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Cadmium and lead uptake by radish (*Raphanus sativus* L.) grown in three different textured soils

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Abstract

Radish (Raphanus sativus L.*) was grown in earthen pots containing soils of three different textures (clay loam, sandy clay loam and sandy loam) and treated separately with different levels of cadmium (0, 1, 3, 5, 7 and 9 mg Cd kg^{-1} soil) and lead (0, 10, 20, 30, 40 and 50 mg Pb kg^{-1} soil). Shoot and root dry weights were reduced to 25-38% and 36-46%, respectively at the highest Cd treatment, and 28-33 and 35-53%, respectively at the highest Pb treatment as compared to the control treatment. Cadmium and Pb application with higher rates significantly decreased the shoot and root yield of radish. Cadmium and Pb concentration in shoot and root increased with rate of Cd and Pb application, respectively. The concentration of Cd started to increase significantly at 3 mg Cd kg^{-1} soil treatment as compared to the control except for shoot in sandy loam soil. Lead treatment at 10 mg Pb kg^{-1} soil caused significantly higher Pb concentration in shoot and root from the control in all the three soils. Among the soils, Cd and Pb concentration in shoot and root were pronounced in sandy loam soil. Total accumulation of Cd showed almost the similar trend as that of Cd concentration in shoot and root. Lead accumulation in root did not show any definite trend of variation with Pb application in sandy loam and sandy clay loam soil. Bioaccumulation coefficients of Cd and Pb were higher in shoot than root. Cadmium and Pb concentration in plant parts were highly correlated with Cd and Pb application in soils respectively.*

Keywords: Radish, cadmium (Cd), lead (Pb), concentration, shoot, root

Introduction

The heavy metal contaminants in agricultural ecosystem have become a social issue world wide. High concentrations of heavy metals in agricultural soils can occur naturally (Singh *et al.,* 1995) or via atmospheric deposition or the application of metal contaminated sewage sludge, fertilizers and animal manures (Alloway and Steinnes, 1999). Singh *et al*. (1995) found high concentration of Cd (2.5 mg kg^{-1}) in alum shale soil of Norway, naturally developed from sulfur bearing rocks. The primary anthropogenic source of heavy metals in soil is agricultural activities. Pesticides and fertilizers that are directly applied to soil can be an important source of metals such as As, Cd and Pb (Bloemen *et al*., 1995). Human activities other than agriculture can also result in enrichment of metals in soils. Irrigation water drawn from streams and lakes that are contaminated with industrial and domestic discharges can cause significant enhancement in metal content of soil (Jensen *et al*., 2000).

Cadmium and Pb have been recognized as two of the most deleterious heavy metal pollutants in the human environment (Christine, 1997). In many agricultural soils, Cd concentration is elevated over natural background levels due to a continuous release of the metal from industrial and agricultural sources (Davis, 1984; Ullah *et al*., 1999). The main sources of Pb in soils are fertilizers, pesticides, exhaust fumes of automobiles in past, the disposal of municipal sludge enriched in Pb (Alloway, 1995). Heavy metal pollutants can easily enter the food chain if heavy metal contaminated soils are used for production of food crops. For example, the disease known as "itai itai" and "minamata" were caused by the production of paddy rice on soil contaminated with Cd and Hg in Japan (Asami, 1981). The entry of Cd into the food chain is of great concern as it can cause chronic health problems in humans such as bone disease, lung edema, renal dysfunctions, liver damage, anemia and hypertension (Staessen *et al*., 1999). Lead is a highly toxic element to humans and most other forms of life. Soils contaminated with Pb are a health risk, particularly when ingested. Fruits and vegetables grown in contaminated soil may become contaminated as a result of plant uptake of Pb from soils or direct deposition of leaded dust onto plant surfaces (Rahlenbeck *et al*., 1999). Therefore, Pb deposited into soil becomes a persistent and long term source of Pb exposure for humans, particularly children. Lead ingestion by women of child bearing age may impact both the woman's health (Lustberg and Silbergeld, 2002) and that of her fetus, for ingested Pb is stored in the bone and released during gestation (Gomaa *et al*., 2002).

In Bangladesh, productive soils, natural water system as well as ground water are being polluted as a result of discharging industrial wastes and effluents randomly on

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agricultural land, into canals, rivers, along roadsides or in the vicinity of industrial operation without any treatment (Kashem and Singh, 1999). Contaminations of agricultural soils of this country with excessive amounts of Cd and Pb have been reported by Ullah *et al.* (1999) and Khan (2001). In this background, the present study was conducted to investigate the uptake of Cd and Pb and their effects on radish, a popular root vegetable crop, in Bangladesh.

Materials and Methods

Pot experiment

Three different textured soils; clay loam, sandy clay loam and sandy loam were collected from (1) agricultural field near new Science Faculty of Chittagong University, (2) agricultural field near Shahid Minar of Chittagong University, and (3) Syedpara at Hathazari Upazilla under Chittagong district from a depth of 0-15 cm, respectively. Soil samples were air dried and ground to pass through a 2 mm sieve to separate dry roots, grasses and gravels, etc. A portion of the soils passed through 2 mm sieve was retained for laboratory analyses. Soil chemical analyses were done by standard methods (Day, 1965; Jackson, 1973). Characteristics of the soils are presented in Table 1.

Earthen pots were filled with soil @ 8 kg per pot. Nitrogen (in Urea), P (in Triple super phosphate), K (in Muriate of potash) and S (in Zinc sulfate) were applied equally in the pots (171 kg N, 51 kg P, 114 kg K and 30 kg S ha^{-1} soil). According to Bangladesh Agricultural Research Council (1997) recommendation, 1/3 N, and whole of P, K, S were applied during soil preparation. Remaining nitrogen was applied in two equal installments after 3 and 4 weeks of seedling emergence. Five healthy and uniform seeds of radish were sown at equal distance in each pot. After one week of seedling emergence, one seedling was kept in each pot and different levels of Cd (0, 1, 3, 5, 7 and 9 mg Cd kg^{-1} soil) and Pb (0, 10, 20, 30, 40 and 50 mg Pb kg^{-1} soil) were applied in separate pots in solution form as $3Cd(SO_4)_2.8H_2O$ and $Pb(NO_3)_2$, respectively. Each treatment was replicated thrice and the pots were arranged in randomized block design. Care was taken to keep uniform seedlings in the pots. Water was applied regularly to the pots to maintain the field capacity of the soils. Plants were harvested after five weeks of Cd and Pb application. Shoot and roots were separately collected.

Plant analysis

Oven dried (65 ^{o}C to constant weight) and ground plant samples were digested with ternary acid (HNO_3, H_2SO_4 and $HClO_4$ mixture at ratio of 5:1:2) (Huq and Alam, 2005). The concentrations of Cd and Pb in the digested solution were measured by atomic absorption spectrophotometer (Varian Spectra AA 220)

Data analysis

The significance of differences between the means of the treatments was evaluated by one way analysis of variance followed by Duncan's Multiple Range Test at the significance level of 5%. Pearson's correlation coefficient was estimated to test the relations between metal concentrations in plant tissues and metal content in soils.

Results and Discussion

Growth of radish as affected by cadmium and lead

Dry weights of shoots and roots of radish were significantly different among the treatments (Table 2). In clay loam and sandy clay loam soil, 1 mg Cd kg^{-1} soil application increased the shoot and root weight of radish but other levels up to 9 mg Cd kg^{-1} soil decreased the weights as compared to the control. There was, in general, a depression of yield due to Cd application in sandy loam soil. A significant reduction in shoot yield from the control treatment was started at 5, 7 and 9 mg Cd kg^{-1} soil treatment in sandy loam, sandy clay loam and clay loam soil respectively. On the other hand, root yield reductions were started correspondingly at 7, 9 and 5 mg Cd kg^{-1} soil. This result corroborates that of Nwosu *et al*. (1995) who found that plant biomass decreased in both radish and lettuce as the concentration of Cd and Pb in their mixture in the soil increased. In their study, plant biomass decreased gradually, but biomass declined sharply in both radish and lettuce when the concentration of Cd reached 400 mg kg^{-1} soil at various concentration of Pb. Cadmium in the soil alone caused significant reduction in biomass in radish ($p< 0.001$) and lettuce ($p<0.001$). Furthermore, there was no substantial evidence of an interaction between the two metals on biomass reduction. At the highest Cd treatment (9 mg Cd kg^{-1} soil) in the present study, shoot and root biomass were reduced to 25-38 and 36-46%, respectively from the control treatment. John *et al*. (1972) reported the effects of Cd on radish growth with 30 different surface soils. In his study, shoot and root weight were reduced by an average of 47 and 67% by the addition of 100 mg Cd kg^{-1} soil, respectively. On the contrary, Kim *et al.* (2002) found no significant reduction of radish yield under 100 mg kg^{-1} o f Cd treated silt loam soil. However, significant reduction of growth and yield of Chinese cabbage and lettuce were found with 50-100 mg Cd kg^{-1} soil and 10-25 mg Cd kg^{-1} soil, respectively. Sadana and Singh (1987) obtained growth reduction of lettuce by 23% by the addition of 4 mg Cd kg^{-1} in a loamy sand soil. The decrease in biomass might be the results of showing a series of physiological disorders by accumulated Cd in plants such as reduction of chlorophyll, sugar and protein content, decrease of photosynthesis and dramatic change of phenol content and related enzyme activities, finally leading to lower yield (Satyakala, 1997). Cadmium may interfere with nutrient uptake by affecting the permeability of plasma membranes, leading to the change in nutrient concentration and composition. Obata and Umebayashi (1997) showed that tolerance of plasma membrane ATPase to Cd appears to be positively correlated with Cd tolerance in the intact plants. The interactions between Cd and other nutrients may lead to changes in nutrient content and physiological disorders as well as a reduction of growth and yield.

Biomass production of radish was significantly affected by the Pb treatments (Table 3). In general, there was a depression of shoot and root yield by Pb application with increasing rate. The trend in depression in both parameters was in consonance with several earlier reports using many cereals and other crop plants such as corn and sunflower (Carlson *et al*., 1975), rice and oats (Mukherji and Maitra, 1976). The poor development of radish root and shoot in Pb treated soil was substantiated by decrease in root and shoot weight. In clay loam soil, however, both shoot and root weights were significantly reduced only at 50 mg Pb kg $^{-1}$ soil treatment from the control. Similar results were found with shoot in sandy loam and root in sandy clay loam soil. The significant reduction in shoot weight in sandy clay loam soil and root weight in sandy loam soil from the control treatment were started at 30 and 40 mg Pb kg^{-1} soil

Table 1. Characteristics of the soils used in pot experiment

Properties	Clay Loam Soil	Sandy Clay Loam Soil	Sandy Loam Soil
Sand (%)	30	57	63
Silt (%)	38	22	20
Clay (%)	32	23	17
pH (1:2.5 H_2O)	5.4	5.5	5.1
Organic carbon (%)	0.97	0.83	0.61
CEC (cmolkg^{-1}soil)	7.86	6.93	6.43
Total N (%)	0.15	0.09	0.04
Total P (%)	0.023	0.029	0.020
Total K (%)	0.36	0.24	0.26
Total Cd (µg g^{-1})	0.07	bdl*	bdl*
Total Pb (µg g^{-1})	11.2	7.8	9.6
Total Zn (µg g^{-1})	108.7	58.96	55.02
Total Fe (%)	1.574	0.736	1.472
Total Mn (µg g^{-1})	185.06	190.20	86.90

*bdl = below detection limit

Table 2. Effects of cadmium on dry shoot and root yield of radish (g pot^{-1})

Treatment (mg Cd kg^{-1} Soil)	Clay Loam Soil		Sandy Clay Loam Soil		Sandy Loam soil	
	Shoot	Root	Shoot	Root	Shoot	Root
0	14.26 ab	2.23 ab	8.63 ab	1.18 ab	13.66 a	1.60 a
1	16.45 a	2.50 a	9.04 a	1.32 a	11.52 ab	1.21 ab
3	12.99 bc	1.99 abc	7.17 abc	0.92 abc	11.60 ab	1.26 ab
5	12.76 bc	1.79bc	6.60 bc	0.79 bc	10.33 b	1.15 ab
7	11.21 bc	1.53 c	5.62 c	0.80 bc	9.51 b	1.02 b
9	10.62 c	1.42 c	5.30 c	0.63 c	8.81 b	0.95 b
Significance of F value (P)	0.01	0.05	0.01	0.05	0.01	0.05

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT ($P \leq 0.05$)

Table 3. Effects of lead (Pb) on dry shoot and root yield of radish (g pot^{-1})

Treatment (mg Pb kg^{-1} Soil)	Clay Loam Soil		Sandy Clay Loam Soil		Sandy Loam soil	
	Shoot	Root	Shoot	Root	Shoot	Root
0	19.66 a	4.20 a	14.94 a	2.72 a	14.88 a	2.44 a
10	17.72 ab	3.90 ab	13.11 ab	2.60 a	14.69 a	2.21 ab
20	17.75 ab	3.30 ab	11.83 abc	2.53 a	14.71 a	2.30 ab
30	16.60 ab	3.30 ab	10.92 bc	1.81ab	14.25 a	1.76 abc
40	16.57 ab	3.13 ab	10.34 bc	1.85 ab	13.28 a	1.54 bc
50	15.80 b	2.72 b	9.24 c	1.51 b	9.95 b	1.14 c
Significance of F value (P)	0.05	0.05	0.05	0.05	0.01	0.05

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT (P≤ 0.05)

Table 4. Concentration and total accumulation of cadmium (Cd) in radish (expressed in dry weight basis)

Treatment (mg Cd kg^{-1} soil)	Clay Loam Soil		Sandy Clay Loam Soil		Sandy Loam soil	
	Shoot	Root	Shoot	Root	Shoot	Root
Concentration (mg kg^{-1})						
0	0.65 d	Bdl d	Bdl d	Bdl e	Bdl d	Bdl e
1	9.06 d	2.11 d	7.15 d	3.02 e	12.20 c	5.97 e
3	20.26 c	9.59 c	28.90 c	18.79 d	26.25 b	21.82 d
5	26.44 bc	13.09 c	42.89 b	25.89 c	49.32 a	36.54 c
7	32.31 b	21.75 b	47.92 ab	40.95 b	48.55 a	46.53 b
9	45.46 a	30.31 a	57.88 a	49.29 a	51.97 a	56.07 a
Significance of F value (P)	0.001	0.001	0.001	0.001	0.001	0.001
Total accumulation (mg pot^{-1})						
0	0.009 d	bdl d	bdl d	bdl d	bdl d	bdl c
1	0.152 c	0.005 d	0.065 c	0.004 cd	0.141 c	0.008 c
3	0.265 bc	0.019 c	0.202 b	0.016 bc	0.301 b	0.028 b
5	0.338 b	0.024 bc	0.285 a	0.020 ab	0.512 a	0.042 a
7	0.368 b	0.032 b	0.262 ab	0.033 a	0.460 a	0.047 a
9	0.506 a	0.042 a	0.300 a	0.031 a	0.456 a	0.052 a
Significance of F value(P)	0.001	0.001	0.001	0.001	0.001	0.001

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT (P≤ 0.05)

treatment, respectively. The lowest dry weight of shoot and root was found with the highest Pb treatment in all the three soils. At the highest Pb treatment (50 mg Pb kg^{-1} soil), the shoot and root yield were reduced to 28-33 and 35-53%, respectively from the control. The result of the present study is somewhat similar to that of Nwosu *et al.* (1995) with radish and lettuce, and of Huang and Cunningham (1996) with corn. Kosobrukhov *et al.* (2004) reported a considerable decrease in dry weights of plant parts with Pb application. A reduced biomass and yield of rice grown with 1.0 m M Pb in refined sand was reported by Chatterjee *et al.* (2004). The growth and yield reduction of radish may be due to the ill effects of Pb including interference with ion uptake and translocation, disturbed respiration and photosynthesis, changed activity of several enzymes, variation in levels of proteins and NO_3 within the plant system (Lee *et al.,* 1976). Lead accumulation reduced the concentration of chlorophyll in leaves, carotene, protein, sugar, phenols, iron, manganese, copper and zinc in rice (Chatterjee *et al*., 2004).

Table 5. Concentration and total accumulation of lead (Pb) in radish (expressed in dry weight basis)

Treatment (mg Pb kg^{-1} soil)	Clay Loam Soil		Sandy Clay Loam Soil		Sandy Loam soil	
	Shoot	Root	Shoot	Root	Shoot	Root
Concentration (mg kg^{-1})						
0	4.08 e	5.25 e	3.21 d	2.44 d	3.39 d	3.12 d
10	20.13 d	13.19 d	46.47 c	40.35 c	52.42 c	33.10 c
20	40.54 c	24.09 c	57.82 bc	52.80 bc	69.67 b	45.79 bc
30	54.26 bc	42.61 b	69.76 ab	53.58 bc	80.28 ab	53.80 b
40	63.08 ab	45.78 b	76.16 a	58.71 b	85.61 ab	80.72 a
50	70.66 a	62.89 a	79.99 a	76.90 a	88.22 a	88.16 a
Significance of F value (P)	0.001	0.001	0.001	0.001	0.001	0.001
Total accumulation (mg pot^{-1})						
0	0.089 d	0.023 c	0.048 b	0.006 b	0.050 c	0.008 b
10	0.358 c	0.051 bc	0.612 a	0.103 a	0.781 b	0.074 a
20	0.718 b	0.081 b	0.686 a	0.128 a	1.027 ab	0.108 a
30	0.896 ab	0.140 a	0.764 a	0.098 a	1.143 a	0.095 a
40	1.041 a	0.144 a	0.786 a	0.110 a	1.132 a	0.124 a
50	1.119 a	0.167 a	0.744 a	0.117 a	0.884 ab	0.100 a
Significance of Fvalue(P)	0.001	0.001	0.001	0.001	0.001	0.001

Mean values in the column followed by the same letter (s) are not significantly different according to DMRT ($P \leq 0.05$)

Table 6. Correlation between Cd concentration in soil and plant parts; and between Pb concentration in soil and plant parts.

Element	Soil	Shoot	Root
Cadmium	Clay Loam	0.966**	0.968**
	Sandy Clay Loam	0.953**	0.987**
	Sandy Loam	0.926**	0.980**
Lead	Clay Loam	0.944**	0.973**
	Sandy Clay Loam	0.886**	0.877**
	Sandy Loam	0.864**	0.962**

** Correlation is significant at the 0.01 level
*bdl = below detection limit

Cadmium and Lead uptake by radish

Cadmium concentration (mg kg^{-1}) and total accumulation (mg pot^{-1}) in shoot and root are presented in Table 4. Cadmium treatments significantly affected the concentration and total accumulations of Cd in shoot and root in all the three soils. Results indicated that Cd concentration in shoot and root increased with increasing rate of Cd application.

The similar trend was observed in case of total accumulation of Cd in shoot and root with a few exception. Total Cd accumulation in shoot in sandy loam soil was decreased when the rate of Cd application exceeded 5 mg Cd kg^{-1} soil. The concentration of Cd started to increase significantly at 3 mg Cd kg^{-1} soil treatment except for shoot in sandy loam soil.

Table 7. Bioaccumulation coefficient of Cd and Pb in radish (Raphanus sativus L.)

Treatment (mg Cd kg^{-1} Soil)	**Clay Loam Soil**		**Sandy Clay Loam Soil**		**Sandy Loam soil**	
Bioaccumulation coefficient of Cd in radish	Shoot	Root	Shoot	Root	Shoot	Root
0	bdl	bdl	bdl	bdl	bdl	bdl
1	9.06	2.11	7.15	3.02	12.20	5.97
3	6.75	3.20	9.63	6.26	8.75	7.27
5	5.29	2.62	8.58	5.18	9.86	7.31
7	4.62	3.11	6.85	5.85	6.94	6.65
9	5.05	3.36	6.43	5.48	5.77	6.2
Treatment (mg Pb kg^{-1} Soil)						
Bioaccumulation coefficient of Pb in radish						
0	0.36	0.47	0.41	0.31	0.35	0.33
10	0.94	0.62	2.61	2.27	2.67	1.69
20	1.30	0.77	2.08	1.90	2.35	1.55
30	1.32	1.03	1.85	1.42	2.03	1.36
40	1.23	0.89	1.59	1.23	1.73	1.62
50	1.15	1.03	1.38	1.33	1.48	1.48

Bioaccumulation coefficient is the ratio between metal concentration in plant parts (mg kg^{-1} DW) and the metal

The results of the present study are in consonant with the previous findings of the same authors with rice (Kibria *et al*., 2006). Similar results were also found with chinese cabbage, winter greens, celery (NI Wu- zhong *et al*., 2002) and Indian mustard (Jiang *et al*., 2004). Increasing supply of Cd markedly enhanced the concentration of durum wheat in another study by Ozturk *et al*. (2003). Cadmium concentration in shoot and root increased about 4-8 and 9-16 fold, respectively at 9 mg Cd kg^{-1} soil treatment over that in 1 mg Cd kg^{-1} soil treatment in the present study.

Cadmium concentration was higher in shoot than root except at 9 mg Cd kg^{-1} soil treatment in sandy loam soil. Kibria *et al*. (2007) found an opposite trend with *amaranthus* in sandy clay loam soil using the same Cd levels used in the present study. In a pot experiment with ryegrass, Takâes *et al*. (2001) found that accumulation of different heavy metals (Cd, Zn and Ni) was higher in the roots than in the shoots. Cadmium application in soil and total Cd accumulation in shoot and root were highly correlated. Lund *et al.* (1981) also found significant correlations between Cd in the soil and Cd concentrations in the leaves of several crops such as spinach and lettuce.

The highest concentration of Cd was up to 57.88 and 56.07 mg kg^{-1} DW of shoot and root, respectively in the study. The Cd levels in shoot were nearly equal to those in root when the treatments were above 5 mg Cd kg^{-1} soil in sandy loam and sandy clay loam soil. The highest concentration of Cd up to 160 mg kg^{-1} DW in the shoots and 300 mg kg^{-1} DW in the roots of Indian mustard was found by Jiang *et al.* (2004) with 10-190 mg Cd kg^{-1} soil treatment. Kibria *et al.* (2007) reported the highest Cd concentration up to 53.22 and 124.81 mg kg^{-1} DW in the shoot and root of *amaranthus*, respectively with 1-9 mg Cd kg^{-1} soil treatment. Differences in Cd uptake and accumulation have been shown both among plant species (Cakmak *et al*., 2000) and between genotypes of a given a species (Dunbar *et al*., 2003).

To compare the influence of the contamination level on plant Cd uptake, a bioaccumulation coefficient (BC), was used. Bioaccumulation coefficient is the ratio between metal concentration in plant parts (mg kg^{-1} DW) and the metal concentration in soil (mg kg^{-1} soil). Bioaccumulation coefficients were not consistent with the rate of Cd application (Table 6). However, shoot BC were higher than root BC irrespective of Cd application which may indicate the larger transfer of Cd from root to shoot.

Among the soils, Cd concentration was lower in clay loam soil than sandy loam and sandy clay loam soils. This may be due to higher clay, CEC and organic matter content in clay loam soil. The clay constituents of soil play an important role in the soil‘s ability to bind cations of heavy metals (Korte *et al*., 1976). The CEC and organic matter content of the soils have also been reported to affect the availability of metals in soil (Haghiri, 1974). The findings of this study corroborates those of Eriksson (1989) who found that for soils of the same total Cd content, Cd was more soluble and more plant available in sandy soil than clay soil.

The concentration (mg kg^{-1}) and total accumulation (mg pot^{-1}) of Pb in radish were significantly affected by the Pb treatments (Table 5). In general, the Pb concentration in shoot and root gradually increased with increasing Pb application in all the three soils. This trend is consistent with that found in rice by Kibria *et al.* (2006).Total accumulation of Pb in shoot and root also increased with increasing Pb application in clay loam soil. However, the values obtained with 30-50 mg Pb kg^{-1} soil treatments were not significantly different. Lead accumulation in shoot gradually increased with Pb application up to 30 and 40 mg Pb kg^{-1} soil and then decreased in sandy loam and sandy clay loam soil respectively. In these two soils, Pb accumulation in root showed no definite trend of variation with Pb application.

Nwosu *et al*. (1995) reported the effects of Cd and Pb mixture on the uptake Cd and Pb by radish and lettuce. In their study, the uptake of Pb by both radish and lettuce increased as the concentration of Pb increased in the mixture. However, Pb uptake by radish and lettuce declined sharply when the concentration of Cd in the mixture exceeded 400 mg kg^{-1} and 200 mg kg^{-1}, respectively. Also, there was no uptake of Pb by both radish and lettuce as Cd levels in the mixture exceeded 400 mg kg $^{-1}$. Statistical analysis indicated that Pb uptake by radish and lettuce was not significant. Furthermore, there was no interaction between Cd and Pb on Pb uptake by both radish and lettuce. Rolfe (1973) showed that Pb uptake by eight tree species, grown on soil treated with five soil Pb levels (0 to 600 µg g^{-1}), was significantly affected by soil Pb concentration with higher uptakes associated with higher soil Pb levels. At 50 mg Pb kg^{-1} soil treatment in the present study, Pb concentration in shoot and root increased about 2-3 and 2-5 fold, respectively over that in 10 mg Pb kg $^{-1}$ soil treatment. Lead application in soils and Pb concentrations in shoot and root were highly correlated in all the three soils (Table 6). Korcak and Fanning (1985) also found positive relationship between the concentration of Pb in the soil and that in the plant. The concentration of Pb was higher in shoot than root. This is consistent with some reports by other researchers. For examples, Roberts and Johnson (1978) and Preer *et al.* (1980) reported that leafy portions of vegetable crops contained the highest levels of Pb. Lead uptake studies in plants by Lane and Martin (1977) demonstrated that roots have an ability to take up significant quantities of Pb whilst simultaneously greatly restricting its translocation to above ground parts.

Bioaccumulation coefficients (BC) of Pb were higher in shoot than root indicating major translocation of Pb to shoot from root as was also observed with Cd in the study (Table 7). In general, the increase of Pb application in soil led to a decrease of BC in shoot.

Among the soils, Pb concentration was higher in sandy loam than that of clay loam and sandy clay loam soil. Plant uptake of metals in soil depends on biologically available metals. In the case of Pb, previous studies have reported that Pb incorporated into soils is nearly always tightly bound to organic matter and is precipitated out, thus making it biologically unavailable for uptake by plants (Zimdahl and Koeppe, 1977). Davies (1995) showed that soil particle size and cation exchange capacity affected the availability and uptake of Pb. Because the sandy loam soil was low in organic matter and clay content as well as relatively low in CEC than those in the other two soils used in this study, availability of Pb may be enhanced.

Conclusions

Cadmium and Pb application with higher rates significantly decreased the shoot and root biomass of radish. Concentration of Cd and Pb in root and shoot increased with increasing application of Cd and Pb in all the three soils. Among the soils, Cd and Pb concentration in shoot and root were pronounced in sandy loam soil. Bioaccumulation of Cd and Pb were higher in shoot than root. Cadmium and Pb concentration in plant parts were highly correlated with Cd and Pb application in soils, respectively. Vegetable crops like radish grown in soils bearing potentially toxic metals such as Cd and Pb clearly represent a scenario for human exposure through ingestion of contaminated plants.

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