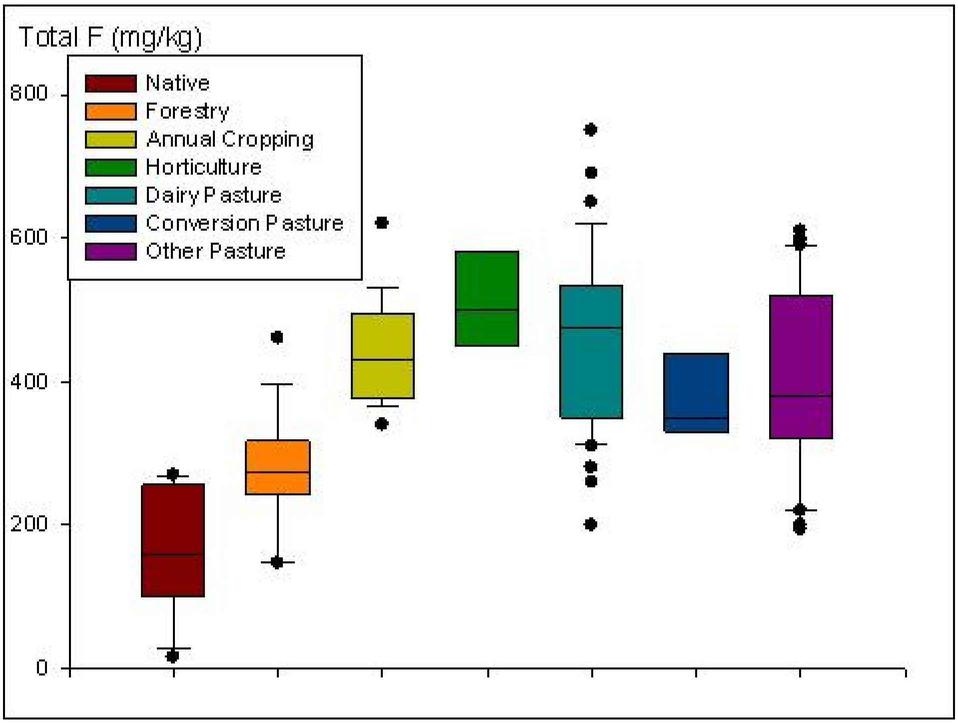


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on fluoride

Fluoride measurements were significantly higher for soils under all other land uses compared to those under native (Figure 18). Dairy pasture had the highest fluoride measurements but horticulture had the highest average. Annual cropping, horticultural, dairy pasture and other pasture receive annual applications of phosphate fertiliser, while conversion pasture has only been fertilised for the 2-3 years since conversion from forest. Native sites are not (intentionally) fertilised and forestry only rarely (perhaps after the third rotation). .

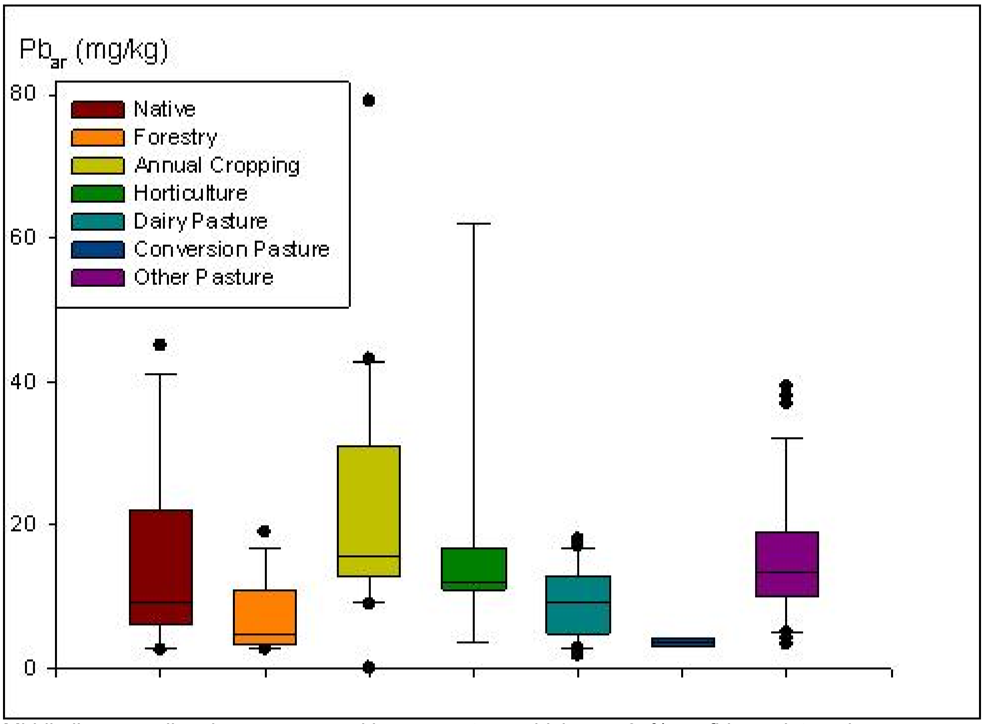
Figure 18: The effect of land use on fluoride



The effect of land use on lead

Lead was significantly higher at sites under annual cropping than those under native, forestry, dairy pasture, conversion pasture and other pasture (Figure 19). Sites under horticulture were also elevated but this was not significant. Both cropping and horticultural sites may have received historic applications of lead-based pesticides, a practice long discontinued. If so, this result illustrates how long metals may impact the land.

Figure 19: The effect of land use on lead

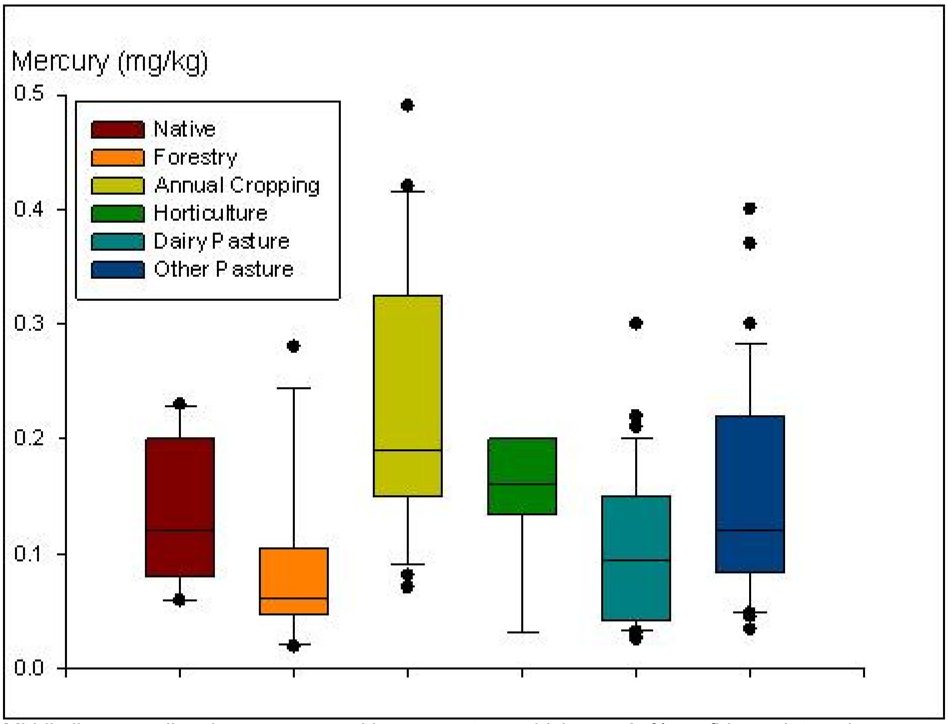


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on mercury

Mercury measurements were significantly higher at sites under annual cropping than at sites under other land uses, indicating accumulation (Figure 20). Mercury is known to have been applied to seeds as a biocide/fungicide.

Figure 20: The effect of land use on mercury

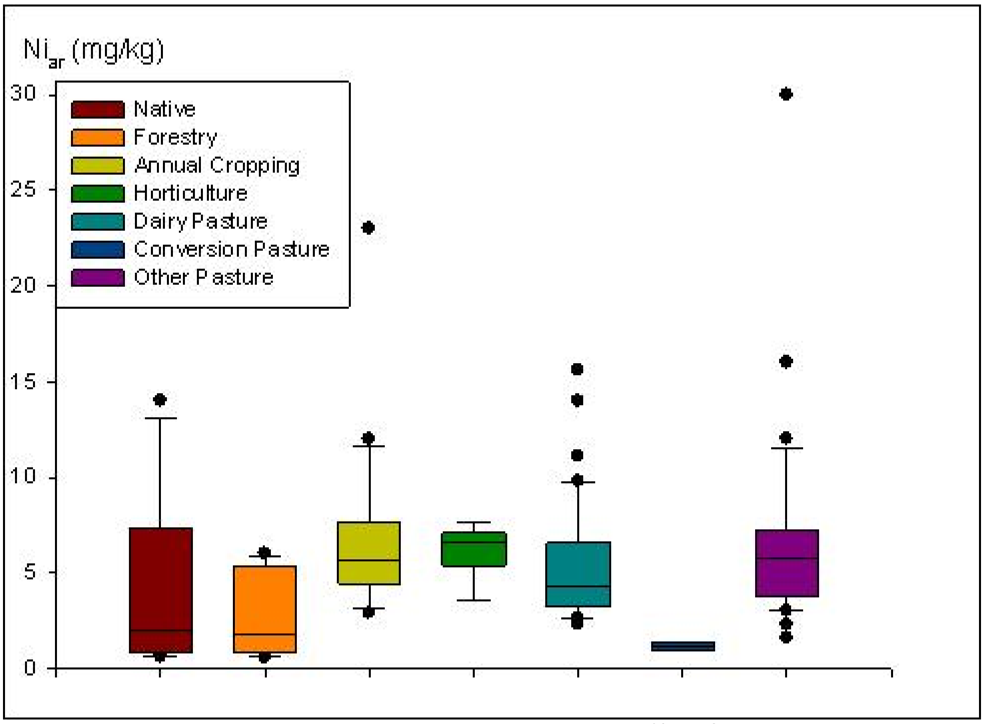


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on nickel

Nickel measurements were significantly higher at sites under annual cropping and other pasture than in those under native, forestry and conversion pasture (Figure 21). Horticulture and dairy pasture land uses were also higher than native and forestry but these increases were not significant.

Figure 21: The effect of land use on nickel

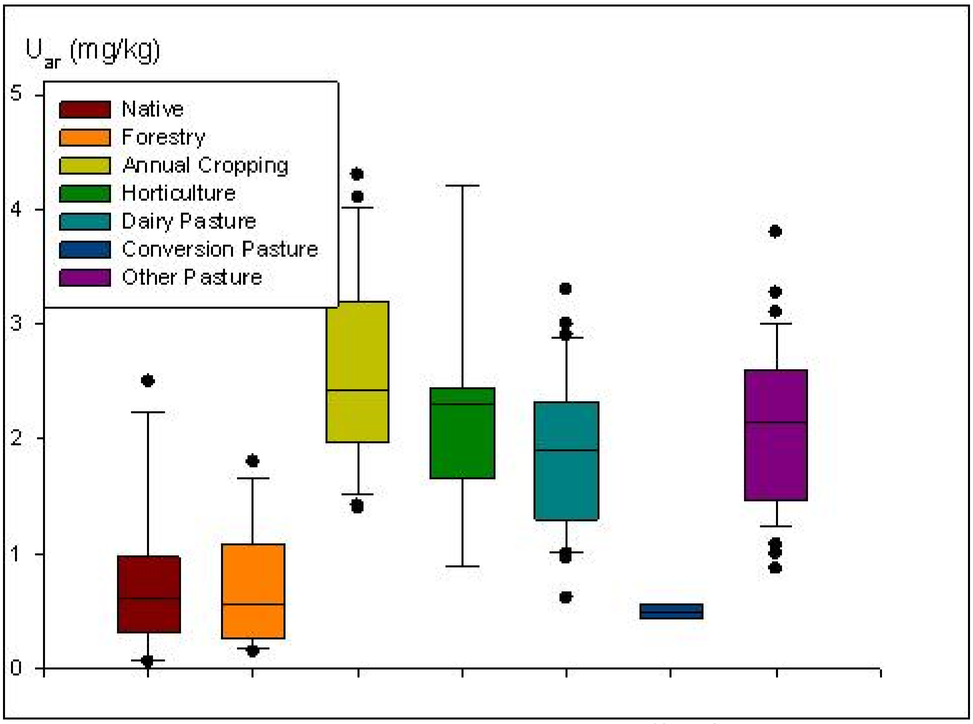


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on uranium

Uranium measurements were significantly higher at sites under annual cropping, horticulture, dairy pasture and other pasture land uses than at sites under native, forestry and conversion pasture (Figure 22). Annual cropping, horticultural, dairy pasture and other pasture receive annual applications of phosphate fertiliser, while conversion pasture has only been fertilised for the 2-3 years since conversion from forest. Native sites are not (intentionally) fertilised and forestry only rarely (perhaps after the third rotation). The highest uranium measurements were under annual cropping and this land use tends to use diammonium phosphate fertiliser, whereas dairy and other pasture tends to use superphosphate fertiliser.

Figure 22: The effect of land use on uranium

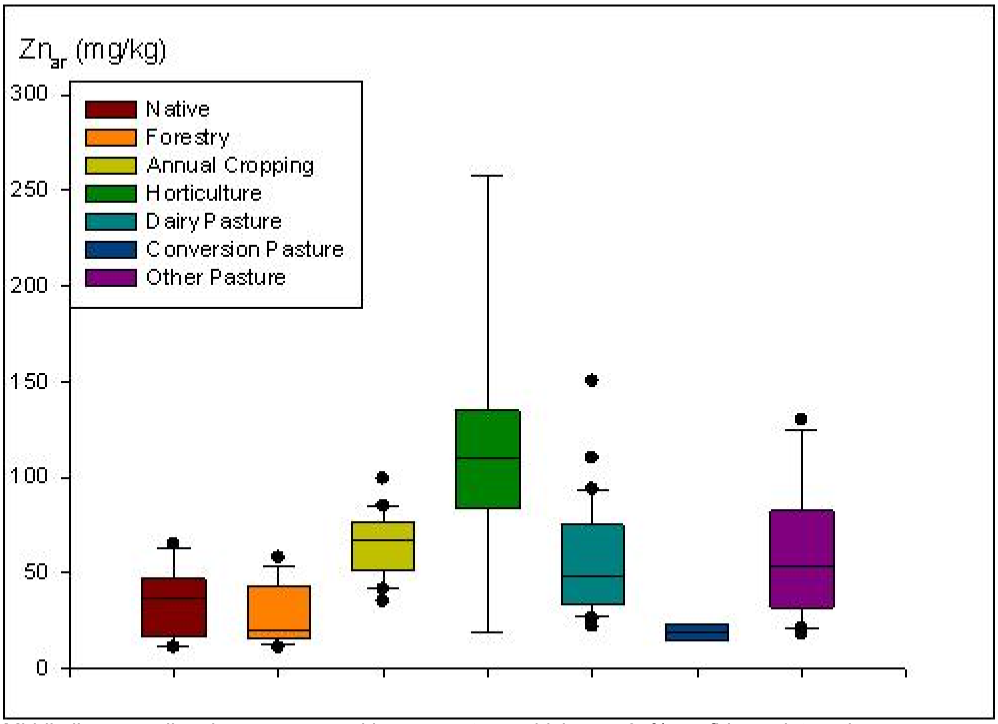


Middle line = median, box = upper and lower quarters, whiskers = 95% confidence interval.

The effect of land use on zinc

Zinc measurements were significantly higher at sites under annual cropping, horticultural, dairy pasture and other pasture land uses than at sites under native, forestry and conversion pasture. Horticultural sites had the highest zinc measurements and also the largest range (Figure 23), consistent with the use of zinc-based fungicides.

Figure 23: The effect of land use on zinc



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

5 Discussion

Key Issues

Five key issues of soil quality were identified from the monitoring. These issues are important as they impact on the soils long-term ability to sustain production and other environmental services. These key issues are discussed in detail below.

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. All farmed land uses measured 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 lower 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, all forestry sites met the lower macroporosity (-10 kPa) target (Table 2). In contrast, only about two thirds of the sites under pasture met the lower target, while between 80-90% of cropping and horticultural sites met the lower target. These results are consistent with excessive trafficking (cropping and horticulture) and stocking pressure (dairy pasture and other pasture) causing compaction, resulting in reduced infiltration and potential increased runoff to waterways. Runoff can carry contaminants and result in increased peak-flows causing localised flooding and bank erosion (McDowell et al 2001, Taylor et al 2009).

Table 2: Percent of soil quality sites meeting the lower macroporosity (-10kPa) targets by land use over 7 years.

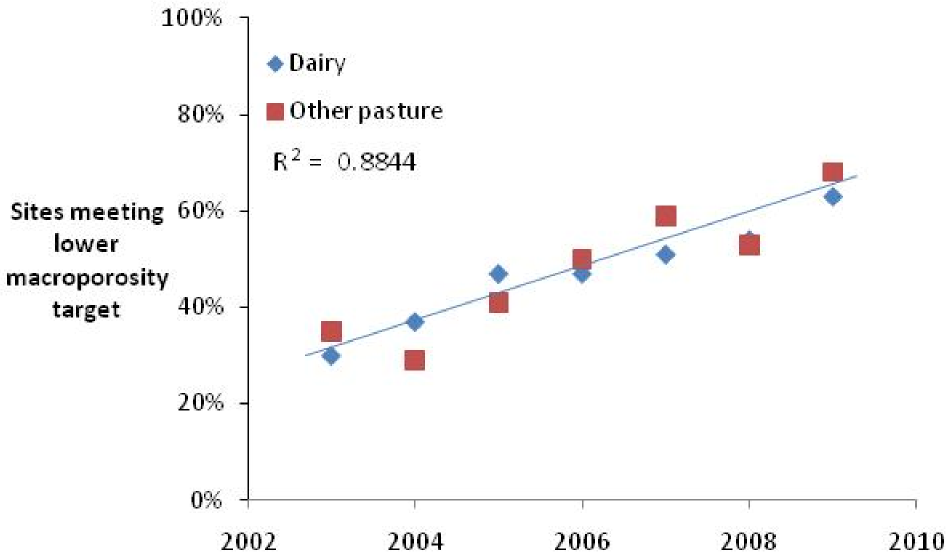
	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	87	81	84	85	89	86	79
Horticulture	78	100	100	100	100	100	100
Forestry	100	100	100	100	100	100	100
Dairy Pasture	63	54	51	47	47	37	30
Conversion pasture	86	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	68	53	59	50	41	29	35

n.s. = No sites sampled

Of note is the higher macroporosity seen for conversion pasture (Figure 12), with 86% of sites meeting the lower target (Table 2). These sites have had stock on them for only a short time and these sites are expected to show more compaction as time goes on.

On the positive, there appeared to be a steady improvement in meeting the macroporosity lower targets by dairy and other pasture (Figure 24), consistent with farmers becoming more aware of compaction and taking measures to prevent its occurrence. Water content at the time of sampling can affect the result, but samples were taken before the drought set in and the trend is very consistent over the 7 years.

Figure 24: Trend in meeting the lower macroporosity (-10kPa) targets by pastoral land uses



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 resistance to degradation (Dick & Gregorich 2004). SOM is essential for the viability and life-sustaining function of the soil.

Total carbon (total C) is the target indicator chosen for SOM assessment. The Waikato region results showed about 90% of cropping sites met the target (Table 3) and this has stayed consistent over the period 2003-2009. Other research indicated that some dairy farms on non-allophanic soils have lost large amounts of soil carbon (Schipper et al 2007), but this is not evident in the monitoring results. A consistent decline in average total C concentration from sites under cropping land use between 2003 and 2009 is evident (Figure 25). Data for the one year of conversion pasture data 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. However, both dairy pasture and other pasture had significantly higher carbon concentrations than those under conversion pasture (Figure 7), 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 9.4% over the last 7 years

Figure 25: Floating 5 year average soil total C (%) concentrations by land uses between 2003 and 2009

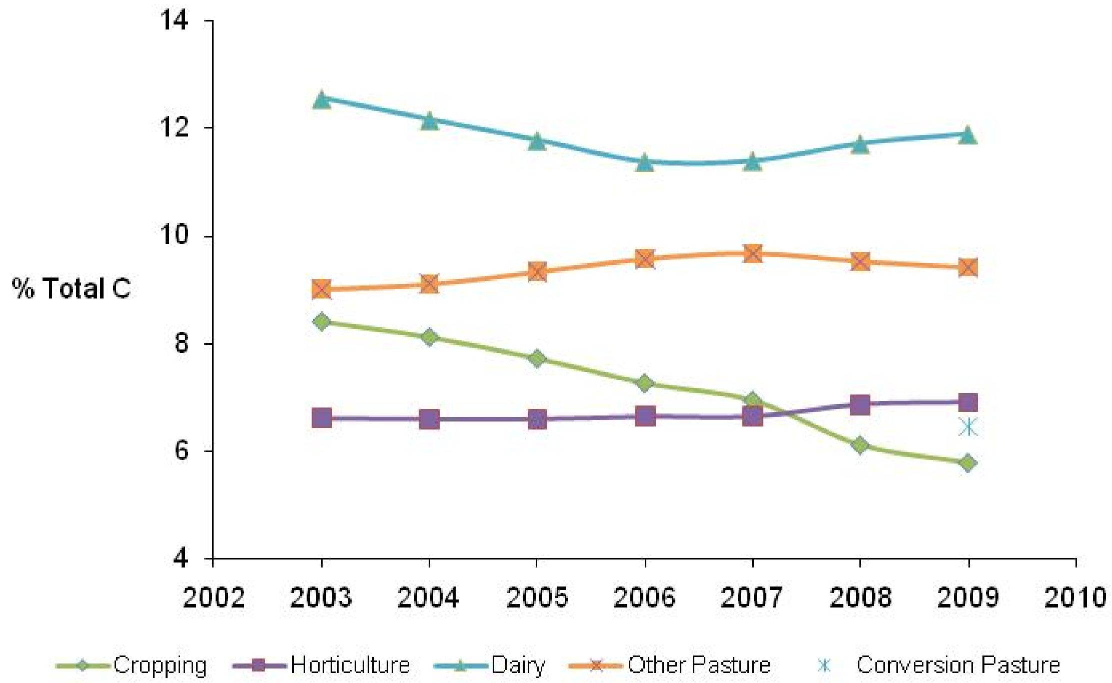


Table 3:Percent of soil quality sites meeting total C targets by land use over 7 years.

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

n.s. = No sites sampled

Excessive or deficient nutrients

Overall, there was little change in Olsen P status over the 7 years 2003-2009. Excessive phosphorus is assessed against the upper Olsen P target of 100, while production limitations due to phosphorus deficiency can be identified by the low Olsen P targets of 5 for forestry, 15 for pasture and 20-25 for horticulture and cropping. Production limitations also can result in increased erosion risk due to reduced vegetative cover to protect the soil. There was an improvement in meeting targets by cropping and the other pasture land uses (Table 4). However, there was a decline in meeting targets by dairy and horticultural land uses.

Table 4: Percent of soil quality sites meeting the upper Olsen P targets by land use over 7 years.

	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	96	96	84	85	85	76	79
Horticulture	89	83	100	100	100	100	100
Forestry	100	100	100	100	100	100	100
Dairy Pasture	79	73	82	80	80	83	83
Conversion pasture	71	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	92	91	93	92	91	88	88

n.s. = No sites sampled

The upper target was exceeded by dairy, drystock, arable and horticultural land uses (Table 4), indicating an opportunity for more efficient fertiliser use. Long-term records of river water quality in the Waikato region show phosphorous concentrations in streams, are increasing at 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).

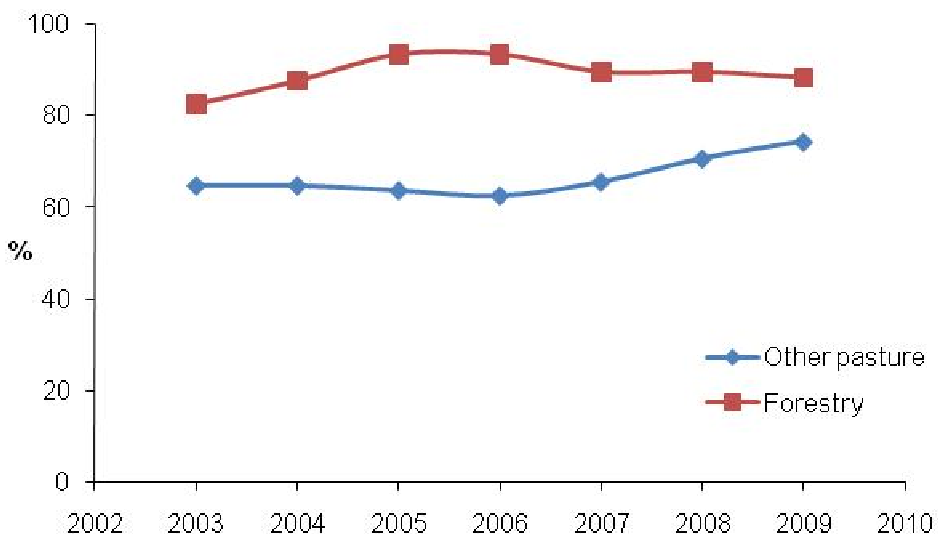
Phosphorus deficiency is measured against the lower Olsen P target. Sites with low Olsen P could have increased yields and increased vegetative cover to protect the soil from erosion, with careful fertiliser management. Several sites had Olsen P below the lower (production) target included 26% of other pasture and 12% of production forestry sites (Table 5). However, other pasture showed a trend of improvement in meeting the targets over the last 4 years (Figure 26), 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 can reflect economic factors more than production ones, e.g. transportation and spreading costs.

Table 5: Percent of soil quality sites meeting the lower Olsen P targets by land use over 7 years.

	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	100	96	100	100	100	100	100
Horticulture	100	100	100	100	100	100	100
Forestry	88	89	89	93	93	87	82
Dairy Pasture	100	100	100	100	100	100	100
Conversion pasture	0	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	74	71	66	62	64	65	65

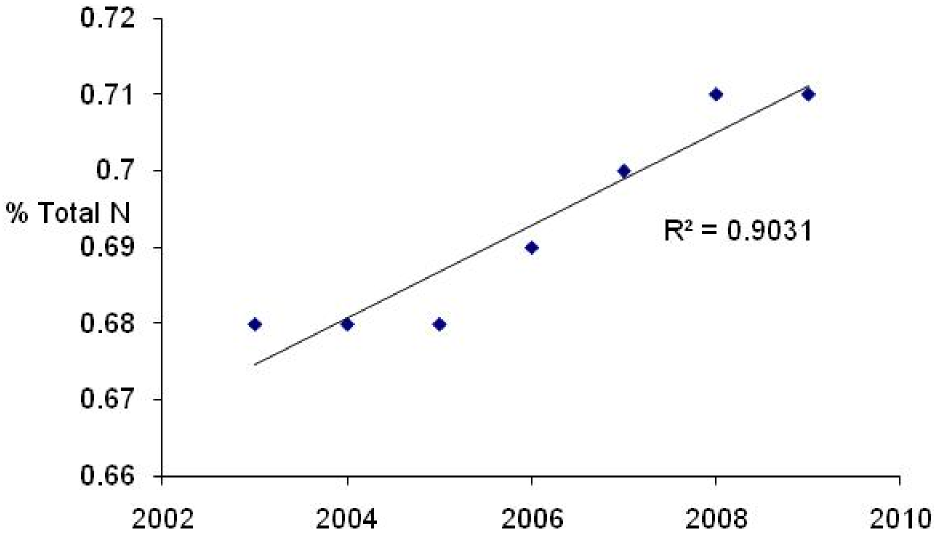
n.s. = No sites sampled

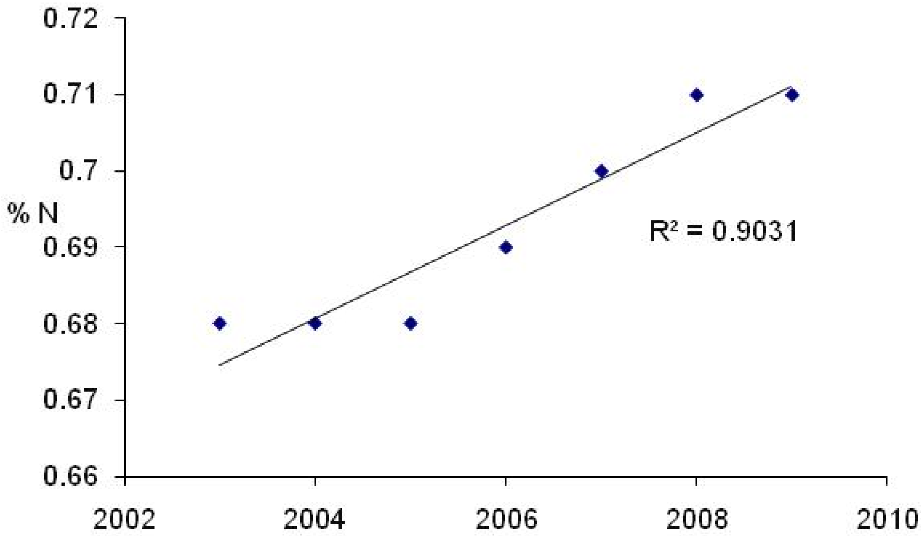
Figure 26: Trend in meeting the lower Olsen P (deficiency) target by forestry and other pasture



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. There is a direct relationship between farming intensity and loss of nitrogen, e.g. losses are 5 to >100 times greater under farmed land uses than forest land (Environment Waikato 2008). Farming in New Zealand generally and in the Waikato Region is intensifying with increased N-fertilisation and stocking rates. The soil quality monitoring results showed, the average total N concentration is trending upwards (Figure 27) and at the same time nitrogen in river systems has increased at nearly 2% of the median value per year (Vant 2008).

Figure 27: Average total N (%N) at soil quality sites





The upper target of 0.7% for total N was exceeded by all land uses. Note that N-fertiliser is not applied to production forestry and the high nitrogen here is reflecting the naturally high soil organic matter or sites previously being pastoral farms (Table 6). Likewise, background sites with naturally high soil organic matter have high nitrogen (Figure 8). Although the total nitrogen content at sites was above the upper target, nitrogen mobilisation was most likely restricted by high C:N ratios (Dise et al 2009).

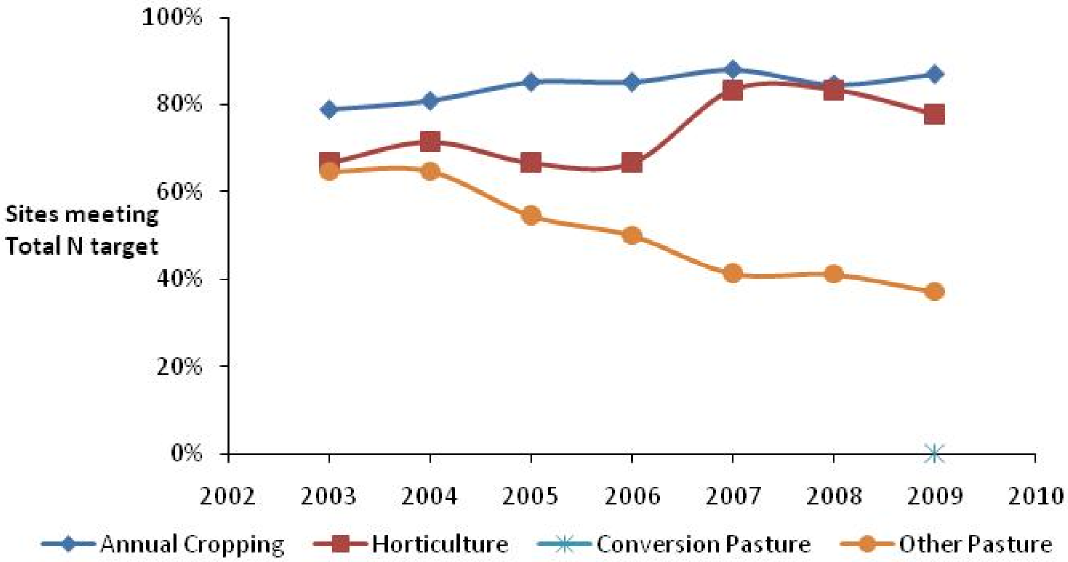
The trend of this indicator is more important than the absolute number of sites meeting this target. Both positive and negative trends were apparent when the number of sites meeting the upper total N target over the period 2003-2009 was assessed. Of concern was the trend showing declining proportion of other pasture meeting the upper total N target (Figure 28), consistent with intensification, including increased N-fertilisation, and likely resulting in increased nitrogen in receiving water bodies. On the positive side, both annual cropping and horticulture show increased meeting the upper total N target. Forestry and dairy pasture have remained fairly static.

Table 6: Percent of soil quality sites meeting the upper total N targets by land use over 7 years.

	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	87	85	88	85	85	81	79
Horticulture	78	83	83	67	67	71	67
Forestry	82	79	84	80	80	81	82
Dairy Pasture	47	46	49	50	50	46	48
Conversion pasture	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	35	41	41	50	55	65	65

n.s. = No sites sampled

Figure 28: Trend in the proportion of other pasture and increase in the proportion of annual cropping and horticulture sites meeting the upper total N target



Until 2009, there were no production limitations due to nitrogen shortage at any of the sites. However, in 2009, 14% of conversion pasture sites were below the total N lower (deficiency) targets, reflecting their low carbon status (Figure 8). Soil carbon is needed to help retain nitrogen.

Anaerobically mineralisable N measures how easily nitrogen in SOM is able to be mineralised (Sparling et al 2003). There was considerable variation in measurements and upper targets were exceeded by all land uses measured at some time during the last 7 years. In 2009, 4% of cropping, 16% of dairy and 11% of other pasture sites exceeded the upper target and may have increased nitrogen leaching risk. In contrast, there were 4% of cropping sites below the lower target (associated with low total C) and these may have sub-optimal production. No trends were evident in anaerobically mineralisable N over the last 7 years.

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 can reflect economic factors more than production ones, e.g. transportation and spreading costs.

Erosion

Many soils within the region are very light and open textured, making them vulnerable to erosion, e.g. Pumice and Allophanic soils. There are three soil quality indicators assessing different aspects of erosion susceptibility; macroporosity (-10 kPa), bulk density and aggregate stability. Macroporosity (-10 kPa) above the upper targets and bulk density below the lower targets implies increased erosion risk. Soil outside these targets is susceptible to erosion, may dry out quickly and roots may find it difficult to obtain purchase and absorb water and nutrients (Sparling et al 2003). Aggregate stability indicates the median size of soil aggregates; the smaller the aggregate size, the greater the risk of erosion.

Macroporosity (-10 kPa) and bulk density results showed a proportion of forestry sites appear to have high erosion risk (Tables 7 and 8). However, it is a commonly accepted practice to leave erosion prone soils in native bush or planted in production forestry to 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, thus reducing erosion risk, while bare ground has higher erosion risk. Environment Waikato (2008) identified increased erosion risk with slope. The proportion of forestry sites meeting targets seems to have recently increased, perhaps linked to the conversion of forest to dairy pasture, which often included compaction by heavy machinery. All horticulture, and most cropping, conversion pasture, dairy pasture and other pasture sites met macroporosity (-10 kPa) and bulk density targets. Sites not meeting these targets may have a higher risk of eroding, especially between crops or at resowing when the land is bare and/or is on sloping ground. No consistent trends in the data were apparent.

Table 7: Percent of soil quality sites meeting the upper macroporosity (-10 kPa) targets by land use over 7 years.

	2009	2008	2007	2006	2005	2004	2003
Annual Cropping	87	81	84	85	85	95	95
Horticulture	100	100	100	100	100	100	100
Forestry	71	53	47	60	60	56	65
Dairy Pasture	100	100	100	100	100	100	100
Conversion pasture	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Other Pasture	97	97	97	96	95	100	100

n.s. = No sites sampled

Table 8: Percent of soil quality sites meeting the lower bulk density targets by land use over 7 years.

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

n.s. = No sites sampled

There is sufficient data to assess aggregate stability results for the last 5 years (2005-2009). Annual cropping, conversion pasture and other pasture had sites that failed to meet targets. These sites had aggregates sized below the minimum for average production (<1.5 mm) and these sites may be at increased risk of eroding. The conversion of pine forest to pasture appears to have had a severe impact on aggregate stability as only 57% of conversion pasture met the aggregate stability target (Table 9). Note that 100% of forestry sites met this target and that forest sites had significantly higher aggregate stability compared to conversion pasture (Figure 13). Annual cropping had a decreasing proportion of sites meeting the aggregate stability target, indicating a continued decline in soil stability.

Table 9: Percent of soil quality sites meeting the aggregate stability target by land use over 5 years.

	2009	2008	2007	2006	2005
Annual Cropping	70	77	76	78	78
Horticulture	100	100	100	100	100
Forestry	100	100	100	100	100
Dairy Pasture	100	100	100	100	100
Conversion pasture	57	n.s.	n.s.	n.s.	n.s.
Other Pasture	97	100	100	100	100

n.s. = No sites sampled

Diffuse Contamination with Trace Elements

Introduction

Soil trace elements were identified as being important to monitor in Kim & Taylor (2009). Elements fall into two groups, elements linked to use of phosphate fertilisers (cadmium, fluoride and uranium), elements linked to the use of agricultural chemicals used in farming (arsenic, chromium, copper, lead, mercury, nickel and zinc).

Data has been collected for a shorter time than for the soil quality indicators and it has only been within the last 3 years that sufficient data has been collected to make an initial assessment. The discussion below should be considered indicative with confirmation coming over the next 2-3 years.

Native sites had low concentrations of all trace metals and were considered natural background.

Elements associated with the use of phosphate fertiliser (cadmium, fluoride and uranium)

Phosphate fertiliser is regularly applied to cropping, horticulture, dairy and other pasture sites, but little or no phosphate fertiliser is applied to forestry (sometimes after the third rotation of trees) and none (intentionally) to native sites. Conversion pasture has only been fertilised for the 2-3 years since conversion from forest. As can be expected, given their history of fertilisation, soils under annual cropping, horticulture, dairy pasture and other pasture have much higher concentrations of cadmium, fluoride and uranium than those under forestry, native and conversion pasture (Figures 15, 18 and 22). Historic accumulation rates of cadmium and fluorine in Waikato soils were estimated to have averaged 6 µg cadmium /kg per year and 2600 µg fluorine/kg per year (Kim et al 2008). A third contaminant of phosphate fertiliser increasing in the region's soils is uranium. There is a lack of information on what constitutes a safe concentration of uranium in the soil, but it is radioactive and chemically more toxic than arsenic. As suitable guidelines have yet to be developed, a watching brief only is kept on uranium.

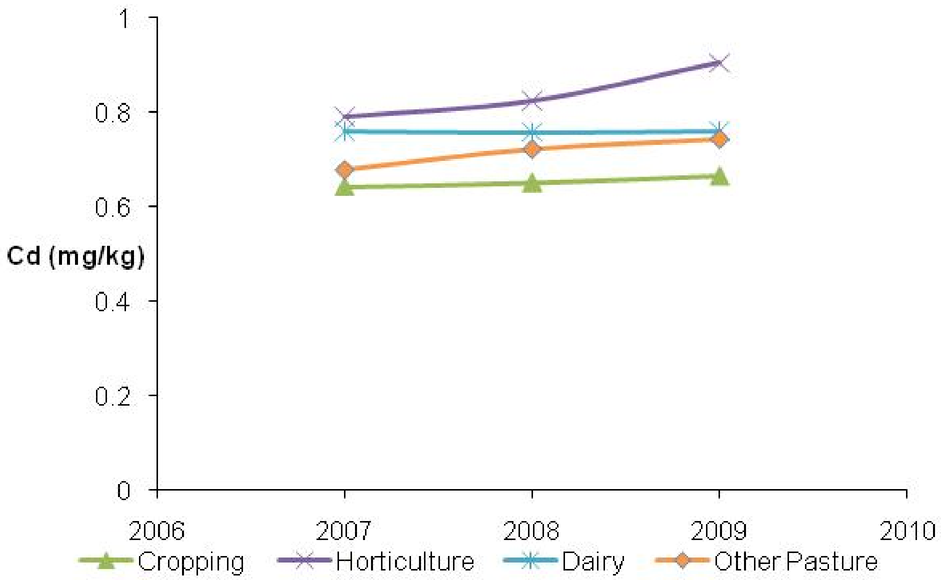
There were sufficient samples to analyse soil cadmium for the last three years 2007-2009). This data showed all cropping, forestry and conversion pasture sites met the cadmium target, which is also the “b” value (1 mg/kg) of the National Cadmium Management Strategy for New Zealand Agriculture (Cadmium Working Group 2011). However, horticulture, dairy and other pasture had a proportion of sites exceeding the target (Table 10) and have significantly higher soil cadmium (Figure 15). Conversion pasture sites have only received a year or two of fertiliser and have cadmium concentrations close to background. Cropping tends to use diammonium phosphate rather than superphosphate fertiliser, which is the predominate fertiliser used by the other land uses. Diammonium phosphate can have less cadmium content than superphosphate but may contain more uranium as discussed below. However, the average soil cadmium concentrations for cropping increased over the 3 years (Figure 29). Other pasture has had a similar increase, while horticulture showed a much larger increase, part of which is explained by the addition of 2 new kiwifruit orchard sites with higher soil cadmium levels. Cadmium is nationally recognised as an emerging issue for human and animal health, trade and ecology (Cadmium Working Group 2009).

Table 10: Percent of soil quality sites meeting the cadmium target by land use over 3 years.

	2009	2008	2007
Annual Cropping	100	100	100
Horticulture	78	83	83
Forestry	100	100	100
Dairy Pasture	81	88	87
Conversion pasture	100	n.s.	n.s.
Other Pasture	71	74	79

n.s. = No sites sampled

Figure 29: 3 year floating average soil cadmium in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture.

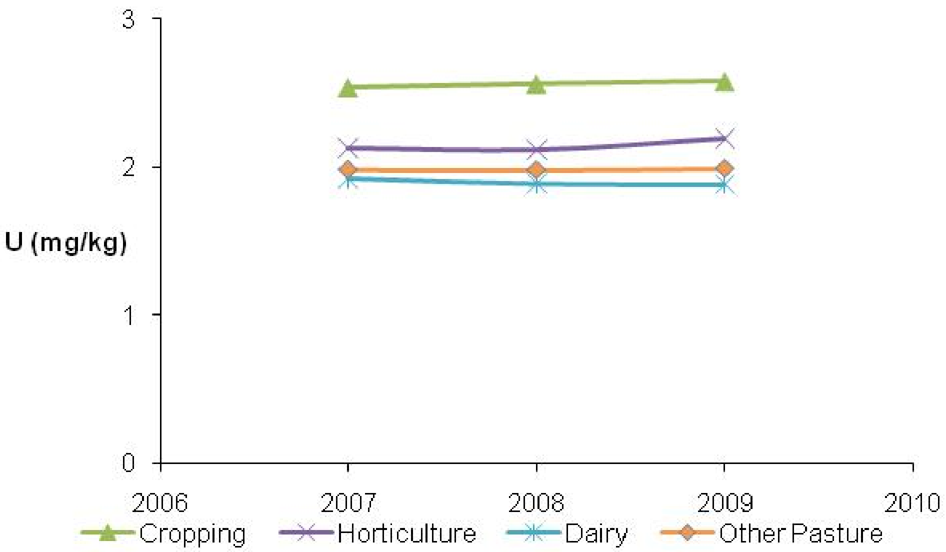


There were sufficient samples to analyse soil fluoride for 2009 only. This data showed all forestry and conversion pasture sites met the fluoride target, while cropping, horticulture, dairy and other pasture had a proportion of sites not meeting the target of 500 mg/kg (Table 11) and have higher soil fluoride concentrations (Figure 18). Conversion pasture sites have only received a year or two of fertiliser but have elevated fluoride concentrations when compared to background ones. Both superphosphate and diammonium phosphate contain appreciable amounts of fluoride (up to 3%). Fluoride is an animal health issue and high concentrations of soil fluoride may restrict land use versatility.

Table 11: Percent of soil quality sites in 2009 meeting the fluoride target by land use.

	2009
Annual Cropping	83
Horticulture	67
Forestry	100
Dairy Pasture	60
Conversion pasture	100
Other Pasture	76

Figure 30: 3 year floating average soil uranium in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture



As there is no accepted target or guideline for uranium, these results are presented as part of a "watching brief". There were sufficient samples to analyse soil uranium for the last 3 years (Figure 30). Not only is uranium radioactive but it is also more chemically toxic than arsenic. The natural background value for uranium in the Waikato region is 0.7 mg/kg. Land under forestry and conversion pasture is very close to this value but cropping, horticulture and pastoral land uses are 2-3 times background (Figure 22). The highest uranium measurements were under annual cropping and this land use tends to use diammonium phosphate fertiliser, whereas dairy and other pasture tends to use superphosphate fertiliser. Fertiliser used in annual cropping may have higher uranium content than that used in other farming practices. Conversion pasture sites have only received a year or two of fertiliser and have uranium concentrations close to background. Annual cropping, horticulture and other pastoral land uses have a tendency for increased uranium over time (Figure 30).

Elements linked to the use of agricultural chemicals and treated timber used in farming (arsenic, copper, lead, mercury, nickel and zinc)

The second group was elements linked to use of agricultural chemicals including animal remedies, veterinary medicines and pesticide use. Similar to the elements linked to the use of phosphate fertiliser, soils under annual cropping, horticulture, dairy pasture and other pasture have much higher concentrations of elements linked to the use of agricultural chemicals and treated timber used in farming, than those under forestry, native and conversion pasture (Figures 14, 16, 17, 19, 20, 21 and 23). Some of these elements, such as copper and zinc, are essential for growth but too much of them are toxic to life. Historic use of the insecticide lead arsenate accounts for much of the arsenic and lead enrichment observed on older horticultural soils. Historic and current use of CCA-treated timber in farming structures may also contribute copper, chromium and arsenic to the soil. Simple copper and zinc compounds remain in widespread use as fungicides and maybe used as a livestock supplement. Widespread use of facial eczema remedies at annual zinc loadings of 5-7 kg/ha/y appears to have caused a significant increase in average zinc in Waikato soils from 28 mg/kg for background soil to 62 mg/kg for farmed soils (Taylor et al 2010). Assuming this accumulation has occurred over the last 25 years gives an estimated annual average accumulation rate of 1.36 mg Zn/kg/y. Mercury, possibly in conjunction with chromium as mercuric chromate, has been used as seed coatings that act as fungicides and biocides.

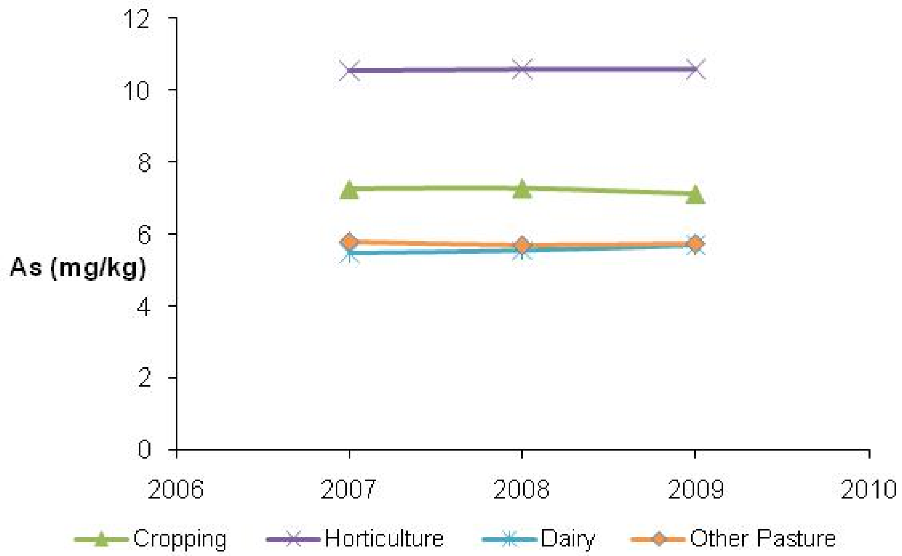
There were sufficient samples to analyse soil arsenic for the last three years. This data showed nearly all sites met the arsenic target of 20 mg/kg except for a few dairy sites (Table 12). The reasons for these dairy sites exceeding targets were not clear but geothermal activity could cause high arsenic concentrations. No horticulture or arable sites exceeded targets despite known extensive historic use of arsenic-containing insecticides, such as lead arsenate (Gaw et al 2006), although concentrations of arsenic were significantly higher in horticultural and annual cropping soils than at sites under other land uses (Figure 14). In comparison, there have been several instances within the Waikato region where developers have sort consent for conversion of orchards to residential land use, but soil arsenic concentrations exceeded both the recommended ceiling limit in agricultural soils (20 mg/kg) and the contaminated land investigation threshold (30 mg/kg) for arsenic under the new land use as a residential dwelling. No clear trends were apparent over the 3 years (Figure 31). Further monitoring will identify if there is a trend or the situation is constant.

Table 12 : Percent of soil quality sites in 2009 meeting the arsenic target by land use.

	2009	2008	2007
Annual Cropping	100	100	100
Horticulture	100	100	100
Forestry	100	100	100
Dairy Pasture	95	98	100
Conversion pasture	100	n.s.	n.s.
Other Pasture	100	100	100

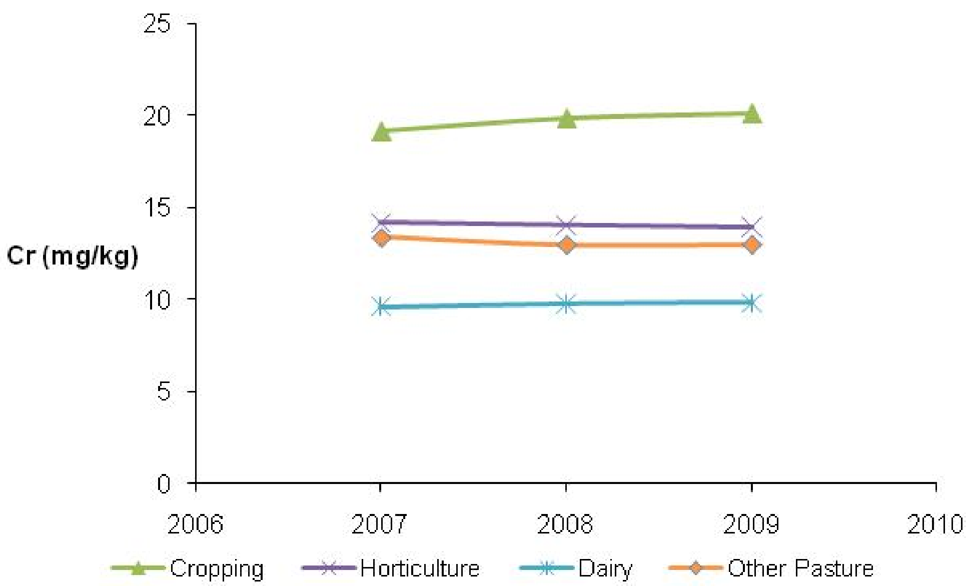
n.s. = No sites sampled

Figure 31: 3 year floating average soil arsenic in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture



There were sufficient samples to analyse soil chromium for the last three years. This data showed all sites met and was well below the chromium target of 600 mg/kg. However, chromium was significantly higher at sites under annual cropping compared to those under other land uses (Figure 16) and seems to be increasing (Figure 32). Further monitoring over the next 2 years is needed to ascertain if this is a trend or not.

Figure 32: 3 year floating average soil chromium in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture



There were sufficient samples to analyse soil copper for the last three years. This data showed nearly all sites met the lower copper target of 5 mg/kg (i.e. there was enough copper for growth), except for about 5% of forestry sites (Table 13). The remoteness and difficulty in supplying copper fertiliser in the correct strength to these sites inhibits any foreseeable change. Animals have a higher requirement for copper than pine trees and copper fertilisation or supplementation would be needed if these sites were converted to pasture.

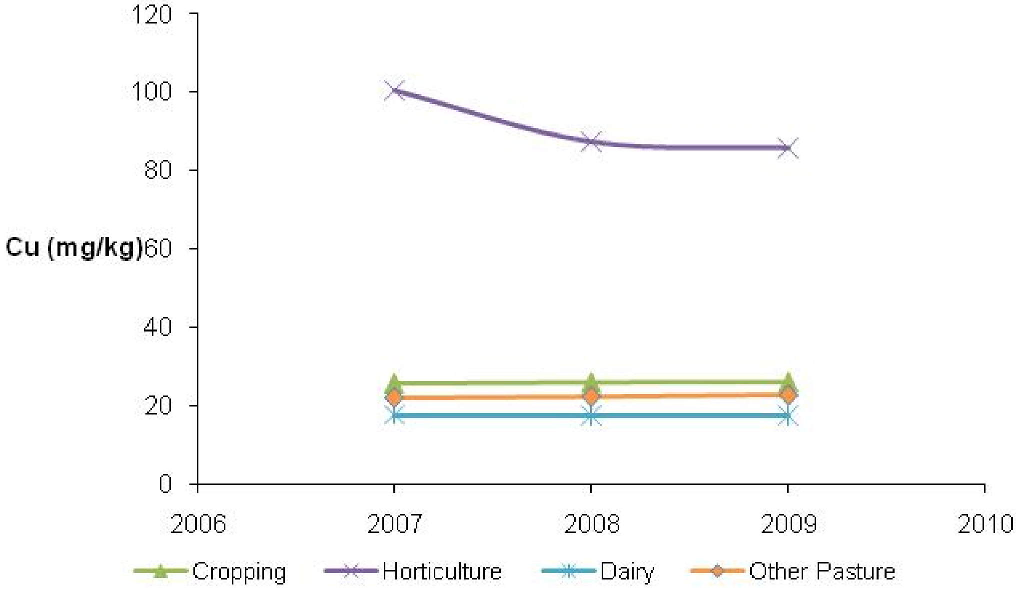
Annual cropping, horticulture, forestry, dairy pasture and other pasture had sites that did not meet the upper copper target of 45 mg/kg (Table 12). This result for farming type land uses is not unexpected given the wide spread use of copper agricultural-chemicals and CCA-treated wood, but the 5% of forestry sites not meeting the upper copper target was surprising. Resampling in 2009 showed this was an aberration. Horticulture had far higher levels of copper than other land uses (Figure 17) likely due to the use of copper fungicides. The apparent decline in average soil copper for horticulture in 2008 (Figure 33) was due to the inclusion of 2 organic kiwifruit orchards into the dataset. The addition of these two sites also increased the percentage of site meeting the copper target. No clear trends for copper have yet emerged but copper remains a potential issue for human and animal health, and ecology.

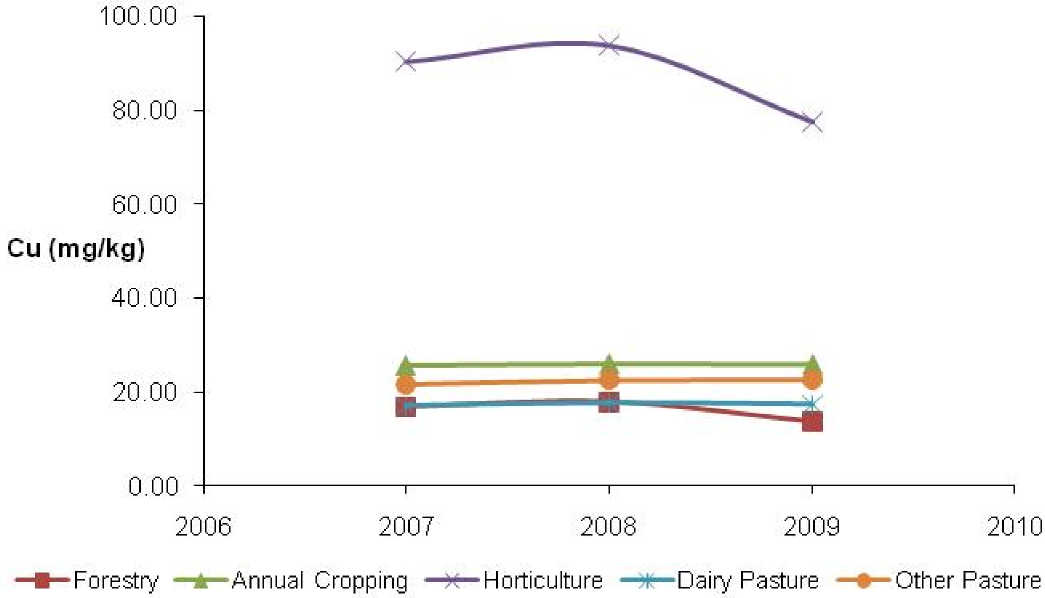
Table 13: Percent of soil quality sites meeting the upper copper target by land use over 3 years.

	2009	2008	2007
Annual Cropping	87	92	92
Horticulture	44	17	17
Forestry	100	95	95
Dairy Pasture	100	98	97
Conversion pasture	100	n.s.	n.s.
Other Pasture	94	97	97

n.s. = No sites sampled

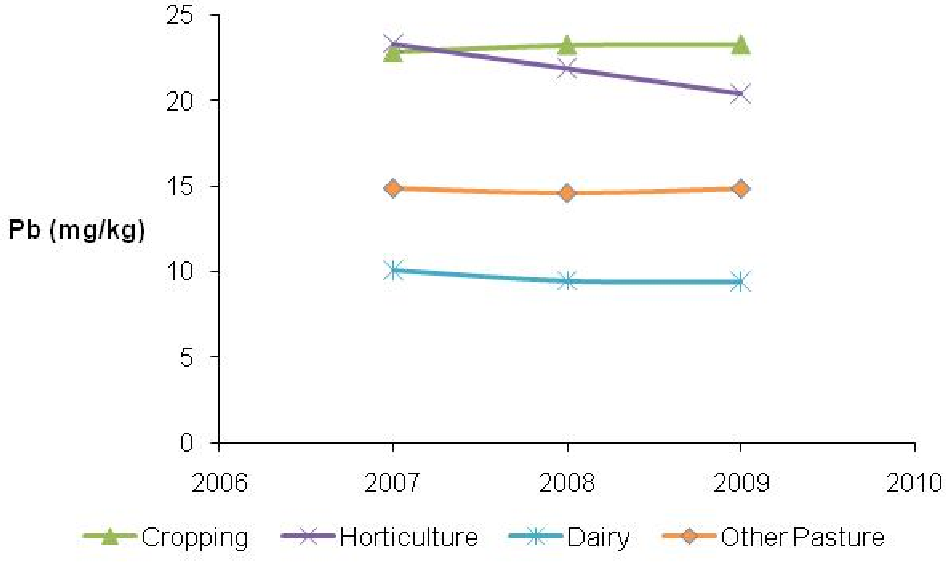
Figure 33: 3 year floating average soil copper in Waikato soils between 2007-2009 under forestry, cropping, horticulture, dairy and other pasture.





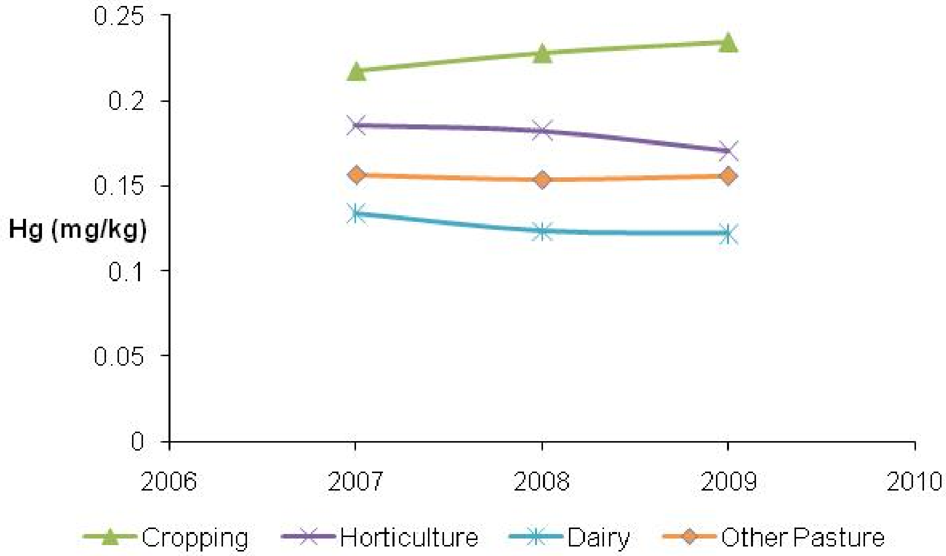
There were sufficient samples to analyse soil lead for the last three years. This data showed all sites met the lead target of 60 mg/kg, but lead was significantly higher at sites under annual cropping compared to native, conversion pasture, dairy pasture and other pasture (Figure 19). However, soil concentrations were fairly stable or reducing (Figure 34). No horticultural or annual cropping sites exceeded targets despite known extensive historic use of lead-containing insecticides, such as lead arsenate (Gaw et al 2006). The removal of lead in petrol and banning the use of lead-containing pesticides has removed the main sources of diffuse lead contamination.

Figure 34: 3 year floating average soil lead in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture.



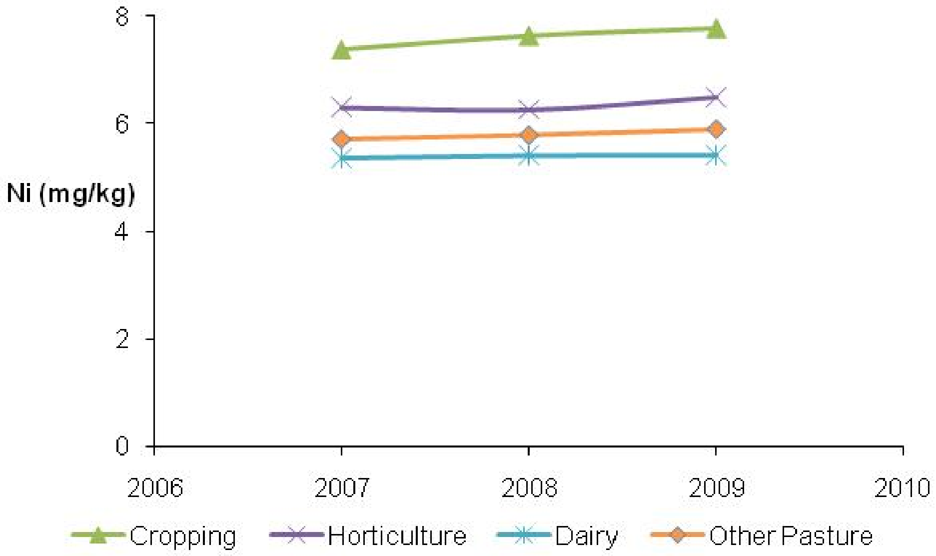
There were sufficient samples to analyse soil mercury for the last three years. This data showed mercury levels are low and all sites met the mercury target of 1 mg/kg. However, concentrations were higher at sites under annual cropping than those under other land uses (Figure 20) and could be increasing (Figure 35). Trends will become clearer with continued monitoring. Mercury is a potential issue for human and animal health, and ecology.

Figure 35: 3 year floating average soil mercury in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture.



There were sufficient samples to analyse soil nickel for the last three years. This data showed all sites met the nickel target of 50 mg/kg. However, concentrations were significantly higher at sites under annual cropping than those under other land uses (Figure 21) and could be increasing (Figure 36). Horticulture may also show a similar trend. Trends will become clearer with continued monitoring. Nickel is a potential issue for human and animal health, and ecology.

Figure 36: 3 year floating average soil nickel in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture.



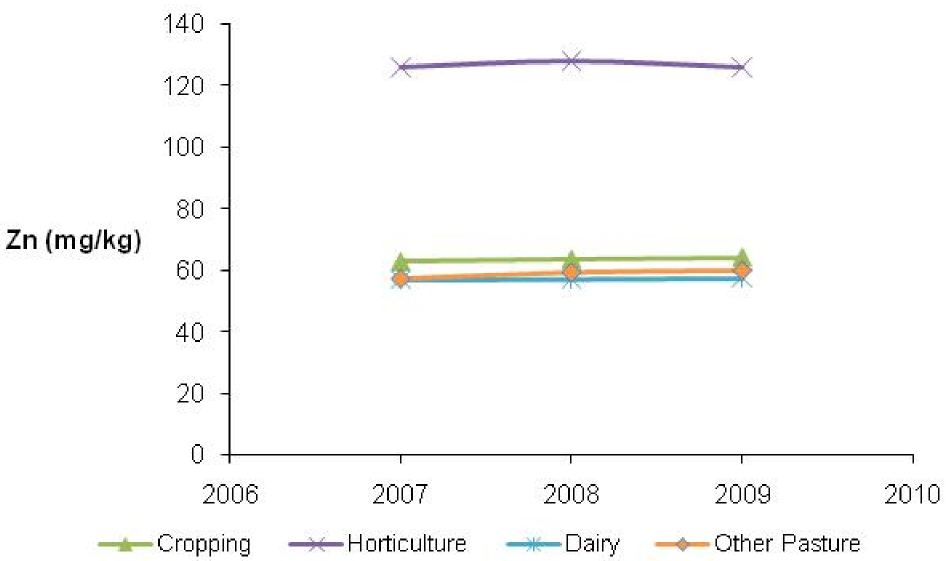
There were sufficient samples to analyse soil zinc for the last three years. This data showed all sites had sufficient zinc for growth and met the lower zinc target of 10 mg/kg. Annual cropping, forestry, conversion pasture, dairy and other pasture sites met the upper zinc target of 200 mg/kg, while horticulture, had a proportion of sites failing to meet the target (Table 14). Horticulture had higher soil zinc levels than other land uses (Figure 23) due to the use of zinc containing fungicides. No clear trends are yet apparent (Figure 37). Trends will become clearer with continued monitoring. Zinc is a potential issue for human and animal health, and ecology.

Table 14: Percent of soil quality sites meeting the upper zinc target by land use over 3 years.

	2009	2008	2007
Annual Cropping	100	100	100
Horticulture	89	83	83
Forestry	100	100	100
Dairy Pasture	100	100	100
Conversion pasture	100	n.s.	n.s.
Other Pasture	100	100	100

n.s. = No sites sampled

Figure 37: 3 year floating average soil zinc in Waikato soils between 2007-2009 under cropping, horticulture, dairy and other pasture.



6 Conclusions

Soil quality monitoring in 2009 showed 26% of sites meet targets, 34% of sites failed to meet 1 target and 40% of sites failed to meet 2 or more targets, both on site and area basis.

Dairy pasture and other pasture had the lowest proportion meeting all targets, while dairy pasture had the highest proportion failing to meet 2 or more targets.

Overall, soil quality results in the region are similar to those from previous years. Sites meeting all existing indicator targets have remained static since 2005. While the proportion of sites not meeting 1 indicator has decreased, the proportion of sites not meeting 2 or more indicator targets is static or increasing slightly.

Five key issues of soil health were identified:

1. Surface compaction
   There appeared to be a steady improvement in meeting the macroporosity lower targets with dairy pasture and other pasture farmers, as a whole, becoming more aware of compaction and taking measures to prevent its occurrence.

2. Loss of organic matter
   Loss of soil organic matter continues with a decline in average total C concentration from 9.9% to 9.4% over the last 7 years. Much of this decline was from sites under annual cropping land use and only about 90% of cropping sites now meet the target. Although all conversion pasture sites met targets, several indicators point to loss of soil organic matter during the conversion process.

3. Excessive or deficient nutrients
   Excess nutrients, such as nitrogen continue to trend upwards, 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 and increased nitrogen in receiving water bodies is likely.

   The overall phosphorus status remained stable. Although there was little change in meeting Olsen P over the 7 years, the upper Olsen P target was exceeded by dairy pasture, other pasture, annual cropping and horticulture land uses, indicating an opportunity for more efficient fertiliser use.

   Until 2009, there were no production limitations due to nitrogen shortage at any of the sites. However, in 2009, 14% of conversion pasture sites were below the total N lower (deficiency) targets, reflecting their low carbon status.

   Phosphorus also had production limitations included 26% of other pasture and 12% of production forestry sites with Olsen P below the lower (production) target. 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 can reflect economic factors more than production ones, e.g. transportation and spreading costs.

4. Erosion
   Macroporosity (-10 kPa) and bulk density results showed a proportion of forestry sites appear to have high erosion risk (Tables 7 and 8). However, it is a commonly accepted practice to leave erosion prone soils in native bush or planted in production forestry to manage erosion. In addition, some annual cropping and a few horticulture and pasture sites have a higher risk of eroding, especially between crops or at resowing when the land is bare and/or is sloping. The conversion of pine forest to pasture appears to have had a severe impact on aggregate stability, which increases erosion risk.

1. Accumulation of contaminants

1.1. Native sites had low concentrations of all trace metals and were considered natural background.

1.2. Elements linked to use of phosphate fertilisers

All cropping, forestry and conversion pasture sites met the cadmium target, while horticulture, dairy and other pasture had a proportion of sites exceeding the cadmium target, and this proportion was increasing (i.e. cadmium was accumulating). Similarly, all forestry and conversion pasture sites met the fluoride target, while annual cropping, horticulture, dairy pasture and other pasture had a proportion of sites exceeding the fluoride target. No trends were reported as there were sufficient samples to analyse soil fluoride for 2009 only. A watching brief is kept on uranium, the third contaminant associated with phosphate fertiliser. Like cadmium and fluoride, enhanced values for uranium were seen annual cropping, horticulture, dairy pasture and other pasture.

1.3. Elements linked to the use of agricultural chemicals

Nearly all sites met the arsenic target except for a few dairy sites. The reasons for these dairy sites exceeding targets were not clear but geothermal activity could cause high arsenic concentrations. All sites met the chromium, mercury and nickel targets, but significantly higher concentrations were seen in cropping soils and they seemed to be increasing. All sites met the lead target, but lead was significantly higher at sites under annual cropping compared to native, conversion pasture, dairy pasture and other pasture. However, soil concentrations were fairly stable or reducing. The removal of lead in petrol and banning the use of lead-containing pesticides has removed the main sources of diffuse lead contamination. Land use classes other than native had sites exceeding the upper copper target consistent with the application of copper-based agrichemicals. No clear trends in average soil copper are apparent. Horticulture had higher soil zinc levels than other land uses (Figure 23) due to the use of zinc containing fungicides. Further monitoring is required to confirm trends.

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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	High	

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	High	Excessive	

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	**100**	200
Pasture on Pumice and Organic soils	0	**15**	35	60	**100**	200
Cropping and horticulture on Sedimentary and Allophanic soils	0	**20**	50	100	**100**	200
Cropping and horticulture on Pumice and Organic soils	0	**25**	60	100	**100**	200
Forestry on all soil orders	0	**5**	10	100	**100**	200
	Very Low	Low	Adequate	Ample	High	

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	

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: Target ranges for trace elements

Element	Target range (mg/kg)
Arsenic	<20
Cadmium	<1.0
Chromium	<600
Copper	5-30
Fluoride	<500
Lead	<300
Mercury	<1
Nickel	<60
Uranium	no accepted target
Zinc	10-90