ORIGINAL ARTICLE

ISSN (Print): 2517-9675
ISSN (Online): 2518-2625

TRANSFORMATION AND ADSORPTION OF LEAD AS AFFECTED BY ORGANIC MATTER AND INCUBATION TIME IN DIFFERENT TEXTURED SALT-AFFECTED SOILS

Muhammad Mazhar Iqbal[1,2*] • Hafeez-ur-Rehman[1,3] • Ghulam Murtaza[1] • Tayyaba Naz[1] • Wasim Javed[1] • Shahzada Munawar Mehdi[2,4] • Shahid Javed[5] • Aftab Ahmad Sheikh[4]

AUTHOR'S AFFILIATION

[1]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan
[2]Soil and Water Testing Laboratory, Chiniot, Department of Agriculture, Government of Punjab, Pakistan.
[3]Soil and Water Testing Laboratory, Gujranwala, Department of Agriculture, Government of Punjab, Pakistan.
[4]Rapid Soil Fertility Survey and Soil Testing Institute, Lahore, Punjab, Pakistan.
[5]Provincial Reference Fertilizer Testing Laboratory, Raiwind, Lahore, Punjab, Pakistan.
*Corresponding author's e-mail: mazhar1621@gmail.com

Key words:

Farm manure, Pb dynamics, residence time, texture, Pb-contaminated soils

ABSTRACT

Background Heavy metals added to soils are slowly transferred and repartitioned among the different solid-phase components of the soil. Organic matter decomposition might affect Pb dynamics from available forms to relatively unavailable or stable fraction in soil. Very little research has been conducted to study the effect of organic matter and residence time on soil Pb release kinetics in different textured salt-affected Pb-contaminated soils.
Methodology In a laboratory study, farm manure (FM) was evaluated for its effect on Pb adsorption in salt-affected sandy loam and sandy clay loam textured soils. The differently textured both soils were contaminated with Pb at 100 mg kg^{-1} soil using $Pb(NO_3)_2$ salt and equilibrated for 60 days at about field capacity. The treatments comprised of three levels of FM (0, 2 and 4% of soil) on air-dry weight basis were applied to investigate the Pb transformations. The Pb-contaminated soils were incubated at field capacity and soil samples were taken at 2, 3 and 4 weeks of aging period to evaluate the Pb transformations. After each incubation time, ammonium bicarbonate di-ethylene-tri-amine-penta-acetic acid (AB-DTPA) extractable Pb was analyzed. Results showed that the plant available content of Pb in soil and remaining content will be considered to be adsorbed.
Results It was observed that in both the soils, decomposition of added FM decreased organic matter (OM) along with extractable Pb after each incubation interval. The AB-DTPA extractable Pb was recorded lower in sandy clay loam as compared to sandy loam textured soil. The minimum AB-DTPA extractable Pb was recorded with the addition of FM at 4% in both the soils.
Conclusion It is concluded that higher rates of applied FM led to increase OM in both the tested soils than the initial or lower rates of FM application. Moreover, the decomposition of added FM decreased OM along with ABDTPA extractable Pb, after each incubation time.

INTRODUCTION

Lead (Pb) is one of the lethal heavy metals that are entering normal and salt-affected soils predominantly via anthropogenic endeavours. These include industrial activities such as mining and smelting processes, urban activities such as use of Pb in gasoline, paints and other materials as well as agricultural activities like application of leaded-pesticides and use of raw sewage for irrigation (Sharma and Dubey 2005; Pourrut et al. 2011).

Pakistan is facing severe shortage of irrigation water during the recent years and thus farmers option to use raw city effluent. Farmers consider it a good source of nutrients, a substitute of good quality irrigation water throughout the year (Ghafoor et al. 2001; Murtaza et al. 2012a) However, use of raw city effluent has some environmental implications owing to high concentration of Pb and other heavy metals. Since industrial effluent loaded with heavy metals is discharged into sewage system from where it is carried to the farmer's fields for irrigation. Continuous use of untreated city effluent could lead to build up of Pb and other metals in normal and salt affected soils (Iqbal et al. 2015).

Lead retention in soils is commonly attributed to

Cite As: Iqbal MM, H Rehman, G Murtaza, T Naz, W Javed, SM Mehdi, S Javed, AA Sheikh (2016) Transformation and adsorption of lead as affected by organic matter and incubation time in different textured salt-affected soils. *J. Environ. Agric.*, 1(2): 140–146.

the ion exchange or specific sorption on silicates, metal oxide-hydroxides and organic matter (Sauve et al. 2000). Decreasing plant uptake of Pb from soils can enable permissible level in crops (Iqbal et al. 2015). It can be decreased by its sorption or precipitation from the soil solution. In this regard, the two most important factors to decrease Pb phyto-availability form soil is the use of organic matter (OM) (Jahiruddin et al. 1985) and increasing residence time (Mclaughlin 2001).

Organic matter addition into soils could affect redistribution of heavy metals from soluble and exchangeable forms to fractions associated with OM or carbonates and the residual fraction (Narwal and Singh 1998). The effect of OM on heavy metal fractionation in soils depends on its degree of humification and soil pH. For example, at high pH the formation of soluble organo-metallic complexes can increase metal solubility. However, in calcareous soils this effect is inhibited (Jahiruddin et al. 1985). Formation of metal-organic complexes affects the behaviour of metals in two opposing ways, complexation by insoluble organic matter (high molecular weight humic acids) decreases bioavailability, whereas the formation of soluble organic complexes (organic acids, siderophores) could enhance bioavailability (Abbaspour et al. 2007).

Furthermore, the rate and magnitude of metal sorption by soils is negatively affected by salinity due to (1) increased competition for the limited number of sorption sites, (2) decreased activity of aqueous trace metal species, and (3) ion pair formation with artificial saline water anions (Phillips et al. 2004). Trace elements concentration could increase in plants due to increase in soil salinity (Iqbal et al. 2016). Accumulation of Pb increased owing to applied NaCl salinity in maize shoots (Izzo et al. 1991) and rice (Iqbal et al. 2015). Soils have a natural ability to attenuate the metals phytoavailability and movement of reactions (Tug and Duman 2010; Murtaza et al. 2012b). When trace elements in high concentration are present, the attenuation capacities of soils become insufficient and it is necessary to combat the situation (Ayuso and Sanchez 2003; Iqbal et al. 2016). It is assumed in general opinion that all other factors being similar, soils high in clay content tend to retain higher amount of trace elements than that of coarse textured soils.

The present study was designed with the objectives: 1) to evaluate the effect of farm manure on adsorption and availability of Pb in texturally different salt-affected soils, 2) to assess the availability of Pb to plants as affected by its residence time in soil.

MATERIALS AND METHODS

The present study was conducted in the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad to evaluate the effect of FM and incubation time on the Pb adsorption and transformations. The present study was performed in two different textured (sandy clay loam and sandy loam) salt-affected soils that were collected from Faisalabad metropolitan. Soils of both the textures were air dried, passed through 2 mm sieve and mixed well separately. The both soils were analyzed for basic physicochemical properties such as texture, pH_s, EC_e, CEC (US Salinity Lab Staff 1954), organic carbon (Jackson 1962), total Pb (Amacher 1996) and AB-DTPA extractable Pb (Soltanpour 1985). The physico-chemical properties of soils used for this study are presented in Table 1. The soils were contaminated with Pb at 100 mg kg^{-1} using salt $Pb(NO_3)_2$ and equilibrated for 60 days at about field capacity. Farm manure was added in both soils (0, 2 and 4% of soil on air dry weight basis.

Table 1 Physico-chemical properties soils used for present study

Characteristic	Value	
Textural class	SL	SCL
Sand (%)	69.2	63.3
Silt (%)	14.1	15.0
Clay (%)	16.7	21.7
pH_s	7.94	7.81
EC_e (dS m^{-1})	7.21	7.23
TSS ($mmol_c$ L^{-1})	85.12	85.35
CO_3^{2-} ($mmol_c$ L^{-1})	Absent	0.40
HCO_3^- ($mmol_c$ L^{-1})	7.5	7.8
Cl^- ($mmol_c$ L^{-1})	18.75	21.0
*SO_4^{2-} ($mmol_c$ L^{-1})	58.87	56.15
Ca^{2+} + Mg^{2+} ($mmol_c$ L^{-1})	14.0	13.0
Na^+ ($mmol_c$ L^{-1})	65.22	70.65
K^+ ($mmol_c$ L^{-1})	1.79	0.51
SAR (mmol L^{-1})$^{1/2}$	24.65	27.71
** Ca^{2+} + Mg^{2+} ($cmol_c$ kg^{-1})	3.67	4.49
Na^+ ($cmol_c$ kg^{-1})	1.16	1.67
K^+ ($cmol_c$ kg^{-1})	0.60	0.36
CEC ($cmol_c$ kg^{-1})	5.43	6.52
Organic matter (%)	0.91	0.86
Saturation percentage	28.40	29.43
AB-DTPA extractable Pb (mg kg^{-1})	1.85	1.59
Total Pb (mg kg^{-1})	9.45	5.68

*By difference = TSS - (CO_3^{2-} + HCO_3^- + Cl^-); ** By difference, CEC - Exch. (Na^+ + K^+); SL: Sandy loam; SCL: Sandy clay loam

The organic carbon and AB-DTPA extractable Pb was determined before and at the termination of specific time intervals (i.e. 2, 3 and 4 weeks) in laboratory incubation study. This showed the plant available contents of Pb in soil and remaining contents will be considered to be adsorbed in texturally different salt-affected soils.

The data collected regarding both soils were analyzed statically by using analysis of variance technique (ANOVA) and least significant difference (LSD) test was applied to differentiate the treatment differences (Steel et al. 1997) using M-STATC Version 1.10 software package while graphs were plotted in Microsoft Excel.

RESULTS AND DISCUSSION

Effect of farm manure and incubation time on organic matter

Statistical analysis showed that the interactive effects of farm manure × incubation time were significant ($p \leq 0.05$) for OM contents. Higher rates of FM application increased OM in both the soils, contents being significantly ($p \leq 0.05$) higher over unamended control treatment. In control of both the soils after the incubation period, there was no significant difference in OM contents after each incubation time. Application of FM @ 2% in both the soils had no significant ($p \leq 0.05$) effect on OM content after 2 and 3 weeks of incubation but it further decreased after 4 weeks. For both the soils receiving FM @ 4%, decreased OM content after 3 and 4 weeks of incubation time over 2 weeks of incubation time. Overall, there was a gradual decrease in OM of both the soils with incubation time (Table 2).

In control of both soils, very little change in OM might be attributed to low contents of less easily degradable organic-C which remained unchanged during the incubation period. The applied FM had high concentration of easily degradable organic-C which led to growth of microbial population in soils (Bernal et al. 1998) to help and expedite the decomposition of added organic matter (McGrath 1994). There was a decrease in OM after each incubation time solely owing to the decomposing activity of microbes. Clemente et al. (2006) reported that in cow manure and compost amended calcareous soil, there was a decrease in total organic carbon over its original level after 14, 28 and 56 days of incubation. Clemente and Bernal (2006) also found that after 2, 8 or 28 weeks of incubation, there was an increase in mineralization of added organic-C in calcareous and acid soils. Nogales and Benitez (2007) concluded that at the end of 32 weeks of incubation period, there was a general decrease in organic-C in olive-derived organic cakes amended calcareous and acid soils.

Effect of farm manure on AB-DTPA extractable Pb during incubation

Farm manure, incubation time, soil texture and their interactions significantly ($p \leq 0.05$) affected the AB-DTPA extractable Pb. Minimum AB-DTPA extractable Pb was recorded after 3 weeks in sandy loam soil amended with 4% FM or after 4 weeks with 2 and 4% FM application. While, in case of sandy clay loam soil, minimum AB-DTPA extractable Pb was recorded after all incubation times when amended with FM @ 2 and 4%. Maximum AB-DTPA extractable Pb was recorded after 3 weeks incubation in control of sandy loam soil. While in sandy clay loam soil, maximum AB-DTPA extractable Pb concentration was recorded for the control after 2 and 3 weeks of incubation. In control of sandy loam soil, there was no significant ($p \leq 0.05$) difference in AB-DTPA extractable Pb for each incubation time. But in control of sandy clay loam soil, there was a decrease in AB-DTPA extractable Pb after 4 weeks of incubation compared to that of 2 and 3 weeks. Application of 2% FM in sandy loam soil had similar effect on AB-DTPA extractable Pb after 2 and 3 weeks of incubation. But after 4 weeks, it decreased. While in sandy clay loam soil, application of FM at 2 and 4% had similar effect regarding the AB-DTPA extractable Pb after each incubation time. Application of FM @ 4% in sandy loam soil decreased the AB-DTPA extractable Pb after 3 and 4 weeks of incubation compared to that after 2 weeks. In sandy clay loam soil, application of FM @ 4% decreased the AB-DTPA extractable Pb for each incubation time. Overall, sandy clay loam texture decreased the AB-DTPA extractable Pb compared to that in the sandy loam soil.

The decrease in AB-DTPA extractable Pb with FM @ 2 and 4% in both the soils might be due to the fact that FM contained a high proportion of humified organic matter which formed stable complexes with Pb (Shuman 1999; Strawn and Sparks 2000). The immobilizing effect of organic matter on Pb could also be due to adsorption or precipitation with native P as insoluble salts such as lead phosphate (Walker et al. 2003). A decrease in AB-DTPA extractable Pb in sandy clay loam soil over the sandy loam soil might be due to its higher clay contents which retained higher amount of Pb because clays have a unique feature for trapping Pb from the environment owing to high specific area associated with their small particle size and ubiquitous occurrence in soils (Msaky and Calvet 1990). Clays can adsorb Pb via ion exchange reactions and by formation of inner sphere complexes at the clay particle edges (Francois et al. 2004). In the present study, there was a decrease in AB-DTPA extractable Pb at each incubation time which might be ascribed to the reactions between metal ions and soils during incubation time. A term that is used to indicate the increased retention of metals including Pb with aging time is fixation. Fixation of metals takes place through the slow diffusion of metals into Fe-oxides (Brumer et al. 1998), hydrous oxides of Al and Mn (Trivedi and Axe 2000), clay minerals (Ma and Uren 1998) and by diffusion or precipitation with carbonates (Nakhone and Young 1993). In calcareous soils, presence of carbonate is supposed to be a major factor in the time dependent sorption of Pb. What means by loss. Sorption/ leaching?

Clemente et al. (2006) reported that after 14, 28 and 56 days of incubation, there was a decrease in soluble and exchangeable fraction of Pb in manure and compost amended soils over that of the control. Shuman (1998) found that commercial compost, spent mushroom compost and cotton gin litter decreased exchangeable fraction of Pb in Pb contaminated soils over control. Brown et al. (2003) reported that in metal contaminated soil, 10% of each compost, pellet and ashed biosolids application decreased the exchangeable fraction of Pb compared to control

Table 2 Effect of farm manure and incubation time on organic matter in texturally different salt-affected soils (SAS)

Incubation time (weeks)	Farm manure (%)	Soil texture		Time mean	Time × manure mean
		Sandy loam	Sandy clay loam		
2	Pb-contaminated SAS control	0.89	0.86	1.53 a	0.878 e
	2 % FM	1.58	1.63		1.608 b
	4 % FM	1.99	2.11		2.090 a
3	Pb-contaminated SAS control	0.90	0.79	1.32 b	0.848 e
	2 % FM	1.59	1.57		1.582 bc
	4 % FM	1.49	1.56		1.528 c
4	Pb-contaminated SAS control	0.90	0.50	1.10 c	0.518 e
	2 % FM	1.23	1.19		1.210 d
	4 % FM	1.56	1.59		1.578 bc
Soil texture mean		1.308	1.323		

Values followed by similar letter(s) are not statically different at $p \leq 0.05$.
LSD: incubation time = 0.03703, manure = 0.03703, texture = ns, time × manure = 0.06413, time × texture = 0.05237, manure × texture = 0.05237, incubation time × manure × texture = non-significant.

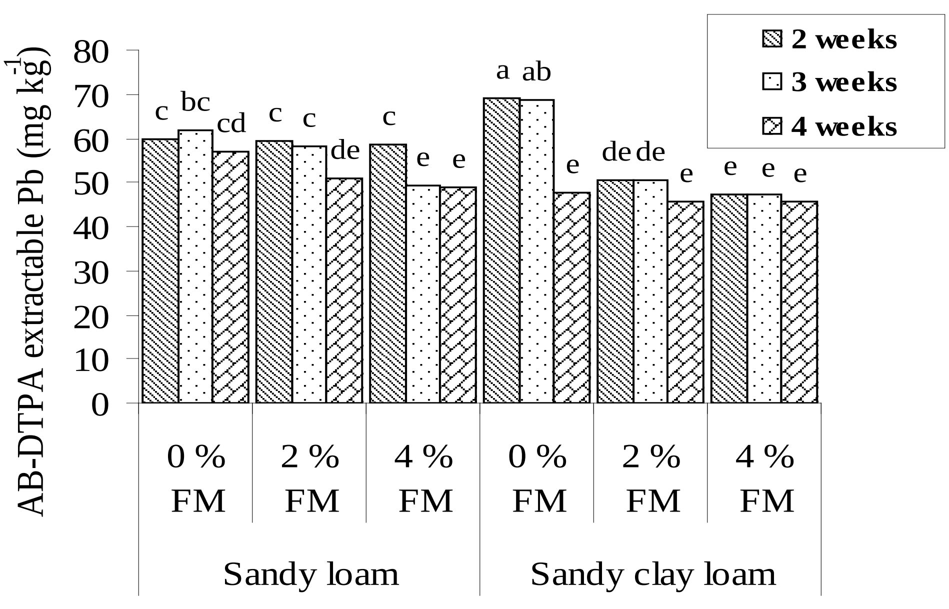

Figure 1 Effect of farm manure and incubation time on AB-DTPA extractable Pb in texturally different salt-affected soils. (LSD: manure = 2.765, incubation time = 2.765, texture = 2.257, manure × incubation time = 4.788, manure × texture = 3.910, manure × time × texture = 6.772, incubation time × texture = non-significant)

treatment. Nogales and Benitez (2007) found that in Pb and Zn contaminated calcareous soil, olive derived organic cakes increased significantly the DTPA extractable Pb after 0, 2 and 4 weeks and then decreased after 8, 16 and 32 weeks of incubation. Ruttens et al. (2006) reported that in compost, compost + cyclonic ashes and compost + cyclonic ashes + steel shots amended soil samples, there was a decrease in exchangeable fraction of Pb after 13 weeks of incubation over control and there was no change in this fraction up to 47 weeks. Lu et al. (2005) found that soil having high clay content decreased more the exchangeable fraction of Pb compared to that in coarse textured soil when both the soils had similar concentration of total Pb. The results of Silviera and Sommers (1977) showed that the H_2O soluble and exchangeable fraction of Pb decreased in soil sludge mixtures when incubated for 7 to 28 days. Muhlbachova (2002) reported that in metal contaminated soil, DTPA extractable increased after one day and reached its maximum value at 2nd day of incubation but DTPA-extractable Pb continuously decreased after 4, 6 and 8 days of incubation and reached its minimum value at day 10 of incubation. Abbaspour et al. (2007) found that in Pb and Cd contaminated fine textured and a coarse textured soil, application of organic matter decreased the exchangeable fraction of Pb in fine textured soil more than that in coarse textured soil after 2 and 12 weeks of incubation.

A decrease in OM contents was recorded in 2 and 4% FM amended soils (Table 2) throughout the incubation period. This decrease was due to decomposition of added manure (McGrath 1994). For the control treatment of both the soils, decomposition did not significantly affect the OM contents during whole of the incubation period and consequently caused no change in AB-DTPA extractable Pb after 2 and 3 weeks incubation, but after 4 weeks, a decrease in AB-DTPA Pb was recorded. In 2% FM amended soils, decomposition of added manure not only decreased the OM contents but also decreased the ABDTPA-Pb after 4 weeks compared to that after 2 and 3 weeks incubation. In 4% FM amended soils, the decomposition of added FM decreased OM along with ABDTPA-Pb after 3 and 4 weeks than that after 2 weeks incubation.

With decrease in OM content, also there was a decrease in ABDTPA-Pb in FM amended soils. It might be attributed to microbial decomposition of manure in soils which released more insoluble acids (humic acid) than soluble (fulvic acid) (Stevenson and Cole 1999). Insoluble organic acids could increase the retention of metals including Pb in soils whereas soluble organic acids do enhance the metal solubility in soil solution (McBride 1994). Clemente and Bernal (2006) reported that application of humic acids derived from compost and peat in calcareous soil decreased the exchangeable fraction of Pb compared to that with the control.

CONCLUSION

It is concluded that higher rates of manure application resulted in more OM in both the soils than lower rates of FM. It was also observed that after each incubation time, there was a gradual decrease in OM of both the soils. Minimum ABDTPA extractable Pb was recorded after 3 weeks in sandy loam soil amended with 4% FM. While in sandy clay loam soil, minimum AB-DTPA extractable Pb was recorded after all incubation times when amended with FM at 2 and 4%. This study also showed that in both the soils, decomposition of added manure decreased OM along with ABDTPA extractable Pb, after each incubation time.

ACKNOWLEDGEMENTS

The authors are highly grateful to Dr. Abdul Ghafoor (Former Professor & Director Research, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad) for his help in research related activities, technical and positive criticism to complete present study.

REFERENCES

Abbaspour A, M Kalbasi, S Hajrasuliah, A Golchin (2007) Effect of plant residues and salinity on fractions of cadmium and lead in three soils. *Soil and Sediment Contamination*, **16:** 539–555.

Amacher MC (1996) Nickel, cadmium and lead. P. 739–768. In: DL Sparks (ed.). Methods of soil analysis. Chemical methods (3rd Ed.). SSSA/ASA, Madison, WI, USA.

Ayuso EA, AG Sanchez (2003) Sepiolite as a feasible soil additive for the immobilization of cadmium and zinc. *Science of the Total Environment*, **305:** 1–12.

Bernal MP, MA Sanchez-Monedero, C Peredes, A Roig (1998) Carbon mineralization from organic wastes at different composting stages during their incubation with soil. *Agriculture Ecosystem and Environment*, **69:** 175–189.

Brown S, RL Chaney, JG Hallfrisch, Q Xue (2003) Effect of biosolids processing on lead bioavailablity in an urban soil. *Journal of Environmental Quality*, **32:** 100–108.

Brumer GW, J Gerth, KG Tiller (1998) Reacrtion kinetics of the adsorption and desorption of nickel, zinc and cadmium by goethite. I. Adsorption and diffusion of metals. *Journal of Soil Science*, **39:** 37–52.

Clemente R, MP Bernal (2006) Fractionation of heavy metals and distribution of organic carbon in two contaminated soils amended with humic acids. *Chemosphere*, **64:** 1264–1273.

Clemente R, A Escolor, MP Bernal (2006) Heavy metals fractionation and organic matter mineralization in contaminated calcareous soil amended with organic materials. *Bioresource Technology*, **97:** 1894–1901.

Francois M, HC Dubourguier, D Li, F Douay (2004) Prediction of heavy metal solubility in agricultural soil around two smelters by the physico-chemical parameters of soils. *Aquatic Science*, **66:** 78–85.

Ghafoor A, S Ahmad, M Qadir, G Murtaza, I Hussain (2001) Movement and retention of lead and chromium in soil applied with irrigation water. *Pakistan Journal of Agricultural Sciences*, **38:** 8–11.

Iqbal MM, G Murtaza, ZA Saqib, R Ahmad (2015) Growth and physiological responses of two rice varieties to applied lead in normal and salt-affected soils. *International Journal of Agriculture and Biology*, **17:** 901–910.

Iqbal MM, T Naz, A Rehman, N Sarwar, G Murtaza, R Ahmad, G Sarwar, O Farooq, M Ali, MW Khan (2016) Assessment of P-Zn interactive effects on growth, P and Zn uptake by wheat in salt-affected soil. *Pakistan Journal of Life and Social Sciences*, **14:** 144–150.

Izzo R, FN Izzo, MF Quartacci (1991) Growth and mineral absorption in maize seedlings as affected by increasing NaCl concentrations. *Journal of Plant Nutrition*, **14:** 687–699.

Jackson ML (1962) Soil chemical analysis. Constable and Co. Ltd. London, UK.

Jahiruddin M, NT Livesey, MS Cresser (1985) Observations on the effect of soil pH upon zinc absorption by soils. *Communications in Soil Science and Plant Analysis*, **16:** 909–922.

Lu A, S Zhang, XQ Shan (2005) Time effect on the fractionation of heavy metals in soils. *Geoderma*. **125:** 225–234.

Ma YB, NC Uren (1998) Transformations of heavy metals added to soil-application of a new sequential extraction procedure, *Geoderma*, **84:** 157–168.

McBride MB (1994) Environmental chemistry of soils. Oxford University Press, New York, NY, USA.

McGrath SP (1994) Effects of heavy metals from sewage sludge on soil microbes in agricultural ecosystem. pp. 247–274. John Wiley and Sons Ltd., Chichester, UK.

Mclaughlin MJ (2001) Ageing of metals in soils changes bioavailability. *Environmental Risk Assessment*, **4:** 1–6.

Msaky JJ, R Calvet (1990) Adsorption behaviour of copper and zinc in soils: influence of pH on adsorption characteristics. *Soil Science*, **150:** 513–520.

Muhlbachova G (2002) The availability of DTPA extracted heavy metals during laboratory incubation of contaminated soils with glucose amendments. *Rostlinna Vyroba*. 1**2:** 536–542.

Murtaza, G., A. Ghafoor, M.Z. Rehman, M. Sabir and A. Naeem, (2012a). Phytodiversity for metals in plants grown in urban agricultural lands irrigated with untreated city effluent. *Communication in Soil Science and Plant Analysis*, **43:** 1181–1201.

Murtaza G, RJ Haynes, K. Kim MH Zia, R Naidu , ON Belyaeva (2012b) Effect of aging biosolids with soils of contrasting pH on subsequent concentrations of Cu and Zn in pore water and on their plant uptake. *Environmental Science and Pollution Research*, **19:** 636–645.

Nakhone NL, SD Young (1993) The significance of (radio) labile cadmium pools in soil. *Environmental Pollution*, **82:** 73–77.

Narwal RP, BR Singh (1998) Effect of organic materials on partioning, extractability and plant uptake of metals in an alum shale soil. *Water, Air and Soil Pollution*, **103:** 405–421.

Nogales N, Benitez (2007) Effect of olive-derived organic amendments on lead, zinc and biochemical parameters of an artificially contaminated soil. *Communications in Soil Science and Plant Analysis*, **38:** 795–811.

Phillips R, DT Lamb, ED Burton (2004) Effects of pH and salinity on copper lead and zinc sorption rates in sediments from Morton Bay, Australia. *Bulletin of Environmental Contamination and Toxicology*, **73:** 1041–1048.

Pourrut B, M Shahid, C Dumat, P Winterton, E Pinelli (2011) Lead uptake, toxicity, and detoxification in plants. *Environmental Contamination and Toxicology*, **213:** 113–136.

Ruttens A, M Mench, JV Colpaert, J Boisson, R Carleer, J Vangronsveld (2006) Phytostabilization of a metal contaminated sandy soil. I: Influence of compost and / or inorganic metal immobilizing soil amendments on phytotoxicity and plant availability of metals. *Environmental Pollution*, **144:** 524–532.

Sauve S, CE Martinez, MB McBride, WH Hendershot (2000) Adsorption of free lead (Pb^{+2}) by pedogenic oxides, ferrihydrite and leaf compost. *Soil Science Society of American Journal*, **64:** 595–599.

Sharma P, RS Dubey (2005) Lead toxicity in plants. *Brazilian Journal of Plant Physiology*, **17:** 35–52.

Shuman LM (1998) Effect of organic waste amendments on cadmium and lead in soil fractions of two soils. *Communications in Soil Science and Plant Analysis*, **29:** 2939–2952.

Shuman LM (1999) Organic waste amendments effect on zinc fractions of two soils. *Journal of Environmental Quality*, **28:** 1442–1447.

Silviera DJ, LE Sommers (1977) Extractability of copper, zinc, cadmium and lead in soils incubated with sewage sludge. *Journal of Environmental Quality*, **6**: 47–52.

Soltanpour PN (1985) Use of AB-DTPA soil test to evaluate elemental availability and toxicity. *Communications in Soil Science and Plant Analysis*, **16:** 323–338.

Steel RGD, JH Torrie, DA Dickey (1997) Principles and procedures of statistics. A biometrical approach, 3rd Ed. McGraw Hill Book Co. Inc., New York, USA, pp 172-177.

Stevenson FJ, MA Cole (1999) Cycles of soils: Carbon, nitrogen, phosphorus, sulfur, micronutrients. 2nd Ed. John Wiley and Sons, New York, NY, USA.

Strawn DG, DL Sparks (2000) Effects of soil organic matter on the kinetics and mechanism of Pb (II) sorption and desorption in soil. *Soil Science Society American Journal*, **64:** 144–156.

Tug GN, F Duman (2010) Heavy metal accumulation in soils around a salt lake in Turkey. *Pakistan Journal of Botany*, **42:** 2327–2333.

Trivedi P, L Axe (2000) Modeling Cd and Zn sorption by hydrous metal oxides. *Environmental Science and Technology*, **34:** 2215–2223.

US Salinity Lab Staff (1954) Diagonsis and improvement of saline and alkali soils. Handbook No. 60, Washington, D.C., USA.

Walker DJ, R Clemente, A Roig, MP Bernal (2003) The effect of soil amendments on heavy metal bio-availability in two contaminated Mediterranean soils. *Environmental Pollution*, **122:** 303–312.