



The effect of irrigation on cadmium, uranium, and phosphorus contents in agricultural soils



Mahdiyeh Salmanzadeh^{a,*}, Louis A. Schipper^a, Megan R. Balks^a, Adam Hartland^a, Paul L. Mudge^b, Ray Littler^c

^a School of Science and Environmental Research Institute, University of Waikato, Private Bag 3105, Hamilton, New Zealand

^b Landcare Research Manaaki Whenua Ltd., Private Bag 3127, Hamilton, New Zealand

^c Department of Mathematics & Statistics, University of Waikato, Private Bag 3105, Hamilton, New Zealand

ARTICLE INFO

Keywords:

Cadmium
Agriculture
Irrigation
Fertilizer

ABSTRACT

Cadmium (Cd) is a toxic metal which has accumulated in New Zealand agricultural soils due to phosphate fertilizer application. Understanding the contribution of plant uptake or leaching of Cd to observed Cd losses from soil is important. The concentration and distribution of Cd in irrigated and unirrigated soils with the same phosphate fertilizer history were investigated. Twenty-two pairs of soil samples from four depths (0–0.1, 0.1–0.2, 0.2–0.3 and 0.3–0.4 m) were taken from irrigated and unirrigated areas in the same field on dairy farms in three regions of New Zealand. The mean concentration of Cd at depths of 0–0.1 m and 0.1–0.2 m, as well as the cumulative masses of Cd (0–0.2, 0–0.3 and 0–0.4 m) in unirrigated soils were significantly higher ($P < 0.05$) than in irrigated soils. The concentration of phosphorus (P) at all depths (except for 0.2–0.3 m), as well as the cumulative mass of P in all depths of unirrigated soils, was also significantly higher ($P < 0.05$) than irrigated soils. However, no significant difference was detected in the concentrations of uranium (U) between irrigated and unirrigated soils. Irrigation induced a ~7% Cd loss from topsoil (0–0.1 m), with the average rate of Cd loss from the top 0.1 m (due to irrigation) being $2.3 \text{ g ha}^{-1} \text{ yr}^{-1}$. This study therefore confirms that irrigation can enhance Cd mobilization, however Cd is mainly adsorbed to the surface soil.

1. Introduction

Cadmium (Cd) has accumulated in New Zealand (NZ) soils mainly from phosphate fertilizers (Loganathan et al., 2003; Schipper et al., 2011) which have been applied to NZ soils since the late 1800s. The dominant productive land use in New Zealand is grazed pasture which is generally accompanied by large amounts of phosphate fertilizer use (Parliamentary Commissioner for the Environment, 2004). There are concerns about the accumulation of Cd in soil because of its entry to the human food chain and potential adverse effects on health (Mortvedt, 1995). Cadmium has been described as being the trace metal of greatest concern with respect to food standards in New Zealand (Taylor et al., 2010). In order to understand the environmental fate of Cd, it is necessary to develop a full mass balance including fertilizer inputs as well as removal in products, erosion, and leaching through the profile.

The magnitude of Cd losses from soil via drainage are not well known with studies of Cd mobility in soils based largely on the mass balance approach. Many studies report minimal cadmium loss from soil. For instance, Loganathan and Hedley (1997) found that after 10

years of phosphate fertilizer application, less than 5% of applied Cd moved below 0.2 m and the uptake of Cd by plants ranged from 1.5 to 4.5% of total inputs. Similarly, Singh and Myhr (1997) were unable to detect downward movement of Cd through the profile of fertilized soils in Norway. Even in a loamy sand in South Carolina with a low cation exchange capacity (CEC), Cd movement below 0.15 m depth was negligible (< 3%) 30 months after the Cd application. Despite the low CEC in the aforementioned study, Fe and Al oxides were identified as the most important adsorbents of Cd in these soils (Martin and Kaplan, 1998). Cadmium appears to be even more immobilized in organic soils: in a lysimeter study of Cd losses from Organic soils, the leaching of Cd was not significant (less than 1% of added Cd from phosphate fertilizer application) over 12 months (Gray and McDowell, 2016).

While the aforementioned studies reported minimal loss of Cd by leaching, several other studies have found significant movement of Cd through the soil (Nicholson et al., 1996; Zanders et al., 1999a; Gray et al., 2003b). On an Australian sandy Podzol soil, about 50% of added Cd from fertilizer application over 20 years, had been lost from the top 0.075 m, with only 1–5% of soluble Cd taken up by plants. Some of the

* Corresponding author.

E-mail address: salmanzadeh.mahdiyeh@gmail.com (M. Salmanzadeh).

added Cd had moved to a depth of at least 0.15 m (Williams and David, 1976). About 50% of added Cd had accumulated in the top 0.225 m of a NZ soil with less than 2% of Cd was taken by plants, implying that the remainder may have moved down through the soil profile (Rothbaum et al., 1986). McBride et al. (1997) also showed that 15 years after sewage sludge application, about 30% of Cd was removed from the topsoil of an orchard site in USA, which was attributed to possible leaching losses.

The majority of these previous studies were conducted on unirrigated lands and there is some evidence that increased water application through irrigation might increase Cd movement through topsoil due to increased infiltration (McLeod et al., 2015). The concentration of Cd in irrigated topsoils (0–0.075 m) of the Winchmore research farm in New Zealand (Lismore stony silt loam) was less than in non-irrigated topsoils (McDowell, 2012). Furthermore, at Winchmore, the concentration of Cd at depths of 0.075–0.15 and 0.15–0.30 m in irrigated soils was higher than in non-irrigated soils suggesting movement of Cd down the soil profile (McDowell, 2012). However, the Winchmore trial was flood irrigated and therefore may not be representative of the expanding area of pastures irrigated by overhead sprinklers in New Zealand (about 74% of NZ irrigated pastures are now being sprinkler irrigated) (Heiler, 2008; Irrigation New Zealand, 2013). Reliable data on Cd losses from irrigated soils are currently lacking. Like Cd, uranium (U) is also a contaminant of phosphate fertilizers in NZ soils, and has been classified as “very toxic” (Health and Safety Executive, 1995) and is potentially mobile (Taylor and Kim, 2007). Uranium and phosphorus (P) have important roles in soils and U, Cd, and P are accumulating in agricultural soils from the same source (phosphate fertilizers).

The objective of this study was to determine the potential for loss of Cd, U, and P due to irrigation. We took advantage of the wide scale soil sampling campaign of adjacent irrigated, and unirrigated pastures, conducted by Mudge et al. (2016) that demonstrated losses of carbon and nitrogen stocks under irrigation. On each farm, both irrigated and unirrigated areas were sampled in the same field to ensure uniform fertilizer history and therefore Cd, U, and P inputs.

2. Materials and methods

2.1. Site and soil

Soil samples were taken from 22 paired irrigated and unirrigated pasture sites (grazed by dairy cattle) in three regions of New Zealand (Fig. 1). Ten cores (0.0254 m diameter) were taken from each irrigated and unirrigated areas in the same field. On six of the 22 farms, two fields were sampled, and the two irrigated samples from the two fields were combined, as were the two unirrigated samples, giving one irrigated and one unirrigated sample. Samples from each group of 10 cores were combined for each of depths of 0–0.1, 0.1–0.2, 0.2–0.3 and 0.3–0.4 m and bulked into one composite sample for each depth. One site in the Canterbury region was sampled to only 0.3 m due to high stone content lower in the profile. The selection criteria considered when choosing sampling locations have been fully described by Mudge et al. (2016) along with further information on irrigation duration (ranging 3–20 years), soil orders, type of irrigation and long-term climate data (1972–2011) for each sampling site. The irrigated and unirrigated areas within a field were identified using local knowledge, Google Earth imagery, Irrigation Resource Consents and help from rural professionals (Mudge et al., 2016). Paired sites were selected based on the following criteria: 1. Irrigated and unirrigated areas were within 100 m of each other; 2. The irrigated areas had been irrigated for at least three years, while unirrigated areas had never been irrigated; 3. Soils and topography were the same between irrigated and unirrigated areas, and 4. Farm management (such as fertilizer application) was the same in irrigated and unirrigated areas (expect for irrigation) (Mudge et al., 2016).

2.2. Chemical analysis

Soil samples were digested following the method described in Salmanzadeh et al. (2016): the air dried (50°C) and sieved (< 2 mm) soil samples were digested using Aqua Regia (1 mL HNO₃ and 0.33 mL HCl) at 50°C. After centrifuging for 10 min at 4000 rpm and filtering at 0.45 µm, Cd, P, and U concentrations were determined using ICP-MS (Waltham, MA, USA) following calibration using NIST-traceable standards (Inorganic Ventures, Christiansburg, VA, USA). The detection limit of ICP-MS was 130 µg kg⁻¹ for P, 6.0 µg kg⁻¹ for Cd, and 0.02 µg kg⁻¹ for U.

The pH of soil samples was measured following Blakemore et al. (1987). Total carbon (C) of the soil samples was reported by Mudge et al. (2016).

2.3. Data analysis

The cumulative mass of elements in each depth was calculated using the element concentration, and soil dry bulk density calculated from the mass of oven dry soil for each depth and the sample volume (depth 0.1 m and diameter 0.0254 m).

The Minitab 17 software package and Wilcoxon signed rank test was used to test the significance of difference between the mean concentrations and cumulative mass of Cd, P, and U for all depths individually. The Wilcoxon signed rank test can be used to test the significance of differences when data are not normally distributed and was used to check the degree of significance in differences in Cd, P, and U concentrations and cumulative masses in the studied soils.

3. Results

3.1. Cadmium concentration and cumulative mass

The mean Cd concentration in unirrigated soil samples was higher ($P < 0.05$) than that for irrigated soils at depths of 0–0.1 m and 0.1–0.2 m (Table 1). The cumulative mass of Cd for depths of 0–0.2, 0–0.3 and 0–0.4 m in unirrigated soils was higher ($P < 0.05$) than in irrigated soils (Table 1).

There were no significant differences in soil dry bulk density between unirrigated and irrigated areas at the 0–0.4 m depth (with the mean of 1.15 T m⁻³ in unirrigated and 1.14 T m⁻³ in irrigated areas) as well as individual depths. However, soil dry bulk density at the 0–0.1 m depth in irrigated areas was marginally higher ($P = 0.05$) than in unirrigated areas, which may be the reason for the significant difference in Cd concentration for the top 0.1 m but not for total mass in the same depth (Table 1).

The number of years of irrigation may be expected to impact on the mobility of Cd, however, there was no significant relationship ($R^2 = 0.13$, $P < 0.05$) between irrigation duration and the amount of Cd loss from 0 to 0.4 m in irrigated soils (Fig. 2).

The estimation of losses of fertilizer-derived Cd from surface soils is not straight forward because the Cd content of fertilizers and the amount and type of fertilizers used at each site through time is not well documented. As we did not have detailed information about the fertilizer history of the sampling locations, we could not directly calculate the loss of anthropogenically added Cd in phosphate fertilizers. However, it was possible to calculate the amount and percentage of Cd loss due to irrigation using the difference in the total mass of Cd in irrigated and unirrigated soils divided by the number of years of irrigation (3–20 years) (Table 2). To assess whether the calculated loss of Cd due to irrigation was greater than the measurement error, standard deviation of Cd determinations on paired soil samples was calculated. This standard deviation used different aliquots of the primary soil samples (independently digested by Aqua Regia and analysed by ICP-MS). This gave a final standard deviation of 0.003 mg kg⁻¹ between replicated measurements of five paired soil samples. While this measure

Download English Version:

<https://daneshyari.com/en/article/5537980>

Download Persian Version:

<https://daneshyari.com/article/5537980>

[Daneshyari.com](https://daneshyari.com)