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INVESTIGATING THE CADMIUM STATUS OF A WAIKATO DAIRY FARM

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Abstract

A 102 ha Waikato dairy farm on an Allophanic soil (average Olsen P 44, pH 6.3) near Morrinsville, with a long history of superphosphate use, was selected to carry out sampling for soil and plant cadmium (Cd) in a high number of paddocks. In November 2011, soil Cd levels in each paddock averaged 1.36 mg/kg (range 0.67 - 2.05 mg/kg) at 75 mm depth and 0.85 mg/kg (0.54 - 1.33 mg/kg) at 150 mm depth. This represented a 38% reduction in soil Cd levels from the deeper compared with the shallower sampling. At 150 mm sampling depth in August 2013, soil Cd levels averaged 0.79 mg/kg and ranged from 0.29 to 1.38 mg/kg. Because the soil Cd levels in the “screening” samples at 0 - 75 mm depth averaged more than 1 mg/kg, the farm was categorised as requiring further “definitive” sampling at 0 – 150 mm depth. Sampling at 0 – 75 mm depth placed the average farm soil Cd in Tier 2 of the Total Fertiliser Management System (TFMS). There was a moderately strong relationship (r^2 = 0.48) between soil Cd levels sampled at 75 and 150 mm depth. This relationship supported the sampling of paddocks for soil Cd at 75 mm depth as part of the sampling for soil nutrient levels to determine whether further “definitive” sampling was required at 0 – 150 mm depth.

There was a very weak relationship (r^2 = 0.05) between soil Cd sampled to 150 mm and plant Cd (12 -198 µg/kg) in November 2011. In August 2013, soil Cd at 150 mm depth was moderately strongly related (r^2 = 0.50) to soil total P (mean 1597 mg/kg, range 616 – 3976 mg/kg) but weakly related (r^2 = 0.02) to soil Olsen P (mean 31 µg/ml, range 14 – 112 µg/ml).

In four paddocks, mean soil Cd levels declined from 1.30 mg/kg at 0 - 100 mm sampling depth to 1.18 mg/kg at 0 - 300 mm to 0.47 mg/kg at 0 - 500 mm.

Introduction

Cadmium (Cd) is a heavy metal that is present in the phosphate rock that is used to manufacture phosphorus P fertilisers such as superphosphate. From fertiliser application, Cd accumulates in soil and is mainly directly ingested by animals from soil contamination of plant tissue where it is stored mainly in the kidneys or is retained in grains and vegetables. The 2009 NZ Total Diet Study showed that dietary Cd intake is well below the Provisional Tolerable Monthly Intake (Abraham *et al*. 2016).

To manage soil Cd levels on farm, the Fertiliser Industry has developed a Tiered Fertiliser Management System (TFMS) which has five tiers (Sneath 2015). Initially, soil Cd levels at 0 – 75 mm are sampled from 5-10 paddocks where soil nutrient levels are monitored. If the mean soil Cd level is greater than 1 mg/kg from these “screening” samples, there is a voluntary requirement for 6 paddocks in each block of the farm (according to soil type, slope, and P fertiliser history) to be further sampled and analysed for soil Cd at the "definitive" depth of 0 – 150 mm. A soil Cd level of less than 0.6 mg/kg (Tier 0) is considered to be similar to background levels where no fertiliser has been applied and no limitations on type or rate of P fertiliser is recommended. Above a soil Cd level of 1.8 mg/kg (Tier 4), no further accumulation of Cd in the soil is recommended. Between these two extremes, there are three more tiers (Tier 1 – 0.6 to 1.0 mg/kg, Tier 2 – 1.0 to 1.4 mg/kg and Tier 3 – 1.4 – 1.8 mg/kg). Depending on the tier, several management mitigation actions are suggested including the use of low Cd P fertilisers (eg. DAP), deep ploughing, improvement of soil organic matter, controlling weeds, grazing younger animals on high Cd paddocks and maintenance of an optimal soil pH.

In the early 1990's, 312 NZ farms were surveyed for soil Cd (Roberts *et al*. 1994). The average soil Cd level at 0 – 75 mm sampling depth was 0.44 mg/kg on agricultural soils compared with 0.20 mg/kg for native (non-agricultural) soils. From 2012 to 2015, 3936 samples were analysed for soil Cd at 0 – 75 mm depth on 1980 NZ farms to determine what proportion were in each tier. A more complete set of results is presented in Abraham *et al*. (2016) but there were only four sampled farms that had their mean soil Cd level in Tier 4. However of these farms that were all in the Otorohanga and Waipa territorial authorities, one had five paddocks sampled, one had two paddocks and two had one paddock. Because there would be an expected large variation in soil Cd levels between paddocks, the sampling carried out on these farms would not produce an accurate mean soil Cd level. Also to prioritise a reduction in soil Cd levels through mitigation strategies in the paddocks that were greater than 1.8 mg/kg, a larger number of paddocks on each farm would need to be sampled.

The reported farm study parallels one carried out on a nearby long term fertilised dairy farm, predominantly with the same soil types, where every paddock was sampled for soil Cd at 0 – 150 mm depth (Stafford *et al.* 2014).

To gain further information on the variability in soil Cd levels between paddocks, determine the relationship in soil Cd at different sampling depths and relate soil Cd to plant Cd and soil P, a long-term fertilised dairy farm near Morrinsville was intensively sampled in 2011 and 2013. The results are reported in this paper.

Study farm

The study farm was situated just west of Morrinsville in the eastern Waikato and had an effective area of 102 ha in 71 paddocks. The soil type was predominantly a well-drained Kereone silt loam (Allophanic soil) with small areas of Topehaehae sandy clay loam (Gley) in some paddocks. The farm had been fertilised with predominantly superphosphate-based fertilisers for about seventy years. The only recent soil disturbance had been shallow cultivation to establish summer crops.

Measurements

In November 2011, 66 of the 71 paddocks on the farm were sampled at 0 - 75 mm and 0 – 150 mm depth. Each paddock had 15 – 20 soil cores taken and bulked for a paddock sample. At the same time, pasture samples were taken from 38 of these paddocks. From each paddock, 15 – 20 sub-samples were cut to grazing height from a site close to where the soil was sampled. The soil and pasture was analysed for Cd.

In August 2013, all of the paddocks were sampled at 0 – 150 mm depth and analysed for Cd, total P and Olsen P. In four paddocks, soil samples were taken at 0 – 100, 0 - 300 and 0 – 500 mm and analysed for Cd.

Results and Discussion

Farm and paddock soil Cd levels

In 2011, paddock soil Cd levels ranged from 0.67 to 2.05 mg/kg at 75 mm depth and 0.54 to 1.33 mg/kg at 150 mm depth. Mean paddock soil Cd levels were 1.36 mg/kg at 75 mm depth and 0.85 mg/kg at 150 mm depth. There was a 38% reduction in soil Cd levels at the deeper sampling depth. The 0 – 75 mm depth "screening" samples placed the farm in Tier 2 and indicated that "definitive" sampling at 0 – 150 mm was required.

At a sampling depth of 75 mm, 38% of the paddocks were in Tier 3 (1.4 – 1.8 mg/kg) of the TFMS and 7% were in Tier 4 (> 1.8 mg/kg). At a sampling depth of 0 – 150 mm, only one paddock (2%) was greater than 1.4 mg/kg.

In 2013, paddock soil Cd levels ranged from 0.29 to 1.38 mg/kg with a mean level of 0.79 mg/kg. The slight reduction in soil Cd levels at 0 – 150 mm sampling depth from 2011 to 2013 reflected the variability over time.

The large degree of variability in soil Cd between paddocks was also reported by Stafford *et al.* (2014) with a farm mean of 1.07 mg/kg at 0 – 150 mm sampling depth with a range from 0.48 – 1.64 mg/kg. This variability was attributed to soil type (Gley soils were lower than Allophanic soils because of their lower P sorption capacity), slope (steeper slopes have lower soil Cd because of transfer of P during grazing and sediment loss) and P fertiliser history.

Effect of sampling depth on soil Cd

Soil Cd levels were higher in November 2011 when sampled at 0 – 75 mm depth (mean of 1.36 mg/kg) than at 0 – 150 mm depth (mean of 0.85 mg/kg). There was a moderately strong relationship (r^2 = 0.48) between soil Cd levels at the two depths as shown in Figure 1.

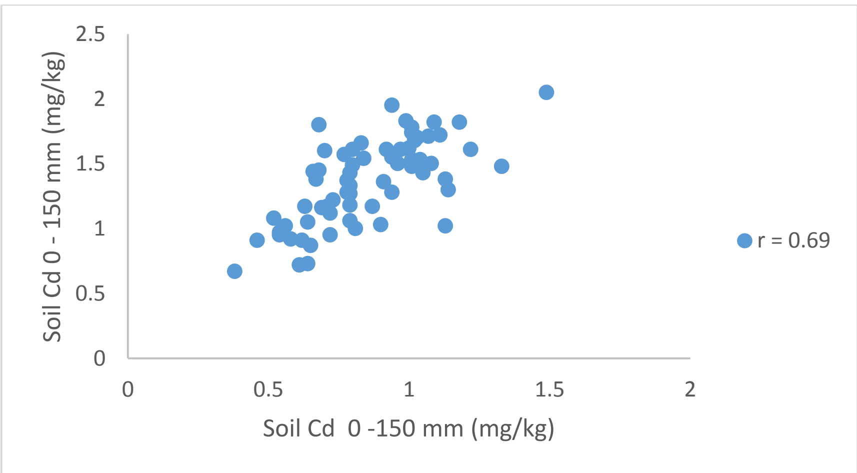

Figure 1: Relationship between soil Cd sampled at 0 – 150 mm and 0 – 75 mm depth

In research on Cd, soils have been sampled at 0 – 150 mm depth but so sampling for Cd can be included in normal soil nutrient testing, farm "screening" samples have been taken at 0 – 75 mm depth. A reasonably close correlation would be expected between the two sampling depths and the results from this study confirm this. Roberts *et al*. (1994) found from a survey of NZ soils that total soil Cd showed the same pattern for sampling depths of 0 – 25 mm and 25 – 75 mm.

For the four paddocks that were sampled at varying depths in August 2013, soil Cd levels averaged 1.30 mg/kg at 0 – 100 mm, 1.18 mg/kg at 0 – 300 mm and 0.47 mg/kg at 0 – 500 mm. Roberts et al. (1994) also reported a reduction in soil Cd levels down to 300 mm on an Allophanic soil. Soil Cd accumulation has originated from application of P which is not very mobile in the soil so it is concentrated in the upper layers of the soil. Pastoral soils are cultivated infrequently so there is little opportunity for mixing of the soil layers which would lead to a more even distribution of soil Cd with depth. However on these soils it does allow the mitigation strategy of deep ploughing down to 300 – 500 mm to dilute the higher Cd levels near the soil surface.

Plant Cd

There was a very weak relationship (r2 = 0.05) between soil Cd and plant Cd as shown in Figure 2 below:

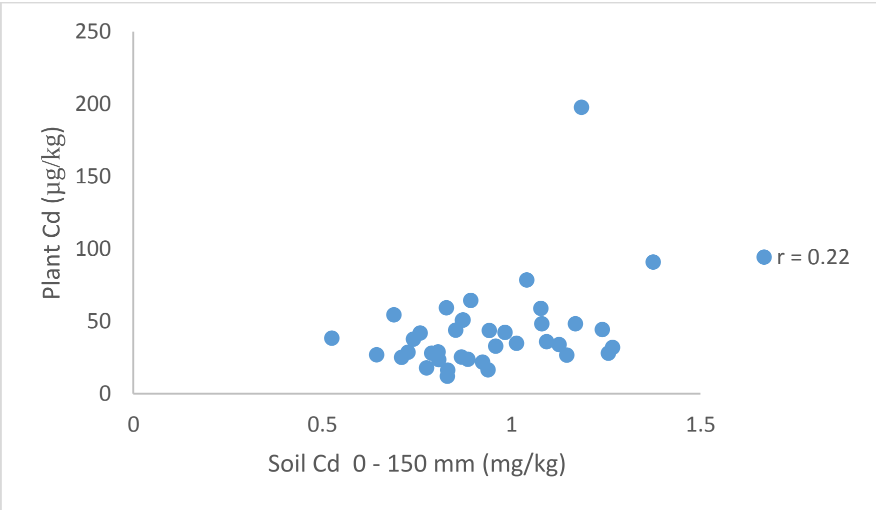

Figure 2: Relationship between soil Cd and plant Cd

From a national survey of 312 farms, Roberts *et al*. (1994) reported a significant correlation between soil Cd sampled at 0 – 75 mm depth and the Cd concentration of grasses but did not state the correlation coefficient. The poor relationship between soil and plant Cd infers that regardless of the soil Cd level, plant Cd which is ingested by animals will remain in a narrow range. However the soil Cd level will influence the amount of Cd that is ingested from plant contamination by soil.

Soil phosphorus

Soil Cd levels at 150 mm sampling depth were moderately strongly correlated (Figure 3) with total soil P (r^2 = 0.50) but only weakly correlated (Figure 4) with Olsen P.

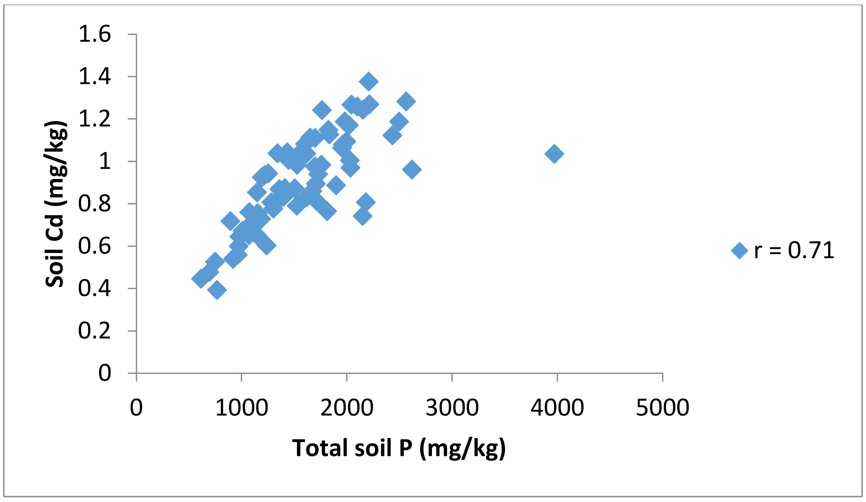

Figure 3: The relationship between total soil P and soil Cd levels.

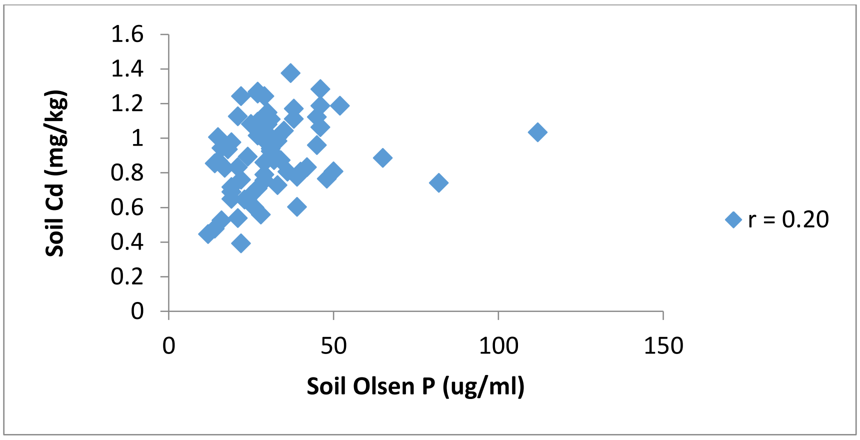

Figure 4: The relationship between soil Olsen P and soil Cd levels.

A strong relationship between total soil P and soil Cd was also reported by Roberts *et al.* (1994) and Stafford *et al.* (2014). The latter authors also reported a weak relationship between soil Olsen P and soil Cd levels. Cadmium is mainly bound to the soil organic matter and allophane (in these soils) which are more accurately measured by total P rather than Olsen P.

Conclusions

There was large variability in soil Cd levels between paddocks on a long-term fertilised dairy farm. Averaged over all paddocks, the farm average soil Cd level at 0 – 75 mm was in the range 0.6 – 1.0 mg/kg indicating that little remedial action to reduce levels is required.

There was a reasonably strong correlation between soil Cd levels at 0 – 75 mm and 0 – 150 mm sampling depth which supported the concept of using the shallower depth to screen the farm to determine if deeper sampling at the "definitive" depth of 0 – 150 mm is required.

Paddock soil Cd levels were moderately strongly correlated with soil total P which inferred that soil Cd accumulation could be attributed to application of P fertiliser.

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