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UNDERSTANDING THE INFLUENCE OF SOIL PROPERTIES ON PLANT UPTAKE OF CADMIUM IN NEW ZEALAND AGRICULTURAL SOILS

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Introduction

The New Zealand economy relies heavily on the primary production sector and the use of phosphate fertilisers. Cadmium (Cd) occurs naturally in the phosphate rock used to produce phosphate fertilisers and is present in fertiliser at varying levels. Cd may be taken up into plants and thereby into people and livestock. Plant uptake from soil is the key factor affecting food chain transfer. The plant uptake of Cd is influenced by a number of factors including crop species and cultivars (e.g. Alexander et al. 2006; Cheng et al. 2008). Furthermore, soil properties including soil pH, organic matter (OM), salinity, cation-exchange capacity, clay content, and availability of macronutrients, and micronutrients such as Zn, have all been recognised to influence Cd uptake in plants (Grant et al. 1998; Chaney 2012). Relationships between soil properties and plant uptake are often used as the basis for setting soil guideline values to ensure protection of human health from consumption of home-grown produce and to ensure food standards are met (Cavanagh 2013; De Vries and McLaughlin 2013). Amending soil properties provides a means to reduce plant uptake of Cd, as does the use of low Cd-accumulating cultivars (e.g. Grant et al 2007).

Wheat, potatoes, onions and leafy green vegetables are key crops to provide a perspective on the significance of Cd in New Zealand agricultural soils. Bread and potatoes are the main sources of dietary Cd (Vannoort & Thomson 2011), which in turn is the dominant source of Cd in the non-smoking population (FAO/WHO 2010). Potatoes and onions are the highest value vegetable exports in New Zealand, valued at around $105M and $97M respectively in 2014 (Plant and Food Research 2014). Finally, leafy green vegetables are considered to be higher accumulators of Cd relative to root and tuber vegetables or fruit (e.g. Alexander et al. 2006), and in this respect can provide a sensitive indicator of plant uptake of Cd from New Zealand agricultural soils.

Several factors influence Cd uptake into plants (and therefore the human food chain) and, to manage the health risks of Cd, we need a better understanding of the soil-plant relationships involved. To address the lack of New Zealand-specific science on factors influencing plant uptake of cadmium, a two-year project is nearly complete, primarily funded by the Ministry for Primary Industries and the Fertiliser Association of New Zealand, with additional funding and support from Vegetables New Zealand, Onions New Zealand, Foundation for Arable Research, the New Zealand Flour Millers Association, Baking Industry Research Trust, DairyNZ, Landcare Research and regional councils. A key focus of this project is to understand the influence of soil properties on Cd uptake in key agricultural crops: leafy greens, potatoes, onions and wheat. As part of this, soil and plant samples were collected from existing industry trials and/or commercial fields in the main commercial growing areas for each crop across New Zealand and analysed for Cd and a range of soil properties. Field trials to assess the effect of lime and compost additions on minimising Cd uptake in potatoes at three locations (Pukekawa, Manawatu and Canterbury) and wheat (Canterbury only) are also being undertaken. This information also provides a baseline assessment of Cd uptake into New Zealand crops, and insight into management practices that can reduce plant uptake of Cd. This paper provides an overview of the field survey and trial work to date.

Methods

Field survey

Composite soil and plant samples were collected from existing industry trials and/or commercial fields (Figure 1). At each location 3 plots were established randomly across a field, plot size varied depending on the crop. Within each plot the edible portion of five plants (e.g. tuber, bulb, grain) and five soil cores (25x150 mm depth) were collected. At each site, in addition to the plot samples, a single composite sample was collected by taking 10 cores along a 50m transect.

Soil samples were oven-dried (35°C), sieved < 2 mm and sent to Hill Laboratories for analysis for Olsen P, pH, CEC and to Lincoln University for cadmium and trace element, total carbon and chloride analysis and measures of plant available Cd (not reported here). Wet weight and dry weight (drying at 60°C to a constant weight) of plants were recorded to allow reporting of results as fresh weight. Dried plant samples were sent to Lincoln University for analysis of cadmium and trace elements. A sub-sample of the transect sample was sent for particle size analysis by Landcare Research's Environmental Chemistry Laboratory at Palmerston North (not reported here). Selected transect samples will also undergo additional analysis to provide insight into metal oxide and clay composition at different locations.

The plant uptake factor (PUF) was used to measure plant uptake (i.e. phytoavailability) of Cd in different soils:

$$PUF = \frac{Cd_{plant}\ (mg/kg\ (DW))}{Cd_{soil}\ (mg/kg\ )}$$

Field trials

The effect of compost and lime addition on Cd uptake in potatoes was assessed at three locations (Figure 2), with Cd uptake by wheat and spinach also assessed in Canterbury and Manawatu respectively. The generalised treatment regime is shown in Table 1; actual treatments depended on soil properties at the individual sites. The amount of lime to be added to trial plots to enable the desired pH range of treatments to be achieved was determined through preliminary incubation studies to assess the effect of lime addition to soil from each site. Fine lime was used to enable more rapid pH change compared to agricultural lime. Amendments were applied 2-3 weeks prior to planting to enable them to react with the soil prior to plant growth.

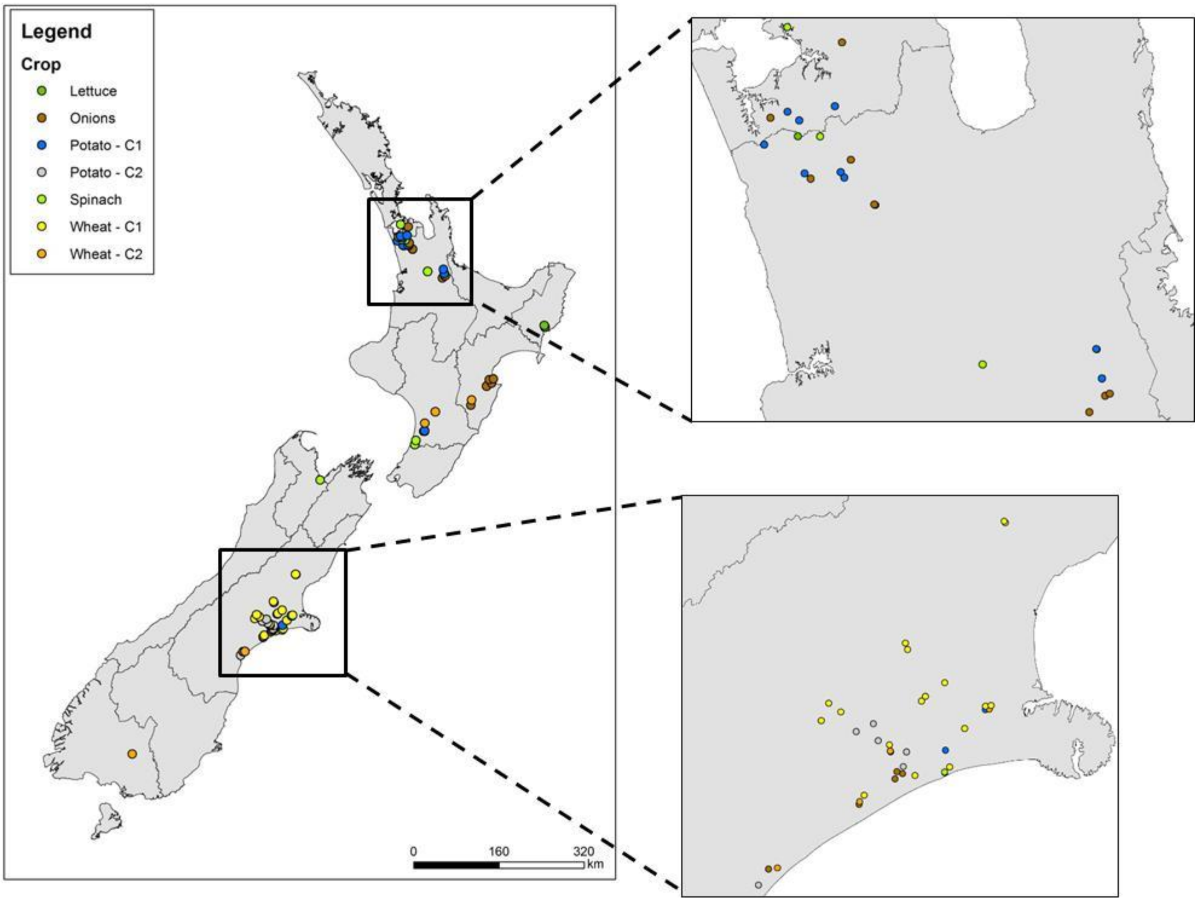


Figure 1. The location of sampling of different crops during the field survey conducted early 2016. Three replicate plots were sampled for crop and soil samples, with an additional transect soil sample collected at each location. C1 and C2 are separate cultivars.

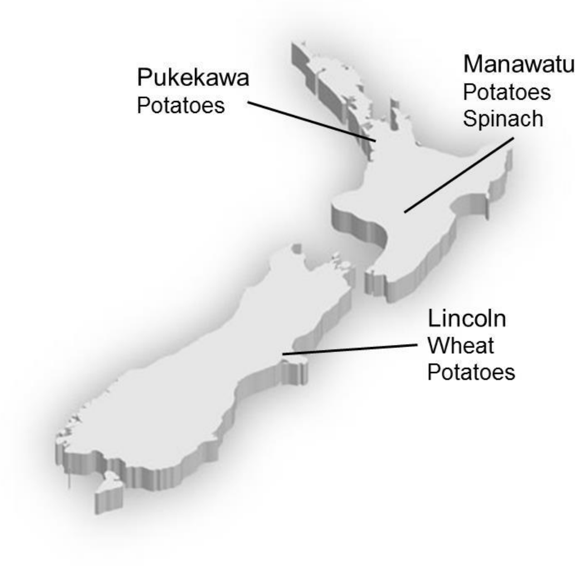


Figure 2. Crops and location of field trials undertaken over 2016/2017.

Table 1 Generalised treatment regime for the field trials; exact treatments depended on the soil pH at the field trial site.

Target pH	Treatment (pH)	Compost
5.6	acid (sulphur)	0
6	0	0
	0	med (25 t/ha)
	0	high (50 t/ha)
6.3	low lime	0
	low lime	med
6.7	med lime	0
	med lime	med
7	high lime	0
	high lime	med

Plot sizes varied with crop (wheat 3m×1.65m, potatoes 4m ×4 rows (3.4m), spinach 2m × 1.05 m), with treatments arranged using a randomised block design. Soil sampling of each plot was undertaken prior to addition of amendments, just prior to planting and at the time of harvest. Additional sampling was undertaken on a fortnightly- monthly basis to assess pH over time.

Results

Field survey

Wheat

The plant availability of Cd is generally higher in Canterbury, the main wheat growing area, compared to other regions, although soil Cd concentrations were generally lower (Figure 2). Sampling in other regions is limited. Preliminary analyses showed no clear relationship between Cd in wheat grain and soil properties (pH, total C, CEC and soil Cd concentrations).

For the bread wheat cultivar, the highest grain Cd concentrations were found in the Canterbury irrigated site, with lower concentrations in the unirrigated site (Figure 4). Soil Cd concentrations appear to be slightly lower in the unirrigated site, which may account for the lower Cd concentrations although pH at this site is slightly lower which should lead to an increase in Cd uptake (data not shown). Further testing is required to establish whether higher Cd concentrations in irrigated wheat is a consistent trend.

Limited additional sampling has been undertaken over the recent growing season, and comprehensive data analysis will be undertaken on the complete data set.

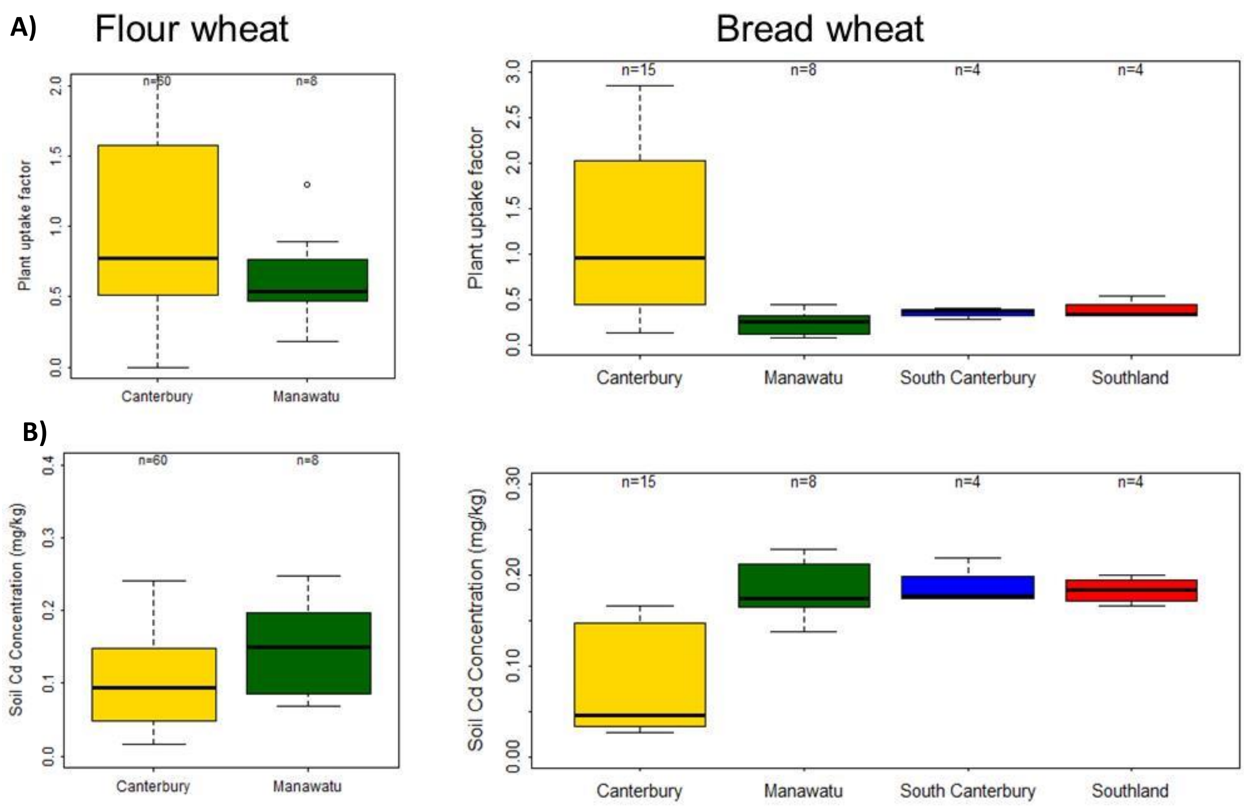


Figure 2. A) Plant uptake factor of flour and bread wheat cultivars collected at different locations within different regions. B) Range in soil Cd concentrations (mg/kg) at the wheat sampling sites. N= individual plot samples, with 3 or 4 plots sampled per site. Showing median solid line in box, with upper box = 75% percentile; LBV – lower box value = 25% percentile; outliers are represented by circles and are values that are greater than 1.5 times the interquartile range.

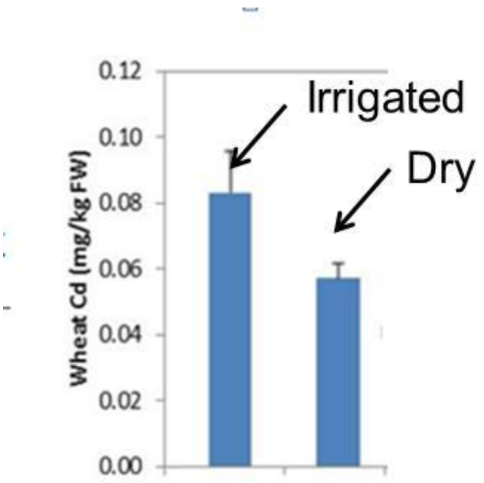
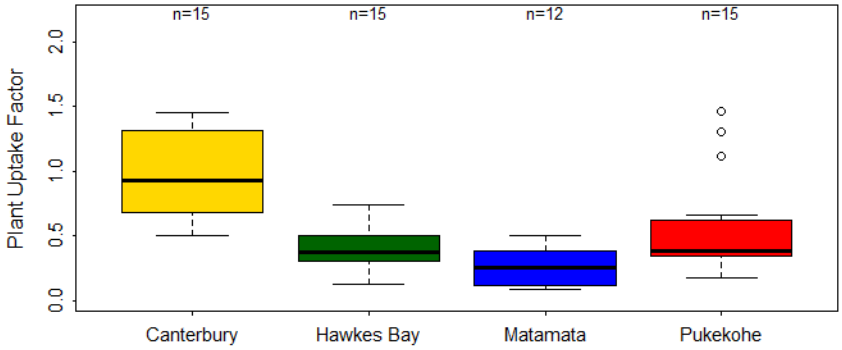


Figure 4. Difference in Cd concentrations (mg/kg fresh weight) in bread wheat grain from replicated irrigation trial plots.

Onions

Plant availability of Cd is higher in Canterbury, which has the lowest soil Cd concentrations, compared to other regions. Comparatively high plant availability is observed at one site in Pukekohe, which had slightly lower pH than most other sites. Plant uptake of Cd can be higher at lower pH and preliminary analysis indicated that pH and total soil Cd were the most significant explanatory variables for plant uptake ($R^{2=}0.42$). Higher soil Cd concentrations occurred in the Pukekohe and Matamata regions, with the highest soil Cd concentrations occurring in a humic Organic soil with low bulk density.

A)



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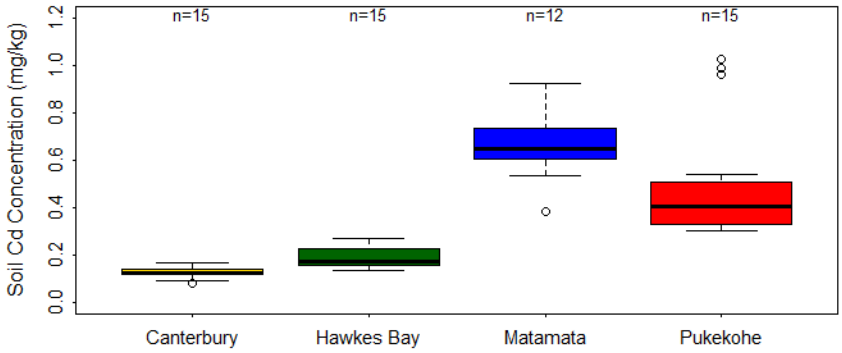

Figure 5. A) Plant uptake factor of one onion cultivar collected at different locations within different regions. B) Range in soil Cd concentrations (mg/kg) at the onion sampling sites. N= individual plot data, with 3 plots sampled per site; the one site with high plant uptake by onions is not the same location as the high soil Cd concentration, which is from a site with low soil bulk density. N= individual plot samples, with 3 or 4 plots sampled per site. Showing median solid line in box, with upper box = 75% percentile; lower box = 25% percentile; outliers are represented by circles and are values that are greater than 1.5 times the interquartile range.

Additional sampling has been undertaken over the recent growing season, and comprehensive data analysis will be undertaken on the complete data set (which includes additional soil properties).

Potatoes

Once again, plant availability of Cd is higher and soil Cd concentration lower in the Canterbury region compared to the other regions. Markedly higher uptake is observed in potatoes from one site in Pukekohe although the reason for this high uptake is unclear as the site had fairly typical pH, CEC, total C and soil Cd concentrations. Preliminary data analysis did not identify any relationship between plant Cd concentrations and soil properties (pH, total C, CEC and soil Cd concentrations).

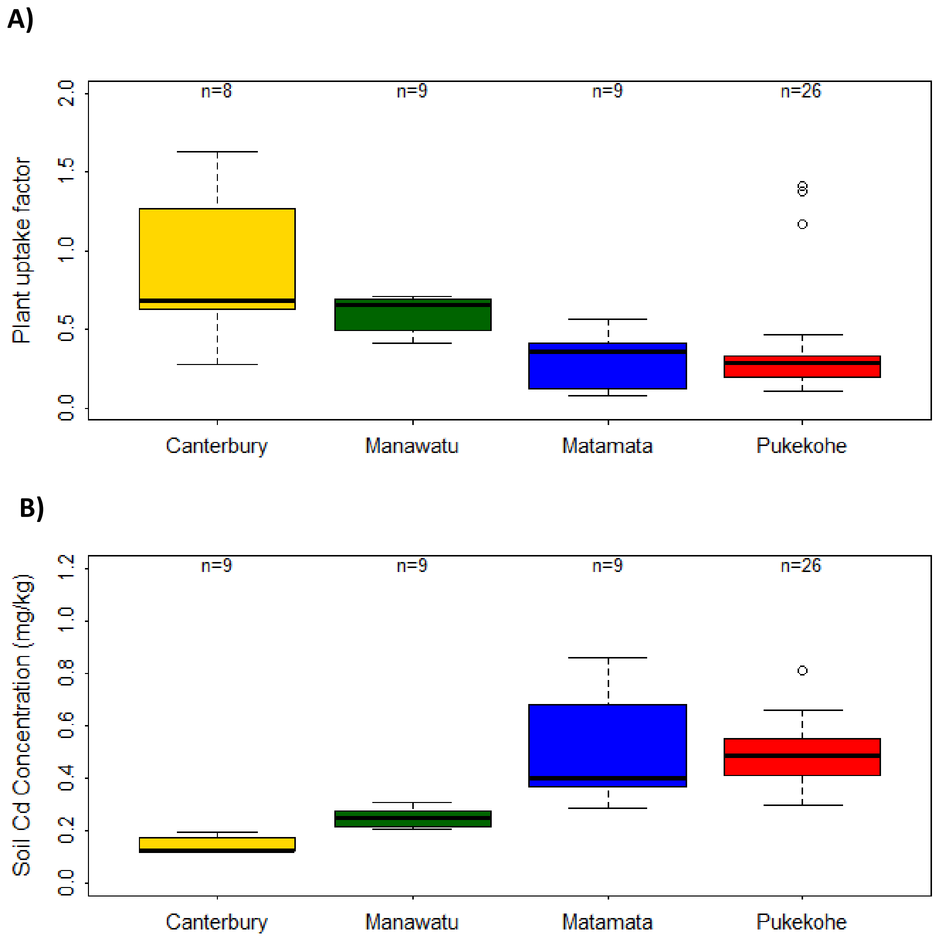

Figure 6. A) Plant uptake factor of one potato cultivar collected at different locations within different regions. B) Range in soil Cd concentrations (mg/kg) at the potato sampling sites. N= individual plot data, with 3 plots sampled per site; the one site with high plant uptake by onions is not the same location as the high soil Cd concentration, which is from a site with low soil bulk density. N= individual plot samples, with 3 or 4 plots sampled per site. Showing median solid line in box, with upper box = 75% percentile; lower box = 25% percentile; outliers are represented by circles and are values that are greater than 1.5 times the interquartile range.

Additional sampling has been undertaken in regions other than Pukekohe over the recent growing season, and comprehensive data analysis will be undertaken on the complete data set (which includes additional soil properties).

Spinach

As expected, plant uptake in spinach was higher than for other crops. There was considerable variation between regions with Tasman having the highest availability (Figure 7). Differing Cd concentrations were found in baby-leaf spinach collected at different times from the same location (data not shown), and may suggest crop management, in particular water management, may influence Cd uptake. There was no consistent trend in Cd uptake between baby and bunching spinach, with higher uptake found in bunching spinach from Pukekohe compared to baby spinach from the same crop and similar uptake in baby and bunching spinach from Canterbury (data not shown).

A)

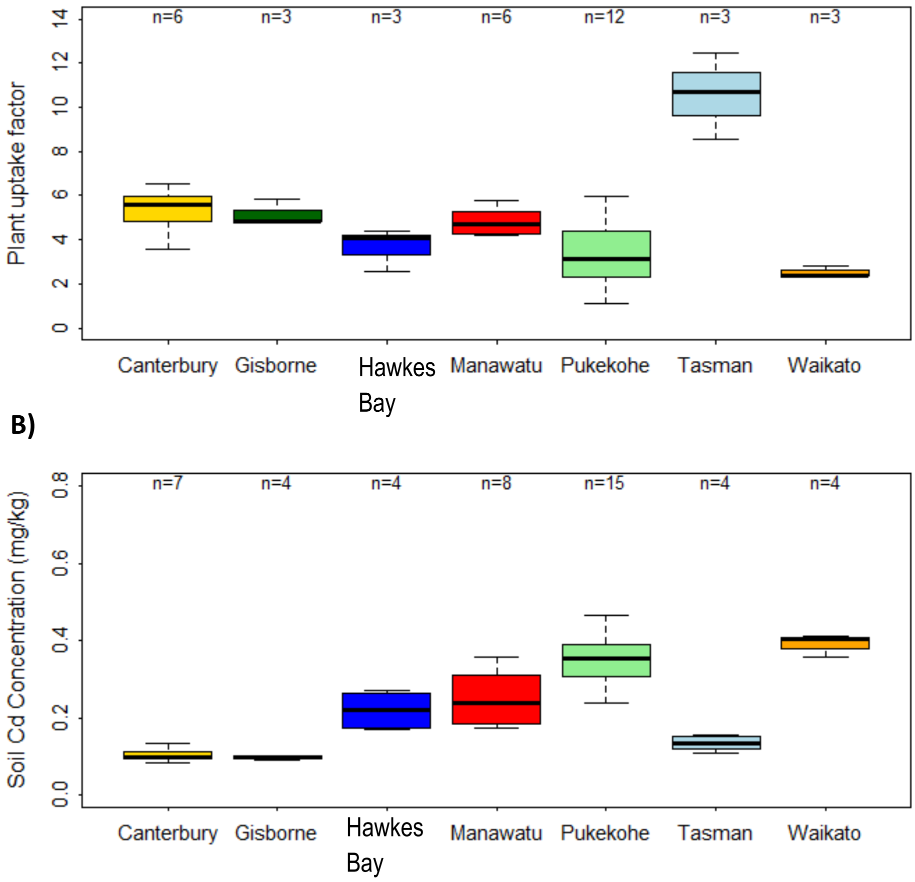

Figure 7. A) Plant uptake factor of baby leaf and bunching spinach of one cultivar collected at different locations within different regions. B) Range in soil Cd concentrations (mg/kg) at the spinach sampling sites. N= individual plot data, with 3 plots sampled per site; the one site with high plant uptake by onions is not the same location as the high soil Cd concentration, which is from a site with low soil bulk density. N= individual plot samples, with 3 or 4 plots sampled per site. Showing median solid line in box, with upper box = 75% percentile; lower box = 25% percentile; outliers are represented by circles and are values that are greater than 1.5 times the interquartile range.

Lettuce

Higher plant uptake was observed in lettuce varieties collected from Gisborne compared to those collected from Pukekohe region and Canterbury (Figure 8) although there was no consistent trend in Cd concentrations in different lettuce varieties collected at the same location (data not shown). Gisborne soils have comparable Cd concentrations to the Canterbury soils, and lower Cd than the Pukekohe soils.

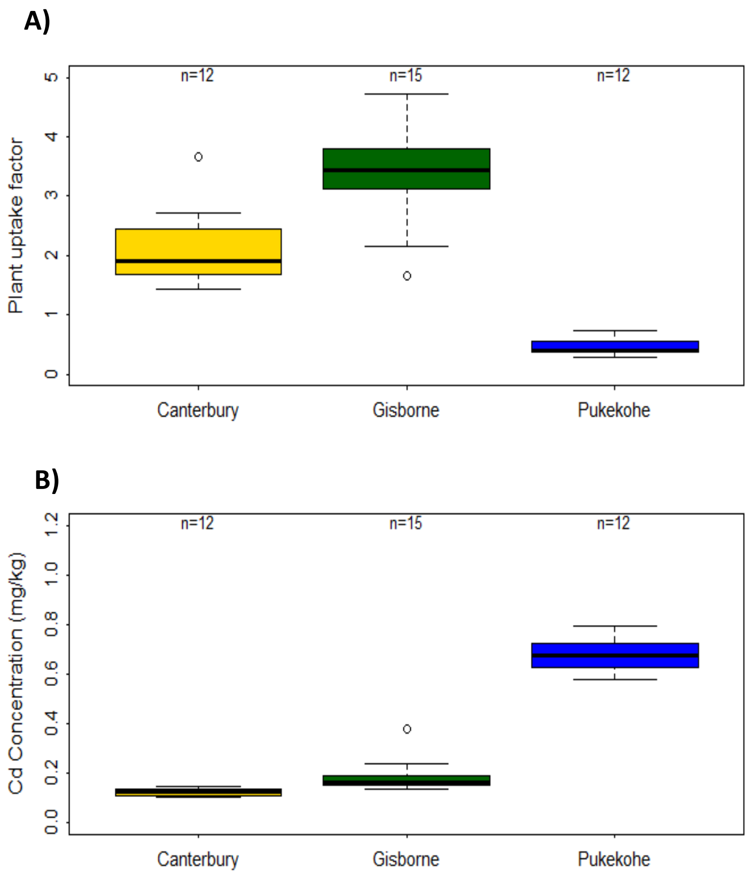

Figure 8. A) Plant uptake factor of lettuce cultivars collected from the same locations within different regions. B) Range in soil Cd concentrations (mg/kg) at the lettuce sampling sites. N= individual plot data, with 3 plots sampled per site; the one site with high plant uptake by onions is not the same location as the high soil Cd concentration, which is from a site with low soil bulk density. N= individual plot samples, with 3or 4 plots sampled per site. Showing median solid line in box, with upper box = 75% percentile; lower box = 25% percentile; outliers are represented by circles and are values that are greater than 1.5 times the interquartile range.

Field trials

At the time of writing, all trials have been completed with the spinach trial abandoned due to heavy rain during the first week of April, which resulted in the crop dying. The timing of amendment application, planting and final harvest is shown in Table 2. Sample analysis is underway.

Table 2. Status of field trials

Crop	Site	Amendments applied	Planted	Harvested
Wheat	Lincoln	11th May 2016	10th Jun 2016	24th Jan 2017
Potatoes	Pukekawa	7th Jun 2016	17th Augt 2016	17th Jan 2017
	Lincoln	19th Sept 2016	4th Oct 2016	22nd Mar 17
	Manawatu	23rd Sept 2016	27th Oct 2016	10th Apr 17
Spinach	Manawatu	10th Feb 2017	1 Mar 2017	Abandoned due to flooding

Summary and next steps

There were obvious regional differences in plant availability of Cd in the different crops. This in turn may be attributable to differences in soil type with uptake higher in Recent, Gley and Pallic soils typical of growing areas in Canterbury and Gisborne and generally lower uptake in Allophanic and Granular soils typical of growing regions in Pukekohe and Matamata – but there are exceptions that are not explained by general soil properties (pH, total C, CEC, soil Cd). Additional soil analyses to determine metal oxide content, and clay mineralogy may provide insight into the reason for these differences and is currently being undertaken.

Additional sampling has also been undertaken over the recent growing season and will provide additional data to examine the relationship between soil properties and plant uptake of Cd. More comprehensive data analysis will be undertaken on the full data set, and will examine the influence of additional soil properties e.g. particle size analysis, total chloride, zinc concentrations on plant uptake of Cd.

Analysis of the field trial samples will offer insight into the efficacy of potential management options (lime and compost addition) in reducing Cd uptake by crops. These field trials should provide further insight into the effect of pH and total C on plant uptake of Cd.

Acknowledgements
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