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Organic and Inorganic Amendments Affect Soil Concentration and Accumulation of Cadmium and Lead in Wheat in Calcareous Alkaline Soils

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Irrigation with untreated effluent in periurban agriculture could result in accumulation and bioconcentrations of cadmium (Cd) and lead (Pb). Different amendments were used to investigate their effect on availability, concentration, and uptake of metals by wheat in texturally different soils. Crop was irrigated with water containing Cd and Pb at 20 mg L^{-1}, thereby adding 260 mg pot^{-1} of each metal. Amendments included calcium carbonate at 6 or 12%, gypsum at 50 or 100% of the soil gypsum requirement, farm manure at 7.50 or 15.00 g kg^{-1} soil, and a control. Amendments decreased ammonium bicarbonate diethylenetriaminepentaacetic acid (AB-DTPA)–extractable Cd and Pb concentrations and uptake by wheat. Dry matter, concentration, uptake, and extractability of Cd and Pb were greater in sandy loam soil compared with those in sandy clay loam soil irrespective of amendments. Sequential extraction showed that more metals were extracted from the control in all fractions and that predominantly metals were found in the carbonate fraction.

Keywords Amendments, cadmium, calcareous alkaline soils, lead, wheat

Introduction

A major environmental concern stemming from the unplanned establishment of industrial units and unscientific disposal of municipal effluent generated by human activities is the contamination of soil and water with salts, metals, organics, and pathogens in developing countries such as Pakistan. In soil, solubility of heavy metals could be predicted by their geochemical forms, which may alter their phytoavailability (Xian 1987). Several studies have been conducted to assess phytoavailability of heavy metals in contaminated soils using metal sequential extraction methods (Xian 1987, 1989; Adriano 2001; Meers et al. 2007).

Heavy metals persist in soils mainly because of their undegradable nature, that is, their long half-life (Lasat 2002; Chen, Lee, and Liu 2000). Cadmium (Cd) is of special concern because of its toxicity hazard to plants, animals, and humans (Kirkham 2006). Cadmium is more soluble and mobile than other heavy metals in soils (McBride 1994), whereas lead (Pb) is relatively immobile and thus less available to plants. Lead is a common

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pollutant in the urban and periurban environments owing to the use of leaded mineral in Pakistan. It is a nonessential element for plants and becomes toxic or even lethal to living organisms when absorbed in small quantities (Walker et al. 2006). Lead could adversely affect seed germination (Wierzbicka and Obidzinska 1998), induct leaf chlorosis, inhibit root and shoot growth, and decrease photosynthesis (Poskuta et al. 1988).

A major source of Cd and Pb contamination in urban and periurban soils of Pakistan is generally untreated effluent discharged from different industries, which are used for irrigation. Farmers around cities irrigate their soils with untreated raw effluent because of its high nutrient contents and assured supply in periurban areas. This untreated raw effluent used for irrigation is of hazardous quality because of high electrical conductivity, high sodium adsorption ratio, and contents of organics, microbes, and several heavy metals. Continuous irrigation with untreated city effluent could result in the accumulation of heavy metals along with soil salinity and/or sodicity problems (Hussain 2000).

Soils contaminated with heavy metals require special soil-management techniques to limit the solubility and thus plant availability of heavy metals. The remediation techniques of heavy metal–contaminated soils include physical remediation, chemical remediation, phytoremediation, and agroecological engineering techniques (Chen et al. 1999; Chen, Lee and Liu 2000). Chemical remediation could stabilize heavy metals in soils, and this is extensively used.

For chemical remediation, metal-immobilizing amendments are used to decrease their solubility, leaching, and bioavailability through various processes including adsorption onto mineral surfaces, formation of stable complexes with organic legends, surface precipitation, and ion exchange (Kumpiene, Lagerkvist, and Maurice 2008).

The extensively used immobilizing agents include Ca salts such as gypsum, dolomite, and phosphates and incorporation of some nontoxic organic materials into polluted soils to decrease solubility of heavy metals in soils through precipitation, adsorption, or complexation (Mench et al. 1994; Chen and Lee 1997; Hussain 2000). Application of calcium carbonate–containing amendment significantly decreased the solubility of heavy metals in contaminated soils (Liu et al. 1998; Isoyama and Wada 2007) and increased soil pH, and all these combined to decrease the metal uptake by rice, wheat, and cabbage (Chen, Lee, and Liu 2000). Many reports indicated that sulfur-containing amendments and organic-waste application to contaminated soils lowered the concentration of soluble Cd and Pb in soils (Kaplan et al. 2005).

It is commonly believed that, when all the other factors are similar, soils high in clay contents tend to retain greater amounts of trace elements than coarse-textured soils because clays have a unique feature for trapping metallic pollutants from the environment owing to their high specific surface area associated with their small particle size and presence in soils. Most of the studies (Bose et al. 2008; Ping et al. 2008) focused on the aspects of mobility of heavy metals in response to inorganic and organic amendments but very little information is available regarding the effectiveness of these amendments in texturally different soils. The objective of this study is to compare the availability of Cd and Pb and their speciation in different textured contaminated soils in response to application of organic and inorganic amendments and uptake of Cd and Pb by wheat.

Materials and Methods

General

Two soils having sandy loam (coarse loamy, mixed, hyperthermic Typic Calci-argids) and sandy clay loam (fine, mixed, hyperthermic Typic Calci-argids) textures were collected, air dried, ground through a 2-mm sieve, and stored in plastic bags. These soils were analyzed (Table 1) for pH using a Jenco pH meter 6718 (Taipei Hsien), electrical conductivity using a conductivity meter (HI 8033, Hanna Instruments, Woonsocket), particle-size distribution by the hydrometer method (Bouyoucos 1962), organic carbon by the Walkley–Black wet combustion method (Nelson and Sommers 1982), cation exchange capacity (CEC) by ammonium acetate extraction (Rhoades 1982), lime by the calcimeter method (Moodie, Smith, and McCreery 1959), and gypsum requirement by the method described by Schoonover (1952). The ammonium bicarbonate diethylenetriaminepenta-acetic acid (AB-DTPA)–extractable Cd and Pb were determined following the procedure of Soltanpour (1985). The wheat crop was irrigated with canal water [electrical conductivity (EC) 0.27 dS m^{-1}; sodium adsorption ratio (SAR) 0.68; RSC (residual sodium carbonate) nil; Pb 0.08 mg L^{-1}; and Cd 0.01 mg L^{-1}] into which 20 mg L^{-1} Cd as cadmium nitrate and Pb as lead nitrate salts were dissolved regardless of their concentration in canal water. A total amount of 260 mg pot^{-1} Cd and Pb salts were added through 13 L irrigation water to raise the wheat crop.

Pot Experiments

Seven chemical treatments (Table 2) were applied to evaluate the Cd and Pb concentrations in soils and accumulation in wheat. Pots lined with polyethylene bags were filled with 12 kg of soil. Prior to filling pots, soils were treated with (1) farm manure from cattle, 7.5 g kg^{-1} (FM-1) and 15 g kg^{-1} (FM-2); (2) gypsum, 50% soil gypsum requirement (GYP-1) and 100% soil gypsum requirement (GYP-2); (3) calcium carbonate, 6% (CC-1) and 12% (CC-2); and (4) unamended control (Ct). Each treatment was performed in triplicate. Gypsum was added at soil gypsum requirement to counter the effect of sodium on plant growth. Wheat (*Triticum aestivum* L.) cv. Inqlab-91 was sown on 20 December 2002, and fertilizers [125 mg nitrogen (N; urea), 54 mg potassium (K; potassium sulfate), 53 mg phosphorus (P; diammonium phosphate)] were added to each pot. Plants were harvested by cutting the plant shoots 1 cm above the soil surface and threshed manually to separate grains and straw. Roots were also extracted from pots. Plant samples were washed with 1% hydrochloric acid (HCl) followed by distilled water. The harvested plant material was oven dried at 65 ± 5 °C to constant weight and ground to pass through a 40-mm sieve. Ground plant material (0.5 g) was digested with 10 mL 1:3 nitric (HNO_3)–perchloric acids ($HClO_4$) mixture to near dryness or colorless residues. The digestion solutions were filtered through Whatman No. 42 filter paper and diluted to 50 mL. Concentrations of Cd and Pb in digests were determined with a Hitachi polarized Zeeman Z-8200 atomic absorption spectrophotometer (Hitachi, Japan). Postexperiment soil samples were drawn with a sampling tube from top to bottom of the pot, thus ensuring representative samples.

Extraction of Cadmium and Lead in Soils

The ammonium bicarbonate (AB)–diethylenetriaminepentaacetic acid (DTPA) extracting solution was prepared by dissolving 79.06 g ammonium bicarbonate (NH_4HCO_3) and 1.97 g of DTPA in a liter volume of solution. Soil (10 g) was placed in a 250-mL Erlenmeyer flask with 20 mL of freshly prepared extracting solution and shaken on a reciprocating shaker at 180 cycles per minute with the flasks uncovered (Soltanpour 1985). The concentrations of Cd and Pb in these filtrates were determined by atomic absorption spectrophotometry (Hitachi polarized Zeeman Z-8200 atomic absorption spectrophotometer; Hitachi, Japan).

Table 1

Soil properties and concentrations of Cd and Pb in both salt-affected soils for pot experiments

Soil	pH	EC_e (dS m^{-1})	SAR	$CaCO_3$ (%)	OM (%)	Sand (%)	Silt (%)	Clay (%)	CEC	SGR	AB-DTPA extractable soil (mg kg^{-1})	
											Cd	Pb
SL	8.25	6.20	29.3	2.07	1.40	66.6	16.0	17.4	4.10	3.44	0.18	1.50
SCL	8.15	5.82	26.8	5.40	1.05	52.7	26.3	21.0	3.90	2.58	0.16	1.00

Notes. SL, sandy loam; SCL, sandy clay loam; CEC, cation exchange capacity [cmol(+) kg^{-1}] dry soils; SGR, soil gypsum requirement (g kg^{-1} soil); SAR, sodium adsorption ratio; OM, organic matter; AB-DTPA, ammonium bicarbonate diethylenetriaminepetaacetate.

Table 2
Chemical properties of amendments

Amendment	Metal	Unit	Value
Farm manure	Cd	mg kg^{-1}	0.10
	Pb	mg kg^{-1}	0.22
Gypsum	Cd	mg kg^{-1}	0.07
	Pb	mg kg^{-1}	0.19
Lime	Cd	mg kg^{-1}	0.09
	Pb	mg kg^{-1}	0.10
Urea	Cd	mg kg^{-1}	0.03
	Pb	mg kg^{-1}	0.19
DAP	Cd	mg kg^{-1}	0.07
	Pb	mg kg^{-1}	0.21
SOP	Cd	mg kg^{-1}	0.14
	Pb	mg kg^{-1}	0.20

Notes. SOP, sulfate of potash; DAP, diammonium phosphate.

Speciation of Cadmium and Lead in Soils

Sequential extraction of Cd and Pb in contaminated soils treated with different amendments was followed (Tessier, Campbell, and Bisson 1979) to determine (i) exchangeable, (ii) carbonate, (iii) occluded Fe or Mn oxide, and (iv) oxidizable (bound to organic matter) metal fractions. Concentrations of Cd and Pb in these sequential fractions were determined using atomic absorption spectrophotometry (Hitachi polarized Zeeman Z-8200; Hitachi, Japan).

Statistical Analysis

The variance and significant differences between concentrations of Cd or Pb in different chemically treated soils were analyzed by analysis of variance (ANOVA) and Duncan's Multiple Range test (DMR) test using M STAT C version 1.10 package (MSTAT, East Lansing, Mich.) (Russel and Eisensmith 1983).

Results and Discussion

Properties and Concentration of Cadmium and Lead in Soils

Both soils differed in pH_s, electrical conductivity (EC_e), sodium absorption ratio (SAR), calcium carbonate ($CaCO_3$), organic matter, and texture. The pH_s was 8.25 for sandy loam soil and 8.15 for sandy clay loam soil. The organic matter in sandy loam and sandy clay loam soil 1.40 and 1.05%, respectively. The cation exchange capacity (CEC) of sandy loam soil was 4.10 cmol(+) kg^{-1} and that of sandy clay loam soil was 3.90 cmol(+) kg^{-1}. Concentrations of AB-DTPA-extractable Cd and Pb in sandy loam soil were 0.18 and 1.50 mg kg^{-1}, whereas in sandy clay loam soil they were 0.16, and 1.00 mg kg^{-1}, respectively.

Wheat Dry-Matter Yield and Cadmium and Lead Concentrations in Grains

There were significant ($P < 0.05$) main and interactive effects of amendments and soils on wheat dry-matter production. Maximum dry-matter yield from sandy loam soil was recorded with FM-1, followed by FM-2, CC-1, GYP-1, CC-2, GYP-2, and Ct. Maximum increase (33%) in wheat dry-matter production compared with that of control was recorded with FM-1 while wheat dry-matter production decreased with GYP-2. However, in sandy clay loam soil, amendments increased wheat dry-matter yield compared with that of control irrespective of amendment application rate. Maximum wheat dry-matter was obtained with FM-2 followed by G-50, FM-1, GYP-2, CC-1, CC-2, and Ct (Table 3). Maximum increase (45%) in wheat dry matter compared with control was observed with FM-1, whereas it was the least with CC-2. It is worth noting that FM-1 affected maximum increase in wheat dry matter compared with that of control in both the soils. Soils differed significantly with respect to wheat dry-matter production, with sandy loam soil producing more wheat dry matter compared with that of sandy clay loam soil.

There were significant ($P < 0.05$) main and interactive effects of amendments and soils on Cd concentration in wheat grains. Wheat grains accumulated the most Cd (8.50 mg kg^{-1}) with Ct, whereas the least Cd (3.33 mg kg^{-1}) was accumulated with CC-2. Overall, Cd accumulation by wheat grains followed in decreasing order as GYP-1, FM-1,

Table 3
Effect of amendments on dry-matter yield (g pot^{-1}) and Cd and Pb concentrations (mg kg^{-1}) in grains of wheat

	Dry-matter yield		Cd		Pb	
Treatment	SL	SCL	SL	SCL	SL	SCL
Ct	52.67cd	32.63f	8.50a	7.33a	13.00	14.17
FM-1	70.01a	47.30c–e	8.33a	7.00a	11.60	6.17
	(33)	(45)	(−2)	(−4.5)	(−11)	(−56)
FM-2	69.35a	52.20cd	6.67a	6.17ab	7.33	4.17
	(32)	(60)	(−22)	(−16)	(−44)	(−71)
GYP-1	58.57bc	48.96c–e	8.83a	7.17a	11.17	5.00
	(11)	(50)	(4)	(−2)	(14)	(65)
GYP-2	52.65cd	45.82de	5.83ab	6.33ab	7.50	7.83
	(0)	(40)	(−31)	(−14)	(−42)	(−45)
CC-1	65.37a	39.24ef	7.33a	5.67ab	7.33	12.00
	(24)	(20)	(−14)	(−23)	(−44)	(−15)
CC-2	57.26bc	33.90f	3.33b	1.33c	5.17	4.67
	(9)	(4)	(−61)	(−82)	(−60)	(−67)
Mean	60.84A	42.87B	6.97A	5.86B	9.01	7.71

Notes. Data are expressed as mean value of triplicates. Difference letters in a column indicate significant differences between treatments at $P = 5\%$. Ct, canal water; FM-1, farm manure at 7.5 g kg^{-1}; FM-2, farm manure at 15 g kg^{-1}; GYP-1, gypsum at 50% soil gypsum requirement; GYP-2, gypsum at 100% soil gypsum requirement; CC-1, lime at 6%; CC-2, lime at 12%; SL, sandy loam; SCL, sandy clay loam. Values in parentheses indicate percentage increase (+) or decrease (−) over control.

Lower case letters indicate significance of interactions between soils and treatments, while upper case letters indicate significance of main effects of the soils.

CC-1, FM-2, GYP-2, and CC-2. For sandy clay loam soil, maximum Cd concentration (7.33 mg kg^{-1}) in wheat grain was recorded with Ct, whereas the minimum (1.33 mg kg^{-1}) was with CC-2. Amendments decreased Cd concentration in wheat grains compared with that of Ct irrespective of soil type. Irrespective of treatments, wheat grain accumulated more Cd from sandy loam soil than from sandy clay loam soil.

Treatments and soils nonsignificantly affected Pb concentration in wheat grains. The concentration of Pb in wheat grains from sandy loam soil was maximum (13 mg kg^{-1}) with Ct, followed by FM-1, GYP-2, CC-1, FM-2, GYP-1, and CC-2 (Table 3). Treatments decreased Pb concentration in wheat grains, with the decrease being greatest (60%) with CC-2 and least (11%) with FM-1 compared with that of control. For sandy clay loam soil, maximum Pb concentration (14.17 mg kg^{-1}) in grain was observed with Ct followed by CC-1, GYP-2, FM-1, GYP-1, CC-2, and FM-2. The maximum decrease in Pb concentration was recorded with CC-2, whereas it was minimum with CC-1.

The increase in dry-matter yield with the application of farm manure could be attributed to the complexing properties of organic matter, which might have increased the availability of micronutrients from sparingly soluble respective hydroxides (Stevenson 1991; Nardi et al. 2002). Application of greater rates of gypsum and lime decreased wheat dry-matter yield for sandy loam and sandy clay loam soils, which might be due to the antagonistic effect of Ca and P on the absorption of several metal ions, including Cd and Pb (Kabata-Pendias 2004).

The Cd and Pb concentrations decreased in wheat grains with the addition of farm manure and lime, which might have immobilized the Cd and Pb through adsorption, complexation, and precipitation phenomena, resulting in reduced phytotoxicity and accumulation in plants (Cao et al. 2003; Geebelen et al. 2002; Seaman et al. 2003). According to Bolan et al. (2003), Ca^{2+} addition as gypsum and lime inhibited the translocation of Cd and Pb from root to shoot as these metals are accumulated primarily on cell walls of roots with only limited amounts translocated to shoot and grains (Xiong 1997).

Extraction of Cadmium and Lead after Wheat Crop

There were significant ($P < 0.05$) main and interactive effects of amendments and soils on extractability of Cd and Pb in postwheat soil. The extractable Cd was greatest (46.17 mg kg^{-1}) with Ct and least (27.80 mg kg^{-1}) with CC-2 in sandy loam soils. Amendments significantly decreased extractable Cd in postwheat soil, with the decrease being greatest (40%) and least (15%) with CC-2 and GYP-1, respectively. In sandy clay loam soils, amendments significantly decreased extractable Cd. The pattern of decrease was almost the same as observed in sandy loam soil. The extractable Cd was more in sandy loam soils compared with that of sandy clay loam soil irrespective of amendments. The Pb concentration in postharvest sandy loam soil was the greatest for the control (Ct) treatment followed by CC-1, GYP-1, GYP-2, FM-1, CC-2, and FM-2. The maximum extractable Pb (330.8 mg kg^{-1}) was recorded with Ct, whereas the minimum (196.5 mg kg^{-1}) was recorded with FM-2 in sandy loam soil. Similar to Cd, application of amendments significantly decreased Pb in postwheat soil compared with that of Ct, the decrease being greatest (41%) and least (15%) with FM-2 and CC-1, respectively. In sandy clay loam soil, maximum extractable Pb was observed for Ct, which decreased with the application of amendments (Table 4). After wheat harvest, sandy loam soil attained greater concentrations of Cd and Pb than sandy clay loam, which might be due to less adsorption and fixation of Cd and Pb in coarse-textured soils (Singh et al. 2003). The decrease in Cd and Pb concentration in postharvest soils with the addition of farm manure might be due to its

Table 4
Effect of amendments on the extractability of AB-DTPA Cd and Pb in postwheat soils

	Cd		Pb	
Treatment	SL	SCL	SL	SCL
Ct	46.17a	41.17ab	330.8a	236.08a
FM-1	35.47ad	36.80ad	231.0ab	188.7b
	(−23)	(−11)	(−30)	(−20)
FM-2	35.53ad	29.33cd	196.5b	182.8b
	(−23)	(−29)	(−41)	(−23)
GYP-1	39.47ac	29.07c	260.8ab	213.7b
	(−15)	(−29)	(−21)	(−9)
GYP-2	32.27bd	29.13cd	244.2ab	197.0b
	(−30)	(−29)	(−26)	(−17)
CC-1	36.33ad	33.53bd	281.6ab	212.3b
	(−21)	(−19)	(−15)	(−10)
CC-2	27.80d	26.07d	230.6ab	202.3b
	(−40)	(−37)	(−30)	(−14)
Mean	36.15A	32.16B	253.6A	204.7B

Notes. Data are expressed as mean value of triplicates. Difference letters in a column indicate significant differences between treatments at $P = 5\%$. Ct, canal water; FM-1, farm manure at 7.5 g kg^{-1}; FM-2, farm manure at 15 g kg^{-1}; GYP-1, gypsum at 50% soil gypsum requirement; GYP-2, gypsum at 100% soil gypsum requirement; CC-1, lime at 6%; CC-2, lime at 12%; SL, sandy loam; SCL, sandy clay loam; AB-DTPA, ammonium bicarbonate diethylenetriaminepetaacetate. Values in parentheses indicate percentage increase (+) or decrease (−) over control.

Lower case letters indicate significance of interactions between soils and treatments, while upper case letters indicate significance of main effects of the soils.

high CEC and complexing ability (Karaca 2004). Adsorption of Cd and Pb by soil components increased with an increase of organic-matter application because of the presence of ligands or functional groups that can chelate these metal ions and also alter the adsorption characteristics of soil inorganic phase (Christensen 1984; Erikson 1998; Harter and Naidu 1995; Adriano et al. 2004). However, precipitation appears to be the predominant process of Cd and Pb immobilization in an alkaline calcareous soils in the presence of anions such as sulfate and carbonates, especially when their concentration is high (Adriano 2001).

Total Uptake of Cadmium and Lead by Wheat

The application of farm manure caused a nonsignificant increase in Cd and Pb uptake. Generally at greater levels of gypsum and lime, the uptake of Cd and Pb decreased table 5 open (Table 5). However, uptake of Cd and Pb by wheat was more from sandy loam soil compared to sandy clay loam soil. A slight increase in uptake with farm manure could be attributed to high biomass, owing to additional availability of plant food nutrients from sparingly soluble hydroxides as well as from its own decomposition. Further, it seems that farm manure complexed the added metals, which affected slow availability over longer time, and this indirectly also promoted plant growth (Stevenson 1991; Nardi et al. 2002).

Table 5
Total uptake of Cd and Pb (g/pot) by plant (roots plus shoots) in sandy loam and sandy clay loam soils treated with different amendments

	Cd		Pb	
Treatment	SL	SCL	SL	SCL
Ct	0.82ab	0.43c–e	0.81a–c	0.41b–e
FM-1	0.83ab	0.53cd	0.98a	0.39b–e
FM-2	0.81ab	0.47c–e	0.85ab	0.41b–e
GYP-1	0.85a	0.58b–d	0.53a–e	0.32c–e
GYP-2	0.65a–c	0.46c–e	0.38b–e	0.24de
CC-1	0.65a–c	0.34de	0.67a–d	0.36b–e
CC-2	0.48c–e	0.23e	0.31c–e	0.13e
Mean	0.72A	0.43B	0.64A	0.33B

Notes. Data are expressed as mean value of triplicates. Difference letters in a column indicate significant differences between treatments at $P = 5\%$. Ct, canal water; FM-1, farm manure at 7.5 g kg^{-1}; FM-2, farm manure at 15 g kg^{-1}; GYP-1, gypsum at 50% soil gypsum requirement; GYP-2, gypsum at 100% soil gypsum requirement; CC-1, lime at 6%; CC-2, lime at 12%; SL, sandy loam; SCL, sandy clay loam.

Lower case letters indicate significance of interactions between soils and treatments, while upper case letters indicate significance of main effects of the soils.

More from sandy loam than that from sandy clay loam soil might be due to greater availability of nutrients in coarse-texture soils. A decrease in uptake of metal ion (Cd and Pb) with the addition of gypsum and lime application might be due to the antagonistic effect of Ca and P on the absorption of metal Cd and Pb ions (Kabata-Pendias 2004). Moreover, precipitation of Cd and Pb in alkaline calcareous soils could take place, especially in the presence of sulfate and carbonates ions, when their concentration is high (Adriano 2001). This precipitation of Cd and Pb might also have decreased their absorption and uptake, consequently improving plant growth, particularly with greater application rate of gypsum and lime.

Sequential Extractions of Cadmium and Lead

The concentrations of Pb and Cd were the greatest in the carbonate fraction (Table 6). Application of farm manure at a greater rate increased the concentration of Cd and Pb in both the soils, whereas the pattern was the opposite with gypsum and 12% lime treatments applied. Overall, there were more AB-DTPA metals in sandy clay loam soil than in sandy loam soil. Our soil was calcareous and had a high buffering capacity, which helped to retain more metals (Moller et al. 2005; Kabata-Pendias 2004). Application of farm manure at 15 g kg^{-1} in both sandy loam and sandy clay loam soils increased Cd and Pb concentrations in all the fractions. In both the soils, greater application rates of lime and gypsum decreased Cd and Pb concentrations in all the soils fractions because of increased inorganic complexation or an antagonistic effect from Ca added through lime and gypsum, which may suppress Cd and Pb uptake by competing for exchange sites (Kabata-Pendias and Pendias 2001; Bolan et al. 2003).

Table 6
Effect of amendments on speciation of cadmium and lead in postwheat soils

	Exchangeable		Carbonate bound		Fe/Mn oxide		Organic bound	
Treatment	SL	SCL	SL	SCL	SL	SCL	SL	SCL
Lead fractions								
Ct	1.25ab	1.33a	21.42	36.50	28.68a	38.85a	8.17ac	10.66a
FM-1	0.42ab	0.83ab	15.58	27.83	18.92a	26.17a	11.76bc	13.75ac
FM-2	0.50ab	0.92ab	20.33	32.33	24.45a	32.42a	12.42ac	17.43ab
GYP-1	0.92ab	1.27a	21.17	34.42	23.83a	37.58a	11.17ac	11.84ac
GYP-2	0.25b	1.0ab	19.67	25.92	14.70b	27.83a	8.33bc	8.18bc
CC-1	0.67ab	0.75ab	27.42	37.58	21.75a	36.50a	8.33bc	13.29ab
CC-2	0.25b	0.67ab	30.50	38.33	17.25a	15.00b	5.00c	7.97bc
Cadmium fractions								
Ct	5.33ac	8.33a	5.93ac	5.66ac	3.25ac	4.58a	1.33ab	1.25ab
FM-1	3.25bd	4.67ad	3.67bd	5.42ac	2.51ac	2.33ac	0.83bc	1.42ab
FM-2	4.08ad	5.75ac	3.58cd	5.08ac	2.83ac	3.17ac	1.17ac	1.33a
GYP-1	5.33ac	7.42ab	3.75bd	5.92ac	2.33ac	3.50ab	0.83bc	0.83ab
GYP-2	5.08ac	6.67ab	1.83d	5.17ac	1.75ac	3.41ab	0.42c	0.95ab
CC-1	4.00ad	6.50ab	6.17ac	6.58ab	1.92ac	3.25ac	0.67bc	0.92bb
CC-2	1.083d	1.167cd	7.85a	7.33a	0.41c	1.33bc	0.42c	1.08ab

Notes. Data are expressed as mean value of triplicates. Difference letters in a column indicate significant differences between treatments at $P = 5\%$. Ct, canal water; FM-1, farm manure at 7.5 g kg^{-1}; FM-2, farm manure at 15 g kg^{-1}; GYP-1, gypsum at 50% soil gypsum requirement; GYP-2, gypsum at 100% soil gypsum requirement; CC-1, lime at 6%; CC-2, lime at 12%; SL, sandy loam; SCL, sandy clay loam.

Summary

Application of organic and inorganic amendments decreased the AB-DTPA-extractable Cd and Pb from both the sandy loam and sandy clay loam soils. The decreased concentrations of Cd and Pb were more pronounced in sandy clay loam than sandy loam soil. The decrease in AB-DTPA-extractable Cd with amendments in the postharvest soil followed the decreasing order of farm manure gypsum > lime, whereas for Pb the order was gypsum > lime > farm manure. Lime treatment proved more effective in decreasing the total uptake of Cd and Pb. Farm manure application at 30 g kg^{-1} in both sandy loam and sandy clay loam soils increased Cd and Pb concentration process in all the fractions. Greater application rates of lime and gypsum decreased Cd and Pb concentrations in all the soil fractions. The concentrations of Cd and Pb were the greatest in the carbonate fraction.

Conclusions

Amendments decreased Pb and Cd concentrations and uptake by wheat irrespective of soil type. However, the extent of decrease was greater in sandy clay loam soil than sandy loam soil. It could be inferred from the results that application of amendments could mitigate the threat of food chain contamination by decreasing metal concentration and uptake by wheat. Mitigating effect of amendments is more prominent in sandy clay loam soil than in sandy loam soil. Keeping in view the importance of amendments in decreasing metal entry into the food chain, verification of the results from field studies is warranted.

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