SOIL CADMIUM – REVIEW OF RECENT DATA IN RELATION TO THE TIERED FERTILISER MANAGEMENT SYSTEM

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Abstract

Accumulation of cadmium (Cd) in New Zealand agricultural soils is a known long-term management issue. This accumulation is primarily driven through the incidental application of Cd contained in phosphorus fertilisers. Consequently, to manage soil Cd accumulation, the 'Tiered Fertiliser Management System' (TFMS) which imposes increasingly stringent fertiliser management practices as soil Cd concentrations increase, is an integral part of the national Cadmium Management Strategy.

The first step for implementing the TFMS is assessing on-farm soil Cd concentrations. Engaging with farmers to provide clear, sound information and advice is critical to the uptake of the programme. Many farmers have limited understanding of Cd and testing for it introduces a cost with few immediate benefits. Increasing regulation on soil contaminants has been signalled and voluntary uptake of responsible management of soil cadmium under the TFMS is encouraged and supported.

This paper provides a summary of national soil Cd concentrations from soil test data, including that collected on-farm under the first year of the TFMS, and perspectives from farmers and fertiliser industry staff as to the implications for managing soil Cd under the TFMS. Since 2007, around 3900 soil Cd samples have been analysed which form the basis of this update on our national soil Cd status. This includes approximately 1200 samples collected under the TFMS since its inception. Soil Cd concentrations reported over this time period range from <0.01 to 2.14 mg kg^{-1}, with large differences apparent between land use and region. The majority of soil samples that make up this database have been taken to 0-75 mm, or 0-100 mm soil depth, rather than the TFMS 'definitive' 0-150 mm soil sampling depth; hence results will be biased upward. The reason for this is that the TFMS allows for 'screening' to take place using conventional, routine soil fertility assessment so as to minimise initial additional labour and sampling costs. This increases the soil cadmium dataset while providing a precautionary approach for assessment of soil cadmium levels.

Introduction

Cadmium (Cd) is an impurity that is naturally found in phosphate rock, and consequently, in all phosphate fertilisers. Cadmium accumulation in agricultural land was first identified as a long-term management issue in the early 1990s when it was discovered that around 20% of sheep and cattle liver and kidneys exceeded the Maximum Permissible Concentration of 1 mg Cd kg^{-1} fresh weight (FW) as set by the Ministry of Health at the time (Loganathan et al., 2003).

This discovery led to the liver and kidney from slaughtered animals greater than 30 months of age being excluded from trade for human consumption. In addition, it also stimulated a significant amount of research during the 1990s, which identified that soil cadmium concentrations were similar or lower than those reported internationally, although there was a large degree of variation in Cd concentrations between soil types, plant species, and cultivars within species (e.g. Roberts et al., 1994; Gray et al., 2001; Gray & McLaren, 2005).

With increased awareness of soil cadmium as a long term management issue, the fertiliser industry implemented a self-governed approach to restricting the maximum permissible cadmium concentrations in P-fertiliser sold in New Zealand. Over the period 1995-1997, the maximum permissible Cd concentration in P fertiliser was progressively decreased, reaching the current maximum of 280 mg Cd kg^{-1} P in January 1997. Routine independent testing within the Fertmark quality assurance scheme has indicated this level has been consistently achieved, with an annual weighted average in recent years of 180 mg Cd kg^{-1} P reported by Rys (2011).

In recent times there has been renewed interest in Cd amid concerns from regional councils regarding historic and on-going Cd accumulation in agricultural land (Rys, 2011). This culminated in the formation of the Cadmium Working Group (CWG) in 2006 - a group comprised of representatives from local and central government, agricultural and horticultural bodies, crown research organisations, and the fertiliser industry. The CWG was tasked with assessing risks associated with Cd accumulation in rural food production systems, and developing a national cadmium management strategy for managing these risks over the next 100 years (Rys, 2011). In 2011 this strategy was released with the Tiered Fertiliser Management System being a core component (MAF, 2011).

Overview of the Tiered Fertiliser Management System (TFMS)

The TFMS provides primary industry with a framework to self-manage soil Cd accumulation over the long-term. The TFMS is based around five Cd management tiers separated by four soil cadmium concentration 'trigger values', as shown in Table 1.

Table 1. Cadmium management tiers and tier boundary trigger values with the TFMS (MAF, 2011)

Tier	Management action required	Cadmium concentration (mg/kg)	Trigger value (mg/kg)
0	Five-yearly screening soil test for cadmium status	0–0.6	
1	Application is restricted to a set of products and application rates to minimise accumulation, and landholders are required to test for cadmium every 5 years using approved programmes	>0.6–1.0	0.6
2	Application rates are further managed by use of a cadmium balance programme to ensure that cadmium does not exceed an acceptable threshold within the next 50 years	>1.0–1.4	1.0
3	Application rates are further managed by use of a cadmium balance programme to ensure that cadmium does not exceed an acceptable threshold within the next 50 years	>1.4–1.8	1.4
4	No further accumulation above the trigger value	>1.8	1.8

The basis of the TFMS to manage soil Cd accumulation is such that as soil Cd concentration increases, increasingly stringent P-fertiliser management conditions apply, to the point where at 1.8 mg Cd kg^{-1} soil, no further soil Cd accumulation is permitted without a site-specific risk investigation being carried out. Within lower Cd tiers, differentiated soil sampling strategies may be warranted to better quantify soil Cd status and variability within the farm, while P-fertiliser type and/or rate is restricted to manage soil accumulation within each tier.

The fertiliser industry has developed a proposed differentiated sampling strategy whereby 'screening' samples (0-75 mm) that return soil Cd concentrations above the Tier 2 trigger value of 1.0 ppm are then followed up with a 'definitive' soil sampling approach. This 'definitive' approach utilises deeper soil cores (0-150 mm) to provide a standardised approach that is consistent across tilled and non-tilled land. In addition, under 'definitive' testing, a minimum of six monitor paddocks within each land management unit are sampled to provide a more robust representation of the land management area. The deeper cores used in 'definitive' sampling is likely to result in a drop in soil Cd concentration compared to the 'screening' sample due to the dilution effect - although this effect may be less apparent in land regularly tilled since the soil Cd is likely to be more evenly distributed through the soil profile with repeat cultivation.

Observations following implementation of the TFMS

The TFMS was implemented within the fertiliser industry in 2011, initially with training and documentation to support field staff and farmers, with soil sampling on customer properties beginning in 2012. From the implementation of soil sampling in 2012 until the end of 2013, approximately 1200 soil samples have been collected and analysed under the TFMS by Fertiliser Association of New Zealand member companies Ballance Agri-Nutrients and Ravensdown. While this represents only a modest proportion of total agricultural/horticultural properties, this is a significant start in what is a long term management programme. In addition, it should be noted that:

- Not all farmers/growers have soil testing carried out annually; hence it will take some time for the number of properties participating within the TFMS to build.
- Not all farms need to be tested immediately and a repeat soil test within 5 years is not likely to show a reliable change, due to accumulation over this timeframe falling within the variation expected to arise from sampling or laboratory processes
- Within the fertiliser industry, soil sampling for Cd under the TFMS has been prioritised towards rural properties consistently applying a minimum of 30 kg P/ha/year, since Cd accumulation is likely to be greater for these more intensively farmed properties with a long history of higher phosphate applications
- Some farmers choose not to soil test at all, or prefer to deal with fertiliser / nutrient management advisors outside of the two main fertiliser companies, even though often their end purchase may still lie with either of these two companies
- It takes time to grow farmer confidence and some may not elect to participate immediately, instead deferring a decision until a later date.

With the roll-out of the TFMS, some general observations can be made on farmer responses to the management of soil Cd under the TFMS based on feedback from fertiliser industry staff and farmers. These observations can be grouped under the following two themes:

1. Farmers have some awareness of Cd as an issue, but generally limited understanding.

2. Farmers see Cd as a potential threat - it takes time to build farmer confidence as to why they should be testing for it, and anonymity and trust are important

Most on-farm discussions suggest that farmers have heard of cadmium and are aware of it as an issue, but have little in-depth knowledge. Typical feedback from fertiliser company field representatives can be exemplified by the comments as below:

"My customers have generally never thought much about it before - once I talk with them about it they are generally interested to know more, and they genuinely appreciated the discussion".

"Most that I have brought the topic up with have limited knowledge of cadmium. They are happy to listen and I would say 80% of those I have offered the test to have taken up the opportunity".

"I recently visited 5 farmers with the local Field Consultant - most of these farmers new little about cadmium – they were aware of some concerns, but unable to articulate the issues. They were all pleased to have us discuss the issues with them".

This general lack of understanding probably relates to the breadth of day-to-day operational and strategic farm management issues that farmers have to deal with and the long term nature of the issue. In addition, through various industry publications, many farmers are to some extent aware that the fertiliser industry has capped the maximum Cd concentration in its P-fertilisers, leading to comments from farmers such as *"the fertiliser industry already manages it* (Cd in its P-fertilisers) - *how much more do I need to be involved?".*

While most farmers have limited in-depth understanding of cadmium, there are exceptions to this. For example:

"My farm has never been cultivated - the pastures descend from those sown 100 years ago and it was always well fertilised by my father. So I would expect it (Cd) to be high in the topsoil. I'm using less P fertiliser now anyway, but if I have to reduce them I guess my only option is to plough it under".

"It's (Cd) something we need to keep an eye on. I've done tests on my property previously just for my own interest after hearing about it. Some of my levels are higher on the ash soils so I've changed to DAP in those areas".

Most farmers engaged on Cd and the TFMS have generally taken up the offer to undertake soil testing on their properties. As this can be a sensitive issue, this may not be an immediate decision and may take several discussions – *"most of the customers I have dealt with wanted an indication of the likelihood of their farms having high Cd levels before they would confirm they wanted tests carried out – eventually all bar one agreed to doing the tests".*

Farmer trust is important when engaging on the issue of soil Cd - some fear that the information could be used against them. In this respect, there is some advantage with the TFMS being implemented by the fertiliser industry as farmer owned co-operatives - *"these farmers were all comfortable with us holding their information – they trust us".*

Reinforcement that soil Cd results are for the farmers own knowledge to improve P-fertiliser decision making, and that they will be handled anonymously, is critical. Comments from farmers made to fertiliser industry field staff reflecting this aspect are as typified below:

"What do you want from it first?"

"How will the info be used and who has access?"

"I'm happy for it to be done if the results can't be traced back."

Ease of entering into the TFMS is an important aspect to consider. Most farmers are interested in participating so long as there isn't any significant additional cost or work required, which can prove to be a barrier to entry. In this respect, an initial 'screening' soil sampling approach as employed by the fertiliser industry allows for an easier pathway for farmers to enter the TFMS. This allows them to undertake a preliminary risk-assessment for soil Cd using the standard monitor transect approach to soil fertility sampling, thereby imposing minimal additional cost. However, where results have come back higher than anticipated and further investigation using a 'definitive' sampling protocol is warranted, there have been some objections to additional extra costs:

"All were keen to progress with 'definitive' sampling (0-150mm) - but they didn't want to pay for extra tests"

"Why would I pay for something that doesn't provide an immediate return?"

National soil Cd concentrations

The first report summarising New Zealands soil Cd status was that of Roberts et al. (1994). This report was based on data from 312 pastoral farms and 86 'native' (non-P-fertilised) sites. This report indicated that:

- The national mean soil Cd concentration for native sites was 0.2 mg kg^{-1} while for pastoral sites it was 0.44 mg kg^{-1}
- Across all sites, soil Cd ranged between 0.02-1.53 mg kg^{-1} Soil Cd concentration was strongly correlated to soil total-P concentration, indicating a correlation with P-fertiliser use
- Under pastoral agriculture land use, statistically significant enrichment of soil Cd levels occurred in 6 out of 8 soil groups surveyed
- Mean soil Cd concentrations were highest in Yellow Brown Pumice, Yellow Brown Loam and Peat soil groups (corresponding to Pumice, Allophanic and Organic soil orders) at 0.75, 0.70 and 0.69 mg kg^{-1}, respectively.

More recently, as part of CWG activity, Taylor et al. (2007) reviewed national soil Cd levels in a report commissioned by the Ministry of Agriculture & Forestry. This report was based on the results from 1794 samples collected and analysed over two main periods, 1989–1995 and 2000-2006. Including the data of Roberts et al. (1994) as a data subset, the report of Taylor et al. (2007) supported the findings of Roberts et al. (1994):

- The range of soil Cd concentrations was 0 (not detected)-2.52 mg kg^{-1}
- The national mean soil Cd concentration was 0.35 mg kg^{-1}
- The national mean soil Cd concentration for undisturbed (non-P-fertilised) sites was 0.16 mg kg^{-1}
- Soil Cd concentrations were influenced by land use. Dairying had the highest mean Cd concentration (0.73 mg kg^{-1}) followed by kiwifruit (0.71 mg kg^{-1}), berries (0.68 mg kg^{-1}), orchards (0.66 mg kg^{-1}), market gardening (0.46 mg kg^{-1}) and drystock pasture (0.40 mg kg^{-1}) all of which were above the national average. Cropping soils were reported mostly

to be below the national average of 0.35 mg kg^{-1}, possibly due to dilution with tillage as most samples were 0-75 mm or 0-100 mm samples.

- Regionally, the highest mean soil Cd levels were reported in Taranaki (0.69 mg kg^{-1}), Waikato (0.55 mg kg^{-1}) and Bay of Plenty (0.53 mg kg^{-1}) related to the predominance and long history of intensive land use (dairying, horticulture) in these regions, as well as soil type effects (e.g. high capital P-fertiliser requirements for soils of volcanic ash origin).

Since the report of Taylor et al. (2007) there has been an additional ~3900 soil samples collected and analysed for soil 'total' Cd, which form the basis of this national update undertaken for FANZ and MPI (Cavanagh, 2014). This is composed of the ~1200 soil samples collected under the TFMS by fertiliser industry field staff to the end of 2013, in addition to a separate fertiliser industry Cd dataset of ~1500 samples collected and analysed during 2007, and ~1200 samples that have been analysed for Cd by regional councils and Crown Research Institutes.

Soil Cd data collected over the period 2007-2013 and aggregated by land use is shown in Figure 1. Note that there are differences in land use classes as defined within this report and that of Taylor et al. (2007). In particular, 'cropping' in this report includes all tilled land, i.e. annual field crops including commercial vegetable production, forage brassicas, cereals, seed crops , while 'orchard' represents perennial horticultural tree and vine crops (kiwifruit, berries, pip and stone fruit etc).

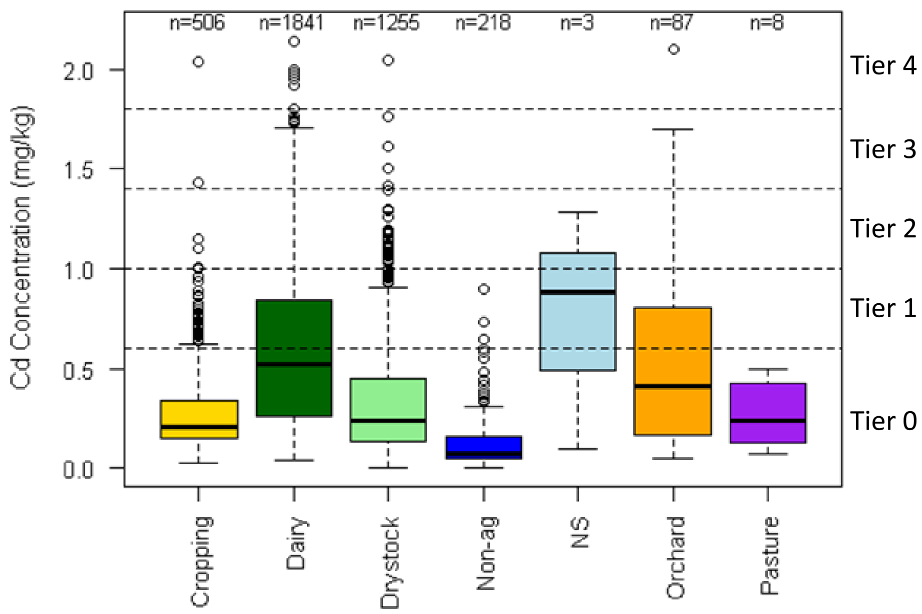

Figure 1. Soil 'total' Cd concentration of samples collected over the period 2007-2013, aggregated by land use (NS = not specified)

This latest, larger dataset indicates similar trends to the report of Taylor et al. (2007) in terms of Cd concentrations by land use. Dairying has the highest mean Cd concentration (0.59 mg kg^{-1}) followed by orchards (0.55 mg kg^{-1}). Cropping and drystock land use have lower mean soil Cd concentrations, presumably due to either lower historic annual P-fertiliser inputs, or the effect of subsoil mixing and dilution with tillage in the case of cropping land use.

Soil Cd concentration aggregated by region is presented in Figure 2. Consistent with that reported by Taylor et al. (2007) Waikato, Taranaki and Bay of Plenty regions have the highest mean Cd concentrations (0.74, 0.70 and 0.58 mg kg^{-1}, respectively). It is important to note that a direct comparison of Cd concentrations (e.g. by land use or region) between this current data set and that of Taylor et al. (2007) cannot be made, as the results are from different sampling locations. A valid comparison of changes in Cd concentrations over time can only be made when samples are collected from consistent monitoring sites.

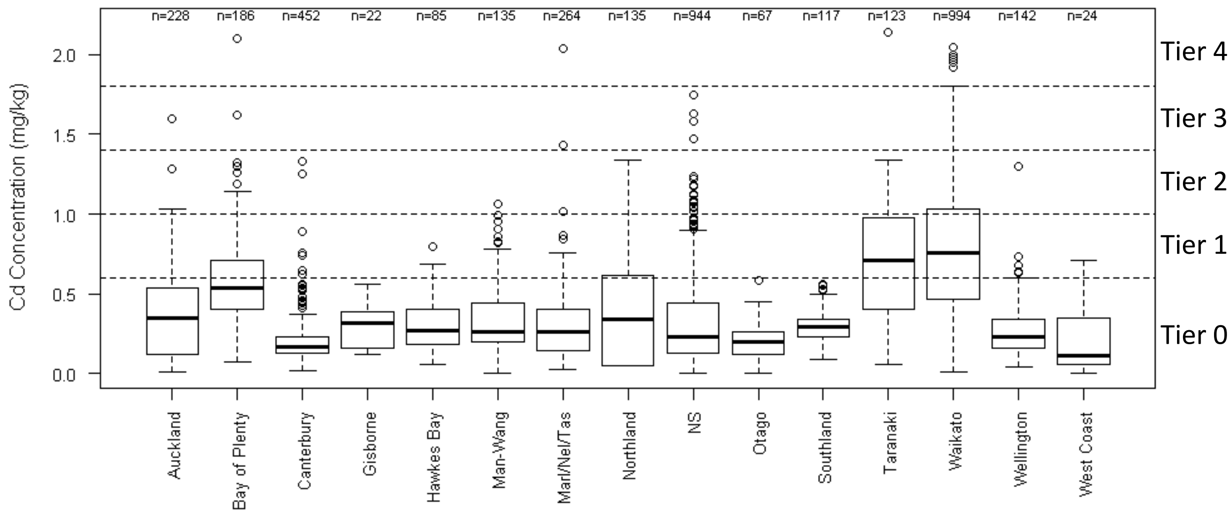

Figure 2. Soil 'total' Cd concentration of samples collected over the period 2007-2013, aggregated by region (NS = not specified)

In this post-2006 dataset around 25% of all samples analysed have been sourced from the Waikato region (see Figure 2). Given the higher Cd concentrations in the soils of this region, such large regional sampling bias has the potential to influence data should it be aggregated and assessed at a 'national' level.

Overall, soil Cd concentrations across all land uses and regions fall within the range 0 (not detectable)-2.14 mg kg^{-1}, with a national mean of 0.44 mg kg^{-1}. This is similar to that reported by Taylor et al. (2007) who gave a range of 0 (not detected)-2.52 mg kg^{-1} and a mean of 0.35 mg kg^{-1}. Notably, very few samples fall within Tiers 2-4 of the TFMS, although farmers should be factoring soil Cd accumulation into their P-fertiliser management decision making process regardless of which tier their property sits.

Summary

The national cadmium management strategy was released in 2011 with the TFMS being an important component to manage risk of on-going soil Cd accumulation resulting from P-fertiliser application. The fertiliser industry has implemented the TFMS, with soil testing beginning in 2012 following development of support material and field staff training.

Soil Cd testing under the TFMS by fertiliser industry staff between 2012 and 2013 has generated around 1200 soil Cd results from commercial farming properties. Feedback from fertiliser industry field staff and farmers suggests that farmers have some awareness of Cd but little detailed understanding of associated risks or potential implications of soil Cd accumulation. Voluntary participation within the TFMS has been successful in most circumstances, albeit with some concerns expressed with regard to confidentiality of results, including how the data will be used and by whom. While entry into the TFMS is eased through use of a simplified 'screening' sampling process, where more 'definitive' follow up testing is required this may present challenges resulting from additional costs and resources to implement it.

In total, since the last national Cd update in 2007 there has been around 3700 soil Cd samples analysed. Results from this most recent dataset are consistent with those reported in previous reviews of our national soil Cd status. Soil Cd concentrations ranged from <0.01 to 2.14 ppm with a mean of 0.44 mg kg^{-1}. Mean soil Cd concentrations were highest for dairying and orchard land use (0.59 mg kg^{-1} and 0.55 mg kg^{-1}, respectively). Mean soil Cd concentrations were highest in the Waikato, Taranaki and Bay of Plenty regions (0.74, 0.70 and 0.58 mg kg^{-1}, respectively). This is largely due to the predominance and history of intensive land use in these regions (higher maintenance P-fertiliser requirements) coupled with soil type effects (e.g. high capital P-fertiliser requirements for soils of volcanic ash origin).

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