DISTRIBUTION OF CADMIUM IN LONG-TERM DAIRY SOILS, ITS ACCUMULATION IN SELECTED PLANT SPECIES, AND THE IMPLICATIONS FOR MANAGEMENT AND MITIGATION

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ABSTRACT

Accumulation of cadmium (Cd) in agricultural soils, and in pasture, fodder and horticultural crop species is an on-going management concern for New Zealand agriculture. Recent implementation of a new National Cd Management Strategy (MAF, 2011) has increased awareness of this issue. Of key concern are long-term dairy farms in some of NZ's most productive farming districts, where future land-use and trade limitations might be apparent due to their intensive phosphorus (P)-fertiliser application history. The research described in this thesis was undertaken to improve national understanding of; i) soil Cd variability within long-term dairy farms, ii) variability in Cd accumulation between different forage plant species and the consequent risk to livestock grazing these forages, and iii) soil / environmental factors and management / mitigation options that can influence Cd phytoavailability.

Two long-term dairy farms on contrasting soils in the Waikato and Canterbury regions of New Zealand showed wide variability in soil total Cd concentrations (Waikato: 0.48-1.64 mg kg^{-1}, Canterbury: 0.15-0.64 mg kg^{-1}). The strong correlation (R^2 = 0.84-0.85) between soil total Cd and total P concentrations indicated the importance of P fertilisation history on soil Cd variability. However, within blocks of common P fertiliser management history, there was also a strong effect of soil type on soil Cd concentration. Slope class only exerted an influence on soil total Cd concentration when slope exceeded 15°, while application of dairy shed effluent did not appear to have any consistent influence on soil Cd accumulation. All paddocks should be tested independently (based on predominant soil type) to allow Cd-enriched zones to be identified for remediation or alternative management purpose. Individual results can be area-weighted to provide a property-mean soil Cd concentration, where this is required.

For both properties, soil Cd concentrations decreased with depth, however this was effect was stronger and more consistent in the Waikato due to its lack of tillage history. Models developed from visible and near-infrared reflectance spectroscopy (NIRS) scanning of intact soil cores (collected to 400-600 mm depth) were able to successfully predict soil total carbon (C) (R^2 = 0.91-0.95) and total nitrogen (N) concentrations (R^2 = 0.91-0.92). This technique shows promise for identifying paddock-specific tillage history, and based on the strong correlation between measured soil total Cd and total C and/or total N within each property (R^2 = 0.83-0.90), for identifying Cd distribution within the soil profile. Such information could be used to quantify the tillage depth required to dilute Cd-enriched topsoil to a desired target.

A glasshouse trial on 12 common animal forage species revealed that chicory and plantain accumulated significantly ($P < 0.05$) greater tissue Cd concentrations than other plant species. A subsequent survey of commercial farms across New Zealand validated these findings, with mean tissue Cd concentrations decreasing in the order chicory (1.82 mg kg^{-1} DM) > plantain (0.80 mg kg^{-1} DM) > ryegrass (0.11 mg kg^{-1} DM) > white clover (0.07 mg kg^{-1} DM). A very large range in tissue Cd concentrations for chicory and plantain (0.40-4.50 and 0.23-2.40 mg kg^{-1} DM, respectively) indicating the sensitivity of these species to soil Cd phytoavailability, although only chicory tissue Cd concentration could be satisfactorily explained (R^2 = 0.745) by the variables soil total Cd concentration, pH and total carbon content.

Although soil redox potential is known to influence Cd solubility, a pot trial on two different soils types (Kereone (Allophanic) and Topehaehae (Gley)) revealed that there was no significant difference in 0.05 M $CaCl_2$ soil extractable Cd or plantain tissue Cd concentrations between cyclical flooded (3 days flooded, 11 days drained) and non-flooded (continuously drained) irrigation regimes. However, there was a large difference in soil extractable Cd concentration between the two soils types, with this difference appearing to be driven by differences in soil pH and organic matter content (and possibly clay mineralogy).

Ultra-fine elemental sulphur and hydrated lime soil amendments were used to produce a wide range in soil pH (approximately 5.0-6.5) in two field trials on contrasting soils. There was a strong negative (linear) correlation (R^2 = 0.64-0.82) between 0.05 M $CaCl_2$ soil extractable Cd concentration and soil pH. Plant tissue Cd concentration was poorly explained by soil pH (chicory R^2 = 0.35-0.52, ryegrass R^2 = 0.19-0.42) and 0.05 M $CaCl_2$ soil extractable Cd concentration (chicory R^2 = 0.11, ryegrass R^2 = 0.28). Perennial ryegrass Cd concentrations remained low (<0.3 mg kg^{-1}) regardless of soil pH, suggesting that animal Cd accumulation risk is low when grazing this plant species, even in Cd-enriched soils at low pH. However, soil pH should be increased to a minimum of 6.5 to decrease livestock dietary Cd exposure when grazing chicory. Mean chicory Cd concentrations were significantly ($P < 0.05$) greater following a period of increased soil moisture, consistent with the increases in Cd solubility observed in the pot trial following soil re-wetting.

This research highlights that Cd accumulation in soil and plants poses a real risk to New Zealand's primary production industries. Existing animal Cd accumulation models indicate that when grazing Cd-accumulating forage species such as chicory and plantain, lamb kidneys may exceed food standard maximum levels in animals much younger than the current meat industry 30-month offal discard age. Understanding Cd accumulation in Cd-sensitive species such as chicory and plantain is important for farmers to be able to manage livestock dietary Cd exposure. Manipulation of soil pH to decrease soil Cd phytoavailability, and utilisation of deep inversion-tillage to bury Cd-enriched topsoil stand out as the most practical management strategies available to farmers. Animal grazing trials on Cd-enriched chicory crops are recommended to evaluate partitioning of ingested Cd, to validate and/or improve the predictions of existing animal Cd accumulation models. Plant breeding opportunities should be a priority focus, to produce chicory / plantain varieties that accumulate lower Cd concentrations in their vegetative tissues.

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