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Fate of Some Heavy Metals in Sandy Soil Amended with Sewage Sludge and Their Accumulation in Plants

S. H. Badawy[1] and R.A. El-Motaium[2]

1- Soil Science Department, Faculty of Agriculture, Cairo University and
2-Plant Research Department, Nuclear Research Center, Atomic Energy Authority, Abou Zaable, Cairo, Egypt.

A POT EXPERIMENT was conducted using tomato plants cultivated in sandy soil amended with different rates (0, 20, 40, 60, 80 t/ha) of sewage sludge collected from El-Gabal El-Asfar Farm, Cairo. The same treatments were repeated for non-cultivated soil. Soil samples were collected at different periods (0, 3, 6, 9 and 12 months) to evaluate the release and accumulation of Cu, Zn, Cd, and Pb in soil and plant. The results demonstrate that soil pH and $CaCO_3$ content decreased with increasing sewage sludge application rate and time. Whereas, soil organic matter increased with increasing the application rate and decreased with time. The highest decrease in soil pH and $CaCO_3$ was found after six months from the beginning of the experiment for both cultivated and non-cultivated soils. However, the decrease in cultivated soil was more than the non-cultivated one. The total content of Cu, Zn, Cd and Pb in soil increased in response to the increase in sludge application rate. No significant changes were observed in soil total metals in relation to the sampling time. The distribution of the different chemical fractions of Cu, Zn, Cd, and Pb of the soil are as follows: residual> organic> oxides> carbonates> exchangeable. The mobile fractions and mobile factors (MF) increased up to 6 months from the beginning of the experiment, then decreased. The concentrations of DTPA-extractable metals (Cu, Zn, Cd, Pb) in soil increased with the increase in sludge application rate. The values of DTPA-extractable metals Cu, Zn, Cd and Pb were higher in cultivated than in non-cultivated soil until 6 months, then they decreased. The highest concentrations of extractable metals were found after 6 months from the beginning of the experiment. The concentrations of Cu, Zn, Cd, and Pb in tomato leaves and fruits increased with the increase in sewage sludge application rate. These metals were higher in leaves than in fruits.

Keywords: Heavy metals, mobility, fractionation, accumulation, distribution.

Municipal and industrial sludges can have a beneficial effect on plant growth and crop yields when applied to soil because of their organic matter and nutrients content. However, sludges may also have concentrations of trace elements (e.g., Cd, Cr, Ni, Cu, Pb, and Zn) that are of environmental concern. Evaluation of the potential mobility and biological uptake of trace metal contamination in soil requires chemical or biological methods to quantify the fraction of soil contaminants available for biological uptake. Such information is important for predictive models and risk assessments in systems where the soil-plant pathway is a key contributor to potentially harmful effect to plants and animals. Single and sequential extraction methods have been used to estimate the pollutant concentrations available for plants uptake (He and Singh, 1993; Narwal and Singh, 1998; Singh *et al.*,1995, 1998; Badawy and Helal, 1997). Several extractants have been used to assess the potential bioavailability of heavy metals for plant uptake (El-Sokkary, 1979; Christensen and Huang, 1999; Kennedy *et al.*, 1997; Aboulroos *et al.*, 1996). According to Pickering (1998), multistep extraction procedures can obtain more detailed information about the status of trace metals in soils relative to single extraction methods. Furthermore, the early stages to single extraction sequence obtain information comparable to that obtained from single extraction methods. The fraction of metals that is readily displaced from the reversible sorption phases can be regarded as mobile fractions. These fractions can be distinguished from those being irreversible sorbed and released after dissolution in the later stages in the extraction scheme (Salbu *et al.*, 1998). Little work was done to study the effect of time on the distribution of heavy metals among the extractable fractions (Sposito *et al.*, 1983; and Aboulroos *et al.*, 1991). The aim of the present work is to evaluate the effect of sewage sludge application and the time factor on: i) the changes of the soil general characteristics. ii) the distribution of the various fractions of Cu, Zn, Cd, and Pb in the soil. iii) the accumulation of these metals in tomato leaves and fruits.

Material and Methods

A pot experiment was conducted at the Plant Science Department Eexperimental Farm, NRC, Anshas. Sandy soil (2.7% clay and 13% WHC) was used and amended with different application rates of sewage sludge collected from El-Gabal El-Asfar Farm, Cairo-Egypt (the analyses of sewage sludge were; pH, 6.64; EC, 4.27; $CaCO_3$, 3.35%; OM, 44%; total Zn, Cu, Cd, and Pb were 760, 219, 5.2, 278 mg/kg, respectively). Treatments were arranged in a Randomized Complete Block Design. Each block included ten treatments [five cultivated with tomato plants (GS cultivar) as a biological indicator for heavy metals accumulation, and five un-cultivated) including a control treatment (recommended chemical fertilizer was applied at a rate of 286 kg N/ha as ammonium sulphate, 143 kg P_2O_5 / ha as calcium super phosphate and 167 kg K_2O/ha as potassium sulphate). Each treatment was replicated four times. Tomato seedlings, GS cultivar, were purchased from a local nursery. Each pot was filled with 5 kg soil. Distilled water was used for irrigation throughout the growing period and the moisture conditions were kept at 65 to 70 % of water-holding capacity (WHC) of the soil. The experiment was repeated for another year.

Soil Sampling and Analysis

Soil samples were collected at different periods from the starting time (0, 3, 6, 9, and 12 months). The samples were air dried, crushed to pass through a 2-mm sieve, and stored for analysis. The general characteristics of soils and sewage sludge; pH, electrical conductivity (EC), organic matter (OM), water holding capacity (WHC), calcium carbonate content ($CaCO_3$), and clay content were determined using the standard methods outlined by Dewis and Freites (1970) and Jackson (1967).

Total Metal Content

One-gram (dry weight) soil samples were digested using 12 ml of a mixture of $HClO_4$ and HF (5:1 v/v) in platinum crucible (Jackson, 1967). The crucible was brought to near dryness, before adding a further 12 ml of the acid mixture, and again burning to near dryness. Finally, 1ml of $HClO_4$ was added and the sample was evaporated until the appearance of white fumes. The residue was then dissolved in 5 ml of concentrated HCl before making up to 25 ml with deionised water. Copper, zinc, and lead were analyzied by Flame Atomic Absorption Spectrophotometer and cadmium by Graphite Furnace Atomic Absorption Spectrophotometer (GF-AAS).

Sequential Chemical Extraction

The sequential extraction procedure of Tessier *et al.*(1979) was used to partition Cu, Zn,Cd, and Pb in soils into five operationally defined fractions; 1) The exchangeable fraction: soils were extracted with 1M NaOAc, pH 8.2 at room temperature for one hour with continuous agitation; 2) The carbonate bound fraction: the reside from 1) was leached at room temperature for 5 hrs continuous agitation with 1M NaOAc, pH 5.0 ; 3) The Fe and Mn oxides bond fraction: the residue from 2) was extracted with 0.04 M NH_2 OH.HCl in 25% (v/v) HOAc at 96 ± 3 °C with occasional agitation for 5 hrs.; 4) The organic matter bound fraction: the residue from 3) was extracted with 0.02 M HNO_3 and 30% H_2O_2, pH 2.0 , for 2 hrs with occasional agitation at 85 ± 2 °C ; then 30% H_2O_2 for 3 hrs with intermittent agitation at 85 ± 2 °C ; after cooling 3.2 M

NH_4OAc in 20% (v/v) HNO_3 was added; 5) The residue fraction: the residue from 4) was digested with HF- $HClO_4$ using the same procedure employed for total. The resulting supernatants from each fractionation step were filtered before analysing the filtrates for metals by Flame Atomic Absorption Spectrophotometer and GF-ASS for Cd using the standard addition technique.

DTPA-Extractable Metals

Available Cd, Co, Ni, and Pb were determined for all samples using 0.005 M DTPA (diethylene triamine penta acetic acid) using the methods of Lindsay and Norvell (1978).

Plant Sampling and Analysis

Tomato plants, from each pot, were collected at maturity stage (at early bloom when vegetative growth was completed according to Reisenauer (1978), then leaves were separated. They were washed with tap water, rinsed with deionized water, oven dried at 60 °C, the dry weight was recorded. The leaves were mixed to form a composite sample, then ground using a micro-mill grinder. The dried samples were stored for metal analyses. Tomato fruits were collected, as they ripe. Representative fruit samples were oven dried at 60°C for analysis. Heavy metals (Cu, Zn, Cd, and Pb) content of plant materials were measured after digestion with HNO_3 - H_2SO_4 - $HClO_4$ acids mixture (Jackson, 1967). Copper, Zn, and Pb concentrations were measured using the Atomic Absorption Spectrophotometer and the GF-ASS for Cd. using the standard addition technique.

Statistical Analysis

The data represent the results of two years, were subjected to analysis of variance, LSD, and correlation coefficient (r) using the microcomputer statistical analysis package (MicroStat).

Results and Discussion

General Properties of The Soil

Data of Table 1 show that the increases in sewage sludge application rate have resulted in a continuous increase in organic matter content (OM), and electric conductivity (EC), and partly decreased soil pH and $CaCO_3$ content; the reduction in soil pH, approximately by one unit, $CaCO_3$ content by 25% and the increase in OM content from 5 to 7 fold, and in EC values by 2 times, comparing the control with the highest sewage sludge application rate at 0 time. The same results reported by Aboulroos *et al.* (1989). A glance at Fig. 1. shows that time and vegetation factors affected the changes of OM. EC, pH, and $CaCO_3$ of the soil. However, the changes were continuously decreased by increased time, the maximum reduction was after 6 months in cultivated soils but, soil organic matter was reduced more at un-cultivated soil. The reduction was approximately 0.7 and 0.6 unit for soil pH, 60 and 30 % for soil $CaCO_3$, and 33 and 40 % for soil OM in cultivated and uncultivated soils, respectively. This could be due to the release of organic acids from sewage sludge and root exudates (El-Motaium and Badawy, 2000).

Distribution of Heavy Metals in Soils

The total contents of Cu, Zn, Cd, and Pb in soil are given in Table 2. The results show that the levels of heavy metals in soil increased with increasing application rate of sewage sludge. Comparing the content of heavy metals of the present study with maximum permitted metal loadings in the soils, established by the USEPA-503 regulation (McBride, 1995) showed that the permitted levels of Cu (750), Zn (1400), Cd (20), and Pb (150 mg/kg) were 30. 10, 15, and 5 times of their levels in the present soil at highest application of sewage sludge. The levels of the various fractions of each metal increased with increasing the sewage sludge application rate, i.e., followed the same pattern of the total content. The data in Table 3 showed that the soluble and exchangeable fractions (F1) represented only a small percentage of the total content, averaged to be 0.62 ± 0.23, 1.52 ± 0.65, 1.77± 0.67, 4.13 ± 1.65% for Cu. Zn, Pb, and Cd, respectively. These lower percentages indicate that heavy metals applied to the soil from sewage sludge were strongly sorbed in non-exchangeable form. Aboulroos *et al.* (1991); Badawy and Helal (1997) showed that the soluble and exchangeable fractions represented only 1-5% from the total Cd, Co, Ni, Pb, Cu, and Zn content of the soil irrigated with sewage effluent. The carbonate fraction (F2) of heavy metals represented an average of 7.47 ± 0.85. 10.1 ± 0.66, 9.1 ± 1.74, 10.34 ± 0.81% for Cu, Zn, Cd, and Pb , respectively. The Fe and Mn oxides fraction (F3) of heavy metals represented an average of 6.4 ± 0.55. 171 ± 3.39, ± 4.40, 13.7 ± 3.28% from the total content for Cu, Zn. Cd, and Pb. respectively. The organic fraction (F4) of heavy metals represented an average of 35 ± 2.14, 26 ± 1.20, 21.9 ± 2.11, 29 ± 1.95% from total content for Cu. Zn. Cd. and Pb , respectively. Also, the residual fraction of these metal approximately represented from 42 to 51% from the total content. At any given time the order of Cu, Zn, Pb, and Cd in the various fractions are as follows: residual > organic> oxides> carbonates> exchangeable. Distributions of different fractions of Cu, Zn, Cd, and Pb expressed as percentages of the total and in relation with the time factor are given in Fig. 2. This indicates that the soluble and exchangeable fractions and organic fraction increased with time up to 6 months then decreased gradually. The carbonates fraction decreased according to Aboulroos *et al.* (1989) due to the release of organic acids from sewage sludge, whereas, the oxides fraction increased with time. This may be due to metal transformation from soluble and exchangeable to oxide form (Aboulroos *et al.*, 1991).

TABLE 1. Changes in soil characteristics with increasing the rate of sewage sludge application and time.

Soil characteristics / Treatment		Time (month)									
		0	3	6	9	12	0	3	6	9	12
		pH					CaCO$_3$ (%)				
Cultivated	Control	8.50	8.40	8.32	8.25	8.28	2.19	2.05	1.79	1.65	1.62
	20t/ha	8.15	8.02	7.65	7.78	7.89	1.61	1.56	1.12	1.23	1.24
	40t/ha	7.95	7.54	7.19	7.28	7.25	2.21	1.95	1.85	1.76	1.68
	60t/ha	7.80	7.46	7.25	7.37	7.35	1.77	1.44	1.15	0.79	0.76
	80t/ha	7.65	7.11	7.00	7.16	7.20	1.65	1.45	0.85	0.68	0.51
Uncultivated	Control	8.54	8.44	8.45	8.40	8.40	2.32	2.25	2.10	2.10	2.00
	20t/ha	8.26	8.15	7.85	7.83	7.93	1.42	1.38	1.27	1.23	1.24
	40t/ha	8.00	7.50	7.23	7.35	7.40	1.60	1.60	1.38	1.59	1.55
	60t/ha	7.90	7.41	7.35	7.30	7.46	2.05	1.63	1.45	1.10	0.95
	80t/ha	7.80	7.26	7.22	7.41	7.44	1.65	1.50	1.10	0.80	0.65
		OM (%)					EC (mmohs/cm)				
Cultivated	Control	0.41	0.45	0.56	0.56	0.54	0.66	0.61	0.95	0.65	0.69
	20t/ha	0.92	0.85	0.74	0.69	0.65	0.82	0.61	0.95	0.66	0.54
	40t/ha	1.32	1.10	1.00	1.00	0.87	1.20	1.00	1.10	0.79	0.6
	60t/ha	1.86	1.45	1.25	1.20	1.00	1.7	1.31	1.18	1.35	1.19
	80t/ha	3.20	2.67	2.15	2.00	1.58	1.84	1.50	1.44	1.12	1.02
Uncultivated	Control	0.42	0.41	0.42	0.40	0.39	0.69	0.68	1.00	0.63	0.64
	20t/ha	0.84	0.65	0.50	0.41	0.40	0.80	0.78	1.06	0.63	0.64
	40t/ha	1.23	1.00	0.80	0.77	0.70	1.11	1.09	1.40	0.73	0.74
	60t/ha	1.57	1.35	0.98	0.85	0.72	1.57	1.54	1.25	1.67	1.68
	80t/ha	2.30	2.10	1.25	1.16	1.00	2.01	1.97	1.78	1.37	1.38

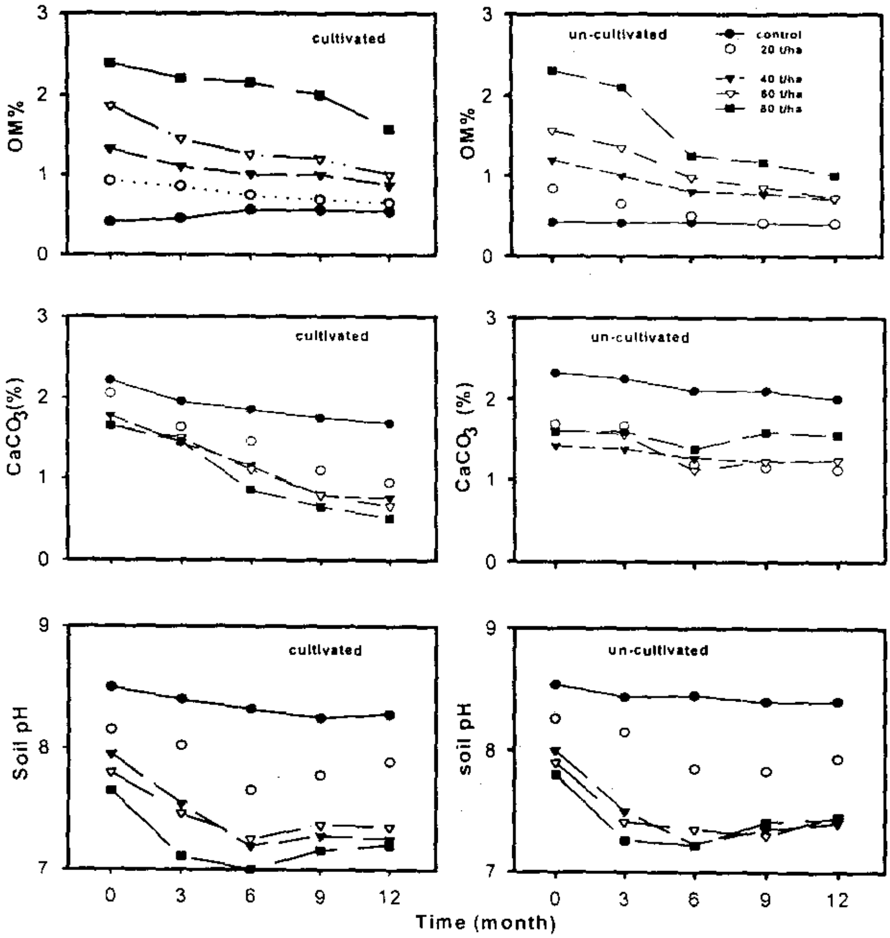

Fig. 1. Changes of soil OM, $CaCO_3$ and pH as a function of time and sewage sludge application rates.

TABLE 2. Changes of the total content of various heavy metals (mg/kg) in sewage sludge treated soil.

Treatment	Cu	Zn	Cd	Pb
Control	7.80 ± 0.65*	61.90 ± 3.73	0.45 ± 0.031	4.10 ± 0.25
20t/ha	16.1 ± 1.27	66.60 ± 0.96	0.60 ± 0.071	9.98 ± 0.74
40t/ha	17.5 ± 0.85	95.08 ± 3.21	0.75 ± 0.041	15.3 ± 0.50
60t/ha	23.7 ± 1.12	102.6 ± 2.86	0.95 ± 0.088	20.3 ± 0.31
80t/ha	25.2 ± 0.84	144.0 ± 4.58	1.35 ± 0.054	27.9 ± 0.59

*Mean value ± Standard Error

TABLE 3. Percentage from total content of different fractions of various metals in soil treated with different application rates of sewage sludge.

Fraction*	Cu		Zn	
	Range	Average ± SD	Range	Average ± SD
F1	0.3 – 1.0	0.62 ± 0.23	0.5 – 2.5	1.52 ± 0.65
F2	6.0 – 8.4	7.42 ± 0.85	9.0 – 11	10.1 ± 0.66
F3	4.8 – 8.9	6.35 ± 0.55	14 – 23	17.1 ± 3.39
F4	32 – 38	34.8 ± 2.14	25 – 28	26.4 ± 1.20
F5	47 – 51	49.2 ± 4.67	50 – 53	51.2 ± 2.75
	Cd		Pb	
	Range	Average ± SD	Range	Average ± SD
F1	2.0 – 7.0	4.13 ± 1.65	0.9 – 2.8	1.77 ± 0.67
F2	7.0 – 12.0	9.10 ± 1.74	9.0 – 12	10.3 ± 0.81
F3	18 – 28	23.9 ± 4.40	11 – 19	13.7 ± 3.28
F4	21 – 24	21.9 ± 2.11	28 – 30	29.7 ± 1.95
F5	40 – 44	41.8 ± 2.33	49 – 52	50.2 ± 1.67

*F1.= exchangeable; F2 = bound to carbonates ; F3 = bound to Fe and Mn oxides; F4 = bound to organic matter; F5 = Residual.

The relative distribution shows that the concentrations of heavy metals decreased in the mobile fractions with time, {(compare 0 time (start) with 12 months (end)}, approximately 29, 17, 51, 43 % of Cu, Zn, Cd, and Pb, respectively. The change of Cu, Zn, Cd, and Pb between mobile and inert fractions was estimated by calculating a mobility factor (MF) {the ratio of mobile to inert fractions}. Selected mobility factor for cultivated soil at 0 time (start), 3, 6, 9, and 12 month (at end) are presented in Table 4. These indicate that the value of MF increased with increasing the time, up to 6 month then it decreased with time. It should be mentioned that low values of MF indicate low mobility of the metals. Almas *et al.* (1999) found that the concentrations of mobile fractions decreased and of inert fractions increased with time in soil treated with organic matter. The MF of Cd is higher than other metals (Cd > Pb > Zn > Cu) this due to the organic complexation of Cd is lower than these metals (Fig. 3).

DTPA-extractable Heavy Metals

Data in Table 5 show a substantial increase in the DTPA extractable metals due to the increase in sewage sludge application rate, followed the same pattern observed with the total metals content. Comparing the values of the highest treatment of sewage sludge with the control, these increased in the order: Cu 17 times < Zn 12 times < Pb 11 time < Cd 6 times. The DTPA- extractable Cu. Zn, Cd, and Pb are negatively correlated with soil pH (r = - 0.837**, -0.915**, -0.644**. and - 0.884**, respectively), soil $CaCO_3$ content (r = -0.519**, -0.668**. -0.594*, -0.674**, respectively), and positively correlated with soil organic matter content (0.544**, 0.573**. 0.545**. 0.595**, respectively).

TABLE. 4. Mean values of mobility factors (MF) for soil heavy metal contents at different time of starting the experiments with 80 t/ha application rates sewage sludge.

Time (months)	MF			
	Cu	Zn	Cd	Pb
0 (start)	0.088	0.127	0.168	0.139
3	0.099	0.137	0.169	0.141
6	0.150	0.159	0.220	0.196
9	0.067	0.108	0.129	0.104
12	0.048	0.067	0.099	0.064

The percentage of the heavy metals extracted by DTPA from total content of Table 6 varied widely from one metal to another, indicating wide variations in their relative availability. These percentages, increased in the order: Zn 4% < Cu 8.5% < Cd 9% < Pb 10 % at the highest sewage sludge application rate. Figure 4 shows the continuous increase in soil DTPA extractable Cu, Zn, Cd, and Pb with increasing the sewage sludge application rate. The maximum increase happened at 6 months in relation to the decrease in soil pH and $CaCO_3$. The availability of these metals to plants decreased after 6 months, indicating transformation of a part of accumulated metal from available to unavilable form with the time. A glance at the data in Table 6 indicated that vegetation increased the percentages of DTPA - extractable Cu, Zn, Cd and Pb comparing with uncultivated soils up to 6 months, after which a reduction of these metals occurred, due to plant uptake in uncultivated soil they decreased, but still more than the cultivated soil.

Heavy Metals in Plant

Data in Table 7 show that the concentration of Cu, Zn, Cd, and Pb in leaves and fruits increased with increasing sewage sludge application rate to the soil. The results indicate that the concentration of heavy metals in the leaves are higher than the fruits. The absolute values of these metals in the leaves are different from metal to another. This depends on the sewage sludge content and the availability of these metals in the soil which are controlled by different soil parameters ($CaCO_3$, pH...etc.). The values of these metals followed the order Zn > Cu>Pb> Cd. The increase in metals content at the highest slude application rate compared with the control was 6 for Cu, 3.0 for Zn, 19 for Cd, and 23 fold for Pb; for leaves and 5 for Cu, 2 for Zn, 31 for Cd, and 25 fold for Pb for fruits, respectively. The concentration of Cd in tomato leaves and fruits was within the normal range. The intermediate concentration of Cd reported by Adriano (1986) was <0.30 ppm for leaves and 0.04-0.06 ppm for fruits. However, the concentration of Pb is within the normal range compared with tomato leaves grown in uncontaminated soil (6.3 ppm for leves and 1.19 ppm for fruits) as reported by Chapman (1975). A highyly significant correlation coefficient was found between both leaves and fruits, and soils DTPA-extractable content of Cu, Zn, Cd, and Pb (0.964** and 0.912**; 0.914** and 0.945**; 0.867** and 0.794**; and 0.887** and 0.909**, respectively).

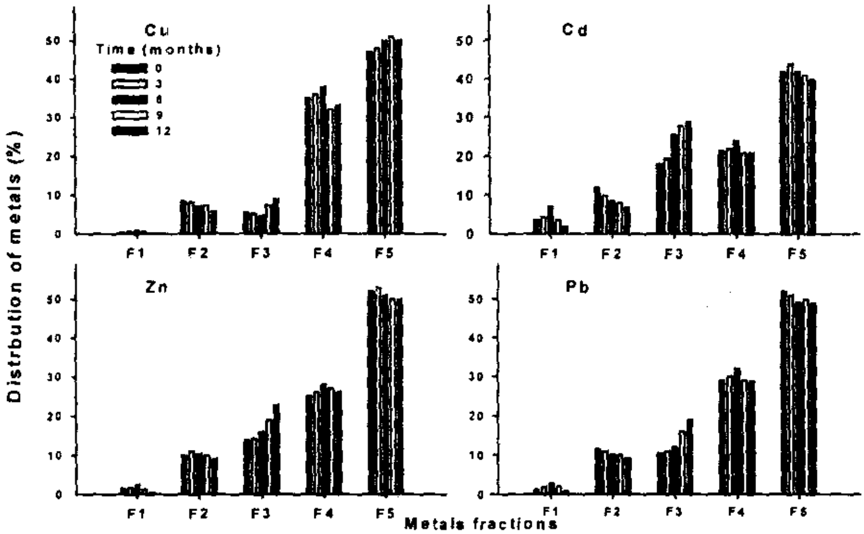

Fig. 2. Relative distrbution of Cu, Zn, Cd and Pb among the different fraction of the soil treated with 80 t/ha sewage sludge, at increasing equillibrium time.

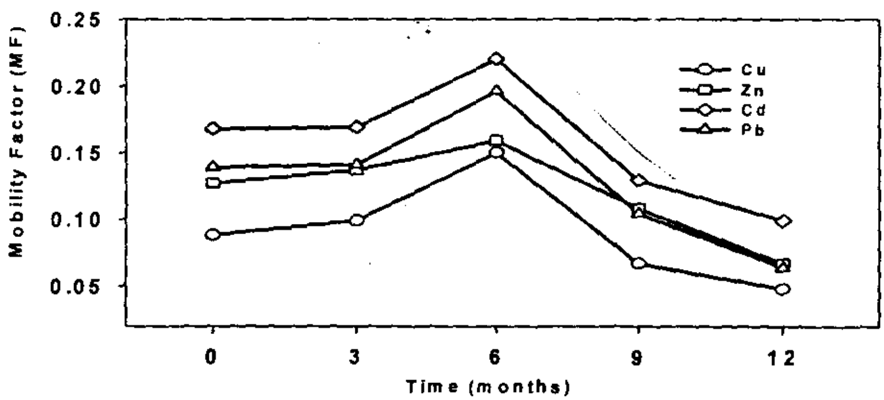

Fig. 3. Changs of mobility factor for Cu, Zn, Cd, and Pb as a function of time in sewage sludge treated soils.

TABLE 5. DTPA extractable-metals (mg/kg soil) in soil amended with different sewage sludge application rates at different periods of time.

Metal (mg/kg soil) / Treatment		Time (month)									
		0	3	6	9	12	0	3	6	9	12
		Cu					Zn				
Cultivated	Control	0.17	0.26	0.40	0.45	0.51	0.48	0.45	0.42	0.30	0.61
	20t/ha	0.20	0.18	4.06	1.32	1.22	2.52	4.20	6.13	4.65	4.07
	40t/ha	2.66	4.17	5.61	2.07	1.97	4.52	6.00	8.45	5.98	5.36
	60t/ha	2.65	5.30	6.96	2.50	2.80	5.23	7.60	10.15	6.63	6.17
	80t/ha	3.46	5.44	8.52	3.02	3.83	6.40	8.87	13.82	7.98	7.83
Uncultivated	Control	0.17	0.40	0.78	0.65	0.70	0.48	0.35	0.42	0.48	0.45
	20t/ha	0.20	0.29	1.84	3.00	2.67	2.52	3.70	5.13	5.40	4.75
	40t/ha	2.66	3.10	4.65	3.93	3.12	4.52	5.80	7.45	6.30	5.67
	60t/ha	2.65	3.79	5.13	4.30	3.1	5.23	5.50	8.40	7.80	7.50
	80t/ha	3.46	4.94	6.50	5.94	4.62	6.40	6.15	10.75	9.25	8.25
		Cd					Pb				
Cultivated	Control	0.02	0.03	0.03	0.01	0.01	0.23	0.25	0.27	0.25	0.24
	20t/ha	0.04	0.10	0.14	0.10	0.10	0.97	1.40	2.29	1.45	1.25
	40t/ha	0.07	0.11	0.20	0.13	0.13	1.25	2.57	3.13	1.98	1.75
	60t/ha	0.80	0.14	0.30	0.16	0.15	2.11	2.93	4.45	2.50	2.47
	80t/ha	0.12	0.20	0.42	0.22	0.22	2.69	3.65	5.54	3.35	3.27
Uncultivated	Control	0.02	0.03	0.04	0.01	0.03	0.26	0.21	0.25	0.27	0.26
	20t/ha	0.05	0.06	0.14	0.12	0.11	0.97	1.29	2.04	1.85	1.39
	40t/ha	0.07	0.09	0.16	0.15	0.14	1.25	1.70	2.50	2.40	2.10
	60t/ha	0.08	0.11	0.20	0.18	0.17	2.11	2.53	3.13	3.47	3.00
	80t/ha	0.11	0.15	0.29	0.24	0.22	2.67	3.01	4.70	4.20	4.00

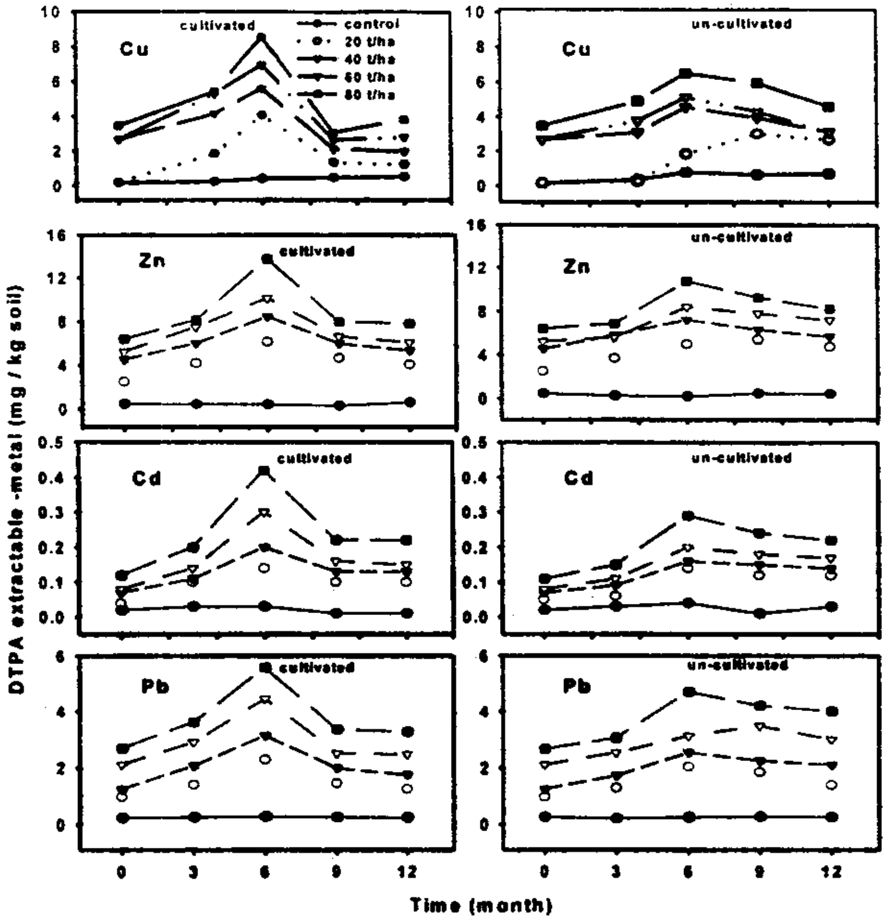

Fig. 4. DTPA extractable-metals as a function of time and sewage sludge application rates.

TABLE 6. Changes in soil DTPA-extractable metal as a percentage from total contents.

Time (month)	Cu		Zn		Cd		Pb	
	C.	Un.	C	Un	C.	Un	Cu.	Un.
0(start)	9.35	8.05	4.05	4.27	9.05	8.17	9.78	10.27
3	14.7	13.54	5.61	4.16	15.5	11.11	13.27	11.58
6	23.06	17.50	8.75	7.17	32.62	21.42	20.45	18.08
9	9.17	16.05	5.05	6.17	17.05	17.89	12.18	16.15
12	10.36	12.49	4.97	5.50	17.00	16.35	11.89	15.38

C= cultivated; Un = uncultivated

TABLE 7. **Heavy metal concentrations (mg/kg dry matter) in different tissues of tomato plants grown on soil treated with differnt rates of sewage sludge.**

Treatment	Cu		Zn		Cd		Pb	
	leaves	fruits	leaves	fruits	leaves	fruits	leaves	fruits
Control	3.8	2.00	28.9	22.5	0.009	0.004	0.14	0.05
20 t/ha	12.8	6.52	45.8	30.5	0.054	0.039	1.42	0.56
40 t/ha	15.6	8.34	69.5	35.8	0.110	0.068	1.85	0.69
60 t/ha	18.9	9.20	75.9	38.8	0.134	0.085	2.54	0.84
80 t/ha	22.5	10.58	86.5	42.5	0.175	0.125	3.25	1.25
L.S.D.0.05	2.92	1.55	4.56	2.58	0.021	0.014	0.27	0.08

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مصير بعض الفلزات الثقيلة فى الأرض الرملية المعاملة بالحمأة وتراكمها داخل النباتات

السيد حسن بدوى* ، راوية عبد الغنى المتيم**

*قسم الاراضى - كلية الزراعة - جامعة القاهرة - الجيزة
**وقسم البحوث النباتية - هيئة الطاقة الذرية - انشاص - القاهرة - مصر

اجريت هذه الدراسة لاختيار تاثير اضافة الحمأة للأرض الرملية على التغيرات في الصور الكيمائية للفلزات الثقيلة (Cu, Zn, Cd and Pb) بمرور الزمن .

تمت تجربة أصص استخدم فيها أرض رملية مضافا إليها مستويات مختلفة من الحمأة (صفر ، ٢٠ ، ٤٠ ، ٦٠ ، ٨٠ طن /هكتار) المجمعة من محطة الصرف الصحى بالجبل الاصفر. قسمت التجربة إلى معاملات بدون زراعة وأخرى زرعت بنباتات الطماطم. تم تجميع عينات الأرض على فترات زمنية: صفر ، ٣ ، ٦ ، ٩ ، ١٢ شهرا من بداية الزراعة. وأيضاً تم تجميع عينات نباتية (ثمار - أوراق) للوقوف على حالة تجميع تلك الفلزات فى الأجزاء المختلفة من النباتات. وقد أوضحت النتائج الآتي:-

١- حدث انخفاض فى كل من رقم ال pH وكربونات الكالسيوم والمادة العضوية فى الأرض مع مرور الوقت . وحدثت أعلى معدلات للتغير بعد ٦ شهور من بداية التجربة فى كل من الأراضى المزروعة وغير المزروعة. بينما كان معدل التغير أكبر فى الأراضى المزروعة.

٢- زاد المحتوى الكلى والصورة الصالحة (المستخلصة بواسطة محلول DTPA) من الفلزات الثقيلة (Cu, Zn, Cd and Pb) فى الأرض مع زيادة معدل الإضافة من الحمأة وليست هناك فروق معنوية مع التغيرات فى الزمن بالنسبة للمحتوى الكلى .بينما كانت هناك زيادة فى الصورة الصالحة حيث كانت أعلى قيم بعد ٦ أشهر من الزراعة . ولوحظ أن الأراضى المزروعة كانت أعلى فى محتواها من الكميات الصالحة من غير المزروعة حتى ٦ شهور من الزراعة ثم بعد ذلك كانت أقل منها.

٣- اختلفت قيم توزيعات الصور المختلفة للفلزات الثقيلة فى الأرض مع مرور الزمن ولكن بصورة عامة كان التوزيع النسبى لجميع الفلزات كالاتى :- الجزء المتبقى > الجزء المرتبط عضوياً > الجزء المغلف بالأكسيد > المرتبط بالكربونات > الجزء المتبادل. وبحساب القيم النسبية للصور المتحركة (MF) كانت أقصى زيادة لها عند ٦شهور من بداية التجربة ثم تبدأ فى التناقص.

٤ - زيادة محتوى كل من Cu, Zn, Cd, Pb فى نباتات الطماطم مع زيادة معدلات الإضافة من الحماة للأرض وكان محتوى الثمار أقل دائماً من محتوى الأوراق . وأيضاً كانت التركيزات فى الثمار والأوراق فى الحدود العادية ولم تصل إلى حدود السمية.