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Cadmium accumulation in three contrasting New Zealand soils with the same phosphate fertilizer history

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ABSTRACT

Cadmium (Cd) concentration in New Zealand (NZ) agricultural soils has increased due to phosphate fertilizer application, but it is not clear whether soils with different properties accumulate Cd at similar rates for given P loadings. Here, the distribution of Cd was measured in three soils: the well-drained Horotiu series (Orthic Allophanic Soil in NZ soil classification, Typic Hapludand in US soil taxonomy), poorly-drained Te Kowhai series (Orthic Gley Soil in NZ classification, Typic Humaquept in US soil taxonomy) and an intergrade between them, Bruntwood series (Impeded Allophanic Soil in NZ soil classification, Aquic Hapludand in US soil taxonomy). All three soils often occur in the same paddock with the same fertilizer history, but have differing drainage and mineralogical characteristics, permitting an assessment of the potential for varying accumulation/translocation of Cd in contrasting soil conditions. Thirty soil profiles from ten paddocks on a dairy farm near Hamilton, NZ, with a uniform fertilizer history were sampled to depth of 60 cm. The Cd concentration in topsoil (0–7.5 cm) samples (mean of 0.79 mg kg^{-1}) was about 7–8 times greater than in deeper horizons ($P < 0.001$). No significant differences in Cd concentration or fractionation among the soil series were detected. Cluster analysis showed that Cd, phosphorus (P) and uranium (U) were highly correlated, consistent with a common source, most likely phosphate fertilizer. The absence of a difference in the Cd depth profiles in the three soils indicates that Cd was preferentially adsorbed to the topsoil and was not significantly mobilized by drainage in the soils. The lack of difference in Cd distribution between contrasting soil series supports the use of one Cd management system tool for all of these soils.

1. Introduction

Cadmium (Cd) is a biotoxic heavy metal which can be adsorbed by soils and then bioaccumulated by plants, animals, and humans (McLaughlin and Singh, 1999). Although many anthropogenic sources of Cd exist, the greatest source of Cd in New Zealand (NZ) soils is phosphate fertilizer (Gray et al., 1999; Loganathan et al., 2003; Schipper et al., 2011; McDowell, 2012). Accumulation of Cd was first highlighted in NZ by reports of Cd bioaccumulation in the kidneys and livers of grazing animals (Lee et al., 1994; Loganathan et al., 2008). The concentration of Cd in NZ agricultural soils has increased especially in the Waikato region where dairy farms predominate and fertilizer is applied at higher rates than drystock farms (Taylor et al., 2007; Stafford et al., 2014). Thus, Cd is one of the most important contaminants in NZ soils because of its widespread accumulation and long-term impact (Gaw et al., 2006). Like Cd, uranium (U) in New Zealand soils is mainly derived from phosphate fertilizer and there is also concern about its increasing concentration and therefore potential toxicity (Schipper et al., 2011).

Prior to 1997 phosphate fertilizers used in New Zealand were mainly produced from Nauru Island phosphate rocks (mean of 450 mg Cd/kg P in fertilizer). Since 1997, the main source of NZ phosphate fertilizers has been changed to phosphate rocks with lower concentrations of Cd and the fertilizer industry has elected to produce phosphate fertilizers with <280 mg Cd/kg P. However, the maximum permissible amount of Cd in NZ phosphate fertilizers remains high relative to phosphate fertilizers produced internationally (Furness, 1998; Oosterhuis et al., 2000).

Research on the amount of Cd in soils of New Zealand (Roberts et al., 1994; Andrews et al., 1996; Gray et al., 2003; Longhurst, 2006; McDowell et al., 2013) and other countries (Holmgren et al., 1993; Holm et al., 1998; Holm et al., 2003; Karimi Nezhad et al., 2014) has generally lacked detailed information on the fertilizer history of sample sites. Site fertilizer history is important to explain trends in Cd accumulation. Cd adsorption has been proposed to vary between soils due to differences in particle size, pH, organic matter content, and abundance of mineral phases able to undergo adsorption/desorption reactions with metal cations (Naidu et al., 1994; Gray et al., 1999). For instance, Cd adsorption has been shown to be greater in Allophanic Soils than in non-Allophanic Soils (Bolan et al., 2003, 2013) implying that soil

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Fig. 1. Soils sampled in this study. Left: Horotiu (Orthic Allophanic Soil, Typic Hapludand), Centre: Bruntwood (Impeded Allophanic Soil, Aquic Hapludand) and Right: Te Kowhai (Orthic Gley Soil, Typic Humaquept).

mineralogy directly contributes to Cd retention. Bolan et al. (2013) showed that there were more surface negative charges in Allophanic Soils than non-Allophanic Soils and that allophanic clay therefore may be one of the reasons for higher Cd adsorption in Allophanic Soils. Bolan et al. (2003) also showed that phosphate addition to soils increases the soil pH, negative charge, and therefore Cd adsorption and the Allophanic Soils have greater increases in Cd adsorption than non-Allophanic Soils. Parfitt (1992) and Yuan and Wada (2012) also stated that allophane has an appreciable amount of variable negative and positive charges and therefore can absorb both cations (such as Cd) and anions.

Past workers have attempted to examine the effect of soil type on Cd accumulation trends. Roberts et al. (1994) determined the concentration of Cd in native and pastoral soils (0–7.5 cm) on eight soil types in New Zealand with varying land uses. The results showed that the mean concentration of Cd in the native (non-agricultural) Allophanic Soils and Gley Soils was not significantly different. The mean concentration of Cd varied between different Soil Orders under pastoral agriculture and the Cd concentration in topsoils of Allophanic Soils was more than non-Allophanic Soils (Roberts et al., 1994). However, Roberts et al. (1994) were not able to separate the effects of fertilizer history on soil Cd differences between Soil Orders because some Soils Orders

Table 1
The fertilizer application history of Scott farm since 2000.

	Rate (kg ha^{-1})	Product	% Superphosphate	Rate of Superphosphate (kg ha^{-1})
Autumn 2000	650	Magnesium phosphate + (Selenium @ 1 kg ton^{-1})		
Autumn 2001	700	Magnesium phosphate + (Selenium @ 1 kg ton^{-1})		
Autumn 2002	650	Magnesium phosphate + (Selenium @ 1 kg ton^{-1})		
Autumn 2003	600	Magnesium phosphate		
Autumn 2004	650	92% Superten + 8% Calcined Magnesite (CalMag)	92%	598
Autumn 2005	570	91% Superten + 4% Durasul Sulphur + 5% CalMag + 1 kg ha^{-1} Selcote Ultra	91%	519
Autumn 2006	570	91% Superten + 3% Durasul Sulphur + 5% CalMag + 1 kg ha^{-1} Selcote Ultra (1% Selenium)	91%	519
Autumn 2007	630	83% Superten + 8% Salt + 5% CalMag + 5% Durasul	83%	523
Autumn 2008	570	91% Superten + 5% Salt + 4% CalMag	91%	519
Autumn 2009	675	77% Superten + 8% Muriate of Potash + 7% Salt + 3% CalMag + 4% Durasul	77%	520
Autumn 2010	635	87% Superten + 8% Bulk Salt + 5% CalMag	87%	552
Autumn 2011	675	77% Superten + 8% Muriate of Potash + 7% Salt + 3% CalMag + 4% Durasul	77%	520
Autumn 2012	615	11% Superten + 81% Serpentine Super + 8% Summit Agricultural Salt (AgSalt) mix	11%	68
Autumn 2013	675	41% Superten + 82% Serpentine super + 7% AgSalt mix	41%	277
Autumn 2014	600	50% Serpentine Super + 50% Superten + 1 kg Selenium ha^{-1}	50%	300