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Release of zinc and cadmium from sludge amended soil as influenced by varying levels of moisture and temperature

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Abstract

Limited information is available related to the effect of moisture and temperature on release of metals from sludge treated soils. In an incubation experiment, effect of ten levels of sludge (0, 1.12, 2.24, 4.48, 8.96, 17.9, 35.8, 71.6, 142, 285 g kg^{-1}), two levels of moisture (field capacity and 2.5 cm standing water) and two levels of temperature (20 and 35 °C) on the release of zinc and cadmium was evaluated in acid and alkaline soils. The results indicated that application of sludge was more effective in enhancing EDTA extractable Zn and Cd in acid soil than in alkaline soil. On an average, maximum increase in release of EDTA extractable Zn and Cd were 32.0 and 5.2 fold in sludge treated soil over control. There was decrease in EDTA extractable Zn and Cd by 37.7% and 25.4%, respectively under submergence as compared to that under field capacity. On an average, the amount of EDTA extractable Zn and Cd increased by 22.6% and 43.6%, respectively at 35 °C than that at 20 °C.

Key words

Acid and alkaline soils, Moisture, Metal release, Sludge, Temperature

Introduction

About 15644 million litres per day (MLD) of sewage water is generated from 35 metropolitan cities (more than 10 Lac populations) in India (CPCB, 2013). This indicates that a huge amount of sludge is generated in our country. The residue product of wastewater treatment *i.e.* sludge has been used in agriculture for many years as a fertilizer, containing organic matter and macro-and micronutrients (Antoniadis and Alloway, 2001). Land application of sewage sludge is becoming more popular due to the possibility of recycling valuable components such as organic matter, N, P and other plant nutrients (Martinez *et al.,* 2002). Sewage sludge has been reported to contain high amount of organic matter (19.8% to 43.4%), indicating its usefulness in organic matter poor tropical soils (Singh and Agrawal, 2008).

pH of sludge may vary from acidic to alkaline range, indicating the possibility of using these waste materials in reclamation of acid and sodic soils (Martinez *et al.,* 2002). It is reported that solubility of sludge borne metal is far more in acid soil than in alkaline soil. pH of sludge also affects the release of metals from sludge. Application of sludge to agricultural land is mainly constrained by the fact that these waste materials often contain trace toxic metals. However, metal concentration in sludge depends on several factors like its origin and treatment processes. Bioavailability of sludge borne metals in soil is further influenced by soil properties such as pH, redox potential (Eh), sesquioxide content and organic matter, as well as sludge application rate (Singh and Agrawal, 2007). Temperature can have marked effect on the rate of decomposition of organic matter; increasing temperature accelerates the microbial decomposition process. Consequently, where sewage sludge is applied, there is a possibility that high temperature may lead to greater quantities of sludge-borne heavy metals being available to plants (Chang *et al.,* 1997; Antoniadis and Alloway, 2001). Role of different ambient temperatures in availability of heavy metals has not been widely studied under tropical condition. Moisture content of soils is another important factor which governs the release of metals from soil sludge mixture. Study on the effect of moisture regimes on transformations of lead and zinc in three sludge treated soils (acidic, neutral and alkaline) indicated high amount of $CaCl_2$ extractable Pb and Zn under flooding than that under field capacity (Tewari *et al.,* 2012). However, this is the area where more studies need to be undertaken to elucidate the release pattern of metals from sludge-treated soils at varying moisture and soil types. Specific objective of the present study was to assess the effect of different levels of temperature and moisture on EDTA extractable Zn and Cd in acid and alkaline soils amended with graded doses of sludge.

Materials and Methods

Collection, processing and characterization of soil samples : To accomplish the objectives of the present investigation, two bulk surface (0-15 cm) soil samples were collected from Cooch Behar district, West Bengal and experimental farm of Indian Agricultural Research Institute (IARI), New Delhi. Soil samples were collected from two locations so as to ensure wide variation in pH, because, pH is one of the most important features which governs the solubility of metals in soils. Soil sample collected from Cooch Behar district belongs to Typic Fluvaquent located in humid (precipitation > 3500 mm annually) tropical tarai agro-climatic zone. Soil of IARI farm belongs to Typic Haplustept in sub-tropical semi-arid agro-climatic zone (annual rainfall 651 mm) of Upper Gangetic Plain. Soil samples were air-dried, ground in wooden mortar and pestle and sieved to pass through 2 mm sieve. The processed soil samples were mixed thoroughly for ensuring homogenization; finally homogenized samples were used for characterization of initial soil properties as well as incubation experiment. pH (soil:water :: 1:2) and electrical conductivity (Jackson, 1973), organic carbon (Walkley and Black, 1934), cation exchange capacity (Jackson, 1973) in experimental soils were determined using standard procedures. Mechanical composition of soil (texture) was determined by hydrometer method (Bouyoucos, 1962). Aqua-regia extractable metals in soil were determined by the method of Quevauviller (1998). Total Zn and Cd content in sludge were also determined using following diacid digestion (Jackson, 1973).

Incubation experiment : For laboratory incubation experiment, series of 15 g processed soil samples were taken into plastic bottle with graded levels of sludge. Sludge was added @ 0, 1.12, 2.24, 4.48, 8.96, 17.9, 35.8, 71.6, 142 and 285 g kg^{-1} of soil which was equivalent to field application of 0, 2.5, 5, 10, 20, 40, 80, 160, 320, 640 t ha^{-1}. This incubation study was conducted as part of ultimate objective of fixing permissible limit of sludge application to agricultural lands. For fixing maximum permissible limit of sludge, evaluation of wide range in rates of sludge application is required. Incubation was carried out at two soil moisture regimes, viz. field capacity and 2.5 cm standing water, and two temperature viz. 20 ºC and 35 ºC for 60 days. Soil moisture regimes at 2.5 cm standing water and field capacity were selected to stimulate the field conditions of rice and other crops, respectively. Similarly, two levels of temperature i.e. 20 ºC and 35 ºC were selected to stimulate mean winter and summer temperature of the tropics. Thus, in all, 80 treatment combinations (10 x 2 x 2 x 2) were laid out in completely randomized design (factorial), with three replications. After 60 days of incubation, soil was extracted with 0.05 *M* EDTA solution by shaking on mechanical shaker for 1 hr according to Quevauviller (1998). Moisture content of soil, as used in incubation experiment was taken into account while preparing EDTA solution so that final concentration of this extractant comes to 0.05 *M*. Zinc and Cd content in extract were analysed by flame or graphite atomic absorption spectrophotometer.

Statistical analysis : The effect of sludge, moisture, temperature and duration of incubation on release of metals in soils was evaluated following Analysis of Variance as per procedure of Snedecor and Cochran(1967).

Results and Discussion

Initial characteristics of experimental soils and sludge were assessed and results indicate that pH was 4.52 and 8.44 for acid and alkaline soils, respectively, with the corresponding values of electrical conductivity of 0.81 and 0.29 dS m^{-1} (Table 1). Mechanical analysis indicated that acid soil of Cooch Behar and alkaline soil of IARI farm belong to sandy clay loam and sandy

Table 1 : Initial characteristics of experimental soils and sludge

Parameter	Acid soil	Alkaline soil	Sludge
$pH_{1:2}$	4.52	8.44	6.71
$EC_{1:2}$ (dS m^{-1})	0.81	0.29	3.32
Mechanical composition			
Clay (%)	22.8	12.3	
Silt (%)	16.5	22.5	
Sand (%)	62.7	63.2	
Texture	Sandy clay loam	Sandy loam	
Organic carbon (%)	0.78	0.57	43.3*
Cation exchange capacity[cmol (p+) kg^{-1}]	15.5	12.6	-
Total Zn (mg kg^{-1})	125	130	1600
Total Cd (mg kg^{-1})	0.41	0.37	5.38

*Total organic carbon

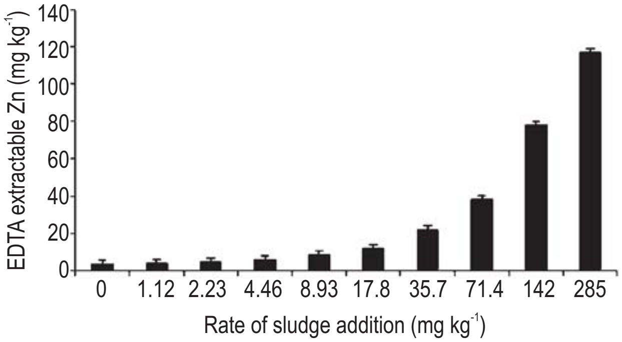

Fig. 1 : Effect of sludge addition on EDTA extractable Zn content in soil after 60 days of incubation. Error bars represent the least significant difference (LSD, $P \leq 0.05$) between two treatments

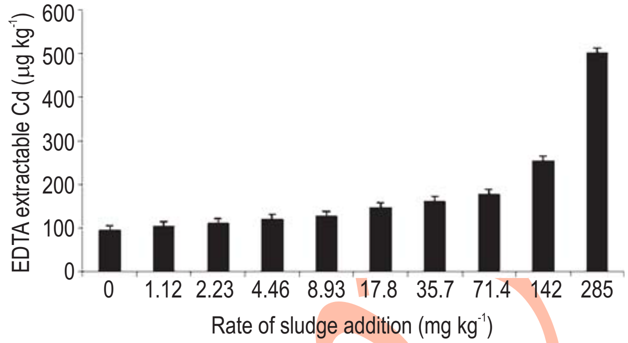

Fig. 2 : Effect of sludge addition on EDTA extractable Cd content in soil after 60 days of incubation. Error bars represent least significant difference (LSD, $P \leq 0.05$) between two treatments

Table 2 : Effect of sludge addition on EDTA extractable Zn (mg kg^{-1}) in acid and alkaline soil incubated at different levels of moisture and temperature for 60 days

Rate of sludge addition (g kg^{-1})	Type of soil	Moisture			
		Field capacity		2.5 cm standing water	
		Temperature			
		20 °C	35 °C	20 °C	35 °C
0	Acid	2.36	7.03	1.67	3.47
	Alkaline	2.84	6.12	1.79	3.28
1.12	Acid	3.9	7.61	2.03	4.4
	Alkaline	2.64	7.68	1.89	3.56
2.23	Acid	4.34	11.3	2.06	4.44
	Alkaline	3.07	8.12	1.97	4.17
4.46	Acid	2.75	4.63	11.2	4.63
	Alkaline	7.65	9.79	2.55	4.91
8.93	Acid	11.9	18	3.79	5.05
	Alkaline	9.02	11.9	3.24	5.63
17.8	Acid	16.6	20.6	7.32	8.52
	Alkaline	14.5	17	3.95	8.15
35.7	Acid	22.6	38	12.3	29.5
	Alkaline	27.4	30.3	9.11	9.84
71.4	Acid	44.9	61.9	43.1	37.9
	Alkaline	47.9	50.8	10	11.1
142	Acid	75.6	115	61.4	74.1
	Alkaline	77.5	89.6	61.2	69.5
285	Acid	157	189	86.7	92.3
	Alkaline	130	139	69.8	75.3

LSD (P=0.05): Sludge x Soil x Moisture x Temperature= 5.35

loam textural classes, respectively. Organic carbon content was 0.78% and 0.57% in acid and alkaline soil, respectively. Total (aqua-regia extractable) Zn and Cd content in acid soil was 125 and 0.41 mg kg^{-1}. Alkaline soil was found to contain 130 and 0.37 mg kg^{-1} of Zn and Cd. pH and electrical conductivity in sludge water suspension (1:2) was recorded as 6.71 and 3.32 dS m^{-1}, respectively. Sludge was found to contain 43.37% (on dry weight basis) total C. Total metal content in sludge was 1600 mg kg^{-1} Zn and 5.38 mg kg^{-1} Cd (Table 1).

Sludge amended soils were extracted with EDTA as this extractant has been standardized for assessing eco-toxicity of metals (Quevauviller, 1998). On an average, EDTA extractable Zn progressively increased from 3.58 mg kg^{-1} (control) to 117 mg kg^{-1} due to addition of 1.12 to 285 g kg^{-1} of sludge (Fig. 1). However, significant increase in EDTA extractable Zn was recorded where sludge was added @ $\geq$ 4.46 g kg^{-1}. Such increase in EDTA extractable Zn in soil is attributed to addition of Zn through sludge. For example, 1.79 and 456 mg kg^{-1} of Zn was added through lowest and highest rates of sludge addition. On an average, EDTA extractable Cd increased from 95.7 to 504 μg kg^{-1} due to the addition of sludge (Fig. 2). This is related to the addition of this metal through sludge as well as dissolution of their native forms. Several researchers have reported earlier that addition of sludge and sewage effluent markedly enhanced the extractable metal content in soil (Rattan *et al.,* 2005; Sharma *et al.,* 2007; Singh and Agrawal, 2007).

Effect of soil, temperature and moisture on EDTA extractable Zn and Cd was statistically significant. Acid soil showed higher EDTA extractable Zn and Cd as compared to alkaline soil. On an average, EDTA extractable Zn content was 32.7 and 26.3 mg kg^{-1} in acid and alkaline soils, respectively; corresponding values of Cd were 226 and 136 μg kg^{-1}. This is related to higher solubility of metals in acid soil than alkaline soil.

Increase in moisture content from field capacity to submergence (2.5 cm standing water) decreased EDTA extractable Zn and Cd from 37.7 to 21.4 mg kg^{-1} and 208 to 155 μg kg^{-1}, respectively. This may be due to formation of metal sulphides and other less soluble complexes with PO_4^{3-}, CO_3^{2-}, HCO_3^- etc (Lindsay, 1979).

EDTA extractable Zn increased from 26.5 to 32.5 mg kg^{-1} due to increase in incubation temperature from 20ºC to 35 ºC. A similar increase in EDTA extractable Cd was recorded to the extent of 149 to 214 μg kg^{-1} as a result of increasing incubation temperature from 20ºC to 35 ºC. This has an important environmental implication because crops on sludge-amended soils in warmer areas (such as tropical countries like India) may take up proportionally more metals than those in cooler climates with similar concentration of heavy metals applied in sewage sludge. Seasonal variation of temperature may also affect the release of metals from sludge amended soil. The results of the present investigation are in concurrence with the earlier findings of Antoniadis and Alloway (2001). However, magnitude of increase in available metals in sludge amended soil was lower than those obtained in the present study. The experiment was conducted at 15ºC and 25 ºC temperature, while the present study was carried out at 20ºC and 35 ºC temperature. Possibly difference in temperature between the present and earlier studies are reflected in the magnitude of change in EDTA extractable metal content in response to change in temperature.

Effect of temperature on EDTA extractable Zn was modified by the levels of soil moisture (Table 2). By and large, increase in EDTA extractable Zn in response to increase in incubation temperature was comparatively larger at field capacity as compared to that under submergence, particularly at higher rates of sludge addition. Also, at field capacity significant increase in EDTA extractable Zn over control was recorded under relatively lower dose of sludge addition as compared to that under submergence. Highest amount of EDTA extractable Zn (189 mg kg^{-1}) was recorded with the application of 285 g sludge kg^{-1} in acid

Table 3 : Effect of sludge and moisture regime on EDTA extractable Cd (μg kg^{-1}) in acid and alkaline soil at 60 days of incubation

Rate of sludge addition (g kg^{-1})	Type of soil	Moisture	
		Field capacity	2.5 cm standing water
0	Acid soil	136	98.2
	Alkaline soil	90.1	57.9
1.12	Acid soil	148	105
	Alkaline soil	97.6	71.8
2.23	Acid soil	159	112
	Alkaline soil	104	73.6
4.46	Acid soil	166	124
	Alkaline soil	112	81.3
8.93	Acid soil	170	133
	Alkaline soil	118	96.7
17.8	Acid soil	190	171
	Alkaline soil	127	110
35.7	Acid soil	206	188
	Alkaline soil	141	115
71.4	Acid soil	227	198
	Alkaline soil	172	121
142	Acid soil	424	262
	Alkaline soil	193	140
285	Acid soil	751	556
	Alkaline soil	422	279

LSD (P=0.05): Sludge x Soil x Moisture =19.8

Table 4 : Effect of sludge and temperature on EDTA extractable Cd (μg kg^{-1}) in acid and alkaline soil at 60 days of incubation

Rate of sludge addition (g kg^{-1})	Type of soil	Temperature	
		20 ºC	35 ºC
0	Acid soil	117	117
	Alkaline soil	57.2	90.8
1.12	Acid soil	124	129
	Alkaline soil	61.3	108
2.23	Acid soil	131	140
	Alkaline soil	66.1	112
4.46	Acid soil	138	152
	Alkaline soil	71.2	122
8.93	Acid soil	144	160
	Alkaline soil	83.1	132
17.8	Acid soil	154	207
	Alkaline soil	90.5	147
35.7	Acid soil	171	223
	Alkaline soil	94.5	162
71.4	Acid soil	190	235
	Alkaline soil	108	185
142	Acid soil	277	409
	Alkaline soil	125	208
285	Acid soil	612	696
	Alkaline soil	163	538

LSD (P=0.05) : Sludge x Soil x Temperature = 19.8

Table 5 : Effect of sludge, moisture regime and temperature on EDTA extractable Cd (μg kg^{-1}) in soil at 60 days of incubation

Rate of sludge addition (g kg^{-1})	Moisture	Temperature	
		20ºC	35ºC
0	Field capacity	93.1	129
	2.5 cm standing water	77.6	78.6
1.12	Field capacity	103	143
	2.5 cm standing water	82.9	94.6
2.23	Field capacity	108	155
	2.5 cm standing water	89.2	96.7
4.46	Field capacity	112	166
	2.5 cm standing water	97.5	108
8.93	Field capacity	115	174
	2.5 cm standing water	112	118
17.8	Field capacity	127	190
	2.5 cm standing water	117	164
35.7	Field capacity	142	206
	2.5 cm standing water	124	179
71.4	Field capacity	164	235
	2.5 cm standing water	134	184
142	Field capacity	240	378
	2.5 cm standing water	162	239
285	Field capacity	440	733
	2.5 cm standing water	335	501

LSD (P=0.05) : Sludge x Moisture x Temperature =19.8

soil incubated at 35 °C temperature under field capacity. Alkaline soil also had the highest amount of EDTA extractable Zn under same treatment. In case of Cd, since four factor-interactions was non-significant, interactive effect of three factors in different combinations are presented in Tables 3 to 5. Perusal of data revealed that effect of temperature on EDTA extractable Cd was significantly modified by moisture content and as well as temperature. Usually, extractable metal in soil increases with increase in temperature (Antoniadis and Alloway, 2001; Adekunle *et al.,* 2009). Release of metals from sludge-treated soil should depends on decomposition/ mineralization of sludge as well as dissolution/precipitation of native soil metals in response to change in soil chemical environment due to sludge addition. Decomposition of organic matter depends both on moisture content and ambient temperature. Franzluebbers (1999) reported that mineralization of natural organic materials is mediated by heterotrophic bacteria and fungi, and soil moisture regulates oxygen diffusion in soil with maximum aerobic microbial activity occurring at moisture level between 50% and 70% of water holding capacity. Agehara and Warncke (2005) reported a profound influence of temperature on carbon mineralization from organic sources. Working with sludge, Alloway (1997) opined that decomposition of organic matter leads to breaking of the humic macro-molecules and this process could release metals formerly bound to organic matter into more labile forms, thus increasing metal availability to plants. He also opined that decomposition of organic matter can have another effect; it may lead to formation of low molecular weight organic ligands which is believed to increase metal availability. Another reason for reduction in extractable Zn and Cd in response to increase in moisture content from field capacity to submergence is probably the formation of metal sulphides under anaerobic condition. In acid soil, extractability of these metals may also be decreased due to decrease in their solubility in response to increase in soil pH under submergence.

It can be concluded that alkaline soil was more suitable for sludge application as compared to acid soil as far as release of Zn and Cd was concerned. Increase in temperature greatly enhanced the release of metal from sludge amended soils. On the contrary, increase in moisture content from field capacity to submergence caused decrease in release of Zn and Cd from sludge amended soils. Such results imply that application of sludge should be more effective in elevating the level of Zn and Cd in soil during summer under field capacity as compared to that in winter under submergence.

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References

Adekunle, I.M., O. Olorundare and C. Nwange: Assessments of lead levels and daily intakes from green leafy vegetables of southwest Nigeria. *Nutr. Food Sci.,* **39,** 413-422 (2009).

Agehara, S. and D.D. Warncke: Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil Sci. Soc. Am. J.,* **69,** 1844-1855 (2005).

Alloway, B.J.: The Mobilisation of Trace Elements in Soils. In: Contaminated Soils. (Ed.: R. Prost), Third International Conference on the Biogeochemistrry of Trace Elements. Paris, pp. 133-145 (1997).

Antoniadis, V. and B.J. Alloway: Availability of Cd, Ni and Zn to ryegrass in sewage sludge-treated soils at different temperatures. *Water Air Soil Poll.,* **132,** 201-214 (2001).

Bouyoucos, G.J.: Hydrometer method improved for making particle size analyses of soils. *Agron. J.,* **54,** 464-465 (1962).

Chang, A.C., H. Hyun and A.L. Page: Cadmium uptake for Swiss chard grown on composted sewage sludge treated field plots: Plateau or time bomb? *J. Environ. Qual.,* **26,** 11-19 (1997).

CPCB: Central Pollution Control Board, Ministry of Environment and Forests, Govt. of India (http://www.cpcb.nic.in/) (2013).

Frazluebbers, A.J.: Microbial activity in response to water filled pore space of variably eroded southern Piedmont soils. *Appl. Soil Ecol.,* **11,** 91-101 (1999).

Jackson, M.L.: Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd. New Delhi (1973).

Lindsay, W.L.: Chemical Equilibria in soil. John Wiley and Sons, Inc. New York (1979).

Martinez, F., C. Cuevas, W. Teresa and I. Iglesias: Urban organic wastes effects on soil chemical properties in degraded semiarid ecosystem. In: Seventeenth WCSS, Symposium No. 20, Thailand, pp. 1-9 (2002).

Quevauviller, P.H.: Operationally defined extraction procedures for soil and sediment analysis. *Trend Anal. Chem.,* **17,** 289-298 (1998).

Rattan, R.K., S.P. Datta, P.K. Chhonkar, K. Suribabu and A.K. Singh: Long–term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater– a case study. *Agri. Ecosys. Env.,* **109,** 310-322 (2005).

Sharma, R.K., M. Agrawal and F.M. Marshall: Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotox. Environ. Safe.,* **66**, 256-288 (2007).

Singh, R.P. and M. Agrawal: Effect of sewage sludge amendment on heavy metal accumulation and consequent responses of Beta vulgaris plants. *Chemosphere,* **67,** 2229-2240 (2007).

Singh, R.P. and M. Agrawal: Potential benefits and risks of land application of sewage sludge. *Waste Manage.,* **28,** 347-358 (2008).

Snedecor, G.W. and W.G. Cochran: Statistical Methods, 7th Ed. The Lowa State University. Press America, Lowa, USA (1967).

Tewari, G., P.C. Srivastava, R. Bali and L. Tewari: Effect of moisture regime on release of Pb and Zn in long term contaminated soils. *Elect. J. Environ. Agric. Food Chem.,* **11,** 205-213 (2012).

Walkley, A. and I.A. Black: An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil. Sci.,* **37,** 29-38 (1934).