Tropical Agricultural Research Vol. 17: 93 - 103 (2005)

Accumulation of Cadmium in Intensive Vegetable Growing soils in the Up Country

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ABSTRACT. *The accumulation of heavy metals such as Cd in soils, is a considerable concern to human health, and agricultural, livestock and aquatic industries. The objectives of this study were to determine the Cd concentrations in some vegetable growing soils and in vegetables of up country; and to establish relationships between vegetable Cd concentrations and soil properties. Crop and soil samples were collected from Kandapola, Sita-Eliya, Bogahakumbura, Haputale and Rahangala. The crops selected were carrot (Dacus carota), leeks (Allium ampeloprasum), potato (Solanum tuberosum) cabbage (Brassica oleracea) knol-khol (Brassica oleracea L.) and lettuce (Lactuca sativa). Soil and plant samples were analysed for total and plant available Cd and Zn. The highest concentrations of soil Cd were found in Haputale (3.85 mg/kg) and Kandapola (1.96 mg/kg). The Cd concentrations of vegetables were greater than 0.2 mg/kg. Based on the bio concentration factor (BCF), the tested samples can be arranged as follows; carrot (183.5) > potato (66.4) ≥ knol-khol (63.4) ≥ leeks (62.3) > cabbage (40.3) > lettuce (28.6). Positive relationships were observed between the total Cd and exchangeable Cd in soils and exchangeable Zn in soils and plant Cd concentrations and the r^2 were 0.81 and 0.86, respectively. A negative relationship was observed with soil pH and plant Cd concentrations and the r^2 was 0.71. Soils collected from many fields in Bogahakumbura, Haputale, Kandapola and Rahangala had Cd concentrations greater than 1 mg/Kg. Total Cd concentration, exchangeable Zn and low pH values in soils were the contributing factors for higher plant Cd levels. This study emphasizes the importance of investigating the sources of heavy metals in up country soils and possible control measures to reduce the associated risk due to food chain transfer of toxic heavy metals.*

INTRODUCTION

Vegetable cultivation is more intensive and highly commercialized in up country intermediate zone (UCIZ) and up country wet zone (UCWZ) of Sri Lanka. Farmers in those areas grow 2 - 3 crops per year in the same land and vegetable farmers in UCIZ and UCWZ apply 2 - 3 times higher doses of fertilizers recommended by the Department of Agriculture (Wijewardena and Yapa., 1999). The application of poultry manure or cattle manure in

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combination with chemical fertilizers in vegetable cultivation has increased considerably in the up country of Sri Lanka recently. The use of animal manure is well adopted by farmers especially for potato and vegetables and to a lesser extent for rice and local tuber crops (Wijewardena and Gunarathna, 2004.) Organic manures are considered as valuable sources of nutrients. However, there are beneficial effects, potential hazards associated with organic manures has received even greater attention (Page and Chang, 1974).

Cadmium is a heavy metal and not currently considered essential to either plant or animal nutrition (Robert *et al.*, 1973). Unlike some other heavy metals in soils (*i.e.*, Pb and Zn), Cd can be absorbed by plants to a level that can be harmful to consumers. The geochemical abundance of Cd is near 0.18 ppm (Robert *et al.*, 1973) and therefore, plants naturally have low levels. Chemical fertilizers, manures and pesticides contain heavy metals either as an active ingredient or as an impurity (Huysman *et al.*, 1994). For example, chemical phosphatic fertilizers such as triple superphosphate can contain appreciable amounts of Cd (Pierzynski *et al.*, 2000) and Cd contamination in soils of many countries is mainly a result of the use of phosphatic fertilizers (McLaughlin *et al.*, 1996). These phosphatic fertilizers also unintentionally introduce other contaminants, such as F, Hg, As, and Pb, into agricultural soils. Similarly, most common pesticides used extensively in the past, also contained heavy metals and the residual soil contamination could be higher than that caused by fertilizers (McLaughlin *et al.*, 1996).

Vegetables are highly recommended foods for humans and large amounts are consumed as part of their daily diets (Cobb *et al.*, 2000). Thus, accumulation of heavy metals in the edible parts of vegetables represents a direct pathway for their incorporation in to the human food chain (Florigin, 1993). Metal accumulation in plants depends on plant species, growth stages, types of soil and metals, soil conditions, weather and environment (Petruzzelli, 1989; Domergue and Vedy, 1992). Accumulation of heavy metals in the human body can cause diseases in digestive system, anemia, chronic nephritic encephalopathy, *etc.* (Lagerwerff, 1972). Cadmium is toxic to human at high levels causing neuropathological symptoms and renal dysfunction. Tolerable daily Cd intake for humans is 1 μg/kg body weight (IFDC, 1996). Even though, there are some data on heavy metal concentrations in manures (Wijewardena and Gunarathna, 2004) and some soils in the up country (Rajapaksha and Raufa, 1999), there is no sufficient data available on heavy metal contents, especially Cd concentrations in crops and soils in the up country of Sri Lanka. The aim of this study was to investigate the Cd concentration in soils and common crops growing in up country area and to establish relationships between crop Cd concentrations and soil properties.

MATERIALS AND METHODS

Background information of the study area was collected using a questionnaire. It included information about the extent of cultivation, addition of organic manure and agrochemicals, type of vegetables and their management practices. Crops and soils were sampled from the locations of Kandapola, Sita-Eliya, Bogahakumbura, Haputale and Rahangala during the period of November 2003 to November 2004. The crops grown in these soils were collected for analysis. The crops were carrot (*Dacus carota*), leeks (*Allium ampeloprasum*), potato (*Solanum tuberosum*), cabbage (*Brassica oleracea*), knol-khol (*Brassica oleracea L.*) and lettuce (*Lactuca sativa*). The sites sampled represented the major vegetable growing areas in the up country. One uncultivated representative soil was collected from Sita-Eliya. Soil samples were collected using stainless steel spade at the depth of 0 - 20 cm. Soils were air dried in the laboratory and crushed to pass a 2mm sieve prior to analysis. All soils were analyzed for initial soil characteristics at the Department of Soil Science, Faculty of Agriculture, University of Peradeniya, and heavy metals were analyzed at the Institute of Fundamental Studies, Hantana. Plant samples were taken along with soil samples that were near to harvesting stage. Plant samples were brushed at the field to free of soil and transported to the laboratory for analysis. Plant samples were thoroughly washed with running tap water and rinsed with 0.5% (5g/1000ml) sodium lauryl sulfate (CH_3 $(CH_2)_{10}CH_2OSO_3Na$) to remove all the soil particles adhere to plant samples. Then they were thoroughly washed with distilled water and rinsed with de-ionized water. Subsequently, above ground and bellow ground plant parts were separated and oven dried at 55 ^{0}C until gain a constant weight. The dried samples were ground using stainless steel sample miller and stored in plastic containers until further analysis.

Soil pH was determined by glass electrode – Calomel method in a suspension of soil: solution ratio 1:2.5 (McLean, 1982). The total Cd and Zn concentrations in the soil were determined using the method described by Sposito *et al.* (1983). In brief, 2 g of air-dried soil sample was digested using 20 ml 4M Nitric acid at 80 ^{0}C water bath for 4 hours. Finally, extract was filtered using Whatman No 42 filter paper and Cd and Zn were measured in graphite furnance atomic absorption spectrophotometer (GBC Aventa Ver 1.33). Total Cd and Zn in plant samples were determined using the modified Zarcinas Cartwright and Spouncer. (1987) method described by Hettiarachchi and Pierzynski (2002) as follows. About 1g of ground plant sample was digested with 10 ml of concentrated Nitric acid for 4 hours at 120 ^{0}C. The extract was filtered with Whatman No 42 filter paper and Cd, and Zn was determined using graphite furnance atomic absorption spectrophotometer (GBC Aventa Ver 1.33). Exchangeable Cd and Zn in soil were determined by adding 20 ml of DTPA extraction solution to 10g of air dried soil and it was shaken for 2 h and solution was filtered using Whatman No 42 filter paper (Lindsay and Norvell, 1978). The filtrate was analyzed for Cd and Zn using atomic absorption spectrophotometer (GBC Aventa Ver 1.33).

Quality control measures were practiced for Cd and Zn analysis in soil and plant samples. Standard sample, SRM 1573a (tomato leaves) from National Institute of Standards and Technology, USA was analyzed as the reference material. Standard quality control practices were adopted during the analysis.

Bioaccumulation was quantified in terms of bio concentration factor (BCF), which is the ratio of plant Cd concentration to total Cd in soil as a percentage. The BCF for this study was calculated for each vegetable in this study.

RESULTS AND DISCUSSION

Soil properties

The description of the location, the cropping history and the commonly used organic manure types were given in Table 1. According to the information gathered, most farmers in Kandapola and Sita-Eliya area intensively cultivate leeks, carrot, beet, lettuce and cabbage throughout the year. On the other hand in Rahangala, Bogahakumbura, and Haputale, potato is grown in the wet season and vegetables in the dry period using irrigation.

The soils collected represent the agro ecological zones of WU3, IU2 and IU3. Taxonomically all the soils belong to the order Ultisols (Panabokke, 1996). The pH of the selected soils was ranged from 5.2 to 7.2 (Table 2). Generally soils of up country wet zone are acidic in nature and it is a major limitation of the up country soils of Sri Lanka (Kumaragamage *et al.*, 1999). However, most of the observed pH values were in the slightly acidic to near neutral soil pH range. The most possible reasons are the addition of poultry manure and application of lime to the fields. The poultry manure application over several years lead to an increase in soil pH (Wijewardena, 1993). Farmers responses revealed that the management practices and the type of vegetables grown were almost similar in all the selected fields. Therefore, observed values for routine soil properties did not show a high variability among the fields especially for soil pH.

Table 1. Description of the soils collected for the experiment

Location	Field	Agro-ecological Zone	Crop Grown	Cultivation History (Years)	Commonly Used Organic manure
Sita-Eliya	1	WU3	Cabbage	>25	CM
	2	WU3	Leek	15-20	CM
	3	WU3	Potato	<15	CM
	4	WU3	Knol-khol	N/I	N/I
	1	WU3	Cabbage	>30	CM
Kandapola	2	WU3	Carrot	>25	CM
	3	WU3	Leek	>20	CM
	4	WU3	Lettuce	>30	CM
	5	WU3	Potato	>25	PM
	1	IU2	Cabbage	>30	PM
Haputalae	2	IU3	Carrot	40-50	PM
	3	IU3	Carrot	30-40	PM
	1	IU3	Cabbage	>40	PM
Bogahakubura	2	IU3	Potato	>25	PM
	3	IU3	Potato	>20	PM
Rahangala	1	IU3	carrot	15-20	PM
	2	IU3	Cabbage	N/I	N/I
Control	1	WU3	uncultivated	>10	N/A

CM=Cattle manure, PM=poultry manure, N/I= No Information, N/A= not applied

Cadmium in soils

The highest total soil Cd concentration of 3.85 mg/kg was shown in field number 2 of Haputale and the second largest amount was recorded at field number 5 of Kandapola (Table 2). The European Community Set Standards in 1986 for the maximum concentration of Cd allowed in agricultural soil treated with sewage sludge ranges from 1 to 3 mg/kg depending on soil properties (McGrath and McCormack, 1999). In Kandapola, the field numbers 3, 4, 5 and 6 and all fields in Bogahakumbura and Rahangala were above or almost near to the lower limit of maximum allowable concentration of Cd. Soils collected from a field uncultivated for more than 10 years, reported only 0.51 mg/kg of Cd. The total Zn concentration in all fields except field number 4 of Sita-Eliya and field number 2 and 3 of Haputale and some fields in Kandapola, Rahangala, and Bogahakumbura were higher than the European Community Set Standards (150-300 mg/kg) for agricultural soil treated with sewage sludge (McGrath and McCormack, 1999). The mean total Cd concentrations reported in agricultural soils range from 0.265 mg/kg (Holmgren *et al.*, 1993) to 0.4 mg/kg (Roberts Longhurst and Brown., 1994). The Cd concentration in all the tested soils in up country agricultural area is greater than 0.5mg/kg.

Table 2. Soil pH and concentrations of total and exchangeable (Exg) Cadmium and Zinc (mg/kg) in soils

Location	Field	pH	Total Cd	Exg. Cd	Total Zn	Exg. Zn
		D. water	---mg/kg---			
Sita-Eliya	1	5.2	0.5	0.29	359.9	28.6
	2	6.1	0.59	0.32	181.5	12.9
	3	6.4	0.88	0.39	252.4	15.2
	4	7.2	0.56	0.38	127.8	29.1
Kandapola	1	6.1	0.39	0.33	150.3	9.2
	2	5.9	0.43	0.31	145.2	4.8
	3	5.6	1.39	0.39	133.7	6.8
	4	6.3	1.31	0.44	181.2	7.5
	5	6.6	1.96	0.48	193.3	8.5
	6	6.8	1.46	0.76	108.0	6.4
Haputalae	1	6.5	0.51	0.48	212.7	6.1
	2	6.1	3.86	1.24	121.4	29.8
	3	5.7	1.45	0.41	149.6	6.5
Bogahakubura	1	5.6	1.31	0.32	194.5	11.8
	2	5.9	1.42	0.32	71.12	1.5
	3	5.2	1.30	0.35	56.12	9.7
Rahangala	1	5.2	1.29	0.39	141.4	5.1
	2	6.2	1.22	0.38	142.7	2.7
Uncultivated soil	1	5.1	0.51	0.26	12.2	2.3

Exg. = Exchangeable

Observed higher values for Cd could be due to several reasons. These areas have been cultivated over 30 years. Soils that were receiving repeated application of poultry manure (Han *et al.*, 2000), and cattle manure, together with phosphate fertilizers for many years lead to accumulate heavy metals like Cd. Therefore, increased and repeated use of these inputs could be a reason for observed increased level of Cd concentration in soils. Farmer responses were as such that the farmers in the *Sita-Eliya* area have been used more cattle manure than poultry manure for their cultivations. Wijewardena and Gunarathna (2004) reported that poultry manure in Sri Lanka contains higher amount of Cd than cattle manure.

Cadmium in vegetables

Concentration of Cd in the vegetable samples (shoot and root/tuber) is given in the Table 3.

Table 3. Concentration of Cd in vegetables collected from experimental fields

Location	Field	Vegetable	Cd (mg/kg)		
			Shoot	Root / tuber	Total
Sita-Eliya	1	Cabbage	2.02	0.82	2.84
	2	Leeks	0.54	1.93	2.47
	3	Potato	N/S	0.86	0.86
	4	Knol-khol	1.93	1.28	3.22
Kandapola	1	Cabbage	0.46	0.35	0.81
	2	Carrot	0.48	0.41	0.89
	3	Leeks	0.48	N/S	0.48
	4	Lettuce	0.30	N/S	0.31
	5	Potato	N/S	0.36	0.36
Haputale	1	Cabbage	0.59	0.34	0.92
	2	Carrot	0.87	2.05	2.90
	3	Carrot	2.71	1.52	4.22
Bogahakumbura	1	Cabbage	0.37	0.49	0.86
	2	Potato	N/S	0.33	0.33
	3	Potato	N/S	0.22	0.22
Rahangala	1	Carrot	0.99	0.65	1.60
	2	Cabbage	0.49	0.62	1.10

N/S - Not enough plant material for digestion

Results showed that almost all vegetables analyzed had exceeded the accepted Cd values for vegetables which is 0.05-0.2 ppm (Kabata-Pendias and Pendias, 1984), indicating that for some of our soils the maximum limit of 1 mg/kg soil Cd levels may not be protective enough. These findings highlight the fact that set limits are by no means universal and should be adjusted depending on soil properties and plant species. For example, on-going field experiments in Australia showed that a limit value of 1 mg /kg of Cd in soil may not be protective in some soils and for some crops, even if the soil pH is maintained at >5.5 (McLaughlin, 2005). Therefore, it is argued that in the absence of basic understanding of metal behavior in each specific situation more precautionary approach would be appropriate. To evaluate the accumulation of heavy metals in selected vegetables, bio-concentration factor (BCF) was calculated for the edible parts of different vegetables. The BCF can be used to asses the heavy metal concentration (mg/kg) in the organisms (plant, microorganisms, and animals) in compared to soil (mg/kg) (Tan *et al.*, 2004). The BCF for Cd for the experimental crops can be arranged as follows in the descending order: carrot> potato ≥knol-khol ≥ leek >cabbage >lettuce (Figure 1). The respective BCF values for Cd were 183.5. 66.4, 63.4, 62.3, 40.3, and 28.6. Generally higher metal accumulations were found in leafy and root vegetables than in other vegetables (Tiller *et al.*, 1976). Plants accumulate trace elements in their parts ranging from 1000 to 10,000 fold (Prasad, 1997).

According to Siedlecka (1995) Cd accumulate more in roots/rhizomes like carrot, radish, potato and beet root than in shoots (stems/leaves).

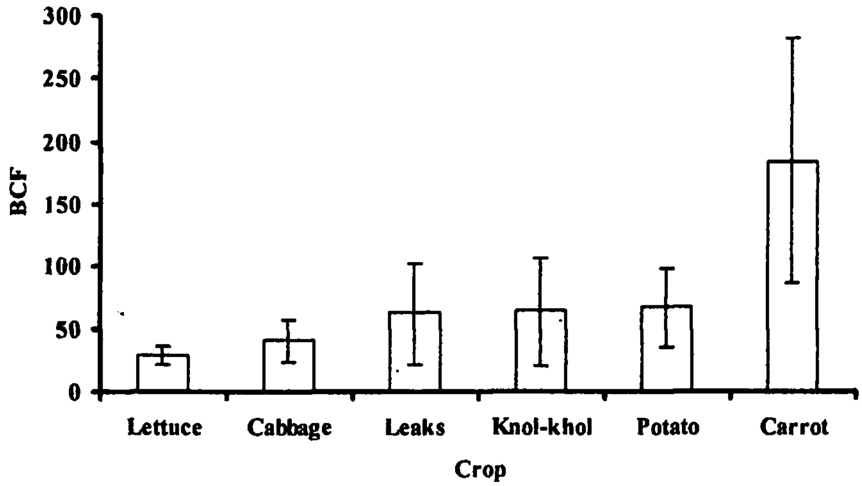

Fig. 1. Cadmium Bio Concentration Factor for crops (BCF was calculated based on dry matter weight)

Relationships among soil Cd, plant Cd and selected soil properties

Positive and significant relationships were observed between total and exchangeable Cd and total and exchangeable Zn, and the r^2 were 0.81 and 0.67, respectively (Table 4). Along with exchangeable Cd concentration increases in soil, the plant Cd also have increased showing a positive relationship (r^2 = 0.66). The soils having high concentration of Cd produced plants with high Cd concentrations (Tiller, 1988). Plant uptake of heavy metals is governed by many factors such as soil properties, plant properties and metals/waste properties (Ryan, 1976). Interaction of all these factors determines the plant availability of heavy metals. Soil pH is one of the major variables that controls Cd uptake by plants (Jakson and Alloway, 1992; and McLaughlin *et al.*, 1997). Results of this study also indicated that soil pH was negatively related with plant Cd concentration and the r^2 was 0.71. Del Casthilo and Chardon (1995) found that the Cd transfer in various crops decreased by ten-fold when pH between 5 and 7.2 dropped by one unit. Similarly soil pH play a significant role in bioavailability of Cd in studied vegetable growing soils. Application of lime increases the soil pH helping in controlling the metal uptake by vegetables. Uptake of metals by plants depends on the bioavailability of metals in soil. As a result, there is a tendency to absorb more Cd by plants grown in up country soils since the pH of these soils were acidic in nature. The negative relationship between pH and plant Cd concentration shows a tendency for lower Cd concentration in plants with increasing pH. The critical pH for contaminated soils is suggested to be pH_w>6.5 because this would ensure strong binding of most metal contaminants.

The pH values of most of the fields reported in this study were below 6.5 and conducive for absorbing more Cd by vegetables. The relationship between exchangeable Zn and plant Cd contents was positive and the r^2 was 0.27 (Table 4). Sorption of Cd decreased with increasing ionic strength in a net negatively charge soils. Sorption of cations by soils is a competitive process. Cadmium form divalent cations, so the presence of other divalent cations likes Zn retard the sorption of contaminants like Cd and increase their phytoavailability (Naidu *et al.*, 1994).

Table 4. Regression relation of soil Cd and plant Cd with other soil parameters

Tested relation	Model	r^2
Total Cd vs Exchangeable Cd	Y = 0.2447x + 0.2048	0.81
Plant Cd vs Exchangeable Cd	Y = 2.1366x - 0.214	0.66
Total Zn vs Exchangeable Zn	Y = 0.0686x - 1.1913	0.67
Exchangeable Zn and plant Cd	Y = 0.075x + 0.4262	0.27
Plant Cd vs pH	Y = -1.114x + 7.489	0.71

X= Total/plant Cd Y=exchangeable Cd/Zn /pH

CONCLUSIONS

Up county vegetable cultivating soils showed soil Cd levels of >0.5 mg/kg and few reported values were higher than the European Community set standards (1 – 3 mg/kg). The highest concentrations were found in Haputale and Kandapola areas. Crop cultivation history of over 30 years, high and continuous application of poultry and cattle manure as well as phosphate fertilizers and other agrochemicals for many years could be the reasons for the Cd accumulations in these soils. There was a positive relationship between the total Cd and exchangeable Cd in soils. Moreover, results showed that the majority of vegetables analyzed had higher Cd concentrations than the accepted range emphasizing the great need for further investigations. The bio concentration factor for carrot was the highest (183.5) while other crops studied followed in the order of potato ≥ Knol-khol ≥ leek > cabbage > lettuce. A negative relationship was observed for pH and plant Cd concentrations while a positive relationship was observed between exchangeable Zn and plant Cd concentration.

ACKNOWLEDGEMENTS

The financial support given by the Council for Agricultural Research Policy under the grant number CARP 12/541/412 is greatly appreciated by the authors. Gratitude is expressed to Prof. Rohan Weerasooriya and Miss. Darshini Aluthpatabendi for assistance in analysis for heavy metals at Institute of Fundamental Studies (IFS), Hantana. Authors appreciate the help given by Mr. Upali Yapa, Research Officer Horticultural Crop Research and Development Institute, Gannoruwa, in collecting soil and plant samples. Our gratitude further extended to Head and Staff of the Department of Soil Science, University of Peradeniya, and Miss. U.P. Kooragama, Technical Assistant of the project, and all personals who helped us in various ways.

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