J. Asiat. Soc. Bangladesh, Sci. 30(1): 47-56, June 2004

AVAILABILITY OF SOME HEAVY METALS IN SOIL DUE TO COMPOST APPLICATION AND ITS CORRELATION WITH THE GROWTH OF *AMARANTHUS GANGETICUS* L.

S. R. MOLLA[1] AND S. M. IMAMUL HUQ[*]

Department of Soil, Water and Environment, University of Dhaka, Dhaka-1000, Bangladesh

Key words : Compost, availability, heavy metals, growth, *Amaranthus*

Abstract

A pot experiment was conducted to study the changes in the availability of Fe, Mn, Cu, Zn, Pb and Cd in two soils [Melandaha (Silt loam) and Dhamrai (Silty clay loam)] due to application of composts viz. aerobic compost and semi-aerobic or barrel compost and the relationship between uptake and growth of *Amaranthus. Amaranthus* was grown up to 42 days. The soils were treated with different doses of composts or composts plus fertilizer or only fertilizer. The recommended doses of composts were 1, 1.5 and 2 t ha^{-1}. After harvest of *Amaranthus*, the soil and plants were analyzed. It was found that for almost all the cases the availability of Fe, Mn, Cu, Zn, Pb and Cd decreased significantly. Uptake of these elements and growth of *Amaranthus* were not related.

Introduction

Metals with atomic numbers greater than 23 and densities more than 5 g c^{-3} are called heavy metals. Brady (1995) defined heavy metals as metals with particle densities > 5 Mg m^{-3}. In terms of plant nutrition some of these are called micronutrients or trace elements. Organic matter and as such composts, because of their chemical nature and properties to bind these elements in the form of chelates change their availability. Heavy metal enrichment of agricultural soils may increase plant availability and movement of heavy metals through the food chain (Chaney *et al.,* 1987; Logan and Chaney, 1983). Both bioavailability and movement of heavy metals are reduced by soil adsorption. Heavy metals adsorption varies among soil types and may depend on one or a combination of soil properties (Adriano, 1986; Alloway, 1990). John (1972) has shown that both soil acidity and organic matter content are properties influencing the uptake of Cd by lettuce and radish. Soil properties often correlated with metal adsorption, include soil pH (Christensen, 1984; Harter, 1983), soil CEC (Harter, 1979; Soldatini *et al.*, 1976), soil organic matter (Gerriste and van Driel, 1984; Zimdahl and Skogerboe, 1977) and clay content (Korte *et al.*, 1976). However, direct cause and effect relationships between soil

---

1 Present address: Iwate University, Morioka, Japan. * Author for Correspondences.

properties and metal adsorption are difficult to determine, as these are often interrelated. Some of these heavy metals are essential for normal growth of plants. The objectives of this study was to observe the changes in the availability of some heavy metals (Fe, Mn, Cu, Zn, Pb and Cd) due to application of compost and the effect of these changes on the growth and heavy metals uptake.

Materials and Methods

The experiment was conducted in the soil fertility research laboratory of the Department of Soil, Water and Environment Science, University of Dhaka to observe the changes of the availability of some micronutrients and heavy metals and their relationship to growth due to compost (two types) application. The composts used are aerobically decomposed (AC) and partially decomposed or "Barrel compost" (BC). Soil representing Melandaha and Dhamrai series were collected from 0 - 15 cm depth in composite manner. Two kg air-dried soil (previously prepared) was taken in each earthen pot. Fourteen different treatments were used. For each treatment, there were three individual replications. So, for two soils the total number of pots were 84 ($2 \times 14 \times 3$). The compositions of aerobic compost are - organic matter 18.82%, pH 7.5, nitrogen 1.66%, phosphorus 1.38%, potassium 1.40%, sulfur 0.38% and sodium 0.27%, but for BC it was 12.90, 7.5, 0.96 , 0.58, 0.80, 0.33 and 0.11%, respectively. The composts were collected from *Waste Concern* which is a research-based organization situated at Mirpur in Dhaka, Bangladesh. The sources of composting materials were household wastes. The treatments were mixed properly with the soil. The pots were arranged in a completely randomized design. *Amaranthus* seeds were sown and after emergence five seedlings were kept in each pot. Water was also added to bring the soil to field moisture condition. After harvest, soil and plant samples were collected. The soils were extracted with DTPA (Diethylene triamine penta acetic acid) (Lindsay and Norvell, 1978). Nitric and perchloric acid mixture digestion was used (Alam *et al.,* 1991) for determination of the micronutrients and heavy metals in plant samples. The extracts were analyzed by using Perkin Elmer 3110 atomic absorption spectrophotometer (AAS).

Results

(A) Changes in diethylene triamine penta acetic acid (DTPA)- extractable heavy metals as affected by compost.

Fe availability: Due to application of AC or AC plus fertilizer to Melandaha soil (Table 1), the availability of Fe decreased significantly for almost all the treatments (except AC_1) and ranged from 6.94 mg kg^{-1} (AC_2) to 9.58 mg kg^{-1} (AC_1). Similarly in BC or BC plus fertilizer treatment (except $BC_{1.5}$ F treatment) the availability decreased and ranged from 7.43 mg kg^{-1} (BC_2 F) to 9.42 mg kg^{1} ($BC_{1.5}$ F). For AC or AC plus fertilizer in Dhamrai soil (Table 2), availability of Fe increased significantly for all treatments ranging from 12.72 mg kg^{-1} (AC_1F) to 14.54 mg kg^{-1} (AC_1). Similar result was also obtained for BC or BC plus fertilizer and the values ranged from 11.56 mg kg^{-1} ($BC_{1.5}F$ and BC_2F) to 14.21 mg kg^{-1}(BC_1F).

Table 1. Heavy metals availability in compost amended Melandaha soil.

	Heavy metal content mg/kg					
Treatment	Fe	Mn	Cu	Zn	Pb	Cd
Control	8.92	30.84	4.41	2.71	0.31	0.04
AC_1	9.58	30.84	4.72	2.76	0.31	0.04
$AC_{1.5}$	8.76	30.63	4.50	2.94	0.30	0.03
AC_2	6.94	27.40	4.24	2.81	0.29	0.03
AC_1F	8.26	28.14	4.46	3.02	0.29	0.03
$AC_{1.5}F$	7.60	27.59	4.28	2.93	0.28	0.02
AC_2F	7.76	28.55	4.39	3.10	0.27	0.03
BC_1	8.26	29.94	4.39	3.06	0.29	0.04
$BC_{1.5}$	8.26	30.21	4.72	3.14	0.29	0.03
BC_2	7.60	28.42	4.50	3.27	0.28	0.02
BC_1F	8.76	29.59	4.37	2.76	0.27	0.03
$BC_{1.5}F$	9.42	28.90	4.76	2.91	0.27	0.03
BC_2F	7.43	27.10	4.26	2.81	0.27	0.03
F	9.09	30.35	7.76	3.00	0.29	0.04

Mn availability : Application of AC or AC plus fertilizer in Melandaha soil (Table 1), caused significant decrease of Mn availability, the values ranged from 27.40 mg kg^{-1} (AC_2) to 30.84 mg kg^{-1} (AC_1). Similarly in BC or BC plus fertilizer treatment Mn availability decreased and ranged from 27.10 mg kg^{-1} (BC_2F) to 30.21 mg kg^{-1} ($BC_{1.5}$). When Dhamrai soil was treated with AC or AC plus fertilizer (Table 2), the availability of Mn decreased significantly (except AC_1 and $AC_{1.5}$) and ranged from 23.92 mg kg^{-1} ($AC_{1.5}F$) to 27.86 mg kg^{-1} ($AC_{1.5}$). Similar result was also obtained for BC or BC plus fertilizer (except $BC_{1.5}$) and ranged from 20.12 mg kg^{-1} ($BC_{1.5}F$) to 27.40 mg kg^{-1} ($BC_{1.5}$).

Cu availability: Due to application of AC or AC plus fertilizer to Melandaha soil (Table 1), the availability of Cu increased for AC_1 (4.72 mg kg^{-1}), $AC_{1.5}$ (4.50 mg kg^{-1}) and AC_1F (4.46 mg kg^{-1}) treatments but for other treatments availability decreased. The availability ranged from 4.24 mg kg^{-1} (AC_2) to 4.72 mg kg^{-1} (AC_1). This change was significant. For BC or BC plus fertilizer, the availability ranged from 4.26 mg kg^{-1} (BC_2F)

to 4.76 mg kg^{-1} ($BC_{1.5}F$). This change was also significant. When AC or AC plus fertilizer were added to Dhamrai soil (Table 2), the availability of Cu increased significantly for all treatments. Similar result was also obtained for BC or BC plus fertilizer (except BC_2F).

Table 2. Heavy metals availability in compost amended Dhamrai soil.

	Heavy metal content mg/kg					
Treatment	Fe	Mn	Cu	Zn	Pb	Cd
Control	11.56	27.31	5.82	2.96	0.41	0.040
AC_1	14.54	27.45	6.27	2.61	0.40	0.039
$AC_{1.5}$	13.55	27.86	6.15	2.42	0.40	0.039
AC_2	13.55	25.24	6.33	2.55	0.39	0.040
AC_1F	12.72	25.44	6.09	2.68	0.41	0.039
$AC_{1.5}F$	14.21	23.92	6.11	2.47	0.40	0.039
AC_2F	12.89	25.44	5.96	2.95	0.40	0.040
BC_1	14.04	27.17	6.33	3.30	0.40	0.040
$BC_{1.5}$	13.38	27.40	6.04	2.76	0.40	0.039
BC_2	12.39	25.79	6.11	3.00	0.39	0.039
BC_1F	14.21	26.07	6.11	2.81	0.39	0.039
$BC_{1.5}F$	11.56	20.12	5.98	3.13	0.38	0.039
BC_2F	11.56	22.47	5.21	2.57	0.38	0.039
F	10.74	21.64	5.12	2.89	0.41	0.039

A= Aerobic compost, C_1 = compost @ 1 t ha^{-1}, $C_{1.5}$ = compost @ 1.5 t ha^{-1}, C_2 = compost @ 2 t ha^{-1}, B= barrel compost, F= fertilizer, ND= non detected.

Zn availability : Application of AC or AC plus fertilizer in Melandaha soil caused the availability of Zn to be increased significantly for all the treatments (Table 1) and it ranged from 2.76 mg kg^{-1} (AC_1) to 3.10 mg kg^{-1} (AC_2F). Similar result was also obtained for BC or BC plus fertilizer; the values ranging from 2.76 mg kg^{-1} (BC_1F) to 3.27 mg kg^{-1} (BC_2). The availability increased linearly when only compost was added. The availability of Zn decreased significantly in Dhamrai soil (Table 2) when it was treated with AC or AC plus fertilizer, the values ranging from 2.42 mg kg^{-1} ($AC_{1.5}F$) to 2.95 (AC_2F). The availability ranged from 2.57 mg kg^{-1} (BC_1F) to 3.30 mg kg^{-1} (BC_1) that was statistically significant for BC or BC plus fertilizer in Dhamrai soil.

Pb and Cd availability : In most cases it was found that the availability of Cd and Pb decreased due to application of compost or compost plus fertilizer but this decrease was not significant.

Discussion

When Melandaha soil was treated with compost or compost plus fertilizer the availability of native Fe decreased (Table 1) for all treatments (except AC_1 and $BC_{1.5}F$). This decrease was most probably due to the formation of insoluble organic chelates. Moreover, this soil may contain high levels of bicarbonate and phosphate that are responsible for lower iron availability, forming relatively insoluble iron salts (Miller and Donahue, 1992). But for Dhamrai soil the result was different (Table 2). This may be due to the fact that after decomposition, compost might have supplied soluble chelating agents that aided in maintaining the solubility of Fe and improving structure of textured soils resulting from application of composts (Tisdale *et al.*, 1993). Similar result was obtained for Mn (Table 1). The low availability of Mn in compost treated soil is attributed to the formation of unavailable chelated Mn^{+2} compounds. It may also be held in unavailable organic complex (Tisdale *et al.*, 1993). Table 2 shows that the availability of Mn decreased for almost all the cases except AC_1, $AC_{1.5}$ and $BC_{1.5}$ treatments. It was found that for most cases the availability of Cu increased for compost application. This was most probably due to the formation of soluble organic complex or chelates (Millar and Donahue, 1992). The availability of Zn increased due to application of compost or compost fertilizer to Melandaha soil. Similar results were also obtained for BC_1, BC_2 and $BC_{1.5}F$ treatments (Table 2). This was most probably due to decomposition of compost; soluble chelated Zn compounds may be formed that enhances Zn availability by keeping Zn^{+2} in solution (Tisdale *et al.*, 1993). For AC or AC plus fertilizer in Dhamrai soil, Zn availability decreased for all treatments. Similar results were also obtained for $BC_{1.5}$, BC_1F and BC_2F treatments (Table 2). The probable cause may be that Zn^{+2} forms stable complex with compost components. The humic and fulvic acid fractions are prominent in Zn adsorption or immobilization by high molecular weight organic substances such as lignin or complexation by initially soluble organic substances that forms insoluble salts (Tisdale *et al.*, 1993). The experimental results show that the availability of Pb and Cd decreased due to application of compost or composts plus fertilizer. This was most probably due to Pd and Cd forming complex with the multidentate ligands of compost, which is responsible for less availability of these two elements (Stumm and Morgan, 1996).

(B) Relationship between growth and some heavy metals uptake as affected by compost.

The correlation coefficient ('r') calculated between Fe uptake (0.48 to 2.24 mg/100 plants) and growth was 0.757* in Melandaha soil for AC or AC plus fertilizer (Table 3). But for BC or BC plus fertilizer, Fe uptake ranged from 0.70 to 1.02 mg/100 plants (Table 3) and the correlation coefficient ('r') was 0.579. Fe uptake ranged from 0.63 to 1.49 mg/100 plants when AC or AC plus fertilizer were added to Dhamrai soil (Table 4). The correlation coefficient ('r') was 0.543 but for BC or BC plus fertilizer, Fe uptake ranged from 0.36 to 1.79 mg/100 plants and the correlation coefficient ('r') was 0.863*.

Table 3. Dry matter yield (g/100 plants) of *Amaranthus gangeticus* L. and heavy metals uptake in compost amended Melandaha soil.

		Heavy metal uptake, mg/100 plants					
Treatment	Yield	Fe	Mn	Cu	Zn	Pb	Cd
Control	13.46	0.85	2.89	6.18	1.64	0.15	0.043
AC_1	14.93	0.85	1.16	2.64	3.21	0.12	0.036
$AC_{1.5}$	19.13	1.03	1.83	13.28	7.40	0.22	0.038
AC_2	17.47	1.46	1.48	7.99	5.10	0.20	0.035
AC_1F	14.07	0.90	1.04	1.20	1.70	0.14	0.034
$AC_{1.5}F$	41.93	2.24	5.77	9.84	10.97	0.77	0.034
AC_2F	21.00	0.48	1.93	3.23	3.27	ND	0.008
BC_1	23.20	0.75	2.91	1.70	2.92	0.43	0.028
$BC_{1.5}$	21.27	0.70	2.97	2.30	2.97	0.30	0.034
BC_2	21.33	0.99	2.08	6.63	4.64	0.34	0.017
BC_1F	25.20	1.01	2.66	2.93	3.19	0.21	0.040
$BC_{1.5}F$	24.87	0.91	2.47	5.63	4.69	ND	0.010
BC_2F	24.33	1.02	2.15	3.52	3.11	0.41	0.020
F	30.60	1.15	3.07	3.56	4.55	0.11	0.012

The correlation coefficient ('r') calculated between Mn uptake (1.04 to 5.77 mg/100 plants) and growth in Melandaha soil for AC or AC plus fertilizer was 0.872* but for BC or BC plus fertilizer, Mn uptake ranged from 2.08 to 2.97 mg/100 plants (Table 3) and the correlation coefficient ('r') was – 0.37. Mn uptake ranged from 1.06 to 2.00 mg/100 plants when AC or AC plus fertilizer were added to Dhamrai soil (Table 4). The correlation coefficient ('r') was 0.206 but for BC or BC plus fertilizer, Mn uptake ranged from 0.48 to 3.30 mg/100 plants and the correlation coefficient ('r') was 0.470.

Cu uptake ranged from 1.20 to 13.28 mg/100 plants when AC or AC plus fertilizer were added to Melandaha soil (Table 3). The correlation coefficient ('r') calculated between Cu uptake (1.20 to 13.28 mg/100 plants) and growth in Melandaha soil treated with AC or AC plus fertilizer was 0.309. But for BC or BC plus fertilizer, Cu uptake ranged from 1.70 to 6.63 mg/100 plants (Table 3) and the correlation coefficient ('r') was 0.362. Cu uptake ranged from 3.83 to 10.30 mg/100 plants when AC or AC plus fertilizer were added to Dhamrai soil (Table 4). The correlation coefficient ('r') was 0.024 but for BC or BC plus fertilizer, Cu uptake ranged from 1.72 to 9.32 mg/100 plants and the correlation coefficient ('r') was 0.289.

Table 4. Dry matter yield (g/100 plants) of *Amaranthus gangeticus* L. and heavy metals uptake in compost amended Dhamrai soil.

	Heavy metal uptake, mg/100 plants						
Treatment	Yield	Fe	Mn	Cu	Zn	Pb	Cd
Control	17.40	0.50	4.28	8.83	2.42	ND	0.021
AC_1	12.93	0.63	1.08	4.09	3.75	0.31	0.026
$AC_{1.5}$	15.53	1.49	1.06	3.83	3.88	0.42	0.031
AC_2	23.13	1.06	2.00	8.59	5.14	0.43	0.019
AC_1F	21.47	1.41	1.96	10.30	7.77	0.46	0.043
$AC_{1.5}F$	21.66	0.80	1.47	5.99	5.09	0.54	0.026
AC_2F	26.00	1.33	1.93	4.35	5.49	0.52	0.062
BC_1	19.87	0.82	1.75	2.29	2.78	0.54	ND
$BC_{1.5}$	17.74	0.59	3.30	9.32	6.32	0.36	0.035
BC_2	06.80	0.36	0.48	4.26	3.13	0.14	0.014
BC_1F	30.20	1.79	2.08	7.85	5.58	0.63	0.036
$BC_{1.5}F$	13.53	0.77	0.96	1.77	2.59	0.21	0.027
BC_2F	12.80	0.73	0.76	1.72	1.58	0.20	0.026
F	25.47	1.90	2.72	2.74	4.19	0.56	0.00

A= Aerobic compost, C_1 = compost @ 1 t ha^{-1}, $C_{1.5}$ = compost @ 1.5 t ha^{-1} , C_2 = compost @ 2 t ha^{-1}, B = barrel compost, F = fertilizer, ND = non detected.

The correlation coefficient ('r') calculated between Zn uptake (1.70 to 10.97 mg/100 plants) and growth in Melandaha soil treated with AC or AC plus fertilizer was 0.807* but for BC or BC plus fertilizer, Zn uptake ranged from 2.92 to 4.69 mg/100 plants (Table 3) and the correlation coefficient ('r') was 0.701. Zn uptake ranged from 3.75 to 7.77 mg/100 plants when AC or AC plus fertilizer were added to Dhamrai soil (Table 4) and the correlation coefficient ('r') was 0.368 but for BC or BC plus fertilizer, Zn uptake ranged from 1.58 to 6.32 mg/100 plants and the correlation coefficient ('r') was 0.522.

The correlation coefficient ('r') calculated between Pb uptake (not detected to 0.77 mg/100 plants) and growth in Melandaha soil treated with AC or AC plus fertilizer was 0.307; for BC or BC plus fertilizer, Pb uptake ranged from ND to 0.43 mg/100 plants (Table 3) and the correlation coefficient ('r') was 0.201. Pb uptake ranged from 0.31 to 0.52 mg/100 plants when AC or AC plus fertilizer were added to Dhamrai soil (Table 4) and the correlation coefficient ('r') was 0.368 but for BC or BC plus fertilizer, Pb uptake ranged from 0.14 to 0.63 mg/100 plants and the correlation coefficient ('r') was 0.322.

Cd uptake ranged from 0.008 to 0.043 mg/100 plants when AC or AC plus fertilizer were added to Melandaha soil (Table 3). The correlation coefficient ('r') calculated between Cd uptake (0.008 to 0.038 mg/100 plants) and growth in Melandaha soil treated with AC or AC plus fertilizer was 0.421; for BC or BC plus fertilizer, Cd uptake ranged from 0.01 to 0.04 mg/100 plants (Table 3) and the correlation coefficient ('r') was 0.304. Cd uptake ranged from 0.019 to 0.062 mg/100 plants when AC or AC plus fertilizer was added to Dhamrai soil (Table 4). The correlation coefficient ('r') was 0.362 but for BC or BC plus fertilizer, Cd uptake ranged from ND to 3.30 mg/100 plants and the correlation coefficient ('r') was 0.225.

Table 5. Correlation coefficient values between growth (dry matter yield) and heavy metals uptake as affected by different treatments of compost.

Treatments	Micronutrient	Correlation coefficient ('r')	
		Melandaha series	Dhamrai series
AC or AC plus fertilizer	Fe	0.757*	0.543
	Mn	0.872*	0.206
	Cu	0.309	0.024
	Zn	0.807*	0.368
	Pb	0.307	0.368
	Cd	0.421	0.362
BC or BC plus fertilizer	Fe	0.579	0.863*
	Mn	-0.370	0.470
	Cu	0.362	0.289
	Zn	0.701	0.522
	Pb	0.201	0.322
	Cd	0.304	0.225

A = Aerobic compost, B= barrel compost, *indicated ('r') significant at 5% level.

It was found that in almost all the cases, the uptake of Fe increased due to application of compost or compost plus fertilizer. The greater uptake has taken place for AC. The similar result was also found for Zn, which is in agreement with Dudas and Pawluk (1975). They found that sewage application resulted in striking increase in uptake of Zn and Cd. Pb uptake increases in almost all the cases. In most cases, uptake of Mn decreased. Similar result was also obtained for Cu, which is not in agreement with Dudas and Pawluk (1975). They found that due to application of sewage significant increases in the uptake of Sr and Cu occurred. Cd uptake decreased significantly for almost all the cases in Melandaha soil. This result is not in agreement with the result of Dudas and Pawluk (1975). They found that sewage application resulted in striking increase in uptake of Cd but for Dhamrai soil the result was in agreement with Dudas and Pawluk (1975).

In most cases the relationship between growth and uptake of heavy metals was not significant. Only the significant relationship between growth and uptake of Fe, Mn and Zn was found when Melandaha soil was treated with AC or AC plus fertilizer. This may be due to the fact that due to application of AC or AC plus fertilizer in Melandaha soil the availability of Zn increased and as a result increased uptake has taken place. The exact reasons for Fe and Mn are unknown. The present observation is also an indicator that the compost prepared from Dhaka urban wastes is apparently free from heavy metals pollution. We have not found any extra release of some of the heavy metals, which is thought to be essential, become toxic if present in excess. The results for the pot experiment indicated that *Amaranthus* growth and the heavy metals uptake were influenced though not significant by soil amendments with composts.

References

Adriano, D. C. 1986. *Trace Elements in the Terrestrial Environment.* Springer-Verlag, New York.

Alam, M. D., S. M. I. Huq, M. S. Rahman, and K. Anam. 1991. *A Handbook on Chemical Analyses of Soil, Plant and Water.* 1st edition. Printed at Modhumoti Mudranalaya. 81, Motijheel C/A, Dhaka, Bangladesh.

Alloway, B. J. 1990. *Heavy Metals in Soils.* John Wiley & Sons, New York.

Brady, N. C. 1995. *The Nature and Properties of Soils.* 10th edition. Prentice-Hall of India Private Ltd., New Delhi-110001. pp. 587.

Chaney, R. L., R. J. B and P. M. Giordano. 1987. Microelements as related to plant deficiencies and toxicities. *In*: L. F. Elliott and F. J. Stevenson (ed.). Soils for management and utilization of organic wastes and wastewaters. *Soil Sci. Soc. Am.*, Madison. Wis. pp. 234-279.

Christensen, T. H. 1984. Cadmium soil sorption at low concentrations: I. Effect of time, cadmium load, pH and calcium. *Water Air Soil Pollution* **21**: 105-114.

Dudas, M. J. and S. Pawluk. 1975. Trace elements in sewage sludge and metal uptake by plants grown on sludge amended soil. *Can. J. Soil. Sci.* **55**: 239-243

Gerriste, R. G. and W. van Driel. 1984. The relationship between adsorption of trace metals, organic matter, and pH in temperate soils. *J. Environ. Qual.* **13**: 197-204.

Harter, R. D. 1979. Adsorption of copper and lead by Ap and B2 horizons of several northeastern United States soils. *Soil Sci. Soc. Am. J.* **43**: 679-683.

Harter, R. D. 1983. Effect of soil pH on adsorption of lead, copper, zinc and nickel. *Soil Sci. Soc. Am. J.* **47**: 47-51.

John, M. K. 1972. Factors affecting plant uptake and phytotoxicity of cadmium added to soils. *Environ. Sci. Technol.* **6**: 1005-1009.

Korte, N. E., J. Skopp, W. H. Fuller, E. E. Niebla and B. A. Alesii. 1976. Trace element movement in soils: Influence of soil physical and chemical properties. *Soil Sci.* **122**: 350-359.

Lindsay, W. L. and W. A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* **42**: 421-428.

Logan, T. J. and R. Chaney. 1983. Utilization of municipal wastewater and sludge on land - metals. p. 235-336. *In:* A. L. Page *et al.* (ed.) Utilization of municipal wastewater and sludge on land. Univ. of California, Riverside.

Miller, R. W. and R. L. Donahue.1992. *Soils: An Introduction to Soils and Plant Growth.* 6th edition. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Soldatini, G. F., R. Riffaldi, and R. Levi-Minzi. 1976. Pb adsorption by soils. *Water Air Soil Pollution.* **6**: 111-118.

Stumm, W. and J. J. Morgan. 1996. *Aquatic Chemistry: Chemical equilibria and rates in natural waters.* 3rd ed. Wiley Interscience, New York.

Tisdale, S. L., W. L. Nelson, J. D. Beaton and J. L Havlin. 1993. *Soil Fertility and Fertilizers.* Macmillan Publ. Co., New York.

Zimdahl, R. L. and R. K. Skogerboe. 1977. Behavior of lead in soil. *Environ. Sci. Technol.* **11**: 1202-1207.

(Received revised on 13 June, 2004)