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Evaluation of Banana Compost Enriched with Microorganisms on Concentrations of Heavy Metals in Corn and Bean Plants

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ABSTRACT

A field experiment was carried out at El Nubaria (North of the Nile Delta) to evaluate the application of banana compost mixed with effective microorganisms on reducing soil and plant pollution by chemical fertilizers. The experiment included 6 fertilizer treatments: control (F_0), 150% compost (F_1), 100% compost ($F_2 \approx 10$ ton/fed; 1 fed = 4200 m^2), 75% compost + 25% of full recommended NPK (F_3), 50% compost + 50% NPK (F_4) and full recommended NPK (F_5). Under the same treatments and without any new additions, bean (*Vicia faba* L. cv. 'Nubaria 1') was planted to evaluate the residual effect of these organic and chemical fertilizers. Corn grain yield (*Zea mays* L. cv. 'Single cross 129' (white)) was increased by adding a high rate of chemical fertilizers but bean seed yield was significantly increased by using all rates of compost compared with the control in two bean seasons (2005/2006 and 2006/2007). Generally, in the second year the amount of cadmium (Cd) in plant tissues could not be detected. However, in the first season, Cd concentration of green leaves and ear leaves, as well as corn and bean yields increased with increasing mineral fertilizers. Application of mineral fertilizers alone increased nickel (Ni) and lead (Pb) concentration in plant tissue, while the reverse was true for compost. There was a significant positive increase in soil extractable Cd, Ni and Pb due to the application of mineral fertilizers compared to the addition of compost. It could be concluded that organic application had a promising effect on reducing Cd, Ni and Pb concentrations in bean and corn plants and in soil in which they grew.

Keywords: cadmium, lead, nickel, organic fertilization

INTRODUCTION

It is important to develop new applications which are sustainable both agronomically and economically, as well as environmentally to produce safe food for human consumption. Heavy metals (HMs) are considered as major environmental pollutants and are both cytotoxic and carcinogenic. One of the sources contributing to the contamination of soil is through the use of fertilizers (Joshi and Luthra 2000).

Composts play an important role in minimizing the use of inorganic fertilizers and consequently minimize potential pollution and improve soil quality (Abdel Moez 2001; Naguib 2002; Preusch *et al.* 2002). Addition of amendments such as fly ash, cow manure, and sludge is usually inexpensive and effective in lowering the metal toxicity of tailings and decreasing DTPA-extractable lead (Pb). Also, sewage sludge could significantly reduce Pb uptake (Chiu *et al.* 2006). On the other hand, compost contains a small amount of zinc (Zn), copper (Cu), Pb and cadmium (Cd): the concentrations of Cd and Pb in all compost-amended media were below the limit of Chinese drinking water standards (Xia *et al.* 2007). Biosolid-amendment slopes decreased the shoot: soil Cd ratio to varying extents depending on their source, properties, and application rate (Kukier *et al.* 2010). In contrast, some organic wastes can also be an important source of pollution, especially of HMs, which are potentially toxic to humans and the environment. A low available fraction indicated that most of the applied HMs with compost will remain in the soil and contribute to soil contamination (El-Naggar 1996; Ramos and Acevedo 2004).

Microorganisms drive the composting process, so creating an optimal environment for microbial activity is crucial for successful and efficient composting (Marriott 2010). Use of effective microorganisms (EM) inocula along with organic/inorganic materials is an effective technique for releasing nutrients from these nutrient sources and absorbs unessential nutrients to hold it in their bodies. The inoculation of agro-ecosystems with EM cultures can improve soil and crop quality (Hussain *et al.* 1999; Medina *et al.* 2004; Abdul Khaliq *et al.* 2006). Similarly, the application of EM to onion, pea and sweet corn increased yields by 29, 31 and 23%, respectively. This may be due to the release of more nutrients into the soil–root system (Daly and Stewart 1999). Different plant growth-promoting rhizosphere bacteria, including *Bacillus*, can help to improve plant growth, plant nutrition (of corn, wheat and legumes), root growth pattern, plant competitiveness and responses to external stress factors (Hoflich *et al.* 1994; Egamberdiyeva and Hoflich 2004). In another study, the use of these treated agro-wastes with fungi created changes in mineral nutrients and soil physiochemical characteristics (Li *et al.* 1997).

The available Pb, Cd and Ni contents in organic-amended soil at the end of an experiment were lower in soil treated with bacteria compared to untreated soil (El-Kassas 1999).

The aim of this study was to evaluate banana compost enriched with EM to assess the effectiveness of reducing HM content in soil and plants compared with chemical fertilization.

MATERIALS AND METHODS

A field experiment was carried out at El Nubaria (North of Nile Delta) Agricultural Research Station during two successive years (2005/2006 and 2006/2007) to evaluate the application of banana compost mixed with EM on reducing the pollution of chemical

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Table 1 The chemical composition of used fertilizers.

Chemical fertilizer	N (%)	P_2O_5 (%)	K_2O (%)	Ni (μgg^{-1})	Cd (μgg^{-1})	Pb (μgg^{-1})
Ammonium sulfate	20.6	-	-	22.3	14.8	39.4
Super phosphate	-	15.0	-	24.2	17.6	12.4
Potassium sulfate	-	-	48	13.0	11.6	113.4
Compost first season	1.23	1.81	2.45	2.98	-	2.65
Compost second season	1.10	1.88	2.64	3.9	-	3.65

Table 2 Some physical and chemical properties of the studied soil.

Characteristics	Value
pH (1 : 2.5 soil : water ratio)	8.11
EC (Soil paste extraction) dSm^{-1}	1.32
Available nutrients (mg kg^{-1})	
Nitrogen	93.15
Phosphorus	7.90
Potassium	186.63
Nickel	0.37
Cadmium	0.156
Lead	0.592
Organic matter (%)	0.47
Calcium carbonate (%)	24.9
Sand (%)	68.91
Silt (%)	16.57
Clay (%)	14.52
Textural class	Sandy loam

fertilizers. Corn cv. 'Single cross 129' (white) was cultivated then followed by bean cv. 'Nubaria 1' (cultivars were obtained from the Agriculture Research Center, Egyptian Ministry of Agriculture) to evaluate the residual effect of organic and chemical fertilizer treatments. The experiment included 6 fertilizer treatments: i) control (F_0 = without any addition), ii) 150% compost (F_1), iii) 100% compost (F_2 ≈10 ton/fed where 1 fed. = 4200 m^2), iv) 75% compost + 25% of full recommended NPK (F_3), v) 50% compost + 50% NPK (F_4) and vi) full recommended NPK (F_5 = 120 kg N/fed as ammonium sulfate + 30 kg P_2O_5/fed as super phosphate + 24 kg K_2O/fed as potassium sulfate). The chemical composition of fertilizers used is provided in **Table 1**.

Compost, P and K fertilizers were added before sowing. N fertilizer was added in three equal portions: before cultivation, 2 weeks after cultivation and 3 weeks after the second addition.

In each plot, four random soil cores were taken and mixed (approximately 0.5 kg of soil each) from a depth of 0-15 cm after the harvest of each crop in both seasons and plant residues were immediately removed. Some physical and chemical properties of the soil used are given in **Table 2**.

Soil samples

Soil samples were collected from all plots at different times: 1) after corn harvest in the first season (first sample); 2) after bean harvest in the first season (second sample); 3) after corn harvest in the second season (third sample) and 4) after bean harvest in the second season (fourth sample).

Soil samples were air dried, crushed and sieved to pass through a 2-mm sieve. Available HMs (i.e., Ni, Cd, Pb) were extracted with NH_4HCO_3-DTPA (79.06 g NH_4HCO_3 and 1.97 g DTPA dissolved in 1 l water to which 1 ml ammonium solution was added to adjust pH to 7.6, shaken with 10 g soil and 20 ml extract for 30 min) according to Soltanpour (1985) and determined by using an atomic absorption spectrophotometer (Perkin Elmer, Model 2308).

Plant analysis

The crops were harvested at physiological maturity and yields were recorded. Plants were carefully removed at approximately 2.5 cm above the soil and dried to constant weight. A portion of these dried plant materials (corn green leaves after 60 day from sowing, corn ear leaf at the end of the season, corn grains and bean seeds) were ground and wet-digested with sulphuric and perchloric acids as described by Chapman and Pratt (1978). The digested aliquots were analyzed for HMs (i.e., Ni, Cd and Pb) content by using the same atomic absorption spectrophotometer as for soil analyses.

Statistical analyses

Experimental treatments were replicated three times in a completely randomized block design. The plot area was 1/400 fed. Data were statistically analyzed through analysis of variance (ANOVA) and least significant difference (LSD) at $P = 0.05$ was applied to make comparisons among treatment means according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Grain and seed yield of corn and bean plants

According to the data presented in **Table 3** the grain yield reached 2.41, 1.81, 3.02, 3.5 and 4.23 times that of control for F_1, F_2, F_3, F_4 and F_5 in the first season and 2.5, 2.15, 2.92, 3.19 and 4.23 in the second season, respectively. The low amount of nutrients mineralized in the composted plots may explain the low grain yield in spite of improved soil physical properties and increased availability of micronutrients. These results are consistent with the findings of Cox *et al.* (2001) who studied the effectiveness of compost and chemical fertilizers in restoring soil quality and barley yield; they found that plots receiving N fertilizer had significantly higher yields than plots not receiving N fertilizer. Also, our data trend was similar to the result of Abou El-Magd *et al.* (2004), Yang *et al.* (2005), and Fan *et al.* (2005), who concluded that like wheat grain yield, corn grain yield was also significantly influenced by treatments, and the mean yield for 6 years was 2.29, 4.39 and 4.75 Mg ha^{-1} for control, manure and mineral fertilizer treatments, respectively. Generally, grain yield in the second season is 1.5-fold greater than that in the first season.

The residual effect of compost applied alone or integrated with mineral NPK on seed yield was significantly increased by using all rates of compost compared with the control in both seasons. The lowest values were found in the control followed by the full recommended dose of mineral fertilizer. However, the highest yield in the first and second seasons were recorded by applying 150% compost (F_1). Eghball *et al.* (2002, 2004) showed that the residual effect of the application of composted beef cattle feedlot manure could maintain the level of corn yield for several years after application.

Table 3 Corn grain and bean seed yields (ton/fed.) in two growing seasons as affected by fertilization treatments.

Fertilization treatments	Corn grains		Bean seeds	
	First season	Second season	First season	Second season
F_0	0.444	0.662	0.361	0.488
F_1	1.070	1.655	3.090	3.546
F_2	0.803	1.420	1.871	2.503
F_3	1.340	1.934	1.549	2.164
F_4	1.554	2.110	1.107	1.520
F_5	1.877	2.799	0.929	1.034
$LSD_{0.05}$	0.140	0.233	0.11	0.17

Heavy metal concentrations and uptake

Cadmium: Data in **Table 4** indicates that Cd, Ni and Pb concentrations (μg g^{-1}) in corn and bean parts were affected by fertilization treatments in both growing seasons. Generally, in the second year the amount of Cd in plant tissues was insufficient to be detected. This may be because: 1) Cd occurs naturally in all soils but at very low levels (De Pieri *et al.* 1996), most Cd was removed from cultivated soil by crop uptake and harvest in the first season. 2) The dilution effect that resulted from plant growth in the second season was higher than that in the first season. 3) Corn and bean

Table 4 Cadmium, nickel and lead concentration (μgg^{-1}) in green leaves, ear leaf, corn grain and bean seeds in two growing seasons as affected by fertilization treatments.

Fertilization	Green leaves			Ear leaf			Corn grain			Bean seeds		
Treatments	**Cd**	**Ni**	**Pb**	**Cd**	**Ni**	**Pb**	**Cd**	**Ni**	**Pb**	**Cd**	**Ni**	**Pb**
First season												
F_0	1.002	0.567	1.828	0.766	0.418	0.994	0.865	0.374	0.922	0.346	0.048	0.577
F_1	0.532	0.350	1.154	0.915	0.273	0.673	0.622	0.165	0.775	0.222	0.029	0.449
F_2	0.848	0.441	1.731	0.828	0.289	0.907	0.507	0.134	0.727	0.185	0.077	0.641
F_3	0.860	0.616	1.892	0.939	0.355	1.010	0.776	0.235	0.920	0.297	0.129	1.026
F_4	0.928	0.688	2.002	0.964	0.379	1.122	0.896	0.268	1.239	0.507	0.172	1.250
F_5	1.169	0.751	2.149	1.137	0.451	1.379	1.038	0.307	1.446	0.692	0.230	1.443
$LSD_{0.05}$	0.37	0.18	0.37	ns	0.10	0.34	ns	0.09	0.47	0.23	0.04	0.52
Second season												
F_0	N.D	0.185	2.540	N.D	0.028	0.924	N.D	0.017	0.264	N.D	0.033	0.528
F_1	N.D	0.161	2.210	N.D	0.052	0.544	N.D	0.009	0.231	N.D	N.D	0.462
F_2	N.D	0.133	2.342	N.D	0.022	0.923	N.D	0.005	0.330	N.D	0.024	0.676
F_3	N.D	0.195	2.474	N.D	0.083	1.089	N.D	0.014	0.363	N.D	0.028	0.759
F_4	N.D	0.228	2.606	N.D	0.100	1.254	N.D	0.047	0.495	N.D	0.054	0.858
F_5	N.D	0.228	2.705	N.D	0.118	1.554	N.D	0.057	0.627	N.D	0.085	0.957

N.D = not detected

plants could absorb exchangeable Cd and it was not organic matter-bound with Cd as concluded by Murakami *et al.* (2005).

These results confirm the findings of McArthur *et al.* (2001) who noticed that total Cd of cultivated prairie (considered part of the temperate grasslands), collected from each of 12 different sites throughout southern Saskatchewan, Canada, were significantly lower than those of virgin soils. Paramasivam *et al.* (2005) showed that Cd concentration in the below-ground plant part of collard greens (*Brassica oleracea*) grown in two different soils was not detected.

In the first season, Cd concentration of green leaves and ear leaves, corn and bean yields increased with increasing mineral fertilizers. This is a logical trend because total Cd content in compost material was not detected but mineral fertilizer contained a substantial amount of Cd, as listed in **Table 1**, especially super phosphate. Moreover, this indicates that Cd ions may be associated with larger humified and less soluble organic materials such as humic and fulvic acids which possess strongest Cd-binding groups (Kaschl *et al.* 2002). These results are compatible with those of many studies. For example, McArthur *et al.* (2001) and El-Ghawi *et al.* (2005) found that application of chemical fertilizers may add Cd to soil and have harmful effects on the environment.

The concentration of Cd in green leaves and ear leaf samples were higher than those in corn grain; this may be due to slow transport to grains. De Pieri *et al.* (1996) reported that high accumulations of HMs are in leaves rather than in the edible parts of plants. Organic amendments are usually effective in lowering metal toxicity (Ramos and Acevedo 2004; Chiu *et al.* 2006).

The residual effect of applying 150 and 100% compost did not allow the Cd concentration in bean seeds to be detected. These results could be explained by increasing of growth and yield of bean. In addition, burning compost during the seasons of cultivation increased the amount of effective groups which blocked Cd ions. Similar findings were observed by Joshi and Luthra (2000).

Nickel: In general, results showed that fertilization treatments exerted a significant effect on Ni in all parts of plants during both growing seasons (**Table 4**).

The values of the control treatment (i.e. to which compost was not added) should be ignored because there are many factors affecting the nutritive levels of control plants, so that all values will be compared with 100% NPK treatment.

The tested fertilizer treatments varied widely in their effect on Ni concentration. Application of mineral fertilizers alone increased Ni concentration in plant tissue, while the reverse was true for compost (**Table 4**). Organic application had a promising effect on reducing Ni concentration. This advantage could be based on, firstly, the fact that compost has a high capacity to adsorb and bind HMs subsequently keeping them out of the soil solution where they would be taken up by plants. Secondly, addition of compost increases biological activity of soils and encourages the multiplication of bacteria, some of which are able to dissolve and adsorb toxic HMs. Furthermore, bacteria which were added during compost preparation, especially *Bacillus subtilis*, posses the ability to absorb HMs and fix them in their cells. In general, these results and findings correspond with those obtained by Somasundaran *et al.* (1998).

Lead: Lead concentrations in various plant tissues increased with increasing mineral fertilization dose, irrespective of the control treatment. The magnitude of increase in Pb concentration by adding 100% NPK in the first season was 7.3, 13.6, 24.2 and 86.2% for green leaves, 22.9, 36.5, 52.0 and 104.9% for ear leaves, 16.7, 57.2, 98.9 and 86.6% for corn grain and 15.4, 40.6, 125.1 and 221.4% for bean seeds compared to F_4, F_3, F_2 and F_1, respectively (**Table 4**). Concerning the second season, no effect could be established for Pb concentration in green leaves by adding various mixtures of fertilizers, but all values were greater than those in green leaves in the first season. This may be due to the Pb content in compost in the second season being higher than that in the first (**Table 1**). Data presented in **Table 4** shows that Pb concentration in 100% NPK plots increased by 23.9, 42.7, 68.4 and 185.7% for ear leaves, by 26.7, 72.7, 90.0 and 171.4% for corn grain and by 11.5, 26.1, 41.6 and 107.1% for bean seeds compared to F_4, F_3, F_2 and F_1, respectively. This could be related to mineral fertilizers, which can be an important source of pollution, especially by HMs, and the precipitation of Pb was primarily through the fixation by compost. Sauvé *et al.* (2000) showed that organic matter has a high capacity to adsorb Pb and concomitantly maintain a low free Pb^{+2} activity in solution; therefore, it is important to assess the adsorption capacity of natural materials and to evaluate their potential to reduce toxicity of Pb. The present discrepancy among investigators may be due to four reasons: 1) the type of organic materials and their chemical composition. The addition of amendments such as fly ash, cow manure, and sludge effectively lower the metal toxicity of tailings and decreasing DTPA-extractable Pb. Also, sewage sludge could significantly reduce Pb uptake (Chiu *et al.* 2006). Morell (1998) showed that soils polluted by deposits of sewage sludge are potentially toxic to plants by containing higher levels of Cu, Pb and Zn than Cd and Cr; 2) the application rate, or 3) the plant type and parts analyzed. Murakami *et al.* (2005) noted that *Oryza sativa* L. cv. 'Milyang 23' possesses the ability to absorb Cd from polluted soils. Other plants change HM availability indirectly by different mechanisms (such as oxidation of complexing agents, respiration of roots, etc.; Hammer and Keller 2002). 4) Physical and chemical properties of soil, especially the content of OM, $CaCO_3$ and pH values.

Heavy metal uptake

Cadmium: **Table 5** reveals that Cd uptake by corn and bean yields in the second season were traces because Cd concentration was lower than detection limit.

In the first year Cd uptake increased with increasing mineral fertilizer dose. Bean uptake of Cd was in the order: $F_5 > F_1 > F_4 > F_3 > F_2 > F_0$.

Nickel: Data in **Table 5** shows the effect of fertilization treatments on Ni uptake by corn grains in both seasons, it the following order: $F_5 > F_4 > F_3 > F_1 > F_2 > F_0$. As for Ni uptake by bean plants, there was no apparent relationship between Ni uptake and fertilization treatments.

The residual effect caused by adding any residue into the soil did not result in phytotoxicity for two reasons: 1) the low content of HMs in all the residues; 2) the high pH of Egyptian soil which reduces the mobility of these HMs.

Lead: The highest value of Pb was recorded by applying all recommended doses of NPK i.e., F_5 treatment followed by 50% compost + 50%NPK (F_4) and 75% compost + 25% NPK (F_3). This trend was true in both seasons (**Table 5**).

According to these results it is difficult to link Pb uptake and different fertilization treatments because many factors are changing at the same time such as Pb concentration in seeds, yield quantity and available Pb in the soil.

The availability of heavy metals in the used soil

Available cadmium: Statistical analysis of available Cd (mg kg^{-1}) listed in **Table 6** reveals that fertilizer applications significantly affected soil Cd in all samples. There were significant positive increases in extractable Cd due to the application of mineral fertilizers in comparison with those obtained when compost was added.

Application of the full recommended dose of chemical fertilizer (F_5), 50% compost + 50% NPK (F_4) and 75% compost + 25% NPK (F_3) increased extractable Cd by 89.4, 64.4 and 7.7%, respectively for the first corn sample compared with the control treatment (F_0). However, application of 100% compost (F_2) and 150% compost (F_1) decreased available Cd more than that of the control by 17.3 and 13.5%, respectively, but without any significant difference between them. This is due to the integration between mineral and organic fertilizers which could increase the available HMs which exist in chemical fertilizers; alternatively, this dose of compost might not have been enough to withhold the entirety of available Cd released from chemical fertilizers. In the second year all treatments increased soil Cd more than the control after corn or bean. All treatments at four sampling times resulted in a decrease in extractable Cd more than the initial value.

Available nickel: The application of compost without chemical fertilizer led to a decrease in available Ni more than the 100% NPK treatment and was lower than the control; significant differences between almost all samples were observed; F_1 and F_2 were significantly different from control treatments. Extractable Ni increased as mineral fertilizer rate increased (**Table 6**).

The percentage increase resulting from 100% NPK treatment was 30.1, 63.7, 235.7 and 136.3% for the first sample (after first corn harvest), 22.4, 47.7, 118.1 and 104.4% for the second sample (after first bean harvest), 22.4, 40.4, 71.3 and 69.1% for the third sample (after second corn harvest) and 30.19, 51.09, 137.93 and 137.93% for the fourth sample (at the end of two years) compared to F_4, F_3, F_2 and F_1, respectively. Based on relative percentages, compost amendments clearly reduced available Ni.

Available lead: The application of fertilization mixtures significantly affected available Pb in the first, second and fourth samples, but this effect was not significant in the third sample. All amendments were able to raise the extractable Pb more than the control treatment except for the residual effect of 100% compost treatment (second sample). The percentage increase in available Pb by adding F_1, F_2, F_3, F_4 and F_5 compared to the control treatment was 51.2, 29.3, 90.3, 115.1 and 154.8% for the first sample, 14.6, -3.7 {The value of available Pb after first bean and under F_2 treatment (0.554) was lower than control (0.575) so this percentage is negative (**Table 6**)}, 43.1, 86.4 and 120% for the second sample, 4.5, 8.7, 17.3, 26.3 and 43.6% for the third sample and 0.6, 30.3, 50.9, 130.9 and 151.5% for the fourth sample, respectively (**Table 6**).

In the first year, all values of available Pb were higher

Table 5 Cadmium, nickel and lead uptake (mg/fed.) of corn and bean yield in two growing seasons as affected by fertilization treatments.

Fertilization treatments	Cadmium				Nickel				Lead			
	Corn grain		Bean seeds		Corn grain		Bean seeds		Corn grain		Bean seeds	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season
F_0	375	N.D	96	N.D	165	13	14	11	435	210	190	316
F_1	654	N.D	513	N.D	176	10	91	N.D	837	421	1177	1599
F_2	378	N.D	243	N.D	105	4	126	57	603	517	990	2065
F_3	1061	N.D	349	N.D	321	23	200	53	1232	752	1549	1995
F_4	1362	N.D	508	N.D	392	99	185	75	1860	1115	1365	1512
F_5	1924	N.D	594	N.D	564	152	206	90	2672	1848	1301	1142
$LSD_{0.05}$	442		325		112	61	83	48	502	497	ns	730

Table 6 Available cadmium, nickel and lead (mg kg^{-1}) in soil after harvesting corn and bean plants in first and second seasons as affected by fertilization treatments.

Fertilization treatments	Cadmium				Nickel				Lead			
	After corn		After bean		After corn		After bean		After corn		After bean	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season
F_0	0.104	0.049	0.111	0.046	0.273	0.211	0.192	0.160	0.621	0.381	0.575	0.165
F_1	0.090	0.076	0.099	0.069	0.223	0.152	0.206	0.087	0.939	0.398	0.659	0.166
F_2	0.086	0.093	0.080	0.085	0.157	0.150	0.193	0.087	0.803	0.414	0.554	0.215
F_3	0.112	0.113	0.108	0.102	0.322	0.183	0.285	0.137	1.182	0.447	0.823	0.249
F_4	0.171	0.139	0.128	0.124	0.405	0.210	0.344	0.159	1.336	0.481	1.072	0.381
F_5	0.197	0.160	0.205	0.141	0.527	0.257	0.421	0.207	1.582	0.547	1.265	0.415
$LSD_{0.05}$	0.04	0.01	0.04	0.01	0.06	0.06	0.07	0.04	0.19	ns	0.11	0.10

than in the initial sample (0.592 mg kg^{-1}). This may be caused by: 1) in beginning of organic decomposition, organic acids dissolved and released Pb from the unavailable to the available pool. In the first year, stable components like humic and fulvic have not been created yet, but in the second year Pb may be tightly bound by large humic molecules and humin, thereby increasing the capacity of the soil to adsorb Pb, as occurs for Cd (Kaschl *et al.* 2002). Cooperband (2002) showed that well-decomposed organic matter reduces the negative environmental effects of HMs by binding contaminants. 2) Plant growth in the second year was higher than in the first therefore, improved root growth and penetration would have increased the depth from which water and nutrients could be absorbed.

Several studies have shown that the application of compost decreases available HMs. El-Naggar (1996), Ramos and Acevedo (2004), and Zhang *et al.* (2004) reported that incorporation of compost into peat-based media significantly decreased the proportions of available Cd, Ni and Pb. Marriott (2010) showed that compost provides many benefits as a soil amendment and as a source of organic matter by reducing the bioavailability of HMs.

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