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Original Research Paper

Heavy Metal Leaching in Coastal Loamy Soil of the Field Treated with Municipal Solid Waste at Puducherry (Pondicherry), India

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ABSTRACT

Leaching of Pb (lead), Mn (manganese), Cu (copper), Zn (zinc) and Cd (cadmium) in coastal loamy field soil treated with Municipal Solid Waste @ 10, 20, 50, 75, and 100 t/ha was assessed at Puducherry in relation to the native soil without treatment. The concentrations (ppm) of the heavy metals on the soil surface (0 cm), 10, 20 and 30cm sub-layers across the treatments and native soil showed that the Pb and Mn concentrations were higher in surface layer and gradually decreased in 10 and 20cm layers, and was low in 30cm layer across the treatments. However, the concentrations of Cu, Zn, and Cd were less in the surface layer and gradually increased in the sub- layers of the soil and were high at 30 cm layer. Among the leached heavy metals, Cu was in higher concentration in the surface layer and the ranking order was Cu > Cd > Zn > Mn > Pb in surface layer across the treatments. The ranking order of the metals at 30 cm depth was same as that of surface with the same ranking order. Thus, the leaching was higher in Cu, Cd and Zn than in Mn and Pb, the latter two being almost immobile and more concentrated in the surface layer. The concentrations of these heavy metals in different layers across the treatments were significantly different from each other ($P < 0.01$) and higher compared to that of the native soil.

INTRODUCTION

Soils polluted with heavy metals are normally found near industrial areas, metropolises, along roads, municipal solid waste dumping sites and areas treated with wastewater sludge. It has been seen that urbanization and industrialization have led to generation of large quantities of wastes. Field trials applying municipal solid waste (MSW) compost as an organic soil additive suggested an appealing alternative, which constituted an important organic mass supplying steady humus (Tidsell & Breslin 1995) and contributing to the improvement of the soil fertility (Anikwe & Nwobodoko 2002, Pigozzo et al. 2006, Perez et al. 2007). However, the repeated application of MSW compost can lead to accumulation of heavy metals in different layers of soils (Qiao et al. 2003, Pattnaik et al. 2006, Iwegbue et al. 2007, Kidd et al. 2007). Municipal solid waste is one of the most important anthropogenic sources of heavy metals for soil (Senesi et al. 1999, Pattnaik et al. 2006, Reddy & Pattnaik 2009, Pattnaik & Reddy 2010), and the amendment of soils with MSW can act as a significant source of heavy metals to soil. These heavy metals can leach into deeper sub-layers of the soil and sometimes reach the groundwater or can be easily available to root system, assimilated by plants and incorporated into food web (Stilwell 1993), and thus, having a significant effect on environmental quality threatening human health (Pinamonti et al. 1997, Jordao et al. 2006).

The toxicity of the metals depends not only on their total concentration, but also on their mobility and reactivity with other components and compounds of the soil system. Some factors increase their mobility and cause more plant uptake. These factors include the properties of the metals, soil texture, pH and competing cations in the soil solution (Rauret 1998). Earlier investigations on the movement of heavy metals in soils showed that metals added to the soil from wastes, accumulate on or near to the soil surface (McBride 1995, Pattnaik et al. 2006).

Although studies have shown leaching of heavy metals from various sources in soil (Dube et al. 2001, Fodor & Szabó 2004, Pattnaik et al. 2006), information on the mobility and leaching of the metals in soil contaminated with municipal solid waste is meagre. Bergkvist (1987) studied leaching of heavy metals in forest soil, while Ruttens et al. (2006) studied influence of compost and/or inorganic amendments of soil on metal leaching in Belgium. Farrel et al. (2010) studied migration of heavy metal in soil as influenced by compost amendments in UK. In India, Malviya & Chaudhary (2006) showed leaching and immobilization of heavy metals in solidified/stabilized products and Pattnaik et al. (2006) reported the heavy metal concentration at different sub-layers in municipal solid waste dumping site, while Yellishetty et al. (2009) assessed metal concentrations and metal mobility in unsaturated mine wastes. However, little information is available on leaching of heavy metal in soil treated with MSW in India. The present study, therefore, attempted to assess leaching of heavy metals in coastal loamy soil treated with MSW in the field at Puducherry (Pondicherry).

MATERIALS AND METHODS

Collection of samples and field experiment: Municipal solid waste was collected from one of the major garbage dumping sites, Karravadikuppam at Puducherry, an erstwhile French town on the east coast of India. Leaching of the heavy metals (Pb, Zn, Mn, Cd, Cu) was examined in sandy loam field soil with treatment of different does of MCW compost (10t/ha, 20t/ha, 50t/ha, 75t/ha, 100t/ha) and control (sole native soil). A field experiment was designed randomly and conducted containing a total of 18 replicates with each treatment having three. Soil samples were collected at different depths of the soil profile - the surface layer, at 10 cm, 20 cm and 30 cm depths across all the treatments. Samples were collected very carefully to avoid mixing of soil samples of different layers. Samples were kept separately in air tight polythene bags that were carefully labelled and brought to laboratory for analyses.

Sample analysis: The soil samples were air dried for 24 hours, and each of the samples was digested with a mixture of HNO_3+ HCl (aqua regia) following the method of Shahmansouri et al. (2005) and Epelde et al. (2008). The concentrations (ppm) of all the metals (Cd, Cu, Pb, Mn, Zn) of all the soil samples of the aforementioned layers and surface soil were then determined using atomic absorption spectrophotometer (AAS) (GBC make-Model Avanta PM)).

Leaching of heavy metals in different layers: The mobility of the heavy metals into different soil sub-layers was assessed based on the metal concentrations present in each layer. The mobility of the heavy metals was calculated to determine relative translocation of metals in different layers across different treatments by using the formula-concentration of metal in receiving level divided by concentration of the same metal in the source level (Barman et al. 2000, Gupta et al. 2008, Nirmalkumar et al. 2009).

Statistical analysis: All the values were presented as the mean ± SD (standard deviation). Two-way ANOVA were used to analyse the significant differences between heavy metal concentrations of different layers (surface layer, 10 cm, 20 cm, 30 cm) across all the treatments and native soil.

RESULTS

Leaching of heavy metals into the soil across different treatments: Assessment of concentrations of the heavy metals (Pb, Zn, Mn, Cd, Cu) at the soil surface, 10, 20 and 30cm sub-layers across different treatments and sole native soil showed that the average concentrations of Pb and Mn were higher in surface layer, which subsequently decreased in 10, 20 and 30cm sub-layers across different treatments with Pb concentration of 23.1 ± 5.2 ppm and Mn of 27.7 ± 2.8 ppm at the 30 cm layer. In contrast, the average concentrations of Cu, Zn and Cd were found lower at surface layer which gradually increased in the subsequent sub-layers and reached higher at 30 cm layer, with Cu concentration of 55.0 ± 6.1ppm, followed by that of Cd of 50.3 ± 2.0 ppm and Zn of 50.2 ± 4.0 ppm.

Concentrations of Mn and Pb were significantly different from each other across the treatments and layers ($P < 0.01$) (Table 1). The range of concentrations of Mn was higher in soil surface layer (38.3 ± 3.9 ppm) with treatment of 100t/ha and gradually decreased in the subsequent sub-layers reaching lower at 30cm layer (31.5 ± 7.0 ppm). Its concentrations in other treatments i.e., 10, 25, 50 and 75 t/ha showed similar pattern reaching the low at 30cm layer. Similarly, in surface layer of native soil, it was higher (32.0 ± 3.7 ppm) and gradually decreased in subsequent sub-layers reaching low at 30 cm layer (23.7 ± 5.3 ppm). The concentration of Pb was higher in soil surface (32.4 ± 5.6 ppm) with treatment of 100t/ha, which gradually decreased in subsequent sub-layers and was low at 30cm layer (26.6 ± 7.3 ppm). Its concentrations also showed similar pattern with other treatments. It was higher in surface layer (21.6 ± 2.6 ppm) of native soil, which gradually decreased in subsequent sub-layers reaching low at 30 cm layer (13.5 ± 2.6 ppm). The concentration of both the metals at different layers across the treatments showed the ranking order of: surface layer > 10 cm > 20 cm > 30 cm (Fig. 1).

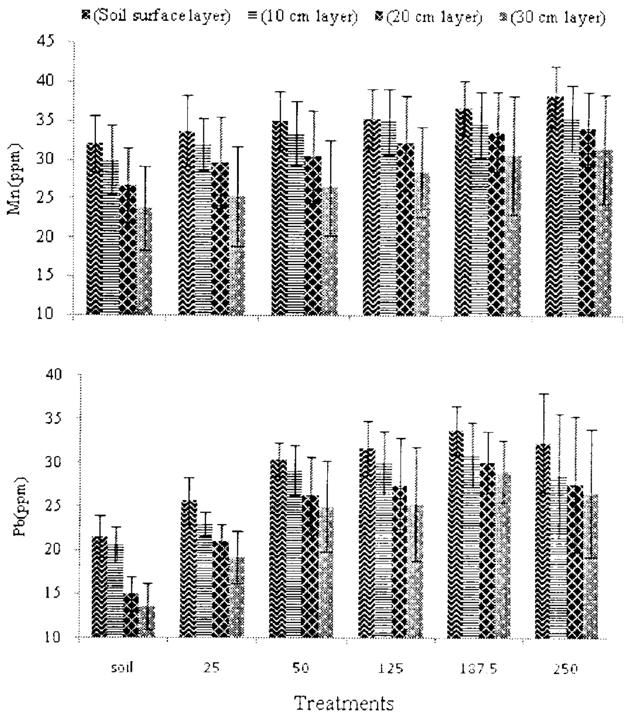

Fig. 1: Concentrations (ppm) of Mn, Pb in different sub-layers of soil treated with 10, 20, 50, 75 and 100 t/ha of municipal solid waste.

Table 1: Analyses of variance of heavy metal concentrations (ppm) present across different sub-layers of soil treated with10, 20, 50 75 and 100 t/ha of municipal solid waste.

Source of Variation	SS	df	MS	F
Mn				
Across treatments	188.7141	3	62.90471	132.9944**
Across soil layers	124.4275	5	24.88549	52.61341**
Error	7.094814	15	0.472988	
Total	320.2364	23		
Pb				
Across Treatments	130.4844	3	43.49479	50.75442**
Across soil layers	506.8383	5	101.3677	118.2867**
Error	12.85449	15	0.856966	
Total	650.1772	23		
Cu				
Across Treatments	192.5001	3	64.16671	69.55065**
Across soil layers	622.498	5	124.4996	134.9458**
Error	13.83885	15	0.92259	
Total	828.837	23		
Zn				
Across Treatments	187.237	3	62.41232	67.70515**
Across soil layers	254.0269	5	50.80537	55.11388**
Error	13.82738	15	0.921825	
Total	455.0912	23		
Cd				
Across Treatments	102.558	3	34.18599	18.67138**
Across soil layers	220.0539	5	44.01078	24.03739**
Error	27.46395	15	1.83093	
Total	350.0758	23		

Level of significance: **P < 0.01

Concentration of Cu, Cd and Zn were significantly different from each other across the treatments and layers (P< 0.01) (Table 1). Concentrations of Cu, Zn and Cd were lower in surface layer (55.5 ± 7.3, 47.3 ± 4.9 and 52.5 ± 4.2 ppm, respectively) and increased gradually in the subsequent sub-layers reached higher concentration at 30 cm layer (67.1 ± 13.0, 57.0 ± 5.4 and 54.5 ± 6.0 ppm, respectively) of treatment of 100t/ha. Their concentrations with other treatments showed similar pattern reaching higher at 30cm layer. The concentrations of Cu, Zn and Cd in surface layer of the native soil were lower (41.8 ± 3.9, 38.2 ± 3.8 and 39.5 ± 3.5 ppm, respectively) and increased gradually reaching higher concentrations at 30 cm layer (48.5 ± 3.4, 47.7 ± 5.9 and 48.7 ± 5.6 ppm, respectively). The ranking order of the concentration of the metals in different layers across the treatments was 30 cm > 20 cm > 10 cm > surface layer (Fig. 2).

Mobility of metals in different sub-layers across the treatments compared to native soil: The concentrations of these metals were higher in the treatment of 100t/ha and was least in the native soil (Fig. 1 & Fig. 2). The concentration of Mn was elevated by 1.1 to 1.2 folds in surface layer and 10 cm layer; 1.1 to 1.3 folds at 20 cm and 30 cm layers across the treatments compared to that of native soil. Concentration of Pb was elevated by 1.2 to 1.6 folds in surface layer; 1.1 to

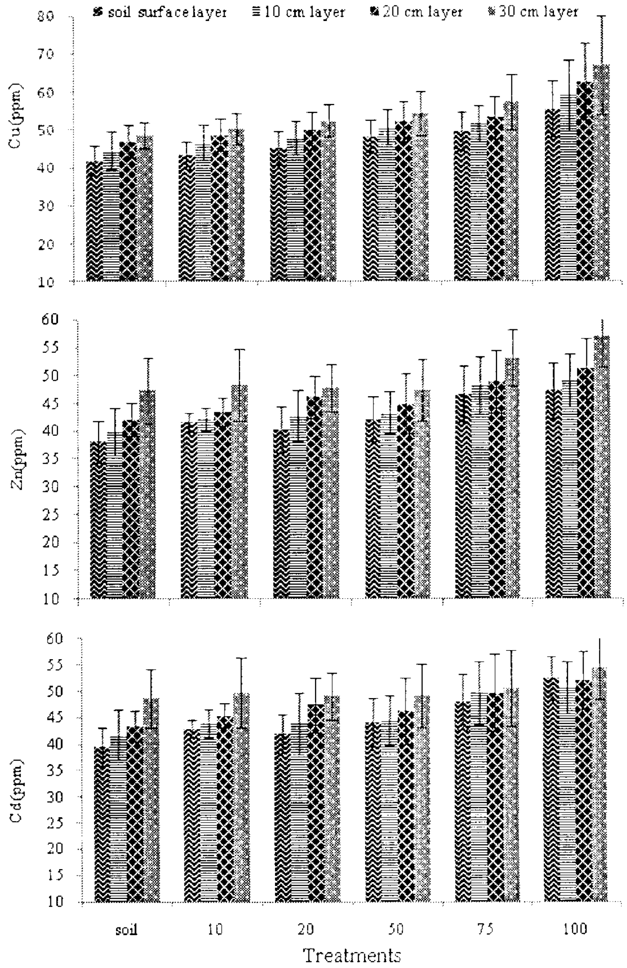

Fig. 2: Concentrations (ppm) of Cu, Zn and Cd in different sub-layers of soil treated with 10, 20, 50, 75 and 100 t/ha of municipal solid waste.

1.5 folds at depth of 10 cm; 1.4 to 2.1 folds at 20 and 30 cm layers across the treatments compared to the soil. Concentration of Cu was elevated by 1.0 to 1.3 folds in surface layer and the subsequent sub-layers across the treatments compared to the soil, and similarly, that of Zn was elevated by 1.0 to 1.2 folds in surface layer as well as other sub-layers across the treatments compared to the soil. The concentration of Cd was elevated by 1.0 to 1.3 folds in surface layer; 1.0 to 1.2 folds at 10 and 20 cm layer and 1.0 to 1.1 folds at 30 cm layer across the treatments compared to the soil.

Mobility of metals in different sub-layers of soil across the treatments: The concentration of Mn decreased by 1.4 to 1.1 fold in 10 cm, 20 cm and 30 cm sub-layers compared to that of surface layer. Concentration of Pb decreased by 1.6 to 1.0 fold in 10 cm, 20 cm and 30 cm sub-layers than that of surface layer. On the other hand, concentration of Cu, Cd and Zn increased by 1.0 to 1.2 fold in 10 cm, 20 cm and 30 cm sub-layers than that of surface layer. Leaching in

Table 2: Correlation matrix of different heavy metals in soil treated with 10, 20, 50 75 and 100 t/ha of municipal solid waste, across different sub-layers.

	Pb	Mn	Cu	Zn	Cd
Sole Soil					
Pb	1				
Mn	0.97062	1			
Cu	-0.95235	-0.98347	1		
Zn	-0.90907	-0.97419	0.929265	1	
Cd	-0.89248	-0.97074	0.93452	0.997467	1
10t/ha					
Pb	1				
Mn	0.95888	1			
Cu	-0.99613	-0.93095	1		
Zn	-0.88117	-0.97848	0.83859	1	
Cd	-0.91331	-0.99014	0.876636	0.997124	1
20t/ha					
Pb	1				
Mn	0.97251	1			
Cu	-0.96774	-0.97479	1		
Zn	-0.99492	-0.96229	0.979784	1	
Cd	-0.99937	-0.97063	0.973585	0.997859	1
50t/ha:					
Pb	1				
Mn	0.96921	1			
Cu	-0.98563	-0.93473	1		
Zn	-0.98695	-0.98964	0.974603	1	
Cd	-0.96151	-0.9988	0.931046	0.989099	1
75t/ha					
Pb	1				
Mn	0.93559	1			
Cu	-0.89875	-0.99446	1		
Zn	-0.85602	-0.98333	0.993283	1	
Cd	-0.98513	-0.95055	0.91267	0.887874	1
100t/ha					
Pb	1				
Mn	0.95468	1			
Cu	-0.91997	-0.99103	1		
Zn	-0.82928	-0.95782	0.971569	1	
Cd	-0.30407	-0.57233	0.648598	0.778329	1

soil was more in Cu which was followed by Cd and Zn, whereas Mn and Pb were concentrated more in surface layer. Pb and Mn are positively correlated with each other and negatively correlated with Cu, Zn, while Cd, Cu, Zn and Cd are positively correlated with each other across different treatments (Table 2).

DISCUSSION

The bulk concentration of Pb and Mn remained in the surface layer of soil, which decreased gradually to deeper sub-layers (Fig. 1) it is probably because of the fact that these elements remained relatively immobilized in the soil. It indicated that these two elements were less leachable even in sandy loam soils. Hence, Pb and Mn may move horizontally along with run-off and contaminate the receiving water bodies and subsequently the aquatic food-chain posing a moderate threat to the environment. The elevated concentration of Pb found in surface layer during the present study is in corroboration with the earlier findings (Fodor & Szabó 2004). On the other hand, the present results showed that Cu, Zn and Cd were in elevated concentrations in deeper sub-layers (30 cm depth) compared to the surface layer (Fig. 2), which showed clear signs of leaching. Hence, it was found that Cu, Zn and Cd were mobile in different sub-layers of soil. These results are also in conformation with the findings of earlier workers showing mobility of Cd and Cu in different layers of soil (Pattnaik et al. 2006, Behbahaninia et al. 2008). In contrast, Fodor & Szabó (2004) reported that Cu and Zn did not show any mobility and remained bonded in the tilled horizon. They stated that the rate of transformation and immobilization of toxic pollutants in soils varied according to elements, and a clear distinction can be made between elements that are mobile in soils (Cd, Zn, Cu) and those that transform rapidly into insoluble forms and become bonded (As, Hg, Cr).

The leachability of heavy metals was ascribed to increase under some types of composts in relation to pH change and possible increases in the formation of soluble metal complexes due to organic matter leaching from the compost (van Herwijnen et al. 2007). Kaschl et al. (2002) concluded that the majority of leached fractions were due to organo-metallic complexes, and were leached easily below the rooting zone; however, in heavier soils, leaching was conspicuously reduced; even under simulated storm events, groundwater was not at risk. This leaching process posed potential environmental and ecological effects on the weathering of coal mine spoils (Querol et al. 1992, Wang et al. 1994). It was reported that the increased soil acidification may have significant increase in the rate of leaching of various metals in soils (Tamm & Hallbicken 1986, Falkengren-Grerupy 1987). Heavy metals are known to bind to organic matter, although binding efficiencies differ amongst elements (Alloway 1990, Pattnaik et al. 2006). Nwachukwu & Pulford (2008) found that the order of strength of binding was higher in Pb than Cu and Zn implying that of the three elements Zn bound to the MSW compost could be most loosely bound and easily leached compared to other two metals. Bishop et al. (2006) demonstrated that conflicting organic wastes have different effects on the leachability of different elements, while van Herwijnen et al. (2007) concluded that general metal availability can be either increased or decreased by compost addition, depending on the type of amendment used.

CONCLUSION

It is concluded that metals showed both horizontal and vertical mobility. Mn and Pb accumulated in surface layers and had low vertical movement, while Cu, Cd and Zn moved down and accumulated in higher concentrations in deeper sub-layers of soil. The ranking order of leaching of the heavy metals in the soil is Cu > Cd > Zn > Mn > Pb, which showed some of these metals have a potency of leaching deeper and faster than other metals. Moreover, the pattern of leaching was found to be metal specific. The present study has revealed the fact that the different heavy metals leach at different rates across the soil layers and different treatments of MSW. These leached heavy metals can, sometimes, reach the groundwater or be easily assimilated by plants and incorporated into food web and thus, having a significant effect on environmental quality threatening human health.

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