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Determination of lead and cadmium concentration limits in agricultural soil and municipal solid waste compost through an approach of zero tolerance to food contamination

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Abstract Cadmium and lead are important environmental pollutants with high toxicity to animals and human. Soils, though have considerable metal immobilizing capability, can contaminate food chain via plants grown upon them when their built-up occurs to a large extent. Present experiment was carried out with the objective of quantifying the limits of Pb and Cd loading in soil for the purpose of preventing food chain contamination beyond background concentration levels. Two separate sets of pot experiment were carried out for these two heavy metals with graded levels of application doses of Pb at 0.4–150 mg/kg and Cd at 0.02–20 mg/kg to an acidic light textured alluvial soil. Spinach crop was grown for 50 days on these treated soils after a stabilization period of 2 months. Upper limit of background concentration levels (C_{ul}) of these metals were calculated through statistical approach from the heavy metals concentration values in leaves of spinach crop grown in farmers' fields. Lead and Cd concentration limits in soil were calculated by dividing C_{ul} with uptake response slope obtained from the pot experiment. Cumulative loading limits (concentration limits in soil minus contents in uncontaminated soil) for the experimental soil were estimated to be 170 kg Pb/ha and 0.8 kg Cd/ha. Based on certain assumptions on application rate and computed cumulative loading limit values, maximum permissible Pb and Cd concentration values in municipal solid waste (MSW) compost were proposed as 170 mg Pb/kg and 0.8 mg Cd/kg, respectively. In view of these limiting values, about 56% and 47% of the MSW compost samples from different cities are found to contain Pb and Cd in the safe range.

Keywords Cadmium · Lead · Cumulative loading limits · Soil · Municipal solid waste compost

Introduction

Indian cities generate municipal solid wastes (MSW) amounting to more than 45 million tonnes every year, of which only about 10% is used for producing composts. However, due to intervention of Honorable Supreme Court of India, serious attempt is being made by the different states for implementing Municipal Solid Wastes Management and Handling Rules 2000 and as a result, production of solid waste compost is expected to rise considerably in the near future. Beneficial use of MSW composts on agricultural land could be practiced without concern if they did not contain large amounts of potentially toxic substances.

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However, such composts produced in different cities of India contain heavy metals in a significant amount due to nonsegregation of wastes before composting (Saha et al. 2008), which are expected to increase heavy metal contents in the soil upon continuous use. In order to regulate the entry of heavy metals in the agricultural land of India, quality control criteria has been put forward through the Fertilizer Control Order 1985 (FAI 2007) in the form of maximum permissible heavy metal concentration in the city waste composts. Such maximum permissible metal concentration limiting values mentioned in the Fertilizer Control Order 1985 of India, however, were not based on any research conducted on Indian soils.

In the USA and European countries, entry of heavy metals, particularly through sewage sludge, is restricted by setting different limits, namely the concentrations of metal in the sludge itself, amount of metal that can be added every year, and the maximum concentrations of metals in soil that can be allowed to build up (McGrath et al. 1994). While the approach adopted in the US regulations relies on the "no observed adverse effect concentration", different countries in the European Union (EU) adopt more conservative approaches ranging from "lowest observed adverse effect concentration" approach (as in Germany) to "zero impact" philosophy of environment protection (as in The Netherlands and Sweden). The principle of not allowing heavy metal build-up beyond background soil concentration level (in case of "zero impact" policy) has some limitations in respect of its implementation. Availability of soil metal is related to processes of distribution (exchange and precipitation/distribution) between soil solid and solution phases and speciation within soil solution (Wolt 1994). As soils across the region vary widely in respect of constituents, chemical properties as well as total metal contents, determination of background metal concentrations in soil requires exhaustive analytical work. Very little work has been carried out in respect of heavy metal contents in soils of noncontaminated area across the regions of India.

Different approaches by various countries, thus, have led to wide variations in cumulative as well as annual metal loading limits and maximum metal concentrations in sewage sludge. For the determination of maximum permissible concentration in sewage sludge, limiting values related to maximum cumulative pollutant loading in soil along with certain assumptions in respect of annual rate of application have generally been used. In USA, Environmental Protection Agency (EPA) computed maximum cumulative metal loading limit based on an analysis of published information generated on 14 pathways of metal transfers. Consumption of vegetables, particularly leafy crop, grown on sludge-amended soils is one of the key pathways of human exposure to Cd (McBride 2003). They calculated reference cumulative soil application rate (or tolerable loading limit) for Cd based on daily reference intake and actual estimated dietary intake by human, uptake response slope of different crops. However, USEPA's final estimate of acceptable Cd loading has an undefined but presumably high degree of uncertainty due to uncertainties, errors, and biases in the estimates of crop uptake coefficients, vegetable consumption, and other variables. Estimation of loading limits based on the analysis of pathway risk assessment caused considerably higher values of loading limits as compared to EU countries (McBride 2003).

In India, however, very little information has been generated in respect of heavy metal concentration limits or cumulative loading limits (CLL) for agricultural soils. Such information is essential for taking policy decisions with respect to unavoidable additions of heavy metal pollutants in crop lands and thereby protecting the environment. This study has been conducted with the objective of determining CLL of Pb and Cd applied through MSW composts in agricultural soil and assessing the extent of risk associated due to the contents of these metals in MSW compost generated in India. Lead is a multitargeted toxicant, causing effects in the gastrointestinal tract, hematopoietic system, cardiovascular system, central and peripheral nervous systems, kidneys, immune system, and reproductive system (ATSDR 1993). Cadmium exposure for longer duration primarily affects the kidneys, resulting in tubular proteinosis as well as "itai-itai" disease involving the skeletal system (Goyer 1991). Even long-term exposure of the toxic heavy metal to lower levels has similar effects to the short-term exposure to high concentrations (Wang and Foulkes 1984). Hence, it is highly desirable that concentrations of these heavy metals in the edible part of the crops do not increase to a level higher than those normally observed in uncontaminated area. Therefore, in our approach of the study, Pb and Cd loadings can be allowed up to the level below which these heavy metals do not contaminate the food chain.

Methodology

A screen-house pot experiment was carried out on a representative light textured acidic soil using spinach crop. Spinach having high metal uptake capacity (Kloke et al. 1984) was chosen for the experiment because uptake response data using such crop are expected to estimate CLL at lower side and, thus, can be safe for all other crops.

Experimental materials

Soil Bulk amount of soil was collected from 0 to 20 cm depth of crop land of Salmara village of Coochbehar district of West Bengal (26°24′30″ N, 89°27′51″ E, and 51 m high from mean sea level). The soil of the area belongs to the Order Haplaquept and is formed by alluvial deposits. Sandy loam texture, acidic reaction, low contents of organic matter and iron oxides, and absence of carbonates are the important properties of the experimental soil (Table 1).

MSW compost Bulk amount of partially stable MSW compost was collected from Vijaywada city. The compost was prepared from biodegradable fraction of city waste which was separated at source during door-to-door collection from individual household. The characteristic of the compost is presented in Table 2. High specific oxygen uptake rate value of 3.8 mg O_2/g VS/h indicates that the compost was moderately stable.

Experimental treatments

Pot experiments were conducted (in separate batches for Cd and Pb) under screen-house condition. Lead and Cd were applied at graded levels of application doses, viz., 0.4 (Pb_1), 30 (Pb_2), 45 (Pb_3), 60 (Pb_4), 75 (Pb_5), 90 (Pb_6), 105 (Pb_7), 120 (Pb_8), 135 (Pb_9), and 150 (Pb_{10}) mg Pb/kg and 0.02 (Cd_1), 4 (Cd_2), 6 (Cd_3), 8 (Cd_4), 10 (Cd_5), 12 (Cd_6), 14 (Cd_7), 16 (Cd_8), 18 (Cd_9), and 20 (Cd_{10}) mg Cd/kg soil. All the treatments were replicated four times. Half of the heavy metal additions were provided through their inorganic (nitrate) salts directly to soil, and remaining amounts were added through heavy metal-enriched compost. The potassium nitrate salt was added in such an amount so as to equalize the

Table 1 Properties of experimental soil

Parameters	Value
pH	4.95
EC (dS m^{-1})	0.096
Organic C (%)	0.54
Oxides of Fe (% Fe)	0.46
Oxides of Al (% Al)	0.26
Sand (%)	53.0
Silt (%)	32.3
Clay (%)	14.7
Cation exchange capacity (cmol/kg)	9.5
Bulk density (g cm^{-3})	2.26
Cd (mg/kg)	0.2
Cr (mg/kg)	4.8
Cu (mg/kg)	29.4
Ni (mg/kg)	26.6
Pb (mg/kg)	10.9
Zn (mg/kg)	57.0

Table 2 Properties of MSW compost used in screen-house experiment

Parameters	Value
pH (1:5 in water)	6.72
EC (dS m^{-1})	3.42
Total organic C (%)	20.9
Total N (%)	1.66
Total P (%)	0.28
Total K (%)	0.42
Specific oxygen uptake rate (mg O_2/g VS/h)	3.8
Cd (mg/kg)	0.3
Cr (mg/kg)	7.03
Cu (mg/kg)	31.3
Ni (mg/kg)	9.8
Pb (mg/kg)	7.9
Zn (mg/kg)	92.8
Mn (mg/kg)	639
Fe (%)	0.64

nitrate added through $Pb(NO_3)_2$ or $Cd(NO_3)_2$ among all the treatments.

To prepare heavy metal-enriched composts, bulk quantity of the partially stable compost was spiked with Cd and Pb (separately) and incubated at room temperature under moist condition for 180 days. Metal-enriched composts were dried in shade and pulverized. Metal-enriched composts and untreated composts were mixed in ratios so as to obtain the desired treatment doses. The compost mixtures were applied to soil at 50 g/kg and mixed thoroughly. Thereafter, treated soils were incubated for 60 days under alternate wetting and drying conditions. Lead and Cd added through their inorganic salts were subjected to various chemical and biochemical reactions (complexation with organic matter and oxides, precipitation into some stable salts like carbonates and sulfides) in compost and soil during the period of incubation. Thus, it has been assumed that incubation with metal and compost for about 8 months resulted transformation into a product resembling contaminated soil.

Spinach crop was grown for 50 days in the pot containing 5-kg treated soils. At the end of growing period, leaves were harvested, washed thoroughly in deionized water, and dried in the oven at 70°C. Thoroughly pulverized leaf samples were digested in di-acid ($HClO_4/HNO_3$ at 10:1 ratio). The digested extracts were analyzed for Pb and Cd.

Analysis of Pb and Cd concentration in MSW compost samples produced in Indian cities

Thirty-six MSW compost samples were collected from 29 cities of 13 states of the country following the methods of USEPA part 503 rule (composite sample of several grab samples combined). The information on sources and types of wastes, their processing at various stages, and methods of composting were collected from the manufacturers and presented elsewhere (Saha et al. 2008).

Cadmium in the oven-dried compost and soil samples was extracted by wet digestion method described by Baker and Amacher (1982). For analysis of Pb, samples were digested with di-acid mixture as described by Burau (1982). Metals in the digested soil, compost, and plant extracts were determined using inductively coupled plasma–optical emission spectrophotometer.

Statistical analysis

The analysis of variance technique was carried out on each parameter in the pot experiment as applicable to completely randomized design (Gomez and Gomez 1984). To determine the significance of difference between means of two treatments, least significant difference was estimated at 5% probability level and Duncan's multiple range test was used for comparing the means. Skewness of frequency distribution curve for concentrations of Pb and Cd in spinach leaf samples was estimated following the procedures indicated by Gomez and Gomez (1984). Significance of difference of means for Pb and Cd contents in different groups of MSW compost samples was estimated through *t* test analysis following the procedure outlined by Panse and Sukhatme (1985).

Results and discussion

Status of Pb and Cd concentrations in leaf tissue of spinach grown in farmers' fields in the uncontaminated area

Results of analysis of spinach leaf samples collected from farmers' fields indicated that Pb and Cd content varied from 0.6 to 6.6 and from trace to 3.8 μg/g with mean values of 2.9 and 0.5 μg/g and standard deviation (σ) values of 1.39 and 0.74 μg/g, respectively. Lead and Cd in higher plants normally vary from 2 to 7 and 0.2 to 3.0 ppm, respectively, on dry weight basis. In Germany, mean concentrations of Cd and Pb in fruit, root, and tuber vegetables from noncontaminated regions varied from <1 to 1.7 and 5.3 to 28.7 μg/g, respectively, with the highest concentrations in spinach (Bergmann 1992). During statistical analysis of the data, slight positive skewness was observed in the frequency distribution curve for both the metals, which, however, were not significant at 5% (for Pb) and 10% (for Cd) probability level during "D'Agostino's *K*-squared test" for goodness of fit normality test. Gaussian distribution is generally observed when the population have not been subjected to biased interferences (like that in polluted area). Distribution of independent random errors of observation takes on a normal distribution as the number of observations becomes large (Gomez and Gomez 1984). In our study, plant samples were collected from about 500 km^2 area which belongs to a plain topography of a rural area with no industrial activity within 250 km. Hence, in the uncontaminated study area, Pb and Cd concentrations in soil and plant tissue are expected to follow a normal Gaussian distribution in the uncontaminated study area. Deriu et al. (2007) also observed concentrations of several heavy metals in barley plants to follow a Gaussian distribution.

Effect of Pb and Cd on aboveground biomass growth

In the screen-house experiment, variation in aboveground biomass growth with increasing doses of Pb (Fig. 1a) was not statistically significant. Though dry weight of leaves correlated negatively with Pb concentration in leaf tissue, the correlation coefficient value ($r = -0.413$) was also not statistically significant. Plants usually show ability to accumulate large amounts of Pb without visible changes in their appearance or yield (Wierzbicka 1995).

Application of increasing doses of Cd resulted progressive decrease in biomass growth (Fig. 1b). Higher doses of application (>18 mg Cd/kg) decreased the leaf dry weight considerably (~48%) compared to control indicating its toxicity on biomass growth. Dry weight of leaves correlated significantly and negatively ($r = -0.68$, significant at 5% probability level) with Cd concentration in leaf tissue.

Effect on metal concentrations in plant tissue

Concentration of Pb in leaf tissue increased with application of Pb up to its highest dose. The highest application dose (150 mg/kg) resulted about 4.5 times increase in tissue Pb concentration compared to control. Wierzbicka (1995) reported that in many plants, Pb accumulation can exceed hundred times the threshold of maximum level permissible for human. Tissue Pb concentration as well as Pb uptake correlated significantly ($r = 0.917$, significant at 0.1% probability level and 0.817, significant at 1% probability level) with Pb concentration in treated soils (soil Pb).

Tissue Cd concentration increased with increasing doses of Cd application up to 16 mg/kg, which, however, decreased sharply (42%) at the highest application rate of 20 mg/kg. Uptake of Cd (micrograms per pot) by spinach leaf biomass also followed the similar trend. This indicates

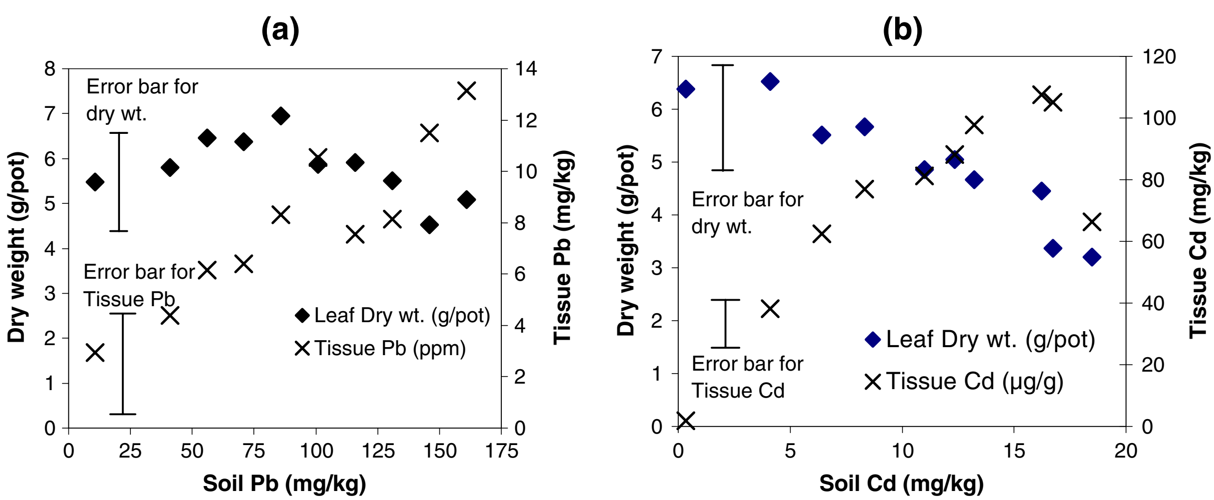

Fig. 1 Effect Pb and Cd concentrations in soil on their concentrations in spinach leaf tissue as well as on dry weight of aboveground biomass

that Cd at very high doses might have caused root injury and thereby preventing its uptake as well as growth of plant. From an experiment under controlled condition, Coughtrey and Martin (1978) concluded that plant roots are damaged first and most severely in cases of heavy metal excesses. Cadmium, when not detoxified rapidly enough, may trigger, via the disturbance of the redox control of the cell, a sequence of reactions leading to growth inhibition, stimulation of secondary metabolism, lignification, and finally cell death (Schützendübel and Polle 2002). Tissue Cd concentration as well as uptake correlated significantly ($r = 0.972$ and 0.900, respectively, significant at 0.1% probability level) with Cd concentration in treated soils (soil Cd) up to Cd_8 treatment.

Transfer coefficient

Transfer coefficient was calculated as the ratio of the concentration of metal in a plant to the total concentration of metal in soil. A higher transfer coefficient indicates a greater mobility of metal from soil into plant. Transfer coefficient for Pb in uncontaminated soil (Pb_1) was about 2.5 to 4.4 times higher compared to Pb in treated soil which ranged from 0.06 to 0.11. The coefficient value (0.27) for uncontaminated soil was considerably higher than the generally observed value (0.01–0.1) reported by Bergmann (1992). In contrast, transfer coefficient for Cd in treated soils (except Cd_{10} treatment) was 1.1 to 1.7 times higher compared to control, which indicates that applied Cd was either equally or more available to plant in comparison to native form. The high mobility of this metal is attributable to the fact that Cd^{+2} is adsorbed rather weakly on organic matter, silicate clays, and oxides unless the pH is higher than 6 (Ross 1994). The coefficient value decreased by about 36% at the highest Cd application dose (20 mg/kg) from level obtained for control soil. Very low values of transfer coefficient for Pb indicate (Fig. 2) that soil–plant barrier for its translocation is very high as compared to Cd. Higher "relative mobility" (exchangeable content/total content) of Cd compared to Pb in soil (Simon 1978) might be the reason for the observed higher transfer coefficient of the former

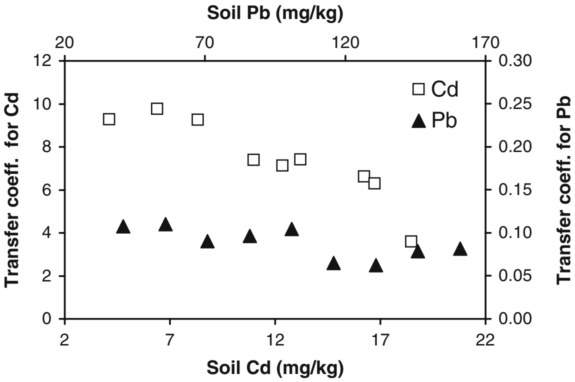

Fig. 2 Effect of soil Pb and Cd levels on their transfer coefficients for spinach

metal. Thus, cadmium, having lower affinity for metal-sorbing soil constituents compared to Pb, has greater potential for transmission to food chain in levels that pose risk to consumers.

Approach for determination of cumulative loading limit of Pb and Cd in soil

CLL for the study area was calculated by subtracting metal concentration in uncontaminated soil from maximum allowable metal concentration in the soil. Maximum allowable metal concentration is defined, in this study, as the total metal concentration in the soil corresponding to the upper limit of background metal concentration range in the spinach leaf tissue (C_{ul}) established through this screen-house experiment. The upper limit of background metal concentration was calculated as:

$$C_{ul} = \bar{x} + 3 \times \sigma$$

where $\bar{x}$ is the mean value of metal concentration in spinach leaf in control treatment (Pb_1 or Cd_1) of screen-house experiment and σ is standard deviation of the metal concentrations in spinach leaf from farmers' fields. As data on heavy metal concentration in the leaf tissue follow a normal distribution around its mean value, probability of a heavy metal-contaminated leaf tissue with a value $\geq C_{ul}$ belonging to a population of uncontaminated leaf sample is less than 1% (Feller 1971). Upper limits of background concentration (C_{ul}) for Pb and Cd in spinach leaf for uncontaminated area in this study were calculated using the above equation as 7.11 and 2.52. Mean Pb concentration in spinach from noncontaminated area of Germany was about four times more than that obtained in case of spinach from the present noncontaminated study area (Bergmann 1992).

Results from the pot experiment were subjected to statistical regression (linear) analysis using "curve fit" microprocessor-based program (Kolb 1986). Best fit linear equations passing through origin (Fig. 3) between plant tissue metal concentration (y-axis) and soil metal concentration (x-axis) were:

$$\text{Tissue Pb} = 0.084 \times \text{Soil Pb}\ (r = 0.905^{***})$$

$$\text{Tissue Cd} = 7.524 \times \text{Soil Cd}\ (r = 0.976^{***}).$$

The data points corresponding to Cd_9 and Cd_{10} were excluded from the regression analysis as these decreased the correlation coefficient (r) value considerably. Slopes (UR) of these regression lines (termed as uptake response slope) were used for computing maximum allowable concentration of metals in soil using following equation:

$$\text{Maximum allowable metal concentration in soil} = C_{\text{ul}}/\text{UR}.$$

Maximum concentrations of metals in the experimental soil that might not contaminate spinach leaves were calculated using the above equation as 85.7 mg Pb/kg and 0.55 mg Cd/kg. Cumulative loading limit of Pb and Cd for the study area was calculated by subtracting metal concentrations in uncontaminated soil from the above values as 73.73 mg Pb/kg soil and 0.33 mg Cd/kg soil, respectively, which are equivalent to about 170 kg Pb/ha and 0.8 kg Cd/ha, respectively.

Status of Pb and Cd content in MSW composts produced in Indian cities

Information on heavy metal contents, considered important quality control parameter for MSW compost, is essential for protecting the soil and water resource from pollution due to its repeated application in agricultural land. Contents of Pb and Cd (Table 3) ranged between 10.8 and 646.7 mg/kg for Pb and trace and 8.4 mg/kg for Cd, and the corresponding mean values were 133.5 mg Pb/kg and 0.99 mg Cd/kg. Average contents of these heavy metals in MSW composts of Indian cities were considerably lower compared to the contents found in the samples from USA and European countries (He et al. 1992), possibly due to less industrialization of former compared to later countries. Mean values of Pb and Cd contents in composts from bigger cities (more than one million population) were higher by about 122% and 222%, respectively, as compared to those in case of smaller cities (less than one million population). Congregation of industries near by bigger cities and contamination of the wastes emanating from these might be a reason for higher

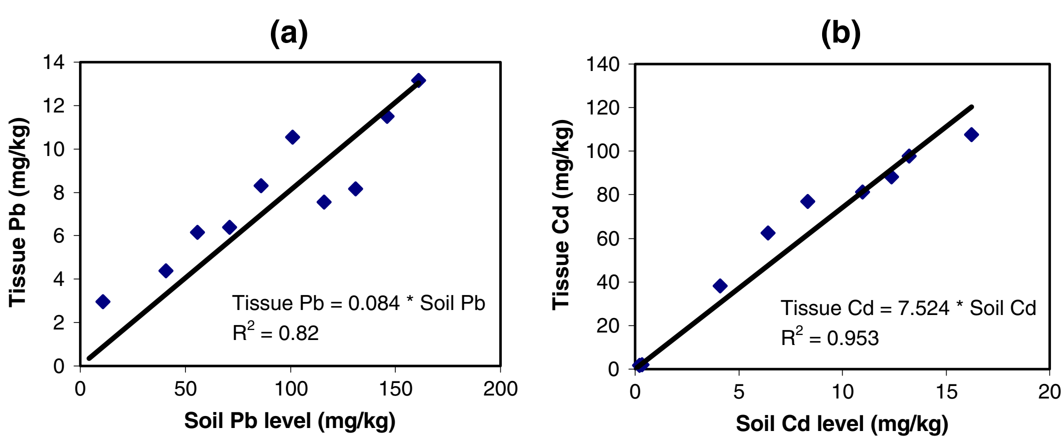

Fig. 3 Relationship between heavy metal concentration in soil and spinach leaf tissue

Table 3 Contents of Pb and Cd in MSW composts as influenced by city size and segregation of wastes prior composting

	Lead (μg/g)		Cadmium (μg/g)	
	Range	Mean	Range	Mean
Effect of city size				
Small (<1 million population)	10.8–345	118.8b	Trace–1.6	0.85b
Big (>1 million population)	39.1–646.7	248.0a	Trace–8.4	2.4a
Effect of segregation				
Nonsegregated	51.6–646.7	249.3a	0.3–8.4	2.2a
Partially segregated	69.5–241.8	166.8ab	0.1–3.9	0.9b
Segregated	10.8–83.2	39.8b	Trace–2.5	0.9b
Overall	10.8–646.7	172.0	Trace–8.4	1.5

Column means for a group followed by the same letter are not significantly different among themselves at 0.05 probability level

metal content in the MSW composts as compared to those from smaller cities. Mean values of Pb and Cd in the composts prepared from segregated wastes were significantly less by 84% and 59%, respectively, as compared to those prepared from nonsegregated wastes. Partial segregation of wastes before composting also reduced Pb and Cd contents in the MSW compost by 33% and 59%, respectively. Municipal solid wastes contain about 40–50% inert materials including toxic metal containing glass, metals, dusts, etc. In about half of the locations, composts are prepared from nonsegregated wastes where possibility of solubilization, absorption, and precipitation of metals on to fine particles exists. Although mechanical sieving after composting process removes all the coarse inert materials, metal-rich finer particles find their way into final product.

Discussion

The USEPA, based on their own risk assessment, estimated that 20 mg/kg of Cd in the top soil represents no significant health risk to highly exposed individuals from dietary ingestion of Cd-contaminated food crops (McBride 2003). As our estimation of limiting value is based on the principle of not allowing food chain to be contaminated due to compost application, "maximum allowable metal concentration" value was computed to be quite low and the value was found nearer to limits set by Denmark, Finland, and Sweden for sewage sludge receiving soils. In Sweden, soil management policy (including land application of sewage sludge) of "no accumulation of possibly hazardous elements in soil" led to very low level of "maximum allowable metal concentration" values. Long-term application of sewage sludge was found to enhance levels of metal adsorbent materials (hydrous oxides of Fe, Mn, Al, etc.) in soil which lowered the Cd uptake response by Swiss chard compared to unamended soil (Mahler et al. 1987; Mahler and Ryan 1988a, b). As composts prepared from city solid wastes contain less metal adsorbent materials like oxides/hydrous oxides of metals (Chaney et al. 2001), heavy metal toxicity is expected to appear earlier in soils receiving MSW compost than the soil receiving sewage sludge. This may be one of the reasons for lower values of maximum allowable Cd concentration value obtained for the experimental soil.

Due to variability in parent materials as well as climatic conditions, wide range of soil types is found in India, and hence, wide variability in their heavy metal immobilizing capacity is expected owing to differences in their constituents and properties. As the experimental soil is acidic in nature and contains lower levels of clay, organic matter, and oxides of Fe, its metal immobilizing capability is expected to be low (McBride 1994; Islam et al. 2007). Hence, the regulatory limiting values, viz., maximum concentration limit and cumulative loading limit for agricultural soil as well as maximum permissible concentrations of Pb and Cd in MSW compost determined for such a sensitive situation (i.e., growing crops with high uptake capacity on low metal fixing capacity of soils), can protect the food crops from their contamination in almost all other agroecological situations in India.

On the basis of computed CLL values, maximum permissible Pb and Cd concentrations in the compost were computed as 170 mg Pb/kg and 0.8 mg Cd/kg, respectively, assuming cumulative allowable MSW compost application rate in crop land as 1,000 Mg/ha during the 100 years of recycling program. The Fertilizer Control Order (1985) of Government of India has set these values for city waste compost as 100 mg Pb/kg and 5 mg Cd/kg, although the basis of establishing these limiting values could not be traced. Thus, our computed maximum permissible limiting value was quite stringent in case of Cd, but was somewhat relaxing in case of Pb. Different member countries of European community as well as USA have set limits with respect to maximum permitted concentrations in sewage sludge-treated agricultural soils (McGrath et al. 1994), which varied from 0.5 to 20 mg/kg for Cd and from 40 to 300 mg/kg for Pb.

Considering the above maximum permissible concentration values, about 56% and 47% of the MSW compost samples collected from different cities contained Pb and Cd in the safe range. While all of the nine MSW compost samples prepared from segregated wastes contained Pb within safe limit, about 44% samples prepared from partially segregated wastes and 37% samples prepared from nonsegregated wastes contained the metal within the permissible limit. About 66%, 78%, and 19% of the composts prepared from segregated, partially segregated, and nonsegregated municipal solid wastes contained Cd within the computed maximum permissible concentrations of 0.8 mg/kg. Bigger cities generated fewer composts (36% for both metals) than smaller cities (77% for Pb and 55% for Cd) containing these heavy metals within safe range.

Conclusion

Knowledge about cumulative loading limit of metals is very important keeping in view of increase in unavoidable entry of metals into soil as a result of rise in anthropogenic activities. The Government of India is in the process of revising its existing regulatory limits related to metal contents in organic fertilizers due to pressures from different stakeholder groups. This study has generated information on maximum permissible loading limits for two important metals Pb and Cd which can prevent contamination of food chain in almost all the situations of soil and crop conditions of the country. Hence, these limiting values can be considered as the basis for formulating different regulatory laws and orders for the purpose of restricting the activities related to metal entry into soil, like limits related to maximum permissible concentrations in fertilizers, manures, and amendment materials, environmental impact assessment prior to initiating industrial activities, giving permission for setting up special economic zone, etc.

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