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REVISION OF THE TIERED FERTILISER MANAGEMENT SYSTEM FOR SOIL CADMIUM

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Abstract

The Tiered Fertiliser Management System (TFMS) is a component of the strategy for long term risk management of cadmium for New Zealand agriculture and horticulture. The TFMS is intended to manage accumulation of cadmium due to the application of phosphate fertilisers to agricultural soils. In response to recommendations arising from a formal, external review of the Cadmium Management Strategy, the TFMS has been revised. The changes to the TFMS further reduce the very gradual soil cadmium loading to ensure soil cadmium concentrations remain at acceptable levels in New Zealand's agricultural soils over the very long term.

Key recommendations specific to the TFMS, as a component of the Strategy were to: revise the soil Cd trigger points to further reduce cadmium input from phosphate fertiliser; make the link between soil Tier values and fertiliser cadmium levels more explicit and in light of international initiatives and limits; and consideration be given to labelling of fertilisers for Cd content. Some changes introduced in response to feedback by the Cadmium Management Group are that the TFMS is no longer limited to just those fertiliser applications greater than 30kg P/ha/yr; the documented recommendations for agronomic good management practices which are known to reduce plant uptake of soil cadmium are to be presented in a separate document; and the principal purpose of the TFMS is brought to the fore.

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 0.1 – 0.5 mg Cd/kg soil, however naturally occurring concentrations in some soils and rocks can be much higher. Igneous and metamorphic rocks tend to show lower values, from 0.02 to 0.2 ppm whereas sedimentary rocks have much higher values, from 0.1 to 25 ppm. (International Cadmium Association, 2019). Some agricultural production areas have recorded soil cadmium as high as 10ppm and more (Howe *et al*., 2005; Paul & Chaney, 2017). This variation in cadmium concentrations is also reflected in the 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 greater (with 15 % phosphorus this can be as high as 640 mg Cd/kg P) (Alloway & Steinnes, 1999). New Zealand has a legacy of using Nauru phosphate rock as a source material for our phosphate fertilisers during much of the 20th Century. This has contributed to the gradual accumulation of soil cadmium in those production areas with a long history and high demand for phosphorus. Waikato, Taranaki and Bay of Plenty typically have higher soil cadmium than other regions of New Zealand,

(Abraham *et al.*, 2016). The fertiliser industry responded in the mid 1990's by setting an upper limit on cadmium concentration in phosphate fertilisers of 280 mg Cd/kg P.
Cadmium concentrations in New Zealand soils occur at levels which are comparable with our overseas trading partners (Kabata-Pendias, 2011). Although concentrations in currently used phosphate fertiliser are very much lower than in the past, a very gradual soil accumulation is attributed primarily to cadmium that is present in phosphate fertilisers applied to our soils to maintain production.

Phosphate fertilisers remain necessary to replenish soil phosphorus removed in saleable produce if primary production levels are to be maintained. To manage the risks associated with soil cadmium in New Zealand production soils, the Cadmium Management Strategy (CMS) was created. The CMS has the objective of ***ensuring that cadmium in rural production poses minimal risks to health, trade, land use flexibility and the environment over the next 100 years***, (Rys, G., 2020).

The CMS has five main pillars:

- Governance;
- Monitoring;
- Management;
- Research;
- Scanning (to identify new emerging issues).

The TFMS is a component of the CMS, within its 'Management' pillar and has been agreed by the Cadmium Management Group[1] as an appropriate mechanism for controlling soil cadmium accumulation. It has the principal purpose of managing phosphate fertiliser applications to control the accumulation of cadmium in agricultural soils.

The CMS was revised in 2019, after an independent review the previous year, (Mclaughlin and Miller, 2018). The TFMS has been amended as part of the revised CMS, taking into account recommendations from the review.

The Tiered Fertiliser Management System

TFMS is a voluntary scheme which involves the monitoring of soil cadmium levels on farms as part of routine soil fertility testing and nutrient management advice. It requires the control of phosphate fertiliser applications based on soil cadmium levels.

It is intended that soil cadmium accumulation will not increase from levels which might occur naturally (below 0.6 mg Cd/kg soil) to the upper threshold of 1.8 mg Cd/kg soil in less than 100 years. For any soils already at this threshold of 1.8 mg Cd/kg soil, no net accumulation of soil cadmium should occur unless there is a detailed site-specific investigation to identify risks.

[1] Membership of CMG comprises: Beef and Lamb NZ; Dairy NZ; Foundation for Arable Research; Horticulture NZ; Fertiliser Industry; Federated Farmers NZ; Potatoes New Zealand; Taranaki Regional Council; Waikato Regional Council; Bay of Plenty Regional Council; Greater Wellington Regional Council; Ministry for Primary Industries (including NZ Food Safety); Ministry for the Environment

Control of accumulation rates is achieved by using the farm's soil cadmium concentration to determine the appropriate choice and rate of phosphate fertiliser product. The phosphate fertiliser products are identified as belonging to one of three phosphate fertiliser groups, each category having an assumed Cd concentration per kilogram of phosphorus.

A key feature is that as soil cadmium increases the loading of cadmium from phosphate fertilisers decreases. Soil Cd levels are represented by Tier 0 through to Tier 4, (Table 1).

Table 1: Summary of soil cadmium tiers 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**	Restrictions introduced on choice and rate of phosphate fertiliser
Tier 2	**1.0 - < 1.4**	Choice and rate of phosphate fertiliser is more restricted
Tier 3	**1.4 - < 1.8**	Choice and rate of phosphate fertiliser is further restricted
Tier 4	**≥ 1.8**	No further cadmium accumulation allowed unless a detailed site-specific investigation is done to identify risks.

To implement the controls the TFMS uses the following table to direct the rate and choice of phosphate fertiliser product at each soil cadmium level (Fig. 1). For example, if the farm soil cadmium level is below 1.0 mg Cd/kg soil, superphosphate with an assumed cadmium concentration of 280 mg Cd/kg P, represented by green colour in the chart, can be applied at rates up to 45kg P/ha/yr. However, if the soil cadmium is currently between 1.2 and 1.4 mg Cd/kg soil the maximum rate of superphosphate would be 25 kg P/ha/yr. As signified by the yellow and blue product ranges, higher rates of phosphorus can be applied using fertiliser derived from phosphoric acid or nitric acid production methods. These products are assumed to have lower cadmium concentrations, (at maximums of 220 and 100 mg/kg P, respectively). When following the TFMS, any product certified to be within these assumed limits for cadmium concentration per kilogram of phosphorus, could also be applied at the appropriate rates for each category group.

The controls of phosphate fertiliser rate and choice commence when soil cadmium is at or above 0.6 mg Cd/kg soil. This value represents the 99th percentile of natural background levels. The Tier 4 threshold value of 1.8 mg Cd/kg soil calls for no further accumulation and represents; "*a balance between the need to protect human and environmental health for the long-term and the desire to not unnecessarily impact on farmer livelihoods until there is certainty that the limits are the most appropriate for New Zealand soil ecosystems and humans"* (Warne, 2011).

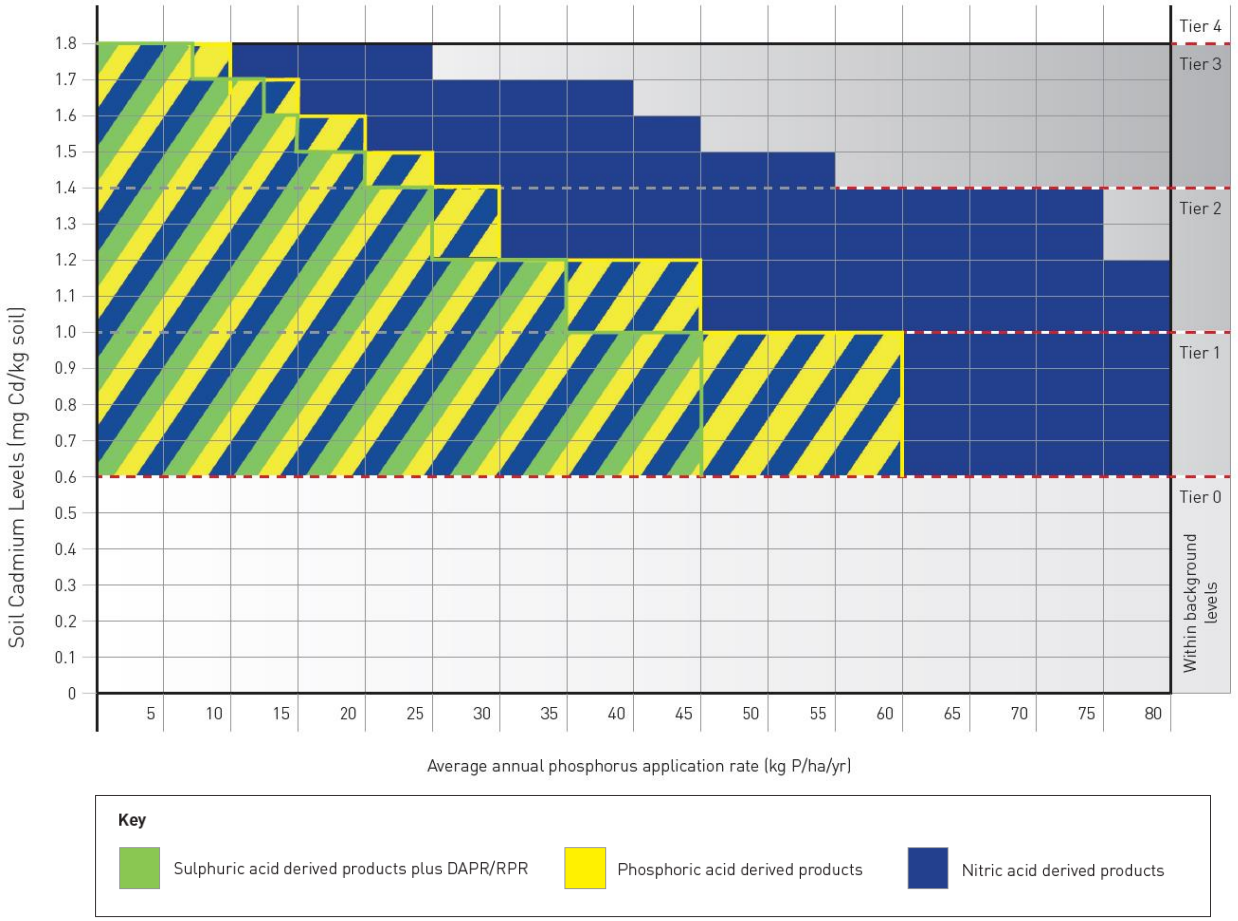


Fig. 1. Representation of choice and rate of phosphate fertiliser product when following the TFMS (revised version, Vers. 3, Dec. 2019)

The TFMS provides a very conservative approach in its assumptions, and if followed will extend the time to very much more than 100 years to reach 1.8 mg Cd/kg soil, if starting at 0.6 mg Cd/kg soil (99th percentile of natural background levels). A conservative timeline is presented because the TFMS assumes there are no losses of cadmium from the soil. However, losses do occur through a number of pathways including plant-uptake and harvest, leaching, and soil erosion. The TFMS assumes that in addition to no system losses, a phosphate fertiliser application is applied every single year and it assumes that in each year the fertiliser product contains cadmium at the maximum level for each of the three fertiliser product categories used. However, the cadmium levels in the fertiliser products are typically well below the assumed concentrations (Abraham, 2016). Hence, soil cadmium accumulation will typically be very much slower than is assumed when following the TFMS, extending the time-line to well beyond 100 years.

Review of the Cadmium Management Strategy, and revision of the TFMS

The formal, external review of the Cadmium Management Strategy in 2018 gave rise to a number of recommendations (McLaughlin M, Miller, D., 2018). These recommendations and the reasons for them have been considered by the Cadmium Management Group, and the Cadmium Management Strategy has been revised accordingly (Rys, G., 2020). As a component of the Cadmium Management Strategy there were three specific recommendations and two indirect recommendation, which applied to the TFMS. These review recommendations, the issues relating to these recommendations and subsequent responses are discussed below. Several additional changes were also introduced by the Cadmium Management Group.

Recommended amendments to the TFMS

The review recommendations which applied directly to the TFMS were:

1) The Tiered Fertiliser Management Strategy be revised and fully implemented for all farmers and growers whose soils are in Tiers 2 and above, (Review Recommendation 3).

2) Revision should consider making the link between Tier exceedance and fertiliser cadmium quality more explicit, (Review Recommendation 3).

3) The trigger points be revised to lower cadmium input levels, (Review Recommendation 3). [It is noted this recommendation relates to Tier 2 and above, where the review makes the observation that at present most dairy farmers are applying 30-40 kg P/ha/yr. Using the 2011TFMS thresholds there is no [*significant*] change in fertiliser Cd concentration until the soil is mid-way through Tier 3 at a soil Cd level of 1.5 mg Cd/kg – the trigger points should be revised to lower values to reduce rates of Cd addition to soil[2]].

4) Indirectly related to TFMS but with implications for it, labelling of fertilisers to include cadmium content should also be considered, (Review Recommendation 3).

5) Indirectly related to TFMS but with implications for it, to reduce the voluntary limit for fertiliser to less than 280 m Cd/kg P, (Review Recommendation 9).

Response to Review Recommendations

1) The review recommendation to implement the revised TFMS to all farmers and growers whose soils are at Tier 2 and above.

This recommendation presupposes that those farms Tier 2 or higher are already identified (with a mean soil cadmium concentration (0 -15cm) of 1.0 mg Cd/kg or higher). A considerable effort has been undertaken as part of the CMS, to monitor and assess soil cadmium levels across New Zealand. It has been identified that the regions with a long history of farming, with soils that have a high phosphorus demand, such a Waikato, Taranaki, and Bay of Plenty typically have

[2] paragraph 1, page 31 of the Review of the New Zealand Cadmium Management Strategy (McLaughlin and Miller, 2018)

elevated soil cadmium relative to other regions of New Zealand. The available data on soil cadmium levels in primary production land identified that in 42 of the 62 territorial authorities sampled, no farms were at Tier 2 or higher, (Fig.2), (Abraham *et al.*, 2016).

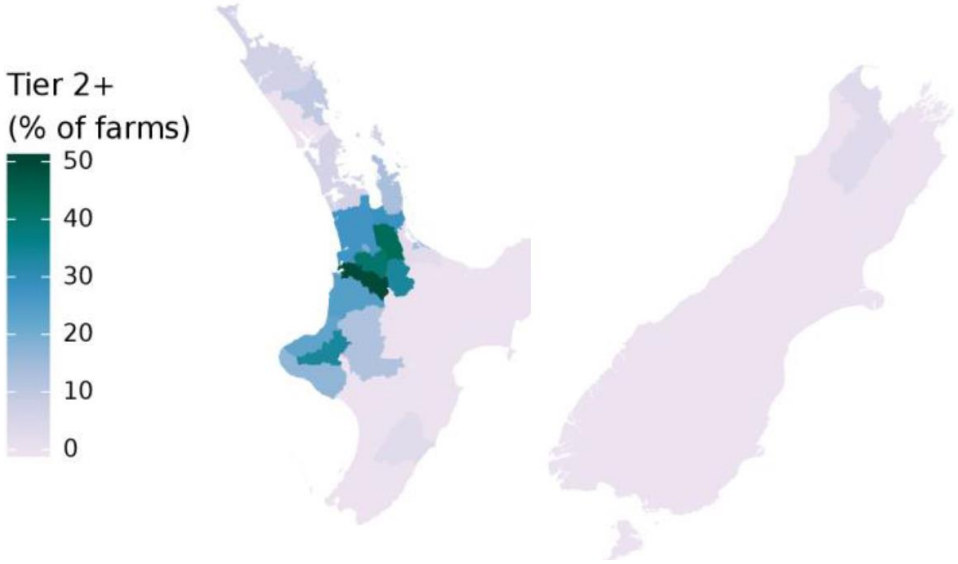


Fig. 2. Percentage of sampled farms within each New Zealand territorial authority that had soil cadmium concentrations in Tier 2 or above (1.0 mg Cd/kg or higher).
(Source: adapted from Abraham, *et al.*, 2016)

To support the recommendation to implement the TFMS on all farms identified at Tier 2 or higher, soil sampling for cadmium is being introduced as a voluntary routine analysis (unless farmers specifically opt out) when conducting soil tests (0-7.5cm) for soil fertility and fertiliser recommendations in the identified known 'legacy' areas of Waikato, Taranaki and Bay of Plenty. The revised CMS requires annual reporting to the Cadmium Management Group on the number of farms tested, results and recommendations.

2) The review recommendation to consider making the link between Tier exceedance and the assumed fertiliser cadmium content more explicit was undertaken.

Consensus was that greater transparency on the conservative assumptions is desirable. The recommendation has been addressed by including the assumed Cd concentration in the fertiliser categories in Table 2 of the TFMS (shown in this paper as Fig 3). The assumed upper limit is applied to each category group, and the Table providing the choice and rate of phosphate fertiliser at any given soil cadmium level is based on the assumption that all fertiliser applied will have cadmium concentrations at this upper limit. To ensure the upper limit of 280 mg Cd/kg P is never exceeded different sources of phosphate rock are sought and if necessary blended during manufacture of superphosphate in New Zealand.

The long-term average reported by Abraham *et al*., 2016, for phosphate fertiliser products was 184 mg Cd/kg P, roughly 66 % of the assumed maximum. With greater transparency in the assumptions used, the revised TFMS includes the option to apply fertiliser at the appropriate rate using these categories, provided the phosphate fertiliser product is certified to have a cadmium

content within the assumed maximum limit. This means there is now provision, for example, for a phosphoric acid derived fertiliser product to be applied at the rates stipulated for nitric acid products, provided it can be certified to meet the assumed upper limit of 100 mg Cd/kg P which applied to nitric acid derived products. Similarly, a superphosphate product certified to be at less than 220 mg Cd/kg P would be appropriate to apply at rates provided for in the phosphoric acid derived products. This not only maintains the objectives of the CMS but provides an added incentive for supply and transparency of lower cadmium products.

Product group for phosphate fertiliser	Assumed upper limit for cadmium concentration (mg Cd/kg P)	Phosphate fertiliser products
Direct Application Phosphate Rock	280	DAPR / RPR (Direct Application Phosphate Rock/ Reactive Phosphate Rock)
Sulphuric Acid Derived Products	280	Superphosphate Sulphur Super Potash Super Serpentine Superphosphate Superphosphate blends
Phosphoric Acid Derived Products	220	Triple Superphosphate DAP MAP
Nitric Acid Derived Products	100	Compound Fertiliser Prills

Fig 3. Revised Table 2 of the TFMS showing the assumed upper limit for cadmium concentration in the respective fertiliser categories. Commonly used products are presented for each category, and any specific product which has a 'certified' or 'declared' value for cadmium concentration, may be applied at the rate appropriate to the upper limits shown in the table.

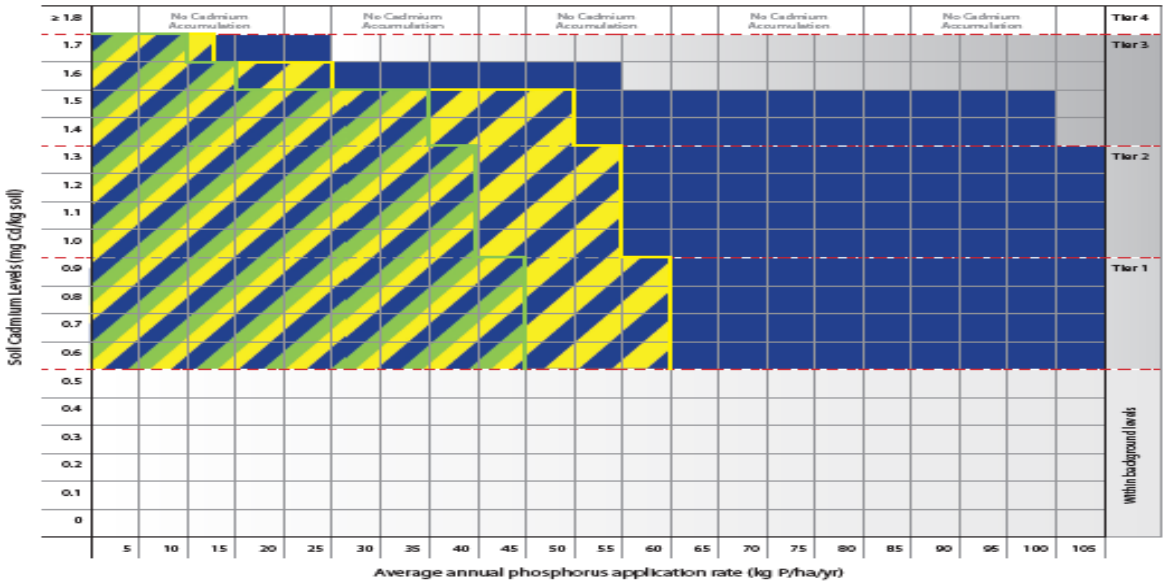
3) The review recommendation for trigger points to be revised to lower cadmium input levels.

It was explained that at Tier 2, (1.0 -1.4 mg Cd/kg soil) and Tier 3 (1.4 -1.8 mg Cd/kg soil) where farmers are applying 30-40 kg P/ha/yr, there was only relatively small adjustment to fertiliser choice or rate, to reduce soil cadmium loading, until mid-way through Tier 3, at a soil Cd level of 1.5 mg Cd/kg.

The choice and rates of fertiliser for the 2011 version of the TFMS, were implemented to be consistent with the agreed accumulation rates following the independent review of the TFMS at that time (Warne, 2011). The principle was that it should take at least 100 years to reach the upper tier values and as soil cadmium levels increases, the rate of accumulation should decrease to the point of nil net accumulation at 1.8 mg Cd/kg soil.

The current review recommendation has been addressed by making a considerable further reduction, (up to 60 % reduction in part of Tier 3, and 45% reduction in part of Tier 2) relative to the previous permitted phosphorus application rates. An additional stepped reduction within both Tier 2 and Tier 3 (Fig. 4) was also introduced and these amendments have increased further the time it will take to reach the upper soil threshold of 1.8 mg Cd/kg soil.

a)



b)

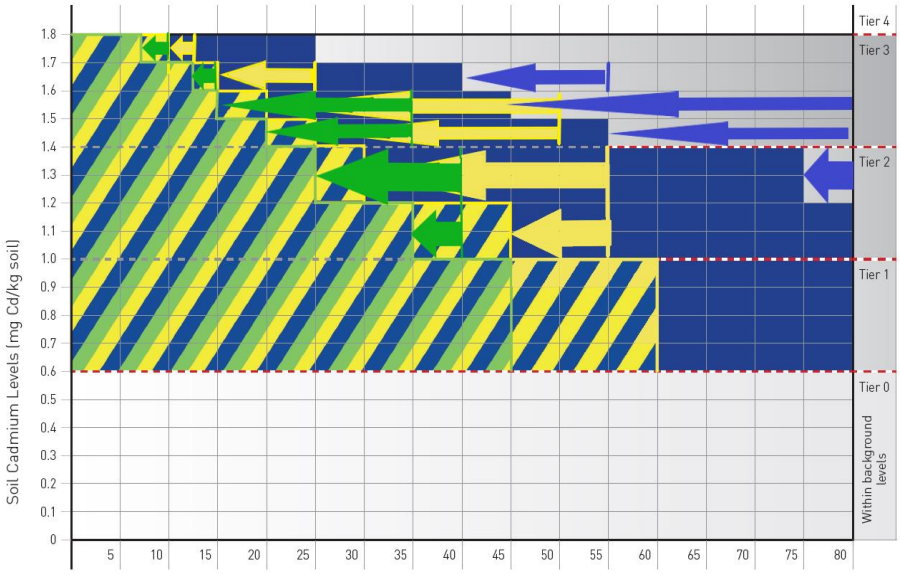


Fig. 4. Reduction in phosphorus fertiliser rates show by the green, yellow and blue arrows, as they apply for each product category, when comparing:

a) the previous 2011 version of TFMS with

b) the revised version of TFMS, where significant reduction have been introduced at Tier 2 and 3, along with an additional stepped reduction within these Tiers.

4) The review recommendation to consider labelling of fertilisers to include cadmium content was undertaken.

A number of difficulties arise if cadmium labels are applied for the different products within these TFMS categories. Firstly, the cadmium content of fertiliser products can vary considerably and is dictated by the cadmium content of the phosphate rock from which the fertiliser product is manufactured. It can vary from shipment to shipment. To keep shipment loads entirely separate and labelled accordingly would require a significant increase in storage capacity, so it is

impractical to provide anything other than a maximum value for broad categories of products, as is presented currently in the TFMS.

Secondly, labelling of cadmium content for each product would introduce consumer guarantee implications if there is an occasional exceedance of the declared concentration. Consequently, any label would require a maximum value to be applied for each product range. Once again, the assumed maximums are the basis of the TFMS as it currently applies. The TFMS is very conservative, and as discussed above, if the TFMS principles are applied on the basis of typical concentrations, this would instead increase phosphate applications and increase soil cadmium loading.

The farmer owned cooperatives consistently seek the lowest cadmium options available at any one time, as it is in the farmers interest to do so, but the TFMS controls are applied based on a very conservative, "worse case" situation. Although it may be attractive for marketing purposes to label the fertiliser products with lower cadmium levels, there are very practical reasons why the labelling of the cadmium concentration in fertiliser products has not been adopted for application of the TFMS.

5) The review recommendation to reduce the upper limit of cadmium in fertiliser from 280 mg Cd/kg P to a lower value is indirectly related to the TFMS.

The basis of this recommendation is believed to be the acknowledgment that industry is consistently achieving cadmium concentrations which are lower than the current industry agreed limit, plus a desire to demonstrate a more favourable value relative to international limits.

International approaches introduce a range of different limits in the cadmium content of fertiliser products. However, international approaches are not linked to the choice and rate of application of these products in the way the TFMS is.

The European Commission has recently introduced legislation for 'CE marked' product with limits on cadmium content of 60 mg Cd/kg P_2O_5 (equivalent to 137 mg Cd/kg P) to encourage the 'Circular Economy' through recycling of waste products, and to encourage development of decadmiation technologies. However, the European Commission legislation also allows for continued importation of product without using the CE Mark, based on national standards. (European Commission, 2019).

In New Zealand the manufacture and use of superphosphate is a key consideration, not just for the phosphorus nutrient but for the equally important sulphur it provides. The source and supply of raw material has to strike a suitable balance for a range of manufacturing quality criteria. Cadmium content is just one of the criteria. For example, product hardness, phosphorus concentration, calcium carbonate content, organic matter content, odour, heavy metal content (including cadmium) all vary depending on the source material and must be managed to ensure suitable production characteristics. While the lowest cadmium product available is always sought, there is inevitably some variability. As discussed above, despite consistently manufacturing to cadmium levels below the declared maximum of 280 mg Cd/kg P, there are commercial and legal risks if a lower limit is declared but cannot be met.

At time of writing the industry average is approximately 140mg Cd/kg P, (close to the European CE marked value), but depending on market and supply circumstances it cannot be guaranteed to always remain at this level. After careful consideration the option to reduce the industry agreed limit to less than 280 mg Cd/kg P has not been adopted. However the commitment remains to produce superphosphate at the lowest cadmium levels feasible, and these will be reported as part of the Cadmium Management Strategy.

Four additional changes implemented

6) Removal of the reference to using the CadBal model to determine phosphate fertiliser choices and application rates.

The CadBal model was developed for the Fertiliser Association of New Zealand (FANZ) by Roberts & Longhurst (1996) and updated in 2005. CadBal is a simple mass balance model, operating at farm scale, and allows the user to estimate the time for soil to accumulate cadmium to any given concentration. It enables the calculation of the maximum concentration of cadmium permitted in fertiliser or biosolids if restricting soil accumulation to a specified limit over a specified time-frame. It provides for a range of soil types and production systems and includes the option for user defined settings for each of the parameters used. The model takes into consideration the cadmium loading from fertiliser, biosolids, water or atmospheric deposition, and also system losses via the harvest of saleable product, leaching and surface erosion.

The initial version of the TFMS provided for the CadBal model to be used to make a phosphate fertiliser recommendation. This enabled a more detailed assessment taking into account site specific information, as an alternative method for deciding phosphate fertiliser choice and rate, (compared to Fig. 1, above).

At 2019, the CadBal software no longer functioned on modern computer operating systems, and new science and information on plant uptake and leaching losses needs to be introduced to the model. The CadBal model is now under review and redevelopment. As a consequence, its application has been removed from the current version of the TFMS.

The renewed development of the model, introducing the best science information available, will help to inform estimates of cadmium movement in the agricultural system. Through a better understanding of the mass balance of cadmium in agricultural systems, it is hoped to understand what loading levels may need to be achieved to ultimately result in no net accumulation. If the requirements for no net accumulation can be achieved, the TFMS will no longer be needed. Until such time as net nil accumulation can be reasonably achieved, the revised TFMS provides for a very conservative approach to control accumulation of soil cadmium (assuming no system losses and assuming maximum cadmium content in fertiliser products). The control on accumulation rates will ensure the agreed soil limits are not exceeded within the agreed timeframes.

7) The TFMS is no longer limited to just those applications greater than 30kg P/ha/yr.

The initial version of the TFMS targeted farming systems most likely to cause accumulation of soil cadmium, and the criteria chosen to facilitate this was an annual phosphorus demand of 30

kg P/ha/yr or greater. During discussion on review of the TFMS, it was decided that the recommendations should apply to all phosphate fertiliser recommendations.

There is no longer a specification for a farm average of 30 kg P/ha/yr before applying the TFMS. In the application of the TFMS a routine soil fertility monitoring programme should include soil cadmium, (0-7.5cm) at least once every 5 years.

8) Removal of recommendations for agronomic good management practices (which are known to reduce plant uptake of soil cadmium).[3]

Management of soil cadmium in agricultural soils applies two separate principles. These are:
a) control the soil cadmium accumulation, and b) control of the factors which influence the uptake of soil cadmium into plants. Plant uptake is the primary pathway to entering the food chain.

Controlling the factors which influence uptake is especially important, as there is no simple direct relationship between soil cadmium concentration and plant uptake. Due to the strong influence of species or variety, and the influence of a number of soil factors, non-compliance with food standards can occur in soils with low soil cadmium. In contrast, crops grown in soils with elevated soil cadmium may still comply with food standards. (Grant, *et al*., 2008); Cavanagh, *et al*, 2017)

The Cadmium Management Group recommended that the agronomic advice and support for priority produce be separated out from the TFMS and be provided through dedicated information booklets, and a specialist communications programme.

The development of dedicated information on managing plant uptake of cadmium is currently being undertaken by a subcommittee of the Cadmium Management Group. While being New Zealand focussed it is anticipated the information will be entirely consistent with advice which is available overseas, such as, for example, the Australian Cadmium Minimisation Programme (NCMC, 2007).

9) The principal purpose of the TFMS, which is to address the accumulation of soil cadmium, is stated more clearly at the start of the documents

In keeping with the decision that management of plant uptake of cadmium should be addressed by dedicated information booklets, it was recommended by the Cadmium Management Group that the principal purpose of the TFMS is clearly stated. That is, to control the accumulation of soil cadmium. The initial version of TFMS, released in 2011, included agronomic recommendations to help reduce plant uptake, however if this information is provided by dedicated information series, this dual purpose of the TFMS is no longer required.

Never-the-less, due to the importance of good agronomic practices and awareness of factors which influence plant uptake regardless of soil cadmium concentration, a brief reference has been retained to advise that:

[3] This step is consistent with Cadmium Management Strategy Review recommendation 6: increased emphasis on managing plant uptake.

In addition to managing fertiliser, a number of other actions may be important for farmers or growers.

- *Choice of crop or plant variety (plant species and variety can have a significant effect).*
- *Follow farm practices that minimise uptake (e.g. management of pH, organic matter, trace element levels, fertiliser placement).*
- *Monitoring soils to understand characteristics that influence plant uptake.*
- *Monitoring higher risk crops, to understand the risk of exceeding food standards under local conditions.*

The revised TFMS states clearly in the introduction that, it has the principal purpose of: "*managing phosphate fertiliser applications to control the accumulation of cadmium in agricultural soils*"

The Strategy is intended to be reviewed once more after a further seven years.

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