MANAGING CADMIUM IN NEW ZEALAND'S AGRICULTURE AND FOOD SYSTEMS

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Abstract

A national Cadmium Management Strategy developed through a collaborative engagement by industry and government agencies seeks to 'ensure that cadmium in rural production poses minimal risks to health, trade, land use flexibility and the environment over the next 100 years'. Since implementing the strategy new information has been collated using New Zealand specific science and surveys of agricultural soils. Current information is provided on changes in cadmium levels in phosphate fertiliser over time, typical soil Cd levels in regions of New Zealand, management of soil cadmium using the Tiered Fertiliser Management System, and levels of cadmium reported in typical diet of New Zealanders.

Introduction

Cadmium is a heavy metal, naturally present at low levels in air, water and soil. Cadmium is accepted as a carcinogen by the inhalation pathway[1]. Safe levels for dietary exposure to cadmium over a lifetime's intake, are provided by the World Health Organization's Provisional Tolerable Monthly Intake value, (25ug/kg of body weight)[2]. Prolonged intake above this level increases the risk of chronic human health effects, including disease of the kidneys.

For the non-smoking population, the main pathway of cadmium exposure is through the trace amounts present in food as a result of its uptake from the soil by forage and food crops. Although it occurs naturally in soil, the sustained application of phosphate fertilisers and bio-solids can lead to an increase in soil cadmium, with implications for uptake by plants. This is not unique to New Zealand and the level of cadmium in New Zealand soils remains comparable to soil cadmium in other parts of the world[3]. No simple relationship exists between soil cadmium and plant uptake, therefore management of plant uptake includes a combination of approaches[4].

Management of soil cadmium in New Zealand agricultural soils was initiated in the early 1990's due to detection of cadmium in kidneys from sheep. Cadmium gradually accumulates in this organ over time, therefore to manage risks of exceeding food standards, kidneys from ruminant animals older than 30 months have been discarded from the human food chain[4]. In 1995, the fertiliser industry established voluntary limits for cadmium concentrations in phosphate fertiliser, set at 280 mg Cd/kg P.

A Cadmium Working Group (CWG) comprising central and regional government, primary industry bodies and fertiliser industry representatives was established in 2006. It was tasked with assessing the potential risks of cadmium in New Zealand's agriculture and food systems and to develop an appropriate response.

The CWG concluded that soil cadmium does not pose a risk to human health in New Zealand, but that there is a small risk of occasionally exceeding food safety standards in some offal types and some vegetables[4]. An occasional mild breach of cadmium food standards is of little practical consequence for human health as the standards provide for a safe level of intake over a lifetime[5]. On the other hand, any exceedance of food standards could present at trade risk, even where there is no human health risk.

The CWG developed the current Cadmium Management Strategy (CMS). The components of the strategy include, governance, food monitoring, soil and fertiliser management, extension and education, and environmental monitoring and research. It was adopted in 2011 and is being implemented by the Cadmium Management Group (CMG). The Strategy has recently undergone independent review and the CMG is in the process of considering the review recommendations for further development of the strategy.

Cadmium in fertiliser

Since 2001, the cadmium concentration in fertiliser has been monitored and independently audited through the Fertmark programme. Results from nearly 3,200 samples of phosphate fertilisers reported between January 2003 to July 2015 were collated and independently assessed (Figure 1)[6].

The average cadmium concentration in fertiliser over this period was 184 mg Cd/kg P with ninety percent of the samples between 108 and 246 mg Cd/kg P. Since 2003, only four samples exceeded the limit. Two of those samples were subsequently found to have been mistakenly taken from rock phosphate prior to blending.

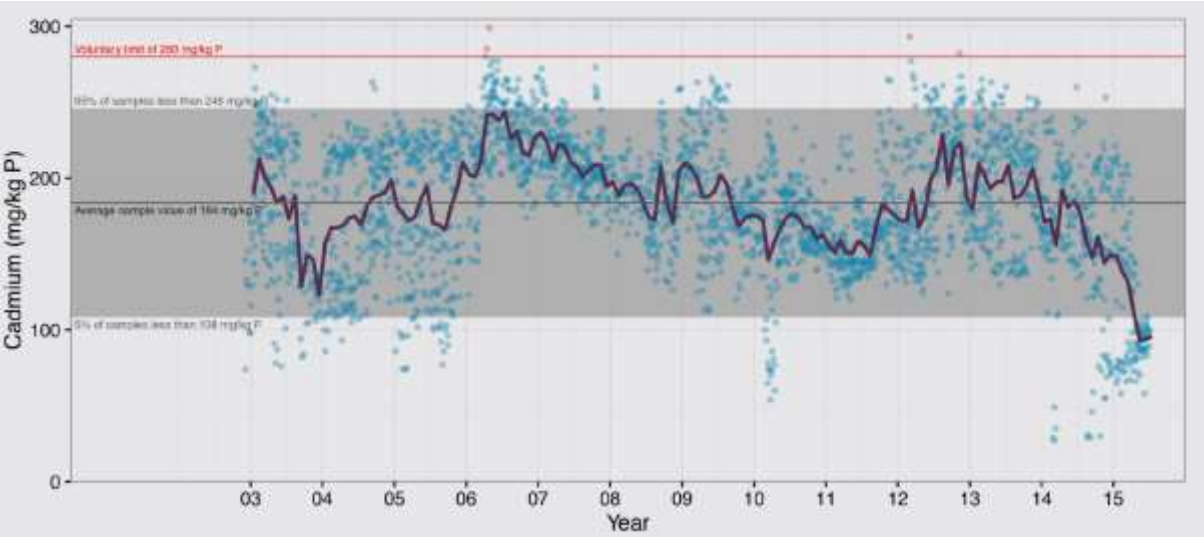


Figure 1: Cadmium concentration in phosphate fertiliser.
(Data: Ballance & Ravensdown Fertiliser Co-operatives, Source: Analysis by Dragonfly Data Science[6]*)*

Rock phosphate is sourced from a range of suppliers for the manufacture of superphosphate with as low a cadmium level as possible, while still meeting manufacturing and product quality criteria. Not all sources of phosphate rock are equally suitable for the manufacture of fertiliser. The availability of rock phosphate with low cadmium levels, together with the required properties for processing and producing fertilisers drives the variability in cadmium concentration in superphosphate used in this country[7].

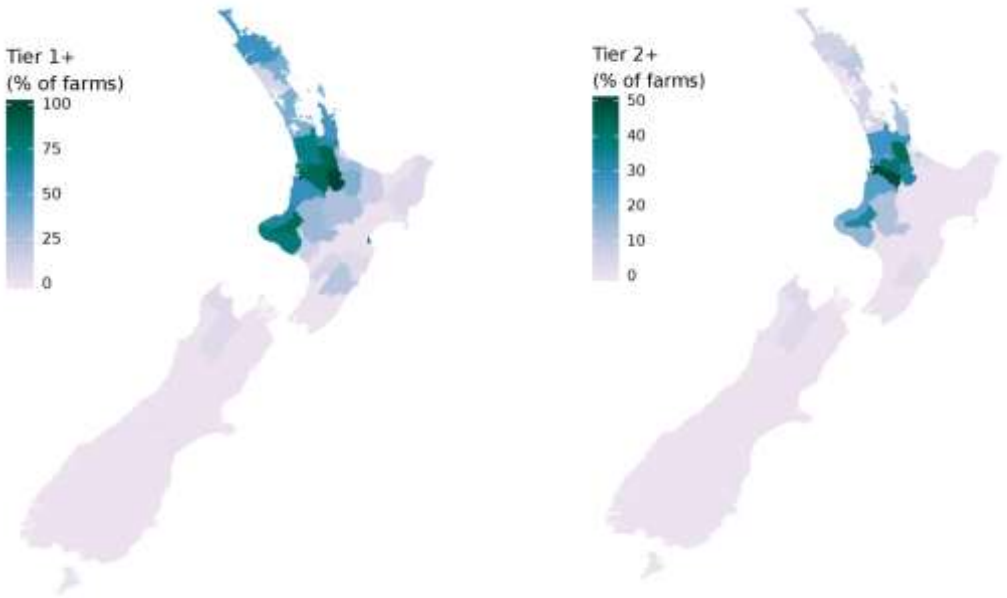
Cadmium in agricultural soil

Status of cadmium in New Zealand's agricultural soils, is provided by over 8,800 soil samples taken across the country between 2007 and 2015 by the fertiliser industry, regional councils and research organisations[6].

The mean concentration of cadmium was 0.43 mg Cd/kg soil and the highest recorded concentration was 3.05 mg Cd/kg. 95% of samples had a cadmium concentration less than

1.16 mg Cd/kg and 0.3% of samples had a concentration at or above the Tiered Fertiliser Management System threshold of 1.8 mg Cd/kg (see below: Managing soil cadmium accumulation).

Data from 1,980 farms from across the country were available for analysis of spatial distribution (Figure 2). Elevated soil cadmium, relative to the rest of New Zealand, occurs in the Waikato and Taranaki[6]. This is almost certainly a legacy effect of a long history of phosphate fertiliser applications to intensive farming operations prior to the mid-1990s, (i.e. before the voluntary limits on cadmium in fertiliser were introduced). It is also very likely be associated with the predominance of volcanic soils in these regions which have a higher phosphorus demand than soils in other regions.



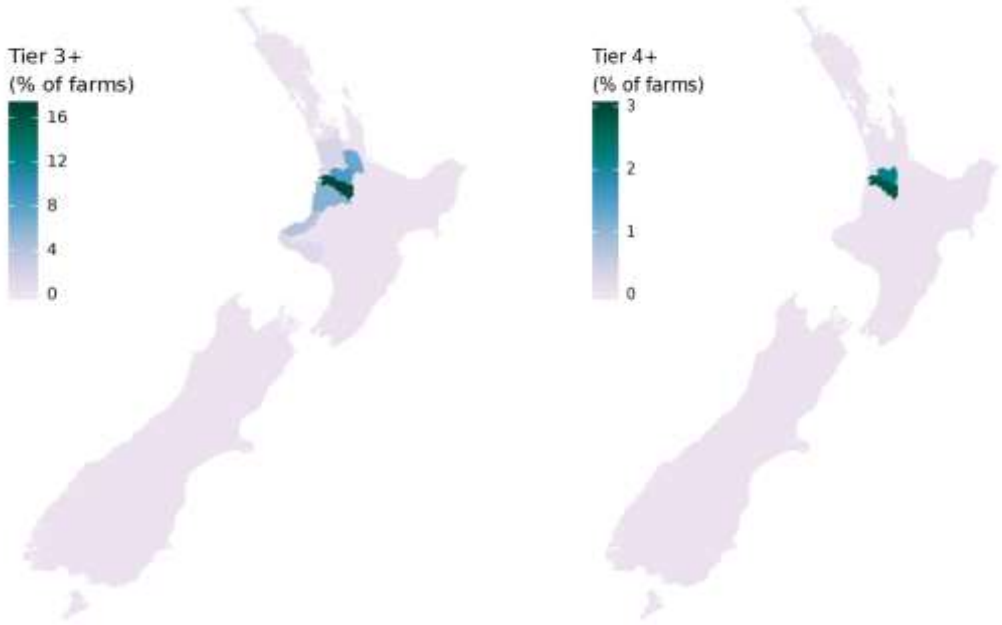


Figure 2: Percentage of sampled farms within each New Zealand territorial authority that had soil cadmium concentrations that were at or above soil cadmium Tier 1, Tier 2, Tier 3 or Tier 4 (0.6-1.0; 1.0-1.4; 1.4-1.8; >1.8 mg Cd/kg soil, respectively) *(Source: Analysis by Dragonfly Data Science.*[6])

Cadmium in groundwater and surface water

While fertiliser derived cadmium is known to accumulate in the surface soils, a review of Cd in groundwater was commissioned by the Ministry of Health. It concluded: "*At present, there is no evidence of a widespread problem of cadmium groundwater concentrations exceeding the metal's maximum acceptable value, or even 50 percent of this value. From this it is concluded that generally cadmium concentrations in groundwater are presently too low to create a hazard to drinking-water supplies sourced from groundwater*." and "*Time-series data were available from a limited number of sites. No evidence was found of a trend in the cadmium concentrations at these sites*". The report does take a precautionary approach, stating: "*However, there may be some sites were localised cadmium concentrations exceed the maximum acceptable value. Hazard identification undertaken during the development and implementation of water safety plans should identify such sites and the measures necessary for minimising the public health risks."* [8]

Results from Waikato Regional Councils groundwater monitoring over the period 2008–2012 showed that Cd was detected in only 16% of the samples and these samples tended to be from high intensity farming areas. The highest Cd concentrations were half of the drinking water standard limit value of 4 µg/L[10].

Results from 1995 to 2017 from the Waikato Regional Council surface water monitoring show that Cd concentrations are below the detection limit of 0.01 µg/L. The Australian New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) for cadmium in water is 0.2 µg/L, so there is currently no evidence to suggest that cadmium is an issue in the Waikato River[10].

Rate of accumulation of soil cadmium

Rate of soil accumulation remains uncertain. Soil survey data from the fertiliser industry and regional council, in the Waikato region between 2007 and 2015 provided no evidence of an increase or decrease in soil cadmium over the survey period (Figure 3).

Due to the gradual accumulation rates, establishing trends in soil cadmium accumulation over a relatively short time is subject to uncertainty from both laboratory error and sampling error. Soil cadmium monitoring reported by Taranaki Regional Council presented both losses and gains in measured soil Cd between 2007 and 2012. These ranged from –0.39 to + 0.23 mg Cd/kg soil[9]. The 20 assessed sites included different land-use activities and soil types, with 12 from pasture and 2 from market garden or arable. Eight of these fourteen sites recorded a slight drop. These observations provide confidence that any soil cadmium accumulation is very gradual and that at the current loading rates decadal time-frames will be required to observe any significant changes in soil cadmium.

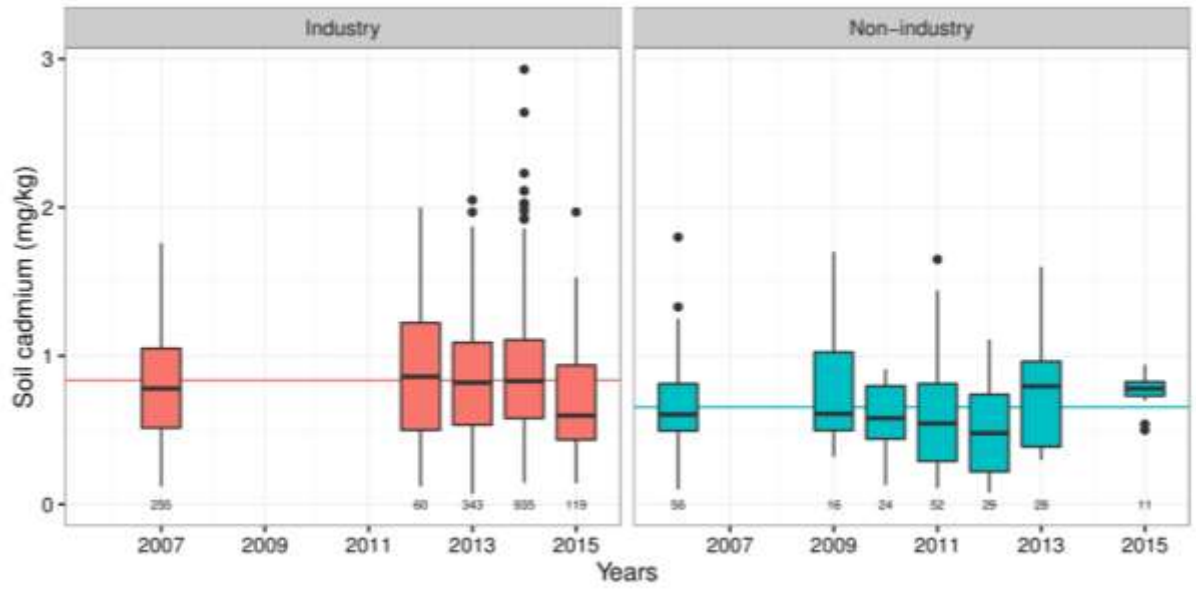


Figure 3: Cadmium levels in Waikato soils 2007-2015.
(Source: Ballance & Ravensdown Fertiliser Co-operatives; non-industry sources include the Waikato Regional Council and researchers. Analysis by Dragonfly Data Science[6])

A similar trend over the period from 2007 to 2015 was demonstrated by State of the Environment monitoring by Waikato Regional Council, as reported to the Fertiliser and Lime Research Centre Conference 2017, (Figure 4)[10].

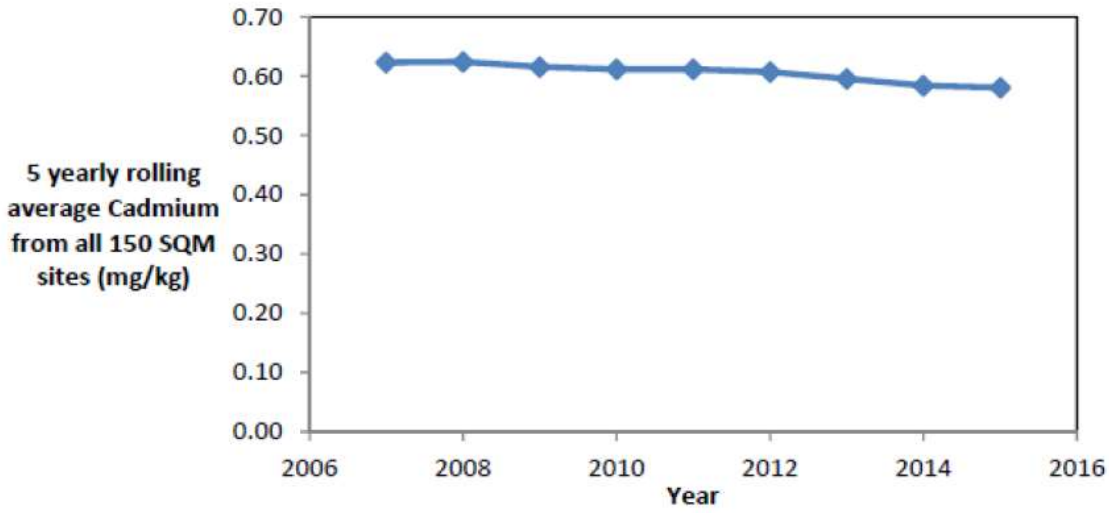


Figure 4 : Rolling average soil Cd *(Source: Waikato Regional Council)[10]*

In contrast to these relative short-term assessments, the long-term phosphate fertiliser trial at the Winchmore Research Station in Canterbury provides an opportunity to examine cadmium accumulation over more than 6 decades under consistent fertiliser management.

One evaluation using measured and modelled time-series data of soil cadmium showed an increase in soil cadmium from the 1950s, peaking in 1992, with no significant change since then (Figure 5)[11]. However, a subsequent evaluation, also commissioned by the fertiliser industry, which included additional soil samples and re-evaluation of archived samples suggest soil cadmium accumulation associated with phosphate fertiliser application may be continuing at this site (Figure 6)[12]. It is of note however, that agronomic optimum for pasture production is found to be well below the maximum rate applied at this research trial site[13]. At the intermediate fertiliser rates, trends in soil cadmium accumulation since the mid 1990's when the voluntary limit in fertiliser cadmium was introduced, also remain unclear. It is likely that further sampling over decades is required before a definitive trend can be established for these rates of application.

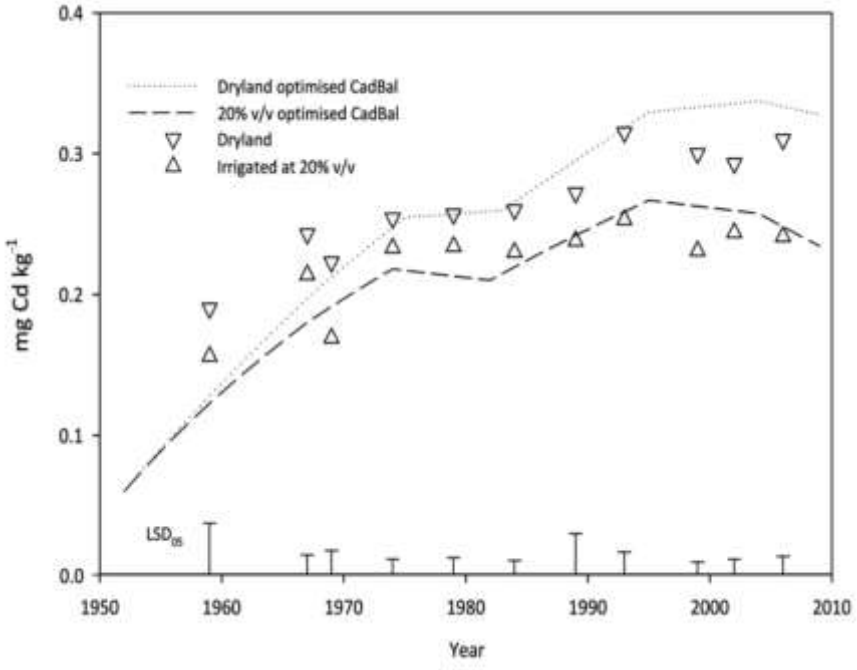


Figure 5: Trends in the amount of soil cadmium at Winchmore.

(Sources: Redrawn from McDowell, 2012. The dashed lines are best fit of a cadmium mass-balance model CadBal, Roberts and Longhurst 2005)[11]

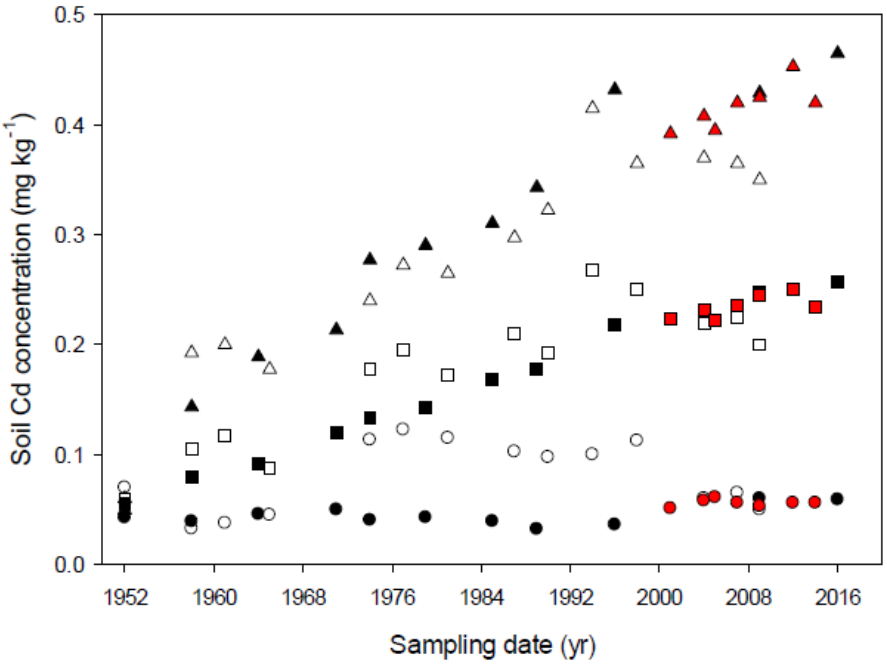


Figure 6: Relationship between sampling date and mean soil cadmium concentrations in plots which received no fertiliser (○ from McDowell (2012); and ● Kelliher et al. (2017) and ● from this study) **or phosphorus applications of 17 kg P ha-1 y-1** (□, ■ and ■) **and 34 kg P ha-1 y-1** (△, ▲ and ▲).
(Source: Col Gray, Rich McDowell, Alasdair Noble, 2017) [12]

Managing soil cadmium accumulation

The first step to managing the rates of soil cadmium accumulation were implemented in the mid-1990s with the voluntary industry limit of 280 mg Cd /kg P. Prior to this, the source of rock phosphate for manufacturing superphosphate contained cadmium in excess of 420 mg Cd/kg P. In order not to exceed the voluntary limit, cadmium levels are managed to a much lower value than 280 mg Cd/kg P. This is achieved by blending different sources of phosphate rock. However, not all phosphate rock are comparable, and long term relationships with suppliers is important to ensure availability of product with the correct manufacturing characteristics still suitable to meet these cadmium limits[7].

Further steps for management of the accumulation of cadmium in New Zealand's agricultural soils were adopted by the Cadmium Working Group. This included the Tiered Fertiliser Management System (TFMS). It provides for accumulation over at least a one hundred year timeframe, and seeks to ensure that soil cadmium levels never exceed 1.8 mg/kg soil. This limit was recommended by an independent international reviewer, as a soil

guideline value providing the best balance for protection of human health, trade, land use flexibility and the environment over the long term[14].

The TFMS recommends that all farms applying at least 30 kg P/ha/yr of phosphate fertiliser should test their soils for cadmium at least once every five years. The TFMS provides a standardised sampling strategy for screening pastoral soils, with a more detailed, definitive soil sampling protocol applied when soil cadmium levels approach critical tier values. As soil cadmium increases there are increasing levels of restriction on choice and rate of phosphate fertiliser for annual applications to ensure soil cadmium accumulation does not exceed the agreed soil limits over the agreed timeframes (Table1) [15].

Table 1. Management of phosphate fertiliser based on the TFMS

Tier	**Soil Cd (mg Cd/kg)**	**Phosphate fertiliser management required**
Tier 0	<0.6	Soil cadmium is within the range of natural background concentrations. No restriction on phosphate fertiliser type or application.
Tier 1	0.6 to <1.0	Low level restriction on the rate of type and application of phosphate fertiliser. Implementation of appropriate management practices.
Tier 2	1.0 to <1.4	Moderate restriction on phosphate fertiliser type and rates of application.
Tier 3	1.4 to <1.8	High restriction on phosphate fertiliser type and rates of application.
Tier 4	≥1.8	No further cadmium accumulation allowed unless a detailed site-specific investigation is undertaken to identify risks and pathways for potential harm.

The recent (2018) review of the Cadmium Management Strategy included a number of recommendations for amendment of the TFMS. The Cadmium Management Group is reviewing the options to best accommodate these recommendations and further reduce cadmium loads.

An important aspect of the Tiered Fertiliser Management System are the crop management recommendations which can apply regardless of soil tier value[16]. This is because there is no simple direct relationship between soil cadmium levels and plant uptake. The following practices should apply where there is an identified risk of increased plant uptake, (Table 2).

Table 2: Recommended practices to manage cadmium uptake in food crops

1	Measure soil cadmium levels once every 5 years (using accredited sampling procedure and accredited laboratory). Take this value into consideration when choosing phosphate fertiliser products
2	Use phosphate fertilisers with lower levels of cadmium
3	Use crop varieties which demonstrate a lower risk of cadmium uptake.
4	Avoid fertiliser blends and irrigation water containing high levels of chloride
5	Maintain soil pH at the upper recommended limits for crop type
6	Maintain high organic matter in soil
7	Alleviate any zinc deficiency in the crop
8	Avoid fertilisers which cause localised acidifying effects
9	Phosphate fertiliser applications should be banded (and not broadcast) where possible (to reduce soil Cd loading)

(Source: Tiered Fertiliser Management System, 2016, Fertiliser Association of New Zealand)[16]

It is recognised that plant species and variety has a strong influence of plant uptake of soil cadmium. Further development of the TFMS will be informed by the New Zealand specific science on soil characteristics, plant up-take and potential management or mitigation options.

Cadmium in food

New Zealand Total Diet Studies (NZTDS) show the level of cadmium intake from food in New Zealand is typically less than 50% of the Provisional Tolerable Monthly Intake (PTMI) of 25 µg Cd/kg bodyweight/month recommended by the World Health Organization[17].

The highest relative cadmium intake, as a percentage of the PTMI, occurs in the diets of toddlers and children. This is attributable to small children having an increased food requirement relative to body weight compared to adults (Figure 7).

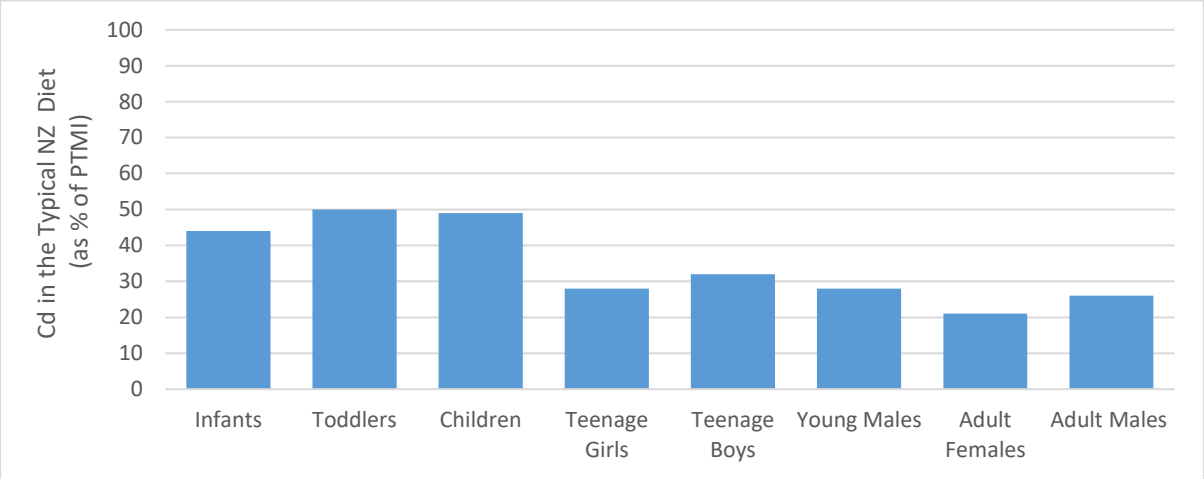


Figure 7: Cadmium in New Zealand diets.
(Source: adapted from MPI, 2016, New Zealand Total Diet Study)

The 2016 Total Diet Study presented with 50% of the PTMI for toddlers, 49% for children and 24% for young adult males, (excluding oysters from the diet). The predominant contributors to cadmium exposure in these groups came from the vegetable group in particular, potatoes, potato crisps and potato fries (37–38% of exposure in children and toddlers). For 5–6-year-old children, mixed-grain bread (7%) and white bread (8%) were also notable sources of exposure, with the grain's food group being an important contributor to total cadmium exposure for all the infant, child and teenage cohorts[17].

Estimates of dietary cadmium exposure from the 2016 NZTDS are within the range reported in overseas total diet studies, and dietary cadmium exposures have largely remained consistent with the ranges reported in the 1997/98 NZTDS and subsequent NZTDSs. There is no evidence of an increase in cadmium exposure through the diet and no consequent elevation in dietary risk[17].

Protection of food standards is a complex topic. International science and recent research in New Zealand show only weak relationships between the level of soil cadmium and the uptake of cadmium by vegetables and forage plants. Elevated levels of cadmium uptake and mild exceedance of food standards can occur in crops grown in soils with low cadmium levels. Complex combinations of factors including plant cultivar, soil type and soil chemistry have an influence on plant uptake. Ongoing studies are required to better understand the factors influencing cadmium accumulation in different soil groups and uptake into plants. Managing soil cadmium levels remains just one aspect of ensuring that food produced in New Zealand continues to meet food safety standards. Cultivar selection plus the management of soil properties and agronomic practices, along with the adoption of other suitable mitigations, will also be required.

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