THE TIERED FERTILISER MANAGEMENT SYSTEM FOR MANAGING SOIL CADMIUM IN AGRICULTURAL SOILS IN NEW ZEALAND

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Abstract

Soil cadmium levels are gradually increasing in agricultural soils around the world due to the natural trace levels which are found in phosphate rock from which phosphate fertiliser is manufactured. Trace levels applied to soil will accumulate in the surface soil bound to organic matter and soil colloids, with accumulation rates dictated by the cadmium content in phosphate products and the rate of phosphate fertiliser applied over the long term.

Soil cadmium levels in New Zealand do not currently present a risk to human health, trade or the environment and in order to control soil cadmium and maintain acceptable levels of soil cadmium over the long-term the Cadmium Management Group has been charged with the role of implementing an agreed Cadmium Management Strategy.

One integral component of the Cadmium Management Strategy for New Zealand is the Tiered Fertiliser Management System for the application of phosphate fertilisers. This system, developed by the fertiliser industry, was endorsed and adopted by the Cadmium Management Group as an appropriate means to ensure soil cadmium remains within acceptable limits over the next 100 years at least. It provides an upper threshold for agricultural soils, where no further soil cadmium accumulation will occur unless there is a detailed site specific investigation to identify risks and pathways for potential harm.

The Tiered Fertiliser Management System requires monitoring of soil cadmium with a series of soil cadmium trigger values which give rise to increasingly stringent controls on the soil cadmium accumulation through choice and rate of phosphate fertiliser products used. At all tier levels, soil and crop management options are available to influence cadmium bio-availability and exposure pathways. New Zealand specific research will inform and contribute to further development and enhancement of the Tiered Fertiliser Management System for controlling soil cadmium accumulation in New Zealand's agricultural soils.

Introduction and Background

Cadmium is an element which occurs naturally in the Earth's crust and consequently its soils. Typically average concentrations in soil range from 0.2 – 0.5 mg Cd/kg soil, however naturally occurring concentrations in some soils and rocks can be very much higher depending on a number of factors. Igneous and metamorphic rocks generally have lower concentrations, while sedimentary origins can give rise to much higher cadmium concentrations (International Cadmium Association, 2015). This variation in cadmium concentrations is reflected in natural sources of phosphate rock, from which phosphate fertilisers are derived. In some regions, as occurred with Nauru phosphate rock, cadmium concentrations can be at 100 mg/kg rock or more (with 14 % phosphorus this can be as high as 640 mg Cd/kg P) (Alloway & Steinnes, 1999).

When phosphate rocks are used to manufacture superphosphate fertiliser, there is no economically viable mechanism to remove cadmium and so the trace levels in the parent rock remain present in the fertiliser product (Van Kauwenbergh, 2002). With repeat application of phosphate fertiliser over many years, the trace levels of cadmium applied along with the phosphate fertiliser gradually accumulate in surface horizons of the soil, usually within the top 15 cm (Loganathan & Hedley, 1997).

Clearly there is a global requirement for increasing food production and therefore application of phosphate fertilisers to agricultural land. Management of the gradual accumulation of soil cadmium is a global issue.

Chemically cadmium has a similar ionic structure to zinc but unlike zinc, cadmium is not an essential trace element for life. Plants and animals have no known requirement for cadmium, however it is relatively easily available for uptake into plants. This provides a pathway for uptake into the food for animals and humans (Kabata-Pendias & Mukherjee (2007). However, uptake of cadmium by different plant species and even different varieties within a species can vary enormously (Grant, et al., 2008). A large number of other factors such as soil type, soil pH, levels of organic matter can affect the uptake of cadmium into plant parts, therefore, there is no simple direct relationship which can be drawn between soil cadmium levels and the cadmium content of food produced from that soil (Grant, et al., 1999).

Food consumption is not the only pathway for human exposure to cadmium. Smoking of cigarettes is another well recognised pathway for human exposure to cadmium. Cadmium can be released to the environment in a number of ways, including natural occurrences such as volcanic activity (into the atmosphere or into the sea). Inhalation from industrial sources can result in occupational exposure, while industrial atmospheric emissions in some countries can also give rise to gradual increases in soils and crops. Fossil fuel combustion, smelting operations, (particularly for non-ferrous metal ores), and municipal waste incineration are examples of industrial sources of atmospheric cadmium emissions. The application of municipal sewage sludge to land can give rise to increases in soil cadmium levels (World Health Organisation, 2010).

Food consumption however, remains one of the primary pathways for exposure and because plant uptake can vary considerably depending on the plant species/varieties and soil factors, it is food standards which provide the most consistent risk based management of cadmium exposure for the protection of human health.

The most recent, 2009 Total Diet Study for New Zealand, taking 25+ year old males as an example, shows that the estimated dietary exposure in New Zealand is moderate compared to the Total Diet Study results of trading partners (MAF, 2011). Figure 1, adapted from this study, also shows that the average diet for New Zealanders remains well below the World Health Organisation (WHO) Provisional Tolerable Monthly Intake of 25µg/kg Body Weight/month. Intake values per month were deliberately chosen rather than daily or weekly, to send a clear message that it is intake over the long term and not incidental (daily or weekly) intake levels which apply (FAO/ WHO, 2010).

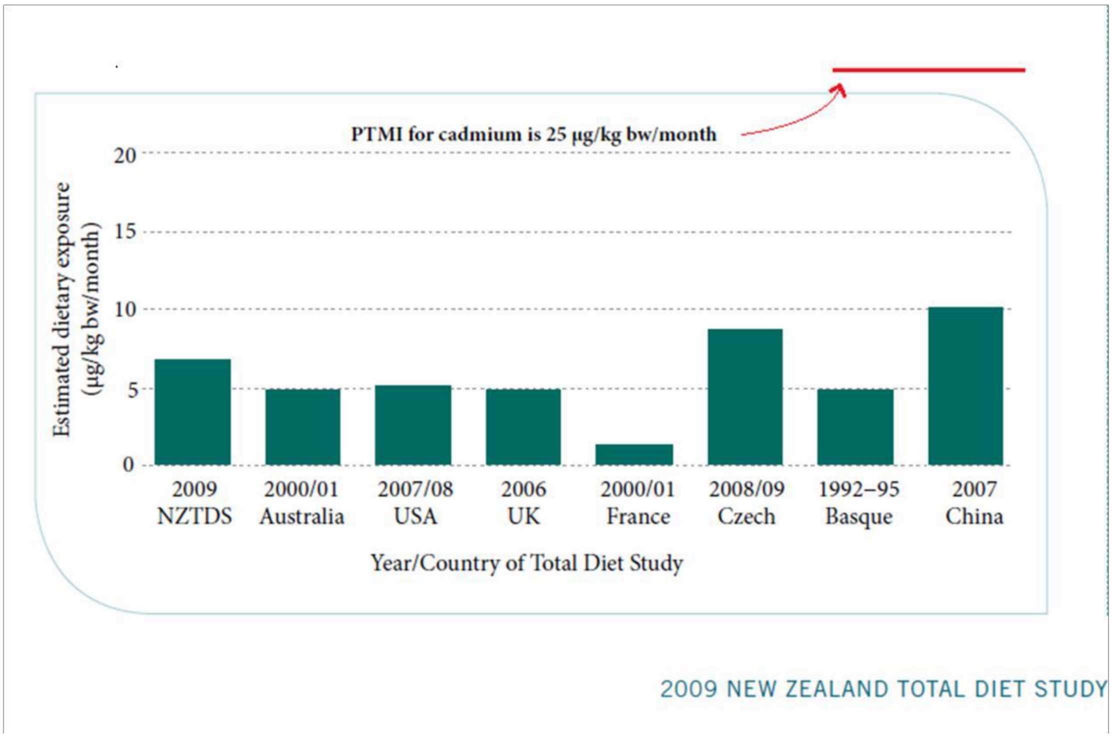

Figure 1: Comparative dietary exposure to cadmium (+25 year males)

In contrast to the WHO Provisional Tolerable Monthly Intake values, the European Food Safety Authority (EFSA) determined its own independent Tolerable Weekly Intake value for cadmium of 2.5 µg/kg B.W./week (EFSA, 2009). This value is equivalent to less than half that of the WHO recommendations and marginally greater than the current average intake values shown for China in Figure 1 above.

Both assessments used the same epidemiological dataset, but differences in methodology were applied in: i) the identification of the reference point biomarkers, ii) the statistical approach to account for the variability and uncertainty of the biomarker of exposure, iii) the methodology for transforming urinary cadmium concentrations into dietary intake values (EFSA, 2011).

In the 'Conclusions and Recommendations' of The Scientific Opinion of the Panel on Contaminants in the Food Chain (CONTAM) in the EFSA report (EFSA, 2009), it is stated under 'Risk Characterisation' that:

- *The CONTAM Panel noted that the mean dietary exposures in European countries are close to or slightly exceeding the TWI of 2.5 µg/kg b.w.*
- *Subgroups such as vegetarians, children, smokers and people living in highly contaminated areas may exceed the TWI by about 2-fold. Although adverse effects on kidney function are unlikely to occur for an individual exposed at this level, the CONTAM Panel concluded that exposure to Cd at the population level should be reduced.*

It could be concluded from these statements that when the EFSA adopted Tolerable Weekly Intake levels known to equal or exceed mean dietary exposures in European countries, with no recognised adverse health effects at double this recommended intake level, the EFSA is taking this approach to signal a desire for reduced cadmium in the environment.

Reducing cadmium in the environment is the aim the Cadmium Management Strategy. However, despite considerable international research, there is not yet any economically feasible means to eliminate cadmium from phosphate fertiliser products (Fertilizers Europe, 2014). For this reason the approach adopted by the fertiliser industry in New Zealand since the late 1990's has been to use blends of different sources of phosphate rocks to manage the cadmium levels to remain below the voluntary industry limit of 280 mg Cd/kg P (MAF, 2008).

The Cadmium Management Strategy in New Zealand

Controlling the cadmium concentration in phosphate fertiliser to ensure it never exceeds 280 mg Cd/kg P has been the first and most significant step in managing soil cadmium accumulation over the long term. This initiative has been followed by further review of cadmium in agricultural soils in New Zealand.

The Chief Executives' Environment Forum (CEEF) established a Cadmium Working Group, to investigate and assess the potential risks surrounding cadmium in New Zealand's agriculture and food systems, and to develop responses as required (MAF, 2008).

The Cadmium Working Group comprised: Ministry of Agriculture and Forestry (providing the role of Chair), Food Safety Authority, Ministry for Environment, Regional Councils (represented by Waikato, Bay of Plenty, Taranaki, Greater Wellington and Canterbury Regional Councils), Agriculture Sector Groups (represented by Dairy industry, Sheep & Beef New Zealand, Horticulture New Zealand and Foundation for Arable Research), Federated Farmers of New Zealand, Fertiliser Manufacturers Research Association of New Zealand and fertiliser co- operatives Ballance Agri-nutrients and Ravensdown.

The Cadmium Working Group developed the Cadmium Management Strategy, which in 2011 was approved and adopted by the CEEF (MAF, 2011). On delivery of the report the Cadmium Working Group was disestablished by the CEEF and the Cadmium Management Group formed, comprising essentially the same membership with the differences arising from changes in names and restructuring of some of the organisations involved. e.g. New Zealand Food Safety now resides within Ministry for Primary Industries and remains fully engaged with the strategy. The Cadmium Management Strategy provides for;

- Governance
- Monitoring
- Management
- Research
- Education.

All members of the Cadmium Management Group are engaged in implementing the strategy, and it was agreed the strategy is to stand for seven years and be reviewed at the end of this period to determine progress and future direction (MAF, 2011).

The Tiered Fertiliser Management System (TFMS)
The TFMS was developed by the fertiliser industry in New Zealand and approved and adopted by the Cadmium Working Group as an appropriate mechanism to control the accumulation of cadmium in soil. It remains a key component of the Cadmium Management Strategy now being implemented by the Cadmium Management Group.

The principles behind the TFMS are to measure and monitor soil cadmium levels on farms as part of wider routine nutrient management advice, and manage where necessary the choice of phosphate fertiliser and the rate of application. As soil cadmium levels increase the type and rate of phosphate fertiliser application becomes increasingly restricted. In this way soil cadmium accumulation is controlled to ensure that agreed soil cadmium levels will not be exceeded within the agreed time frames.

It was agreed by the Cadmium Working Group that the soil cadmium threshold at the top tier should be at a level below which any environmental, human health or trade risks would be created. What was more difficult to determine, given the wide range of soil guideline values applied under different circumstances internationally, was the soil cadmium levels which should equate to the soil trigger values in the TFMS. Initially, only three trigger values were envisaged and these were labelled 'a', 'b' and 'c'.

It was decided to commission an international expert review of the proposed TFMS, including recommendations for the soil cadmium values which should apply. This expert review was conducted by Dr Michael Warne, Centre for Environmental Contaminants Research, CSIRO, Australia.

Dr Warne determined that two critical soil cadmium Tier values must be decided. The first being the level at which restrictions on phosphate fertiliser use could be reasonably imposed on the farming community, and the second, the soil cadmium level at which no further accumulation is advised. In deciding these Tier values, the current estimates for soil accumulation in New Zealand and international soil guideline values were considered.

A third consideration which was not part of the terms of reference for the review, but which was resolved during the process was the appropriate time frames over which accumulation between these soil values 'a' and 'c' may be allowed to occur. A period of 'at least 100 years' was settled on.

The key recommendations for the appropriate soil cadmium levels were (Warne, 2011):

- The 'a' limit should be the 99th percentile of the New Zealand background soil concentrations of Cd which is 0.6 mg Cd/kg;
- The 'b' limit should be 1.0 mg Cd/kg;
- The 'c' limit should be 1.8 mg Cd/kg;
- An additional limit termed 'b2' which is 1.4 mg Cd/kg was also recommended.

These review recommendations were considered and formally accepted by the Cadmium Working Group, and it is intended that it should take at least 100 years for soil at the Tier 1 trigger value of 0.6 mg Cd/kg soil to reach the Tier 4 trigger value of 1.8 mg Cd/kg soil.

It was agreed that at the Tier 4 trigger value there should be no further net accumulation unless there is a detailed site specific investigation to identify risks and pathways for potential harm.

The Tiers presented in the TFMS (FANZ, 2014), are represented in Table 1 below.

Table 1: Summary Soil Cadmium Tier Levels in the Tiered Fertiliser Management System

	Soil Cadmium (mg Cd/kg soil)	**Management required**
Tier 0	**0.0 - < 0.6**	(Soil cadmium is within the range of natural background levels) No restriction on phosphate fertiliser
Tier 1	**0.6 - < 1.0**	Some restrictions on phosphate fertiliser rates, and implement appropriate management practices
Tier 2	**1.0 - < 1.4**	Choice and rate of phosphate fertiliser becomes a little more restricted and implement appropriate management practices
Tier 3	**1.4 - < 1.8**	Choice and rate of phosphate fertiliser is further restricted and implement appropriate management practices
Tier 4	**≥ 1.8**	No further cadmium accumulation allowed unless a detailed site specific investigation is done to identify risks and pathways for potential harm

Farm management actions which can be implemented as the Tier 4 trigger value is approached or exceeded include; use of very low cadmium fertiliser products, withholding P fertiliser altogether, ploughing the soil to a depth of at least 30 cm to mix the surface soil and dilute cadmium levels or consider a change in land-use to eliminate the pathway for uptake.

To maintain flexibility in farming options, farmers should consider the cadmium loading and reduce accumulation rates regardless of soil Tier values.

The TFMS is being implemented on farms which have a history of applying or are currently applying phosphorus at 30 kg/ha/yr or more. Farmers are encouraged to include soil cadmium tests in the routine soil fertility tests undertaken, and to test at least once every 5 years. Following the TFMS, the sampling of farm soils by the fertiliser industry, supplemented by regional council assessments, is building an improved understanding of the national distribution of soil cadmium levels in our agricultural soils.

Figure 1, shows that the vast majority of farms sampled have soils which remain within the range of natural background levels, i.e. Tier 0 (Cavanagh, 2014). Farms with a long history of phosphate fertiliser application, particularly on those soils with high phosphate retention which require higher rates of fertiliser applications, are likely to show higher soil cadmium levels. This is reflected in the dairy industry and orchard industry figures shown in Figure 1, below. The orchard land-use figures have been dominated by samples from Kiwifruit farms which have a high phosphate demand. Median soil cadmium concentrations for all land use rest within Tier 0, while 75%ile cadmium concentrations for dairy and orchards rest within the Tier 1 grouping. The 'non-specified' soil values showed the most elevated soil cadmium levels but as the number of samples is only three, and the land use is not specified, this category can be disregarded for the purpose of this comparison. Within this set of close to 4000 samples, only isolated cases occur in the Tier 3 or Tier 4 categories.

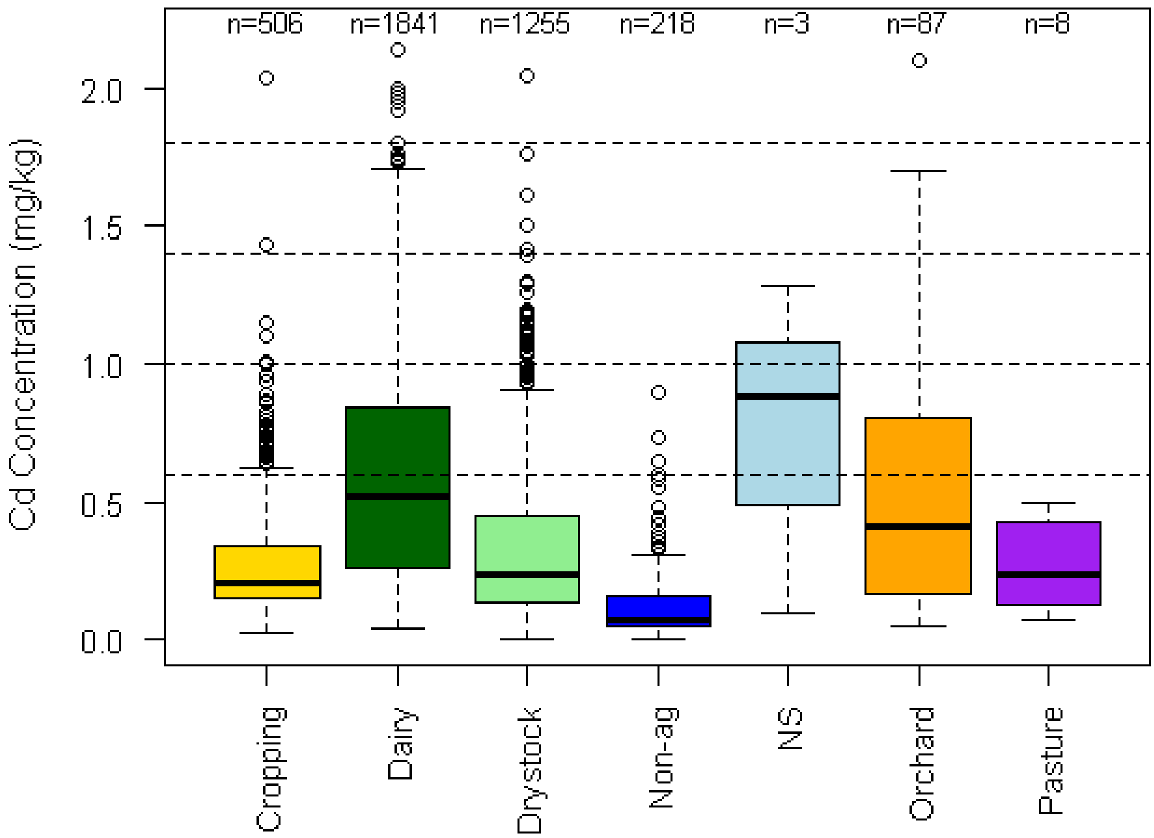

Figure 1: Distribution of soil cadmium concentrations in samples collected post-2006, classified by Land-use categories NS = land use not specified

For those farms which are identified as having soil cadmium levels in Tiers 1 - 3, the TFMS requires management of the choice and rate of phosphate fertiliser to be applied.

In practice, the mechanism to decide phosphate fertiliser product and rate can be achieved utilising the Fert Research Cadmium Balance (CadBal) Model. This is a mass balance model developed in New Zealand to estimate soil cadmium accumulation resulting from phosphate fertiliser application. As an alternative and more conservatively, product and rate can be selected simply by reference to a table presented within the TFMS, (see Figure 2 below).

Phosphate fertiliser products are categorised within the TFMS by the manufacturing process which influences the cadmium concentrate within these groups of products. Reactive rock phosphate (RPR) and sulphuric acid derived products, such as superphosphate do not have any opportunity for by-products to siphoned off during manufacture. Therefore all cadmium in the rock is retained in the final product. For these products the upper limit of 280 mg Cd/kg P is assumed. In reality, they are likely on average to be much lower than this due to the selection and blending of rocks with lower cadmium content.

For products derived by phosphoric acid, such as mono-ammonium phosphate, di-ammonium phosphate, or triple superphosphate there is an opportunity for some of the phosphoric acid produced to be streamed for alternative applications and thereby giving on average, a slightly reduced cadmium content in these products. For the purposes of the TFMS an assumed value of 220 mg Cd/kg P is applied.

For nitric acid derived products, such as NPK compound fertilisers, for example Nitrophoska or YarraMila complex fertilisers, the assumed cadmium content is 100 mg Cd/kg P. In reality, they are likely, on average, to be much lower than this.

The TFMS provides for a time period of at least 100 years for soils to accumulate from the Tier 1 trigger value of 0.6 mg Cd/kg soil to the Tier 4 trigger value of 1.8 mg cd/kg soil. The table in the TFMS takes a conservative approach when providing for this accumulation rate by assuming that all phosphate fertiliser product applied over that period contains cadmium at the maximum concentration allowed under the agreed values. In reality, the average concentration values, (verified by independent Fertmark auditing), are well below this voluntary limit (MAF, 2008). The assumptions used in the calculation of the soil accumulation provide for a standard soil bulk density of 1.0, a soil sampling depth of 15cm, (the definitive soil sampling depth adopted by TFMS) and no system losses of cadmium.

Using the assumptions given above, rates of phosphorus application have been derived for each of the soil cadmium tiers between 0.6 and 1.8 mg Cd/kg soil. Due to the typically lower cadmium content, higher rates of nitric acid derived product can be applied than phosphoric acid derived product. In turn, more phosphoric acid derived product can be applied than sulphuric acid or RPR product for any particular farm soil cadmium value.

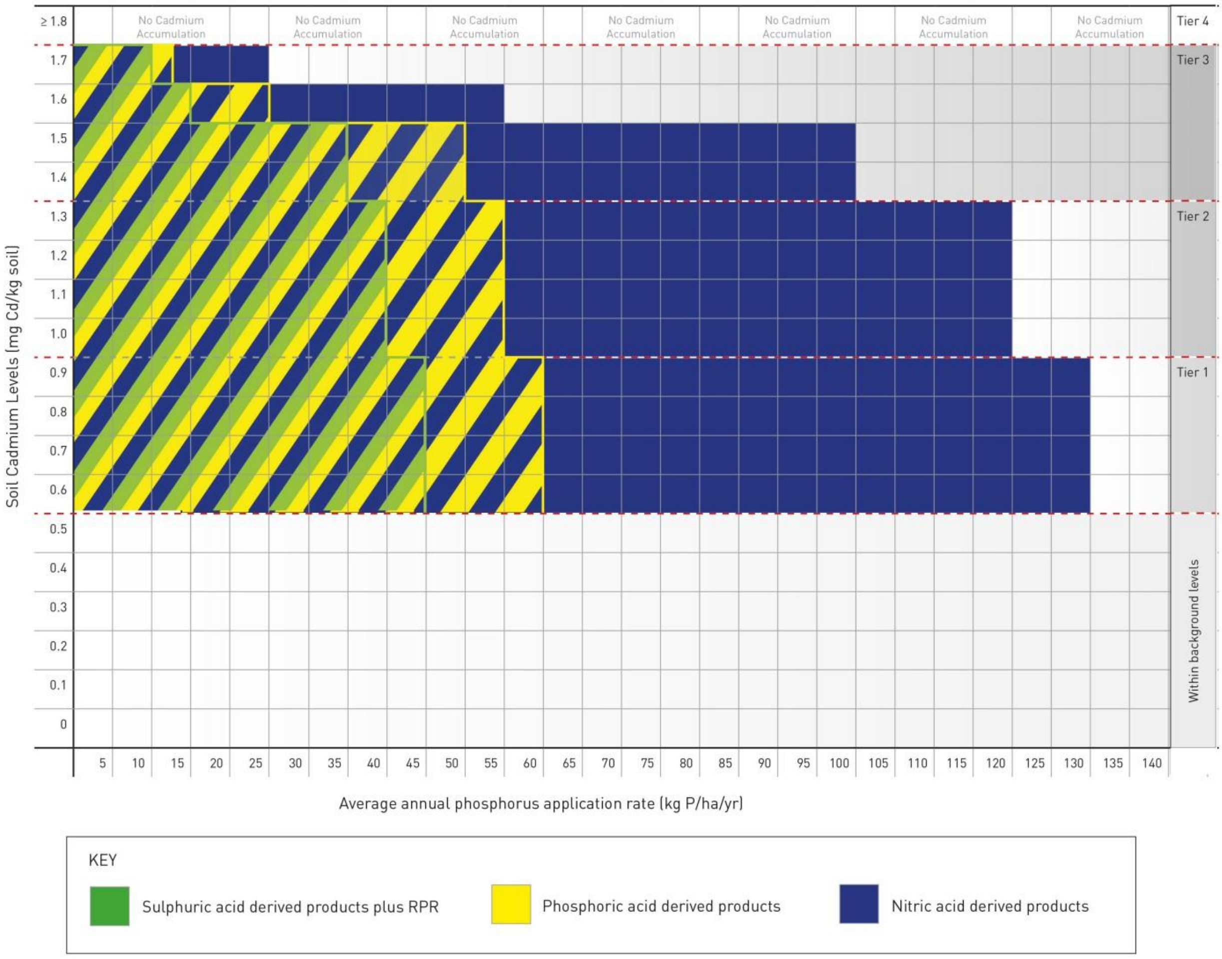

Figure 2: Product selection and maximum rate of average annual P application for soils at Tiers 1–4, following the Tiered Fertiliser Management System

The table utilised for the TFMS in effect provides for a maximum cadmium loading rate based on the assumptions of cadmium concentration in fertiliser, soil depth, soil bulk density, average annual fertiliser application rates and system losses. It is designed so that the cadmium loading is reduced at each increase in soil tier level and that it takes 'at least' 100 years to accumulate from a value of 0.6 mg Cd/kg soil to 1.8 mg Cd/kg soil. This maximum accumulation rate, based on the assumptions given above is presented in Figure 3. It shows a conservative approach to managing soil cadmium where the period for accumulation is extended well beyond 100 years.

Further, as noted above, the cadmium concentration in phosphate fertiliser is on average lower than that assumed in the TFMS. Using the average cadmium content reported by independent Fertmark audits of 180 mg Cd/kg P, but retaining all other assumption, the time to approach the Tier 4 limits when applying the moderately high phosphate application of 50 kg/ha/yr, is closer to 200 years as presented as a dashed line in Figure 3 below.

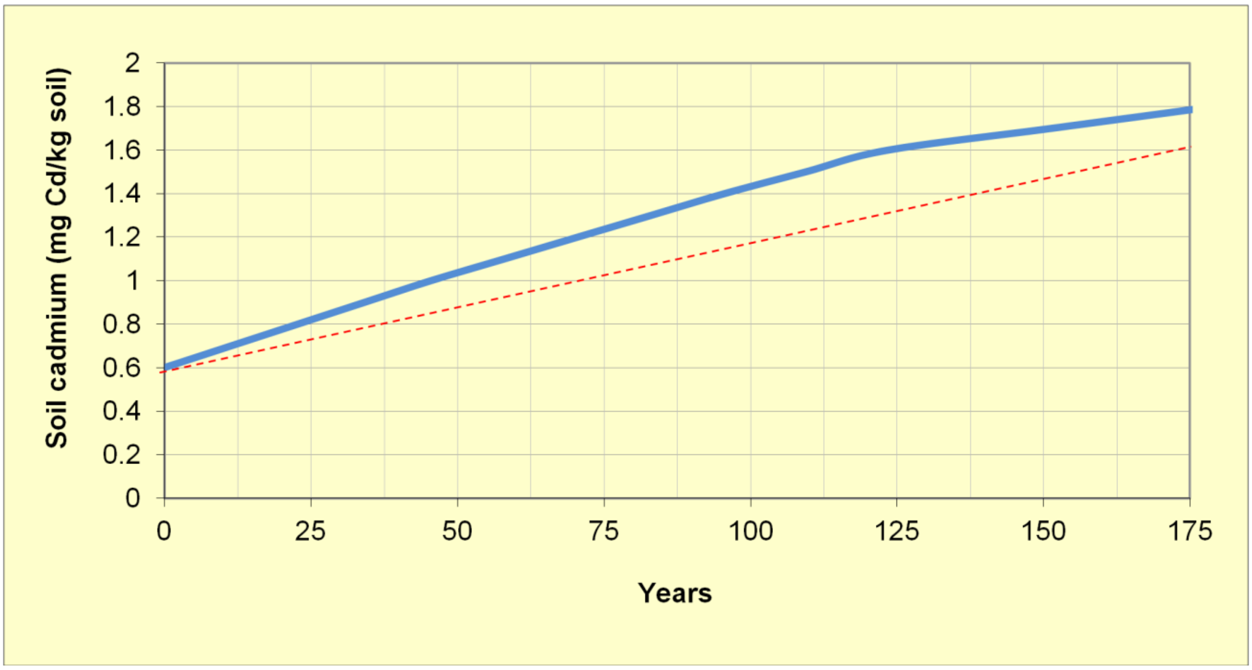

Figure 3: Anticipated maximum soil cadmium accumulation rate under the TFMS
(The broken line shows an accumulation rate assuming annual applications at 50 kgP/ha/yr with 180 mg Cd/kg P)

In addition to managing soil accumulation rates, the TFMS also encourages and supports the implementation of farm management practices which reduce the bioavailability and uptake of soil cadmium by plants.

Recommended management practices listed within the TFMS include:

- Measure soil cadmium levels once every 5 years
- Use phosphate fertilisers with lower levels of cadmium.
- Use crop varieties which demonstrate a lower risk of cadmium uptake
- Maintain soil pH at the upper recommended limits for crop type
- Maintain high organic matter in the soil
- Avoid fertiliser blends and irrigation water containing high levels of chloride
- Alleviate any zinc deficiency in the crop
- Avoid fertilisers which cause localised acidifying effects
- Phosphate fertiliser applications should be banded (and not broadcast) where possible

Research and Evaluation
As part of the Cadmium Management Strategy there is a requirement to undertake New Zealand specific science and a review the appropriateness of the measures being taken (MAF, 2011).

The programme is being overseen by the Cadmium Management Group. Soil monitoring is being undertaken by the Regional Councils as part of their statutory environmental monitoring programmes, and by the fertiliser industry as part of routine soil fertility monitoring. While a definitive soil sample depth of 15 cm applies to cultivated soil (mostly arable and vegetable crops), a screening sample depth of 7.5 cm applies to uncultivated soils (mostly pasture) to ensure the most rapid collection of data from across a wide range of soil types and landscapes. These sampling depths match the routine soil sampling depths calibrated to soil fertility advice. If specialised soil cadmium assessments at the same soil depths used by Regional Council monitoring were required, then industry contribution would be significantly curtailed. By encouraging soil cadmium to be included in routine soil sampling, farmer engagement, as part of the TFMS is greatly increased and soil data is most rapidly gathered.

Further specific research is being undertaken as, funding permits, to assess the influence of plant species and varieties on cadmium uptake under New Zealand specific conditions. This is an important aspect of the management of soil cadmium when following a risk based management process based on food standards. Soil health and function is being addressed through investigation on the potential impact of soil cadmium on key micro-flora such as rhizobia. International studies suggest that soil cadmium guideline values protective of human health will also be protective of environmental healt h, (CCMA, 1999) however New Zealand specific science to determine appropriate guidelines to maintain soil health and function is an important consideration of the review. Research is being undertaken to establish mitigation and remediation options with some promising indications being presented by soil ameliorants such as composts and lignite (Cavanagh, et al., 2014). New Zealand specific data for plant uptake, soil accumulation rates and cadmium cycling under different farm systems will also inform and improve the current Cadmium Balance (CadBal) model owned and operated by the Fertiliser Association and its member companies.

Putting soil cadmium into perspective

It is important to remember that soil cadmium levels in New Zealand agricultural soils are comparable to, or low compared to those observed internationally. For example surface soils from major agricultural production areas in the United States are reported to contain cadmium within the range of <0.01 to 2.0 mg Cg/kg soil and references other areas in North America and Europe which range from 0.06 to 4.3 mg Cd/kg soil up to 8.9 mg Cd/kg soil (Kabata-Pendias, 2011).

The levels of cadmium within the typical New Zealand diet are well within World Heath Organisation Provisional Tolerable Monthly Intake levels and do not present any risk to human health, environment or trade.

The Cadmium Management Strategy is designed to ensure the risks remain minimal over the next 100 years at least and is overseen by central government, regional councils, agricultural sector groups, the fertiliser industry and farmer representative bodies, all with an interest in maintaining productive healthy agricultural soils.

This issue is one of a number of environmental, health and trade issues which must be managed appropriately in New Zealand and around the globe. Greenhouse gas emissions, soil degradation, water quality degradation, nutrient loss, pesticide and agrichemical management, food safety and animal welfare are other examples. For soil cadmium many of these issues are being managed through improved science, enhanced efficiencies, good agricultural practices, more comprehensive monitoring and investigation of new technologies to responsibly deliver the essential services provided by agricultural production, within environmental limits.

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