Trace Element Concentrations in Some Marlborough Soils

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Report Prepared by:
Colin Gray
Environmental Science & Monitoring Group

Marlborough District Council
Seymour Square
PO Box 443
Blenheim 7240
Phone: 520 7400
Website: www.marlborough.govt.nz

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Executive summary

Trace elements can accumulate in soils from a range of different sources. At elevated concentrations these have the potential to have an adverse effect on soil and plant fertility, animal health and in some cases accumulate in the human food chain. It is therefore important that we have information on the concentrations of key trace elements in soils.

Soils were sampled from 126 sites across Marlborough that represented different soil types and land use activities in the region. At each site composite soil samples were taken and analysed for Olsen P and total recoverable arsenic, cadmium, copper, nickel, chromium, lead, zinc and, at selected sites, total fluorine.

Trace element concentrations in Marlborough agricultural soils (with the exception of cadmium) were generally low and were similar to concentrations found in other parts of New Zealand. Furthermore, concentrations were also similar to typical background concentrations found in New Zealand soils.

With the exception of cadmium, there did not appear to be any difference in trace element concentrations between land use activities. For cadmium it was found that there were higher concentrations on dairy sites; possibly related to higher inputs of phosphate fertiliser which has been shown to contain cadmium as an incidental impurity.

More intensive investigation of dairy farm sites revealed that soils at these sites had accumulated both cadmium and fluorine. While soil cadmium concentrations were above background, in the majority of cases in the medium term concentrations are unlikely to accumulate to concentrations that will exceed proposed guideline values. For fluorine, based on the results of this study, at normal soil ingestion rates, soil fluorine concentrations are unlikely to result in fluorine toxicity to grazing animals.

It is recommended that at the sites where cadmium exceeded the 0.6 mg kg^{-1} trigger value, that monitoring for soil cadmium take place every 5 years and farmers be provided with a range of options as a means of reducing and managing cadmium accumulation in soils as outlined in the tiered fertiliser management strategy developed by the cadmium working group.

Contents

1. Introduction

Regional councils (and Unitary Councils) have a responsibility for promoting the sustainable management of the natural and physical resources of their region. One of the physical resources that we have a duty under the Resource Management Act (1991) to monitor and report on is soil. Specifically the "life supporting capacity of soil" and determine whether current practices will meet the "foreseeable needs of future generations". To this end the current Marlborough Regional Policy Statement has as one of its objectives; '*Soil productivity and avoidance of erosion and soil degradation*.'

One form of potential soil degradation which is attracting increasing amounts of interest in New Zealand is soil contamination from the accumulation of inorganic chemicals such as trace elements. Trace elements can accumulate in soils either naturally through weathering of minerals contained in soil parent material or from anthropogenic sources. Anthropogenic sources include the land application of biosolids (i.e. copper, zinc, cadmium, nickel, lead, chromium), livestock manure (i.e. arsenic, zinc), agrochemicals (i.e. copper, zinc, lead, arsenic), irrigation water (i.e. iron, manganese), fertilisers (cadmium, fluorine, uranium) and atmospheric deposition (i.e. copper, zinc, cadmium, nickel, lead, chromium). While many trace elements are essential for healthy plant and animal growth, i.e. copper, zinc and nickel, at high concentrations in soils these can have a negative impact on soil fertility and plant and animal health. Furthermore, some trace elements, i.e. cadmium, lead and arsenic are not required in soils and their accumulation can also have a negative impact on soil, plant and animal health, and in some cases there is potential for them to accumulate in the human food chain.

Some examples in the Marlborough region where there has been an accumulation of trace elements in soils from anthropogenic activities include the accumulation of arsenic and sometimes copper in soils at former sheep dip sites, the accumulation of lead, copper and arsenic in soils from pesticide application in orchards, lead accumulation in soils from lead painted dwellings, accumulation of copper, lead, arsenic, chromium, mercury and tin in boatyard sediments and localised copper, chromium and arsenic accumulation derived from treated pine posts in some vineyard soils.

One trace element that has been subject to a large amount of interest in New Zealand over the last couple of years is cadmium. Cadmium is an incidental impurity in rock phosphate used in the manufacture of phosphate fertiliser. As a result of the long-term application of phosphate fertiliser, there is the potential for accumulation of cadmium in agricultural soils over time, especially at sites where there are relatively large inputs of phosphate fertilisers. The accumulation of cadmium in soils is important because it is a biotoxic heavy metal that can enter the food chain, either by being taken up from the soil by crops or grazing animals eating pasture. Cadmium in agricultural products may become an issue if concentrations accumulate in excess of maximum levels set by the Australian and New Zealand Food Safety Authority (ANZFA, 1997), which is currently at 0.1 mg kg^{-1} fresh weight. Further, accumulation of cadmium in agricultural products may also affect international trade of these products with non-tariff barriers increasingly being used by our trading partners to limit our exports.

In response to concerns about the likely continued accumulation of cadmium in some New Zealand soils, the Chief Executive Environmental Forum established the Cadmium Working Group (CWG). The CWG, comprising central and regional government and agricultural representatives were tasked with identifying and highlighting the risks to New Zealand of elevated cadmium concentrations in soil. The group has recently published a second report outlining a strategy for the long term risk management of cadmium in soils. A central part of the strategy is a tiered fertiliser management strategy under which specific management actions will be linked to trigger values for cadmium concentrations in soil.

The aims of this report are:

1. Summarise soil trace element data that has been collected annually as part of Council's State of the Environment soil quality monitoring programme since 2007.

2. Report on trace element concentrations in soils, in particular cadmium data, which has been collected from a range of dairy farm sites in Marlborough.

3. Compare the results of the cadmium data with the proposed trigger values as suggested by the CWG. The reason for using dairy farm sites is that they have been identified nationally as a land use activity where cadmium has accumulated in soil as a result of comparatively high phosphate fertiliser usage (MAF, 2008).

2. Materials and Methods

2.1. Soil Sampling

Soils used in this study were sampled as part of two different programmes. Seventy-five soils were sampled as part of the Council's State of the Environment soil quality monitoring programme. Samples collected (0 – 100 mm soil depth) were composites comprising 25 individual cores taken at 2 m intervals along a 50 m transect. Topsoils were sampled from six different land use activities including vineyards (17), cropping (18), pasture (20), dairy (10), native bush (3) and exotic forest (7) representing four different soil orders, i.e. Brown, Pallic, Gley and Recent soils (Hewitt, 1998).

The second group of soils were sampled from 51 dairy farm sites representing three soil orders i.e. Pallic, Recent and Brown soils. Soils were composite samples comprising 15 - 20 individual soil cores taken randomly across a paddock at each site. Samples were taken from 0 – 75 mm soil depth.

2.2. Soil Chemical Analysis

Soils were air dried and sieved to < 2 mm before chemical analysis. All samples were analysed for soil Olsen P (extractable phosphorous) by extracting soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen, 1954) and measuring the phosphate concentration by the molybdenum blue method. Total recoverable copper, chromium, cadmium, arsenic, lead, nickel and zinc in soils were determined by digesting soils in nitric/hydrochloric acid and analysing trace elements in the digest by inductively coupled plasma mass spectrometry (US EPA 200.2). Soils from 14 dairy sites were also sampled from the 0 – 35 mm soil depth analysed for total recoverable fluoride. Total fluoride was measured by alkaline fusion of samples with fluoride measured by an ion selective electrode.

2.3. Statistical Analysis

Median, minimum, maximum and 25th and 75th percentiles were calculated for individual trace elements using STATISTICA. Where appropriate, summary data was presented as Box and Whisker plots. Figure 1 gives as example of a Box and Whisker plot. The length of each box shows the range within which the central 50% of the values fall, the centre square is the median value, with the box hinges (borders) at the 25th and 75th percentiles. The whiskers show the range of values that fall within the inner fences (but do not necessarily extend all the way to the inner fences). Values between the inner and outer fences are plotted with crosses. Values outside the outer fence are plotted with empty circles.

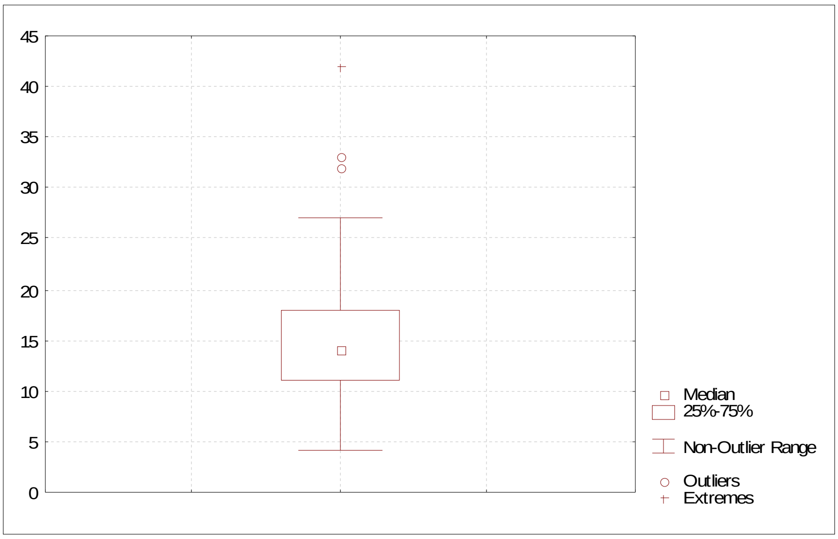

Figure 1 Example of a Box and Whisker plot

3. Results and Discussion

3.1. Soil Quality Monitoring Sites

3.1.1. Arsenic

Soil arsenic concentrations ranged from 2.0 – 7.3 mg kg^{-1} with a median concentration across all sites of 4.0 mg kg^{-1} Figure 2. Soil arsenic concentrations found in this study are similar to concentrations found in other New Zealand studies. For example, Longhurst et al. (2004) found median arsenic concentrations ranging from 2.3 to 9.5 mg kg^{-1} for Pallic and Peat Soils respectively sampled from 312 farmed pastoral sites, while a mean background concentration of 4.5 mg kg^{-1} (range 0.02 – 24 mg kg^{-1}) was found at 99 sites in a study in the Auckland region (Auckland Regional Council, 1999). In Wellington, the Regional Council found a mean soil arsenic concentration of 5.2 mg kg^{-1} across 23 dairy farm sites (Sorensen, 2009). Soil arsenic concentrations in some farmed Waikato soils ranged between 0.7 – 94 mg kg^{-1} with a mean concentration of 8.6 mg kg^{-1} (Taylor et al., 2010). Arsenic concentrations ranged between 0.9 – 36.9 mg kg^{-1} in a study of background trace element concentrations in soils from non-urban sites in the Canterbury region (Canterbury Regional Council, 2006).

Despite different land use activities, there was little difference in soil arsenic concentrations between sites (Table 1). This is similar to what was found in other regions (Greater Wellington Regional Council, 2005).

Table 1 Median trace element concentrations (mg kg^{-1}) under different land use activities

	Arsenic (mg kg^{-1})	Cadmium (mg kg^{-1})	Chromium (mg kg^{-1})	Copper (mg kg^{-1})	Nickel (mg kg^{-1})	Lead (mg kg^{-1})	Zinc (mg kg^{-1})
Cropping	4.0	0.17	22	13	17	12	76
Dairy	5.1	0.42	27	20	13	15	81
Drystock Pasture	3.4	0.10	16	12	12	11	68
Exotic Forest	4.6	0.10	14	14	11	11	50
Native Bush	5.0	0.10	22	16	12	16	76
Vineyard	4.0	0.10	20	17	15	12	75

3.1.2. Cadmium

Soil cadmium concentrations ranged from 0.10 to 1.02 mg kg^{-1} (Figure 2) with a median concentration of 0.12 mg kg^{-1}. Soil cadmium concentrations found in this study are in line with what has been found in other parts of New Zealand. For example Roberts and Longhurst (1994) found soil cadmium concentrations ranged between 0.02 – 0.77 mg kg^{-1} with a mean concentration of 0.2 mg kg^{-1} for 86 native (non-agricultural soils) soils sampled at sites across New Zealand. A mean background concentration of 0.18 mg kg^{-1} (range 0.05 – 0.77 mg kg^{-1}) for the 0 – 15 cm soil depth was found at 99 sites in the Auckland region (Auckland Regional Council, 1999). Cadmium concentrations ranged between 0.01 – 0.34 mg kg^{-1} in a study of background trace element concentrations in soils from non-urban sites in the Canterbury region (Canterbury Regional Council, 2006). In comparison soil cadmium concentrations were higher in some farmed Waikato soils ranging between 0.10 – 2.0 mg kg^{-1} with a mean concentration of 0.71 mg kg^{-1} (Taylor et al., 2010).

Overall cadmium concentrations were significantly ($P < 0.05$) higher in soils sampled from the dairy sites compared to the other land use activities, with a median concentration of 0.42 mg kg^{-1} (Table 1). A very similar result was found for soils collected as part of the soil quality monitoring programme in the Wellington region where cadmium concentrations on the dairy sites had a mean concentration of about 0.4 mg kg^{-1} which was approximately double the concentrations found for the other land uses monitored (Greater Wellington Regional Council, 2005).

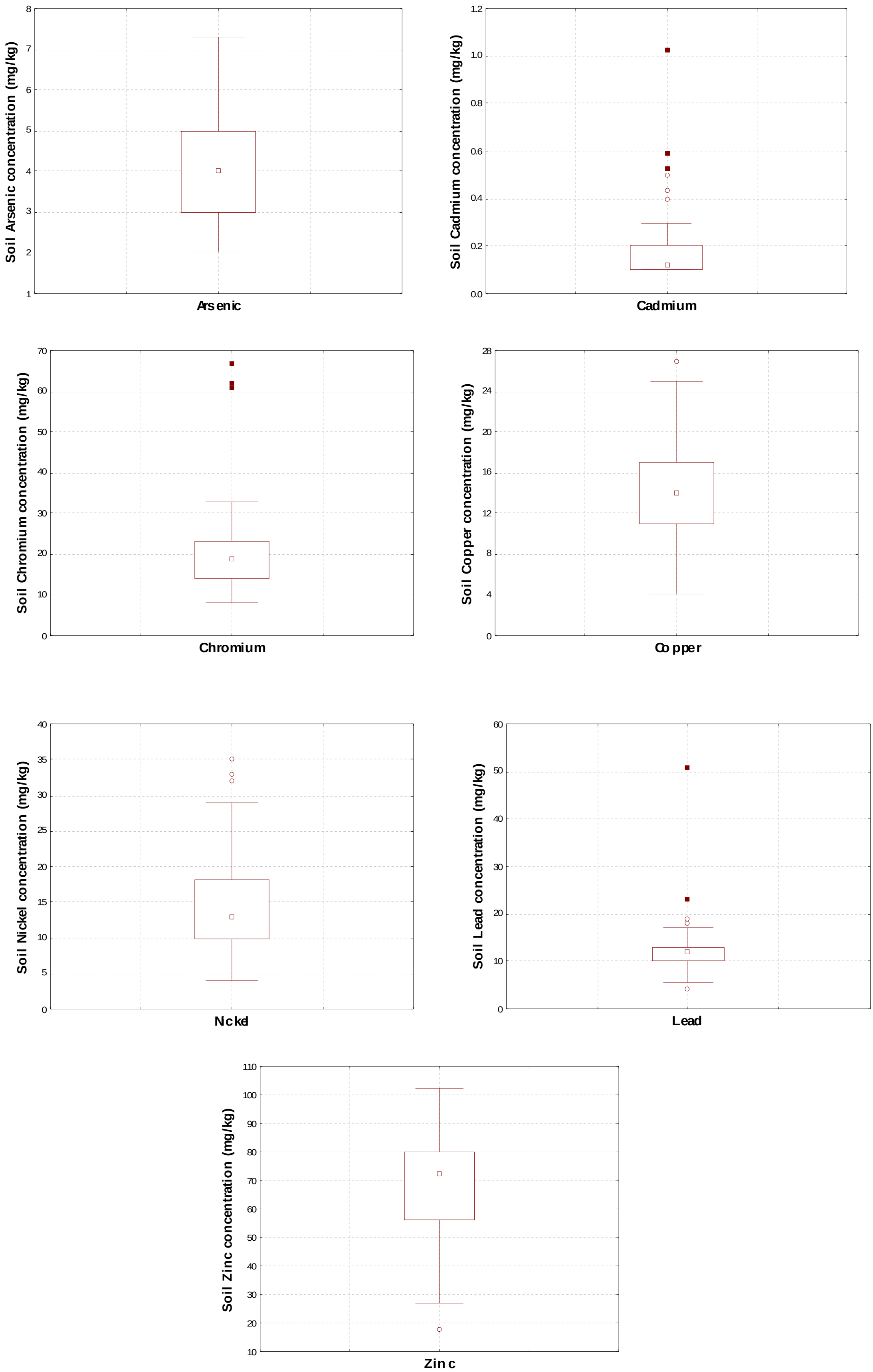

Figure 2 Trace element concentrations (mg kg^{-1}) at the soil quality monitoring sites

3.1.3. Copper

Soil copper concentrations ranged from 4.2 to 27 mg kg^{-1} (Figure 2) with a median concentration of 14.0 mg kg^{-1}. The copper concentrations are very similar to those found for 312 farmed New Zealand pastoral sites with median concentrations ranging from 8.7 to 32.3 mg kg^{-1} (Longhurst et al., 2004). Similarly, Wells (1957) found a mean copper concentration of 17.5 mg kg^{-1} in some New Zealand pastoral soils. While in soils sampled from non-urban sites in the Canterbury region, copper concentrations were also similar to the present study with concentrations ranging between 2.1 – 27.3 mg kg^{-1} (Canterbury Regional Council, 2006). In comparison, in a survey by the Auckland Regional Council (1999) a higher mean soil copper concentration of 27 mg kg^{-1} (range 1 -111 mg kg^{-1}) was found for the 0 – 15 cm soil depth.

Interestingly there was little difference in soil copper concentrations between the different land use activities and specifically vineyard sites that are recognised as having significantly higher inputs of copper than other land use activities (Table 1). This finding contrasts with the results found in the Wellington and Waikato regions in their soil quality monitoring which showed that the horticulture sites had significantly higher soil copper concentrations that the other land use activities (Greater Wellington Regional Council, 2005; Taylor et al., 2010).

The findings in this study may reflect that soils were only sampled in the inter-row part of the vineyard and not directly under the vines where copper is more likely to accumulate after spraying. It is also possible that the climate in Marlborough has negated the need for large amounts of copper to be used to control disease. In response soil quality monitoring in 2010 sampled soils both in the inter-row and under the vine at vineyard sites. No significant difference was found in soil copper concentrations between the vine and inter-row region despite copper spray application being targeted to the vine area (Table 2). Furthermore, data from Nobilo Wines indicates that soil copper concentrations (0 – 30 cm soil sampling depth) that have been under viticulture for 20+ years were only at 30 mg kg^{-1}, still below a recommended soil copper concentration of 34 mg kg^{-1} (Stephen Bradley pers comms.).

Table 2 Copper concentrations (mg kg^{-1}) in soils sampled either under the vine or in the inter-row

Soil type	Sampling location	Soil copper concentration (mg kg^{-1})
Seaview	Vine	13
	Inter-row	13
Kaituna	Vine	20
	Inter-row	20
Woodbourne	Vine	18
	Inter-row	19
Wairau	Vine	20
	Inter-row	24
Kaiapoi	Vine	21
	Inter-row	20
Omaka	Vine	23
	Inter-row	22

3.1.4. Lead

Soil lead concentrations ranged from 4.2 to 51 mg kg^{-1} (excluding the outlier value of 94 mg kg^{-1} found at one of the vineyard sites) with a median concentration of 12 mg kg^{-1} (Figure 1). Soil lead results compare to median lead concentrations ranging from 6 mg kg^{-1} for Peat soils to 16 mg kg^{-1} for Granular soils for New Zealand farmed pastoral soils found by Longhurst et al. (2004). In soils sampled from non-urban sites in the Canterbury region, lead concentrations were also similar to the present study with concentrations ranging between 3.6 – 44.4 mg kg^{-1} (Canterbury Regional Council, 2006). Soil lead concentrations in some farmed Waikato soils ranged between 3 – 95 mg kg^{-1} with a mean concentration of 16 mg kg^{-1} (Taylor et al., 2010). The Wellington region found soil lead concentrations (0 – 10 cm soil depth) between 7.3 – 32 mg kg^{-1} for 23 dairy sites with a mean concentration of 16.9 mg kg^{-1} (Sorensen, 2009).

Despite different land use activities, there was little difference in soil lead concentrations between sites (Table 1).

3.1.5. Nickel

Soil nickel concentrations ranged from 4 to 35 mg kg^{-1} with a median concentration of 13 mg kg^{-1} (Figure 2). This range is similar to nickel concentrations found in soils sampled from non-urban sites in the Canterbury region which ranged between 2.9 – 20.7 mg kg^{-1} (Canterbury Regional Council, 2006). Concentrations are also similar to those found in the Wellington region across 23 dairy sites where concentrations ranged between 4 – 24 mg kg^{-1} and for 22 horticulture/cropping sites where concentrations ranged between 6 – 33 mg kg^{-1} (Sorensen, 2009; 2010). Soil nickel concentrations in some farmed Waikato soils ranged between 1 – 34 mg kg^{-1} with a mean concentration of 6.1 mg kg^{-1} (Taylor et al., 2010). In Northland, soil nickel concentrations in 25 soils (0 – 10 cm soil depth) under a range of land use activities ranged between 2 – 50 mg kg^{-1} with mean concentration of 17 mg kg^{-1} (Northland Regional Council, 2007). Nickel concentrations also compare to a mean background concentration of 58 mg kg^{-1} (range 0.93 – 320) for the 0 – 15 cm soil depth found for 99 sites in the Auckland region (Auckland Regional Council 1999). However, this range was influenced by high nickel concentrations on soils derived from volcanic origin. When this data was excluded values ranged between 0.93 – 57.2 mg kg^{-1} which is more in line with the results found in the present investigation, which is appropriate as there were no soils sampled in this study that had parent materials of volcanic origin.

3.1.6. Chromium

Chromium concentrations in soils ranged from 8 to 67 mg kg^{-1} with a median concentration of 19 mg kg^{-1} (Figure 2). These values are very similar to concentrations found in the Wellington region where concentrations ranged between 10 – 50 mg kg^{-1} for 23 dairy sites with a mean concentration of 19 mg kg^{-1} (Sorensen, 2009). In Canterbury chromium concentrations found in soils sampled from non-urban sites ranged between 4.6 – 26.4 mg kg^{-1} (Canterbury Regional Council, 2006). In the Auckland region a mean background concentration of 35 mg kg^{-1} (range 2.2 – 286) for the 0 – 15 cm soil depth was found across 99 sites (Auckland Regional Council, 1999). However this range, as for nickel is influenced by high chromium concentrations on soils derived from volcanic origin. When this data was excluded the values ranged between 2.2 – 149 mg kg^{-1} which is more in line with the results found in the present investigation.

3.1.7. Zinc

Zinc concentrations ranged from 18 to 102 mg kg^{-1} (Figure 2) with a median concentration of 72 mg kg^{-1}. Concentrations are similar to those found in soils in many other parts of New Zealand. For example, zinc concentrations in a survey of soils in the Wellington region ranged between 33 - 120 mg kg^{-1} for 23 dairy sites and between 15 – 107 mg kg^{-1} for 22 market garden/cropping sites (Sorensen, 2009; 2010). Soil zinc concentrations in some farmed Waikato soils ranged between 1 - 258 mg kg^{-1} with mean concentration of 62 mg kg^{-1} (Taylor et al., 2010). In Northland, soil zinc concentrations in 25 soils (0 – 10 cm soil depth) under a range of land use activities ranged between 9 – 133 mg kg^{-1} with mean concentration of 49 mg kg^{-1} (Northland Regional Council, 2007). Zinc concentrations sampled from non-urban sites in the Canterbury region had zinc concentrations that ranged between 12.1 – 116 mg kg^{-1} (Canterbury Regional Council, 2006).

There appeared to be slightly lower soil zinc concentrations in the exotic forest land use (Table 1) which may reflect the likelihood of no zinc inputs into these land uses or it could be related to soil order as soil zinc concentrations on the Brown Soil order were lower on average than the other soil orders (data not shown).

3.2. Dairy Farm Sites

3.2.1. Arsenic, Copper, Chromium, Lead, Nickel and Zinc concentrations

Median trace element concentrations for arsenic, copper, chromium, lead, nickel and zinc in soils sampled from the dairy sites are given in

Figure 3. For arsenic (4 mg kg^{-1}), copper (20 mg kg^{-1}), lead (11 mg kg^{-1}) and zinc (69 mg kg^{-1}) trace element concentrations were very similar to the concentrations found in the survey of soil quality monitoring sites. However for both chromium and nickel, concentrations were about twice as high as the concentrations found at the soil quality monitoring sites. This was largely influenced by very high chromium (range 110 – 178 mg kg^{-1}) and nickel (range 68 – 182 mg kg^{-1}) concentrations in one soil type - the Ronga soil. A possible source of the chromium and nickel is the soil parent, possibly serpentine minerals which are known to contain elevated concentrations of both these trace elements.

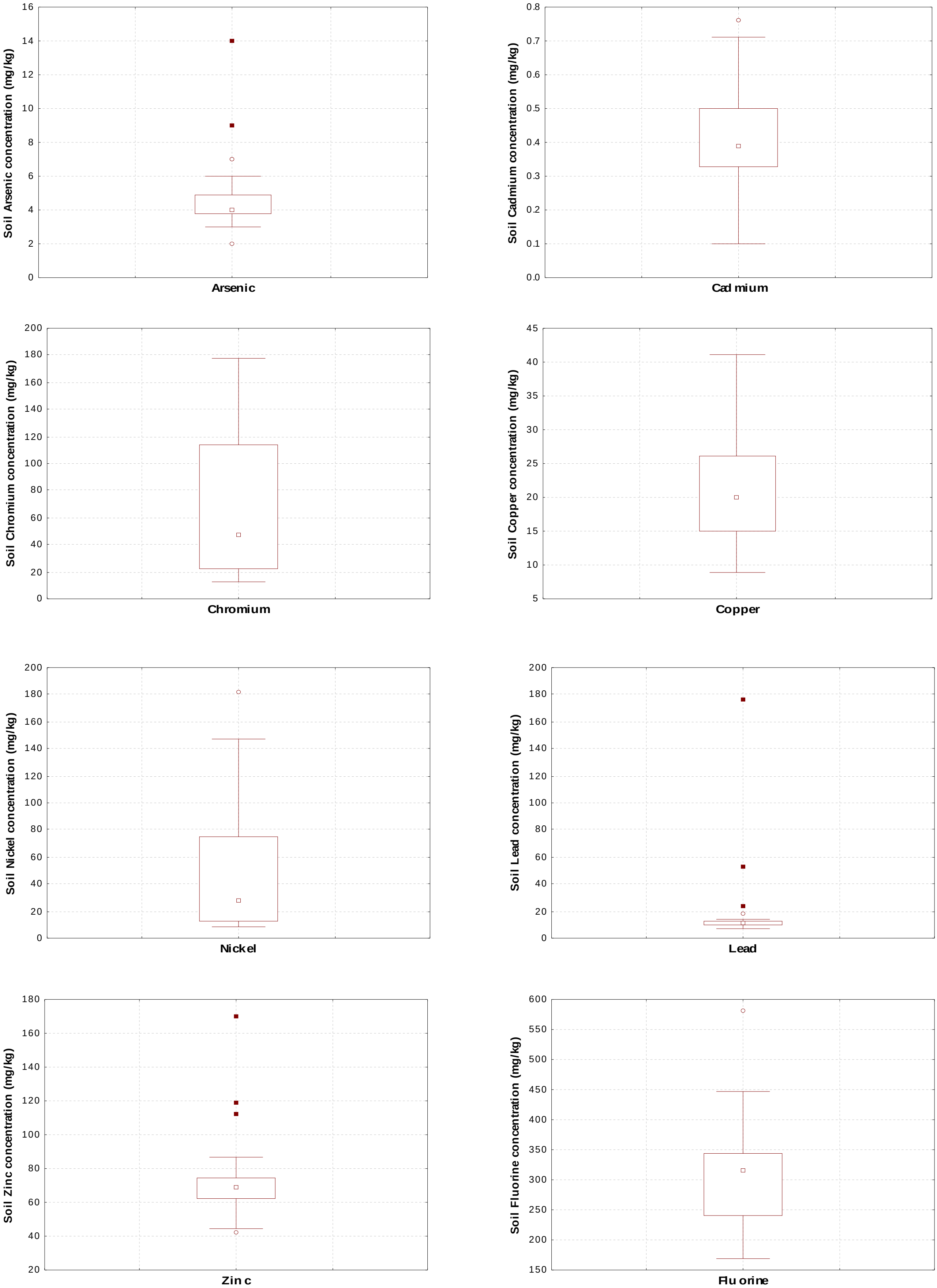

Figure 3 Trace element concentrations (mg kg^{-1}) in dairy farm sites

3.2.2. Soil Cadmium

Soil cadmium concentrations ranged from 0.1 to 0.76 mg kg^{-1} with a median concentration of 0.4 mg kg^{-1} Figure 3. The vast majority of the samples i.e. 45 of the 51 had concentrations below the suggested 0.6 mg kg^{-1} trigger value outlined in the national strategy for managing risks caused by cadmium in agricultural soils (MAF, 2010) and all samples were at or below the proposed 1 mg kg^{-1} threshold value (Figure 4).

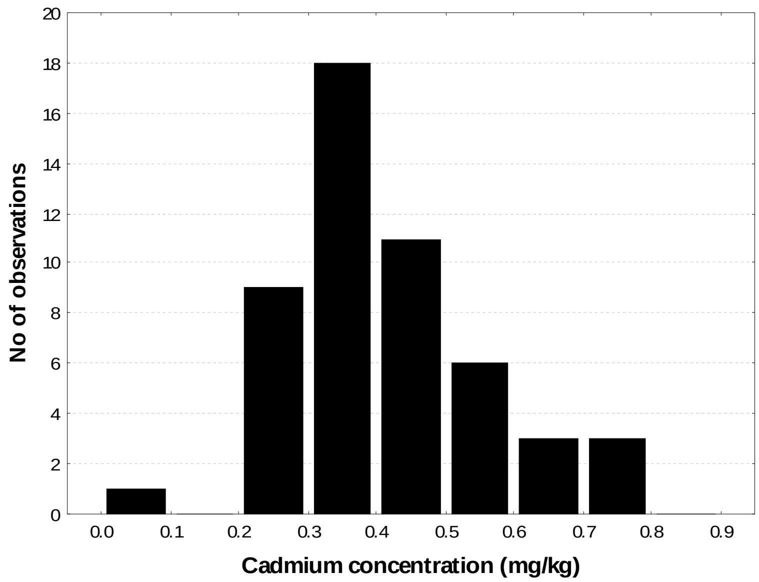

Figure 4 Frequency distribution for soil cadmium concentrations at dairy farm sites

The proposed guidelines suggest that sites with soil cadmium concentration above the lowest trigger value of 0.6 mg kg^{-1} should be monitored for cadmium in soil every 5 years and farmers provided with a range of management options as a means of reducing cadmium accumulation. This will be a cost-benefit equation for each farmer based on factors such as proximity to the 1 mg kg^{-1} threshold, the price of purer forms of phosphate (i.e. lower Cd concentration) and equity value of land that is relatively clean compared with land that has more cadmium. This will be required for the six sites which exceed the 0.6 mg kg^{-1} guideline.

Interestingly there was a lack of relationship between total soil cadmium and Olsen P (Figure 5). This contrasts with what has been found in a number of studies both in New Zealand (Gray et al., 1999; Roberts and Longhurst, 1994) and overseas (McLaughlin et al., 1996) where it has been shown that the main source of cadmium in agricultural soils is from the application of phosphate fertiliser which contains cadmium as an impurity. Hence it would appear that while there has been a significant accumulation of cadmium in some soils in Marlborough there is no strong evidence that the source of the cadmium is from the application of fertiliser.

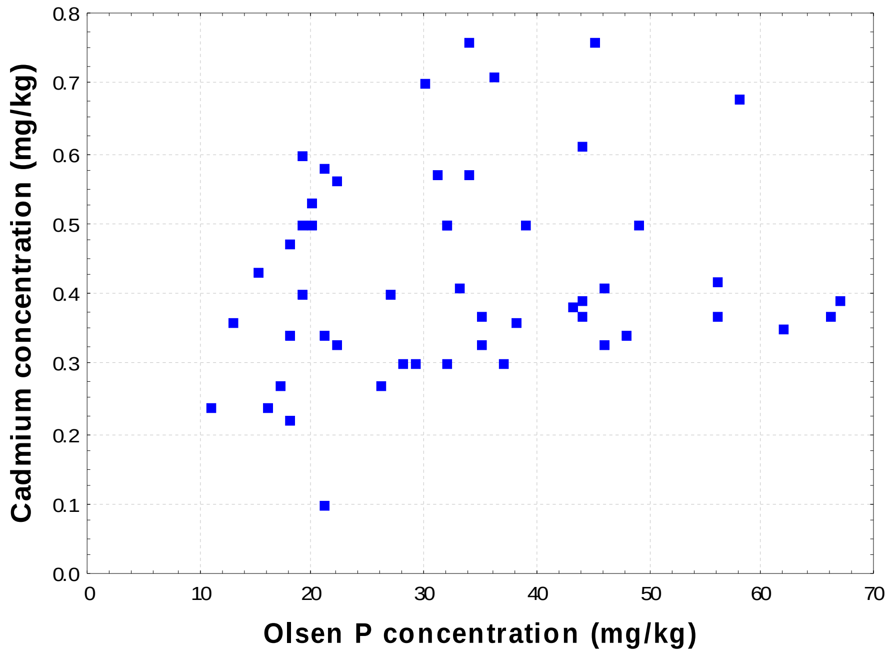

Figure 5 Relationship between Olsen P and soil cadmium concentrations from the dairy farm sites

3.2.3. Soil Fluorine

Total soil fluorine concentrations ranged from 168 to 580 mg kg^{-1} with a median concentration of 316 mg kg^{-1} (Figure 6). Natural soil fluorine concentrations depend on the soil parent material. In New Zealand, Allophanic soils formed from volcanic ash have been found to have concentrations ranging between 175- 200 mg kg^{-1}, whilst soils derived from sedimentary parents, such as those found in Marlborough, have been found to have lower concentrations ranging between 43 - 116 mg kg^{-1} (Loganathan et al., 2003). In the Waikato region background fluorine concentrations ranged between 70 – 300 mg kg^{-1} with a mean value of 190 mg kg^{-1} (Taylor et al. 2010). This indicates that the soils in Marlborough have likely received anthropogenic inputs of fluorine.

The results are in line with other studies of the fluorine status in New Zealand soils. For example total fluorine concentrations for 27 topsoils sampled under pasture ranged from 212 - 617 mg kg^{-1} with a mean fluorine concentration of 357 mg kg^{-1} (Loganathan et al., 2006). In another set of New Zealand pasture soils, concentrations ranged between 217 - 454 mg kg^{-1} (Loganathan et al., 2001). While for farmed land in the Waikato, total soil fluorine concentrations ranged between 120 – 900 mg kg^{-1} with an average of 400 mg kg^{-1} (Taylor et al., 2010).

As was found for cadmium, there was a surprising lack of relationship between total soil fluorine and Olsen P (Figure 6). Loganathan et al. (2003) found that for a particular site having the same soil type, total soil fluorine was well related to Olsen P, but the relationship did not hold when data for several soils were combined. This could be because of differences in soil properties e.g. P retention.

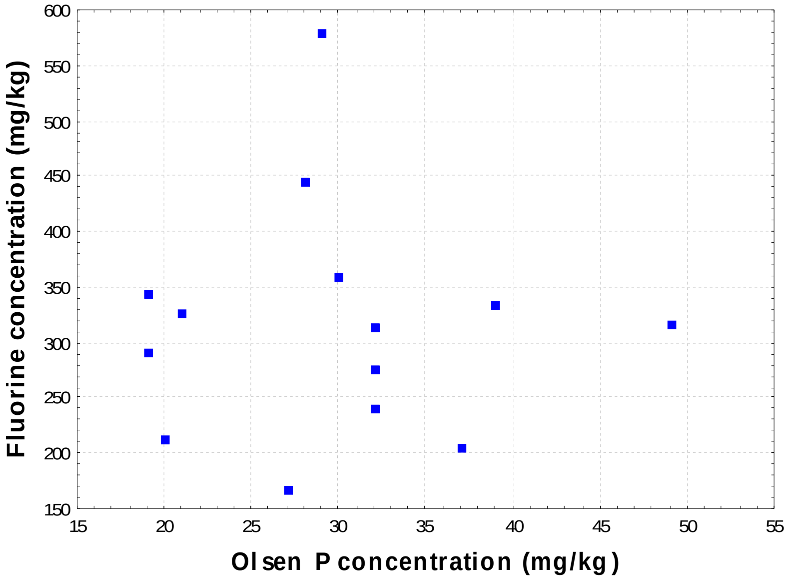

Figure 6 Relationship between Olsen P and total soil fluorine concentrations from the dairy farm sites

Grace et al. (2003) investigated the impact of soil ingestion of fluorine on the metabolism and status of grazing sheep. Based on the results of this study, at normal soil ingestion rates, soils with the range of soil fluorine concentrations found in this study are unlikely to result in fluorine toxicity to grazing animals. However, if soil fluorine concentrations continue to increase in the future, management should include maintaining good pasture cover, reducing stocking rates, especially during winter, and withholding stock from recently fertilised pastures.

4. Conclusions

- Trace element concentrations were generally low and were similar to concentrations found in agricultural soils in other parts of New Zealand.

- Trace element concentrations were also similar to typical background concentrations found in New Zealand soils.

- With the exception of dairy farm sites that had higher soil cadmium concentrations, there did not appear to be any differences in trace element concentrations between land use activities.

- This data will be especially useful to the Marlborough District Council when wanting to evaluate whether soils have been contaminated with anthropogenic of inputs of trace elements to soils as a result of past land use activities.

- More intensive investigation of 51 dairy farm sites revealed that soils on average had accumulated cadmium and fluorine.

- While soil cadmium concentrations were above background concentrations, in the medium term concentrations at the majority of sites are unlikely to accumulate to concentrations that will exceed the proposed guideline values.

- For fluorine, based on the results of this study, at normal soil ingestion rates soil fluorine concentrations are unlikely to result in fluorine toxicity to grazing animals.

- There should be periodical (i.e. every 5 years) long-term monitoring of soil cadmium and fluorine on dairy farm sites to determine changes over time.

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Appendix A

Trace element concentrations (mg kg^{-1}) at the soil quality monitoring sample sites

Site	Land use	Soil type	As	Cd	Cr	Cu	Ni	Pb	Zn
MDC1	Vineyard	Wairau	4	0.10	20	20	29	15	72
MDC2	Cropping	Wairau	4	0.20	22	15	33	14	71
MDC3	Dairy	Wairau	6	0.20	16	19	11	23	102
MDC4	Vineyard	Renwick	4	0.10	13	27	10	11	67
MDC5	Cropping	Renwick	4	0.20	18	17	13	14	91
MDC6	Dryland Pasture	Renwick	3	0.10	18	12	13	11	69
MDC7	Vineyard	Paynter	2	0.10	10	13	6	9	41
MDC8	Cropping/pasture	Paynter	3	0.20	15	13	9	13	75
MDC9	Dairy	Paynter	6	0.30	23	24	15	18	95
MDC10	Vineyard	Omaka	5	0.10	25	24	18	94	75
MDC11	Dryland Pasture	Omaka	5	0.10	25	14	18	12	68
MDC12	Vineyard	Seddon	5	0.10	22	17	18	12	75
MDC13	Cropping	Seddon	5	0.10	23	16	18	12	76
MDC14	Dryland Pasture	Seddon	5	0.10	23	16	18	12	81
MDC15	Native Bush	Ronga	5	0.10	61	25	35	16	88
MDC16	Dairy	Ronga	6	0.40	62	27	35	16	94
MDC17	Native Bush	Kaituna	4	0.10	22	16	12	17	76
MDC18	Dairy	Kaituna	5	0.50	33	21	16	15	89
MDC19	Native Bush	Kenepuru	6	0.10	12	16	8	11	53
MDC20	Exotic forest	Kenepuru	5	0.10	14	18	10	15	73
MDC21	Exotic forest	Kenepuru	2	0.10	9	8	4	7	27
MDC22	Dryland Pasture	Kenepuru	3	0.10	11	15	7	9	50
MDC23	Cropping	Seddon	4	0.10	29	13	19	12	84
MDC24	Dryland Pasture	Wairau	4	0.10	22	13	32	17	80
MDC25	Vineyard	Renwick	3	0.10	15	20	13	12	92
MDC26	Vineyard	Seddon	3	0.10	22	14	17	10	75
MDC27	Vineyard	Motukarara	5	0.10	23	18	27	19	74
MDC28	Dryland Pasture	Motukarara	5	0.10	20	16	24	17	70
MDC29	Cropping	Warwick	3	0.27	18	11	13	11	87
MDC30	Vineyard	Sedgemere	4	0.13	26	12	17	12	82
MDC31	Cropping	Sedegemere	4	0.17	25	12	17	12	82
MDC32	Cropping	Seddon	4	0.20	29	16	23	13	97
MDC33	Cropping	Dashwood	3	0.16	22	9	12	11	76
MDC34	Dryland Pasture	Warwick	2	0.15	13	9	11	11	84
MDC35	Dryland Pasture	Jordan	3	0.11	11	4	6	10	42
MDC36	Vineyard	Jordan	3	0.10	11	12	7	10	43
MDC37	Vineyard	Renwick	3	0.17	17	12	12	13	75
MDC38	Dryland Pasture	Renwick	3	0.20	17	9	13	13	72
MDC39	Dryland Pasture	Dashwood	3	0.10	18	8	11	9	57
MDC40	Dairy	Kaituna	4	0.43	17	15	9	13	63
MDC41	Dairy	Rai	7	0.59	67	21	28	13	64
MDC42	Exotic Forest	Pelorus Steepland	5	0.10	29	22	11	12	50
MDC43	Dairy	Pelorus Steepland	5	0.26	28	22	13	12	76
MDC44	Dairy	Manoroa	5	0.25	16	17	12	10	56
MDC45	Vineyard	Dashwood	4	0.12	21	12	13	13	88
MDC46	Vineyard	Sedgemere	2	0.16	13	5	8	9	56
MDC47	Cropping	Sedgemere	3	0.11	13	5	8	8	48

MDC48	Dryland Pasture	Sedgemere	3	0.10	16	7	9	8	54
MDC49	Exotic forest	Hororata	3	0.10	19	5	15	11	53
MDC50	Dryland Pasture	Hororata	3	0.10	20	7	14	11	50
MDC51	Dryland Pasture	Kaituna	4	0.21	20	11	11	10	50
MDC52	Dryland Pasture	Tuamarina	2	0.10	8	4	7	4	18
MDC53	Exotic forest	Tuamarina	6	0.10	8	14	14	9	45
MDC54	Dryland Pasture	Weld	5	0.10	11	12	15	8	67
MDC55	Exotic forest	Weld	5	0.10	14	15	18	14	75
MDC56	Dryland Pasture	Warwick	3	0.21	15	13	12	12	79
MDC57	Dryland Pasture	Wither Hill	4	0.10	11	6	9	6	31
MDC58	Dryland Pasture	Haldon	5	0.11	16	16	14	11	70
MDC59	Exotic forest	Waihopai Steepland	2	0.10	16	9	11	11	46
MDC60	Dryland Pasture	Waihopai Steepland	2	0.12	13	9	9	10	43
MDC61	Cropping	Seaview	4	0.2	23	13	18	12	78
MDC62	Cropping	Galtiymore	5	0.1	19	14	18	11	54
MDC63	Cropping	Marama	4	0.12	22	13	18	11	67
MDC64	Cropping	Broadbridge	3	0.18	23	11	17	12	77
MDC65	Vineyard - wheel	Seaview	4	0.14	24	13	17	11	78
MDC66	Vineyard - wheel	Kaituna	5	0.19	15	20	14	11	76
MDC67	cropping	Wairau	4	0.17	21	14	16	12	60
MDC68	cropping	Woodbourne	5	0.23	22	18	19	18	87
MDC69	Vineyard - wheel	Woodbourne	6	0.18	20	19	17	51	88
MDC70	Vineyard - wheel	Wairau	4	0.14	20	24	15	11	61
MDC71	cropping	Renwick	2	0.17	11	6	9	9	65
MDC72	cropping	Brancott	2	0.16	11	7	9	10	64
MDC73	Dryland Pasture	Kaituna	4	0.14	13	16	11	12	78
MDC74	Dairy	Rai	4	1.02	26	14	10	15	70
MDC75	Dairy	Ronga	5	0.53	28	14	13	15	86

Trace element concentrations (mg kg^{-1}) at the dairy sites

	Olsen P	As	Cd	Cr	Cu	Ni	Pb	Zn	F
1	16	4	0.24	22	17	13	9	60	
2	17	4	0.27	17	15	12	9	55	
3	11	3	0.24	17	13	11	8	44	
4	26	3	0.27	22	14	15	7	42	
5	13	5	0.36	19	18	14	9	59	
6	21	4	0.34	18	15	12	10	61	
7	18	4	0.47	24	10	11	12	55	
8	58	4	0.68	26	12	10	12	65	
9	45	4	0.76	25	9	10	13	66	
10	21	4	0.58	25	11	11	13	79	
11	22	4	0.56	31	10	13	13	56	
12	19	4	0.50	30	11	14	12	49	
13	66	4	0.37	64	14	40	13	65	
14	46	3	0.41	31	13	20	13	68	
15	56	4	0.37	114	18	68	9	67	
16	67	4	0.39	110	20	70	177	119	
17	62	5	0.35	123	15	76	10	60	
18	44	3	0.39	114	22	75	9	72	
19	56	5	0.42	128	22	92	10	71	
20	33	4	0.41	130	23	94	11	81	
21	44	4	0.37	112	20	80	10	70	
22	48	4	0.34	116	20	76	10	69	
23	43	5	0.38	144	26	108	10	72	
24	38	5	0.36	178	26	148	9	65	
25	31	4	0.57	64	38	43	11	76	
26	36	4	0.71	60	31	37	11	74	
27	34	4	0.57	57	29	39	10	74	
28	34	4	0.76	65	31	37	11	73	
29	35	5	0.33	47	41	22	53	112	
30	20	14	0.53	80	23	47	12	77	
31	44	4	0.61	101	16	42	9	54	
32	15	4	0.43	85	18	38	9	62	
33	18	5	0.22	177	27	182	10	67	
34	22	4	0.33	158	27	146	9	71	
35	35	4	0.37	144	26	136	9	77	
36	46	4	0.33	165	26	146	9	80	
37	18	4	0.34	134	25	116	11	73	
38	29	7	0.30	23	21	14	18	79	580
39	32	4	0.30	18	18	11	12	69	277
40	28	9	0.30	26	22	23	24	87	447
41	39	6	0.50	39	32	26	14	170	334
42	21	6	0.10	31	27	32	13	81	328
43	32	2	0.50	14	16	9	9	45	242
44	49	4	0.50	22	20	12	11	69	317
45	32	4	0.50	19	16	9	12	71	314
46	37	5	0.30	13	20	11	11	69	205
47	19	5	0.40	14	20	11	14	63	344
48	27	3	0.40	16	18	9	10	65	168
49	20	5	0.50	94	23	41	11	73	212
50	19	6	0.60	66	22	28	13	68	291
51	30	7	0.70	40	27	17	13	65	361