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Effect of sludge on sorption of cadmium in calcareous soils

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Abstract

The amount of Cd sorbed (x/m) by untreated and treated soils increased while, per cent of added Cd sorbed (X_{Ad}) and distribution coefficient (K_d) decreased with increasing Cd concentration in solution indicating that affinity of soils for Cd decreased with increasing Cd concentration in solution indicating that affinity of soils for Cd decreased with fractional surface coverage or increase in concentration of Cd in solution phase. Cd sorption by untreated and treated soils was satisfactorily described by Freundlich ($R^2 = 0.994$ to 0.998) and two-surface Langmuir equations ($R^2 = 0.987$ to 0.999). The value of Freundlich constant (K_f) and total sorption capacity ($b_1 + b_2$) calculated from the two-surface Langmuir equation increased due to enrichment of soil with sludge @ 25 and 50 g kg^{-1} . Total sorption capacity and Freundlich K_f were positively and significantly correlated with organic carbon and CEC of the soils indicating that application of sludge to the soils had a dominating role in enhancing the Cd sorption due to increase in organic surfaces/adsorption sites to the soils and formation of stable complexes with organic matters.

Keywords: Cadmium, sorption isotherm, bonding energy, sorption maxima, distribution coefficient, sludge

Introduction

Industrialization and urbanization have resulted in discharge of large amount of waste effluents and sewage sludge. The solid portion of sewage i.e. sludge is rich in organic matter and essential plant nutrients. Hence, its application of agricultural land has increased in recent years. These waste materials also contain substantial amount of heavy toxic metals like cadmium (Cd) and therefore, their disposal into the agricultural lands increases its level in soils which may result adverse effects on the growth and quality of the crops (Bingham *et al.* 1975) [3]. The Cd is a potentially hazardous pollutant in the environment and it is highly toxic to human beings and animals even at very low concentration (Flick *et al.* 1971) [24].

In natural system, the bio-availability of trace metals is primarily controlled by adsorption-desorption reactions at particle solution interface (Backes *et al.* 1995) [2]. The availability of Cd to plants depends upon the sorption of Cd by soils which is influenced by pH, organic matter, clay content, cation exchange capacity and $CaCO_3$ (McBride 1989) [25]. Organic matter influences the concentrations of heavy metals in soil solution directly by forming the organo-metallic complexes of varying stability constants (Stevenson 1982) [20] and contributing to CEC of the soil and indirectly by affecting the reactivities of the oxide minerals and calcite (Elliot *et al.* 1986; wilkens and Loch 1997) [6, 23]. The calcium carbonate present in calcareous soils directly affects mobility and reactivity of heavy metal through surface interaction and indirectly through their effect on soil pH. The high affinity of calcite surface for cadmium was attributed to similarities between ionic radii of the Cd^{2+} (0.095 nm) and Ca^{2+} (0.100 nm). The present investigation was therefore, conducted to study the influence of sludge retention of Cd in calcareous soils for utilizing the organic wastes like sewage sludge in economic and environmentally safe manner.

Materials and methods

Ten calciorthents surface soil samples (0-0.15m) varying in clay, organic carbon and $CaCO_3$ were collected from different locations in Samastipur, Bihar. All the samples were air dried, ground to pass through a 2-mm sieve and were stored in a plastic container at room temperature.

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The physic-chemical properties of these processed soils samples (Table 1) were determined by using standard procedure as described by Jackson (1973). The sludge was collected from Patna municipal waste treatment plant. The bulk sludge was air dried, ground and pass through 2-mm sieve. It was stored in air tight polythene bag. The sludge sample was analysed for organic carbon, total N, total P and total K which indicated that it contained 455 g kg⁻¹ organic carbon, 15.00 g kg⁻¹ total N, 5.64 g kg⁻¹ total P and 6.5 g kg⁻¹ total K. Total and DTPA extractable Cd in the sludge were analysed by method described by Tessier *et al.* (1979) [21] and Lindsay and Norvell (1978) [11], respectively. The total Cd was found 1.00 mg kg⁻¹. The each soil sample was mixed with sludge @ 25 and 50 g kg⁻¹. For this, the 400 g of the each soil sample was spreaded on a polythene sheet and mixed properly with 10 and 20 g well pulverized sludge separately. Therefore, the mixed soil samples were transferred on a polythene bag and standard with distilled water and allowed to dry at room temperature (25±2 °C). Four wetting and drying cycles were repeated for 30 days. These soil samples were again air dried, ground and passed through 2-mm sieve. The physic-chemical properties of the sludge enriched soil samples are given in Table 2. The Cd sorption was determined in untreated and treated soil samples.

Cadmium sorption for each of untreated and treated soil samples was determined by transferring 2 g of each soil in 125 ml plastic bottles separately. The 20 mL aliquot of CdCl₂ containing 5, 10, 25, 100, 250, 500 and 750 μ mol Cd L⁻¹ was added in each bottle. The ionic strength of the solution was kept constant with background electrolyte KNO₃ containing ambient concentration of 0.01 mol L⁻¹. The plastic bottles was stoppered and shaken for one hour and kept for 72 hours in incubator cum shaker to attain equilibrium. The time required for a solution containing soil and cadmium chloride solution to attain a quasi-equilibrium was estimated by conducting a pilot trial. Therefore, suspensions were centrifuged at 5000 rpm for 20 minutes. The centrifuged suspension was passed through a filter paper Whatman No. 42 to get clear solution. The filtrate was analysed for Cd with acetylene flame by atomic absorption spectrophotometer. Sorbed cadmium was calculated from the difference between initial and corresponding equilibrium concentration. The distribution coefficient (K_d) was calculated as K_d = Cd sorbed (m eqv) per g of soil used/ Cd in solution (meq) per mL at equilibrium.

Evaluation of sorption data

The following adsorption isotherm models for the fit of data were tested

(a) Linear equation

$$x/m = K_L \cdot C_e$$

Where,

x/m is amount of Cd retained by soil (μmol kg⁻¹); C_e is concentration of cadmium in solution (μmol L⁻¹); K_L is curve fitting parameter for equilibrium models.

(b) Freundlich equation

$$x/m = K_f \cdot C_e^{1/n} \quad (n > 1.0)$$

Where, K_f and n are constants and x/m and C_e have the same significance as in the Linear equation.

(c) Langmuir equation

$$C_e/(x/m) = (1/K_L b) + (C_e/b)$$

Where, x/m is the amount of Cd sorbed per unit mass of the sorbent; K_L is the constant related to banding energy; b is cadmium adsorption maximum and C_e is concentration of cadmium in solution (μ mol L⁻¹).

(d) Two-surface Langmuir equation

$$x/m = \{(k_1 b_1 C_e)/(1+k_1 C_e)\} + \{(k_2 b_2 C_e)/(1+k_2 C_e)\}$$

Where, x/m is the amount of Cd sorbed per unit weight of sorbent, k₁ and k₂ are curve fitting parameters related to bonding energy in part-I of isotherm (straight line corresponding to lower solution Cd concentration) and part II of isotherm (straight line corresponding to higher Cd concentration), respectively; b₁ and b₂ are also curve fitting parameters related to corresponding sorption maxima and C_e is the concentration of Cd in solution.

Results and discussion

The amount of Cd sorbed (x/m) by untreated and treated soils increased progressively with increasing solution concentration (Table 3). The distribution coefficient (K_d) (Table 5) decreased with increasing solution Cd concentrations, the value of X_{Ad} decreased may be due to competition of Cd with increasing amount of electrolyte cations for available surface sites and formation of uncharged ion pair and/or uncharged and negatively charged complexes of Cd with anion of electrolyte. Similarly findings also reported by Mehta *et al.* (2004) [12]. The value of K_d which is a measure of the extent to which an ion is removed from the solution by the sorbent decreased with increasing amount of x/m showing that affinity of soils for Cd decreased with increasing x/m or fractional surface coverage by cadmium. Similar results were also reported by Mehta *et al.* 2004. [12]

At comparable level of Cd, the value of X_{Ad} and K_d increased with increasing organic matter. Further, X_{Ad} and K_d of treated soils at different levels were higher as compared to untreated soils may be due to increase in organic carbon which provides sites for Cd sorption. Addition of organic matter affects adsorption of Cd through an increase in surface of solid matrix and through formation of stable complexes. Thus, the enrichment of soils with sewage sludge increased organic surfaces/adsorption sites resulting increasing Cd sorption. Similar findings were also reported by various workers (Hooda and Alloway 1998) [26].

Sorption isotherm

The experimental data were tried to fit in different adsorption isotherm models to predict the behavior of Cd sorption. The values of coefficient of determination (R²) of the fit of the equation in different models after 72 h at equilibrium (Table 6) indicated that Cd sorption by untreated and treated soils were well fitted in Freundlich (R² = 0.994 to 0.998) and two-surface Langmuir equation (R² = 0.987 to 0.999).

The freundlich parameters for Cd sorption of untreated and treated soils are presented in Table 5. The value of K_f an index of relative affinity of heavy metal sorption varied widely in different experimental soils. The Repura soil (S₆) had highest K_f value may be due to the highest CEC and organic carbon while, Gorai soil (S₁₀) having lowest organic carbon, clay and CEC recorded lowest K_f value. The value of K_f progressively increased due to enrichment of soils at different levels may be due to increase in organic matter content of the soils. The value of 1/n which is indicative of its affinity for solute decreased due to enrichment of soils indicating affinity of Cd for sorbent decreased due to

enrichment. The similar results were also reported by Singh and Pandeya (1998) ^[16] and Kumar (2005) ^[10].

The relationship between the amount of Cd sorbed and the equilibrium concentration of metal by untreated and treated soils were also described by two-surface Langmuir equations. The two-surface Langmuir parameter k_1 (bonding energy constant of part-I), k_2 (bonding energy constant of part-II), b_1 (sorption maxima of part-I), b_2 (sorption maxima of part-II) were obtained by using the method of Sposito (1982). A computer programme Curve Expert 1.1 for Gaussian non linear regression procedure was used for fitting of the curve for two-surface Langmuir equation to the data. The very high values of coefficient of determination (R^2) for the fit of the data in two-surface Langmuir equation Table 6 by untreated and treated soils indicated that data of retention of cadmium in soils confirmed to the two-surface Langmuir adsorption isotherm equation. Representative plot between the observed and predicted values of the amount of Cd retained by soil no. 6 also confirmed good fit of data in two-surface Langmuir equation (Fig 1). The value of b_1 , b_2 , k_1 and k_2 are given in Table 5. The results indicate that two types of adsorption surfaces are playing important role in metal retention. This suggest that there were at least two forms of cadmium, one representing tightly held Cd with low dissociation constant, high energy surface (k_1) and small sorption maxima (b_1) and other representing relatively loosely held Cd, with a high dissociation constant and low energy surface (k_2). It also depicts that the sorption maxima of part-II was higher than part-I of all soils. The results are in agreement with the reports of various workers (Singh and Pandeya, 1998 ^[16]; Adhikari and Singh 2000 ^[1]; Mehta *et al.* 2004) ^[12].

The enrichment of soils with sludge @ 25 and 50 g kg⁻¹ increased the Cd sorption as treated soils exhibit higher sorption capacity (b_1+b_2) as compared to untreated soils (Table 7). The effect of sludge addition is however, more conspicuous at lower level as compared to higher level. It may be attributed to the fact that enrichment of soils with sludge affects the adsorption of cadmium through an increase in surface of solid matrix and through formation of stable complexes. In the present study, an increase inorganic surfaces/adsorption sites with addition of sludge to the soils had a dominating role in enhancing adsorption. The enrichment of soils with sewage sludge at both levels, however,

decreased the pH of the soils. This may be due to decomposition of organic matter and liberation of organic acids (Navas *et al.* 1998) ^[13]. Adsorption is likely to control mechanism at low pH whereas, precipitation predominates at higher pH. Thus, enrichment of soil with sludge may decrease precipitation. At the same time, enrichment of soil with sludge may increase the negative charge on the solid matrix of the soils. Thus, decrease in precipitation and increase in adsorption sites on the solid matrix may result in higher sorption of Cd in sludge treated soils as compared to untreated soils. Thus, it is reasonable to expect that the dominant mechanism involved in Cd sorption may be exchange reaction. Soon (1981) reported that about 82 to 92 per cent of adsorbed Cd was retained by cation exchange and complex sites. Soils treated with sludge increased the amount of exchangeable Cd but reduced the amount of complex Cd compared with fertilized soil. Cadmium retention by cation exchange becomes more dominant as the amount of Cd in the soil was increased. Numerous workers found an increase in adsorption of cadmium on addition of organic matter in soils (Deka and Poonia 2001 ^[5]; Mehta *et al.* 2004) ^[12].

The correlation between total sorption capacity (b_1+b_2) for untreated and treated soils with soil properties are presented in Table 6 which revealed that organic carbon, clay and CEC were significantly and positively correlated with total sorption capacity. This indicates that clay, organic carbon and CEC of the soils were most effective factors influencing sorption capacity of Cd in the soils. The results are in agreement with the report of the various workers (Rattan and Sehgal 1989 ^[15]; Gray *et al.* 1998 ^[7]).

The CaCO₃ was however, not significantly correlated with any of the sorption parameters. Thus, Cd sorption data were reanalyzed in order to understand the role of CaCO₃ on Cd sorption. The soils are grouped keeping one property variable but other remains almost the same. The effect of CaCO₃ was marked on Cd sorption. For example, effect of CaCO₃ was highly marked in Jatmalpur (S₇, 3.5%), Kalyanpur (S₃, 29.5%) and Ladaura (S₈, 42.5% CaCO₃) soils. These soils contains almost similar value of CEC [17.20 to 19.25 cmol (P⁺) kg⁻¹]. The sorption capacity (b_1+b_2) was increased with increased CaCO₃ content (Table 1 and 7). The result are in conformity with the reports of Hundal (2003).

Table 1: Physico chemical properties of experimental soils

Soils	Pusa	Patepur	Kalyanpur	Malinagar	Karua	Repura	Jatmalpur	Ladaura	Berheta	Gorai
Properties	(S ₁)	(S ₂)	(S ₃)	(S ₄)	(S ₅)	(S ₆)	(S ₇)	(S ₈)	(S ₉)	(S ₁₀)
pH	8.01	8.15	8.20	8.16	8.25	8.12	7.95	8.20	8.28	8.08
EC (dS m ⁻¹)	0.35	0.28	0.24	0.25	0.15	0.70	0.22	0.46	0.17	0.16
Organic matter (g kg ⁻¹)	4.80	7.35	6.75	8.10	4.95	12.60	9.01	6.95	6.61	3.15
CaCO ₃ (g kg ⁻¹)	345	370	295	225	425	410	35	420	80	300
CEC [c mol (P ⁺) kg ⁻¹]	10.35	15.38	17.28	21.04	10.69	22.20	17.20	19.25	14.42	9.82
Sand (%)	51.40	46.44	45.81	48.02	45.86	33.00	45.21	30.72	45.80	58.91
Silt (%)	38.02	40.20	33.82	25.30	43.51	47.80	35.82	44.20	39.92	31.90
Clay (%)	10.52	13.30	20.26	26.62	10.59	19.15	18.90	25.30	14.21	9.12
Texture	Loam	Loam	Loam	Sandy clay loam	Loam	Loam	Loam	Loam	Loam	Sandy clay loam
DTPA extractable Cd (mg kg ⁻¹)	0.07	0.05	0.06	0.08	0.05	0.09	0.07	0.08	0.06	0.04

Table 2: Physico chemical properties of sludge enriched soils

Soils	Pusa	Patepur	Kalyanpur	Malinagar	Karua	Repura	Jatmalpur	Ladaura	Berheta	Gorai
Properties	(S ₁)	(S ₂)	(S ₃)	(S ₄)	(S ₅)	(S ₆)	(S ₇)	(S ₈)	(S ₉)	(S ₁₀)
Sludge application @ 25 g kg⁻¹										
pH	7.85	8.03	8.05	7.92	7.93	7.81	7.87	7.93	8.08	7.89
EC (dS m ⁻¹)	0.45	0.51	0.43	0.43	0.35	0.81	0.45	0.77	0.42	0.37
Organic carbon (g kg ⁻¹)	7.15	10.50	8.81	10.20	7.20	14.06	11.20	8.70	8.40	5.41
CEC [c mol (P ⁺) kg ⁻¹]	10.85	15.72	17.97	21.87	10.98	22.87	17.87	20.06	15.03	10.32

DTPA extractable Cd (mg kg ⁻¹)	0.12	0.08	0.12	0.09	0.09	0.12	0.10	0.09	0.11	0.10
Sludge application @ 50 g kg⁻¹										
pH	7.77	7.85	7.88	7.72	7.75	7.71	7.69	7.86	7.87	7.75
EC (dS m ⁻¹)	0.62	0.59	0.66	0.71	0.58	0.93	0.65	0.81	0.64	0.66
Organic carbon (g kg ⁻¹)	8.26	12.10	9.80	11.30	8.10	15.41	11.80	10.10	9.20	6.72
CEC [c mol (P ⁺) kg ⁻¹]	11.05	16.03	18.32	22.20	11.12	23.14	18.15	20.41	15.36	10.48
DTPA extractable Cd (mg kg ⁻¹)	0.14	0.13	0.11	0.14	0.11	0.13	0.12	0.10	0.14	0.10

Table 3: Distribution coefficient (K_d) by untreated and sludge treated soils

Soils	Treatment	Initial Cd concentration in solution (C ₀ , μmol L ⁻¹)							
		5	10	25	50	100	250	500	750
S ₁	1	46.30	38.70	23.04	12.95	9.65	7.46	5.17	3.89
	2	52.49	40.91	26.04	13.92	10.18	7.73	6.01	4.10
	3	60.31	43.29	29.07	14.99	10.74	8.01	6.20	4.28
S ₂	1	70.00	52.26	35.33	22.11	19.40	14.43	9.81	6.09
	2	83.78	64.68	43.10	23.46	20.27	14.74	9.93	6.31
	3	103.09	76.21	55.24	24.47	23.65	14.88	9.99	6.42
S ₃	1	60.30	52.26	32.24	22.11	19.40	14.43	8.51	5.96
	2	83.78	76.21	45.10	24.91	20.94	15.13	9.94	6.30
	3	103.09	92.59	54.05	28.01	22.57	15.37	10.13	6.71
S ₄	1	102.59	91.87	54.05	26.73	22.18	15.41	9.99	6.24
	2	130.45	102.07	68.02	31.63	24.46	16.46	10.39	7.28
	3	130.45	130.20	77.88	35.69	26.24	17.15	10.66	7.34
S ₅	1	70.00	60.0	34.72	22.11	19.40	14.43	9.80	6.10
	2	83.78	64.68	42.19	23.46	20.19	14.74	9.92	6.31
	3	102.59	76.21	55.24	24.91	21.11	15.36	10.13	6.50
S ₆	1	103.59	83.40	55.24	27.47	22.18	15.40	10.39	6.75
	2	130.45	102.04	70.32	31.63	23.43	15.84	10.58	7.24
	3	130.45	114.55	75.19	33.64	24.46	16.14	10.80	7.56
S ₇	1	60.30	46.08	30.30	22.11	19.40	14.64	9.81	5.99
	2	83.78	64.51	41.10	24.91	20.94	15.13	10.03	6.41
	3	103.09	76.21	49.80	29.03	23.23	15.61	10.39	6.91
S ₈	1	84.03	76.21	46.29	4.47	20.43	15.13	9.92	6.42
	2	103.09	83.40	54.05	26.73	22.18	15.61	10.06	6.75
	3	130.452	91.87	65.96	29.86	23.83	16.21	10.23	7.06
S ₉	1	37.17	33.27	18.12	12.48	9.22	4.70	4.0	3.02
	2	41.15	36.67	20.53	13.42	9.89	5.11	4.12	3.27
	3	46.29	38.69	22.67	14.45	11.33	5.44	4.38	3.67
S ₁₀	1	33.24	31.49	16.51	10.97	8.82	5.44	3.75	3.01
	2	37.17	30.08	18.38	11.78	9.44	6.05	4.26	3.23
	3	41.15	33.27	19.90	12.48	10.75	6.43	4.52	3.60

1 = Untreated soil 2 = Sludge treated soil @ 25 g kg⁻¹3 = Sludge treated soil @ 50 g kg⁻¹**Table 4. :** Coefficient of determination (R²) on sorption of Cd in untreated and sludge treated soils

Soils	Treatment	Linear	Freundlich	Langmuir	Two-surface Langmuir
S ₁	1	0.923	0.997	0.915	0.998
	2	0.921	0.996	0.910	0.999
	3	0.923	0.996	0.913	0.999
S ₂	1	0.891	0.995	0.956	0.997
	2	0.899	0.996	0.950	0.999
	3	0.904	0.994	0.948	0.999
S ₃	1	0.887	0.994	0.963	0.997
	2	0.896	0.995	0.959	0.998
	3	0.909	0.995	0.958	0.999
S ₄	1	0.913	0.995	0.940	0.999
	2	0.917	0.996	0.943	0.999
	3	0.925	0.997	0.942	0.999
S ₅	1	0.892	0.995	0.958	0.999
	2	0.903	0.996	0.953	0.996
	3	0.903	0.994	0.952	0.998
S ₆	1	0.909	0.996	0.946	0.998
	2	0.923	0.996	0.943	0.999
	3	0.918	0.995	0.942	0.999
S ₇	1	0.884	0.994	0.935	0.997
	2	0.892	0.994	0.940	0.997
	3	0.913	0.997	0.940	0.998
S ₈	1	0.903	0.995	0.951	0.999
	2	0.901	0.995	0.948	0.997
	3	0.918	0.996	0.947	0.999

S ₉	1	0.912	0.996	0.901	0.987
	2	0.924	0.996	0.903	0.988
	3	0.923	0.996	0.900	0.997
S ₁₀	1	0.921	0.997	0.928	0.994
	2	0.924	0.997	0.924	0.999
	3	0.920	0.998	0.919	0.999

1 = Untreated soil, 2 = Sludge treated soil @ 25 g kg⁻¹, 3 = Sludge treated soil @ 50 g kg⁻¹

Table 5: Freundlich and two-surface Langmuir parameters by untreated and sludge treated soils

Soils	Treatment	Freundlich parameters		Two-surface Langmuir parameters				b ₁ + b ₂ (μmol kg ⁻¹)
		K _f	1/n	Region – I		Region – II		
				K ₁ (1 μmol ⁻¹)	b ₁ (μmol kg ⁻¹)	K ₂ x 10 ⁻³ (1 μmol ⁻¹)	b ₂ (μmol kg ⁻¹)	
S ₁	1	46.98	0.61	1.18	81.10	3.25	3305.95	3387.05
	2	50.35	0.61	1.05	86.14	3.17	3427.23	3513.37
	3	56.75	0.60	1.03	91.72	3.06	3569.52	3661.24
S ₂	1	61.94	0.65	6.09	31.94	6.02	3886.16	3918.10
	2	70.79	0.63	5.07	57.61	5.75	3979.20	4036.81
	3	80.16	0.60	3.20	81.09	5.45	4058.91	4139.91
S ₃	1	58.88	0.61	4.20	30.98	6.52	3790.12	3821.10
	2	74.13	0.59	3.89	65.54	6.00	3914.89	3980.43
	3	84.13	0.59	1.62	110.77	5.49	4106.30	4217.07
S ₄	1	82.41	0.64	1.57	111.13	5.23	4147.59	4258.72
	2	94.84	0.63	1.08	161.02	5.09	4294.47	4455.49
	3	98.62	0.61	0.79	214.36	4.62	4523.88	4738.24
S ₅	1	63.67	0.60	3.95	52.00	6.01	3901.53	3953.53
	2	70.30	0.59	3.69	76.98	5.61	4023.38	4100.36
	3	80.35	0.48	3.42	77.48	5.14	4023.63	4108.11
S ₆	1	83.36	0.60	1.73	106.21	5.30	4196.91	4303.12
	2	94.84	0.59	1.11	164.54	4.60	4499.69	4664.23
	3	102.32	0.48	0.75	216.68	4.05	4752.34	4969.02
S ₇	1	56.23	0.67	3.81	31.24	6.61	3803.64	3834.88
	2	71.45	0.63	1.66	76.91	6.34	3850.26	3927.17
	3	80.16	0.62	1.08	212.93	5.21	4249.04	4370.97
S ₈	1	74.30	0.62	3.57	68.51	5.68	4018.92	4087.43
	2	89.03	0.61	1.85	118.26	5.30	4188.52	4306.77
	3	91.83	0.59	1.13	150.59	5.04	4288.32	4438.41
S ₉	1	44.05	0.58	5.25	28.59	6.81	3383.52	3412.11
	2	46.34	0.58	3.98	60.34	6.12	3552.69	3613.03
	3	49.31	0.57	1.87	101.44	5.61	3741.58	3843.02
S ₁₀	1	39.81	0.66	1.21	64.23	2.51	2811.69	2875.92
	2	41.97	0.60	0.26	147.43	2.42	3865.85	3013.28
	3	44.25	0.60	0.18	160.76	2.01	3235.53	3396.29

1 = Untreated soil, 2 = Sludge treated soil @ 25 g kg⁻¹, 3 = Sludge treated soil @ 50 g kg⁻¹

Table 6: Correlation between soil properties with Freundlich parameters (K_f and 1/n) and total sorption maxima (b₁+b₂)

Soil properties	Treatment	K _f	1/n	(b ₁ +b ₂)
pH	1	-0.390	-0.494	-0.427
	2	-0.333	0.473	-0.477
	3	0.008	0.236	-0.133
Organic carbon	1	0.721*	0.050	0.762*
	2	0.764*	-0.175	0.792**
	3	0.763*	-0.454	0.825**
CaCO ₃	1	0.348	0.097	0.152
	2	0.243	0.231	0.260
	3	0.262	0.108	0.178
Clay	1	0.735*	0.118	0.713*
	2	0.746**	-0.189	0.712*
	3	0.748*	-0.372	0.791**
CEC	1	0.821**	0.056	0.811**
	2	0.851**	-0.189	0.822**
	3	0.817**	-0.511	0.912**

1 = Untreated soil

2 = Sludge treated soil @ 25 g kg⁻¹

3 = Sludge treated soil @ 50 g kg⁻¹

* = Significant at 5% level

** = Significant at 1% level

Conclusions

The results of this investigation indicate that the retention of Cd by untreated and sludge treated soils was satisfactorily described by Freundlich and two-surface Langmuir equation. The enrichment of soil with sludge increased the retention of Cd by soils due to increase in organic carbon and CEC of the soils. The sorption capacity (b₁+b₂) of untreated and treated soils were significantly and positively correlated with organic carbon and CEC indicating application of sludge to the soils had a dominating role in enhancing the Cd sorption due to increase in organic surfaces/adsorption sites to the soils and formation of stable complexes with organic matter. The use of sludge in soils thus, may reduce the potential toxicity hazards of heavy metals in soils and plants.

References

- Adhikari T, Singh MV. Cadmium sorption characteristics of major soils of India in relation to soil properties. Journal of the Indian Society of Soil Science, 2000; 48:757-762.
- Backes CA, McLaren RG, Rate AW, Swift RS. Kinetics of cadmium and cobalt desorption from iron and

- manganese oxides. *Soil Science Society of America Journal*, 1995; 59:778-785.
3. Bingham FT, Page AL, Mahler RJ, Ganje TJ. Growth and Cadmium accumulation of plants grown on a soil treated with a cadmium enriched sewage sludge. *Journal of Environmental Quality*, 1975; 4:207-211.
 4. Cavallaro N, McBride MB. Copper and cadmium adsorption characteristics of selected acid and calcareous soils. *Soil Science Society of America Journal*, 1978; 42:550-556.
 5. Deka AK, Poonia SR. Effect of pH on cadmium sorption in untreated and farmyard manure treated soil from a semi-arid region. *Journal of the Indian Society of Soil Science*, 2001; 49:686-690.
 6. Elliott HA, Liberati MR, Huang CP. Competitive adsorption of heavy metals by soils. *Journal of Environmental Quality*, 1986; 15; 214-219.
 7. Gray CW, McLaren RG, Roberts AHC, Condron LM. Sorption and desorption of cadmium from some New Zealand soils: Effect of pH and contact time. *Australian Journal of Soil Research*, 1998; 36:199-216.
 8. Hundal HS, Raj Kumar, Arora CL. Cadmium adsorption by some alkaline soils of Punjab state. *Agropedology*, 2003; 13(1):17-24.
 9. Jackson ML. *Soil Chemical Analysis*, Prentice Hall of India, New Delhi., 1973.
 10. Kumar V. Distribution, reactions and transport of Cd and Ni in sludge treated old alluvial soils. Ph.D. Thesis submitted to Rajendra Agricultural University, Pusa, Bihar., 2005.
 11. Lindsay WL, Norvell W.a. Development of DTPA Soil Test for zinc, iron, manganese and copper. *Soil Science Society of America Journal.*, 1978; 42:421-428.
 12. Mehta SC, Sinwar Pankaj, Grewal KS. Effect of organic matter and clay content on cadmium adsorption in calcium-saturated soils from semi-arid region. *Journal of the Indian Society of Soil Science*, 2004; 52:434-438.
 13. Navas A, Bermudez F, Machin J. Influence of sewage sludge application on physical and chemical properties of Gypsisols. *Geoderma*, 1998; 87:123-125.
 14. Pandeya SB. Thermodynamics of adsorption of iron-fulvic complexes on soils. *Journal of the Indian Society of Soil Science*, 1991; 39:650-657.
 15. Rattan RK, Sahgal Deepak, Investigation on cadmium adsorption on soils differing in physical and chemical characteristics. *Journal of the Indian Society of Soil Science*, 1989; 37:284-289.
 16. Singh AK, Pandeya SB. Sorption and release of cadmium fulvic acid complexes in sludge treated soils. *Bioresource Technology*, 1998; 66:119-127.
 17. Singh B, Sekhon GS. Adsorption, desorption and solubility relationship of lead and cadmium in some alkaline soils. *Journal of Soil Science*, 1977; 28:271-275.
 18. Soon YK. Solubility and sorption of cadmium in soils limed with sewage sludge. *Journal of Soil Science*, 1981; 59:119-130.
 19. Sposito Garrison. On the use of the Langmuir equation in the interpretation of "adsorption" phenomena II. The "two-surface" Langmuir equation. *Soil Science Society of America Journal*, 1982; 46:1147-1152.
 20. Stevenson FJ. Organic matter reaction involving metal ions in soils. In: *Humus chemistry (Genesis, Composition and Reactions: Wiley Interscience Publication, John Wiley and Sons, New York., 1982, 337-354.*
 21. Tessier AP, Campbell GC, Bisson M. Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry*, 1979; 51:844-851.
 22. Thakur SK, Tomar NK, Pandeya SB. Influence of phosphate on cadmium sorption by CaCO₃. *Geoderma*, 2006; 130:240-249.
 23. Wilkens BJ, Loch JPG. Accumulation of cadmium and zinc from diffuse immersion on acid sandy soils, as a function of soil composition. *Water, Air and Soil Pollution*, 1997; 96:1-16.