Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.2972

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (3):** 582-595 (2017)

Research Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Impact of Long-Term Green Manuring on Adsorption-Desorption Behavior of Zinc in Calcareous Soil

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Received: 12.05.2017 | Revised: 23.05.2017 | Accepted: 24.05.2017

ABSTRACT

*A long-term field experiment was carried out with green manuring to see the Zn- adsorption-desorption behaviors of soil. After completion of 5^{th} cycle, adsorption process was executed by equilibrating 2.0g soil in 40ml 0.01M $CaCl_2$ solution containing 5, 7.5, 10, 15, 25, 50, 75, 100, 150 and 200 mg ZnL^{-1}. The equilibrium Zn concentration varied from 0.44 to 76.16 and 0.42 to 70.52 mg L^{-1} at 15 and 30^0C, respectively due to different treatments with varying levels of Zn-concentration from 5 to 200 mg L^{-1}. Adsorption data were fitted into Freundlich and Langmuir adsorption equations as evidenced by higher Freundlich R^2 values ranging from 0.9909** to 0.9972** at $15^{\circ}C$ and 0.9888** to 0.9980** at $30^{\circ}C$ whereas, Langmuir R^2 values varying from 0.9748** to 0.9955** at 15^0C and 0.9713** to 0.9912** at 30^0C. The maximum adsorption of Zn was observed in the treatment T_9-10 t FYM ha^{-1} every year and followed by green manuring treatments. The desorption study indicated that DTPA extracted maximum adsorbed Zn and followed by NH_4OAc and Distilled water at both15 and 30^0C temperature. In conclusions, Zn adsorption-desorption capacity of soils can be enhanced by manuring which can also increase the use efficiency of micronutrient fertilizers.*

Key words: *Adsorption, Desorption, Freundlich, Langmuir equation, Organics, Zinc.*

INTRODUCTION

Micronutrient deficiencies in Indian soils and crops have been on the increase since the adoption of modern agricultural technology with increased use of high analysis NPK fertilizers generally free from micronutrients. Imbalanced nutrient applications have resulted in failure of nutrient addition to keep pace with nutrient removal by crops especially in case of Zinc[9]. The calcareous soils of Bihar occupying a sizeable area, are deficient in zinc to the extent of up-to 80 per cent of tested soil samples[22] and Symptoms of Zinc deficiency are frequently observed on many crops[20]. Zinc deficiencies are common in plant growing on calcareous and alkaline soils, although the zinc content of these soils is no less than that of non calcareous soils.

Cite this article: Kumar, S., Impact of Long-Term Green Manuring on Adsorption-Desorption Behavior of Zinc in Calcareous Soil, *Int. J. Pure App. Biosci.* **5(3):** 582-595 (2017). doi: http://dx.doi.org/10.18782/2320-7051.2972

The effects of pH, temperature and soil components on Zn sorption by calcareous soils were studied by Lin and Xue[13,14], the sorption isotherms of Zn(II) on the untreated soils and the treated soils to remove $CaCO_3$, organic matters and oxides were respectively determined, the results of the sequential extraction of Zn(II) sorbed on the calcareous soil were reported and it was concluded that at a high pH range the contribution of $CaCO_3$ on Zn sorption was approximately 70% of the total amount sorbed by a yellow fluvo-aquic soil (content of CaCO3, 12.4%) and at low pH the contribution became less significant[23]. The same as Wenming *et al*[25]., indicated that the $CaCO_3$ in calcareous soil is undoubtedly the most significant sink for zinc at high pH range. Occurrence of Zinc deficiency in soil suggested that both native and applied forms of zinc react with the inorganic and organic phases in the soil and thereby affect its availability. Zinc is known to occur in soils in a number of discrete chemical forms differing in their solubility and thus, availability to plants[18,24]. The availability of this nutrient element to plants is governed by dynamic equilibrium involving these different forms and the extent to which the Zn in solution phase is buffered by the response of solid solution phase Zn to crop demand rather than its total content in soil[2,6,8]. Adsorption process of Zn ion in soil controls its availability to plants which is largely influenced by soil properties. It is well known that adsorption of Zn is highly pH dependent and major portion of adsorbed Zn are present as solid or chemically precipitated form at high pH than the ionically adsorbed one. It has been assumed that H^+ ion gets released from adsorbed Zn^{2+} on the surface of Al_2O_3 and Fe_2O_3, suggesting that surface aqua ($-OH_2$) and hydroxy (-OH) groups were involved in Zn adsorption. However, Zn applied to calcareous soils appears to be ionically adsorbed with precipitation as carbonates. Hence, it is important to study adsorption-desorption of Zn in calcareous soils specially as influenced by organics addition[3]. Dhaincha, FYM, green gram, crop residues, sunhemp are important renewable organic sources of nutrients. Large quantities of organic matter are available with the farmers which can be utilized as complementary source to chemical fertilizers. Besides supplementing the fertilizer for major nutrients, green manure and organic manure are also important in improving soil quality[4,10,17].

Organic complex formation should influence the concentration and mobility of Zn. The amount of Zn in solution is likely to exist in equilibrium with specifically adsorbed forms associated with soil organic phase. Organic matter affects Zn adsorption to a great extent. The dissolution of organic matter in the soil solution at high pH reduces Zn adsorption by soil. Such information as well as importance and chemistry of zinc reactions for soil of Bihar in general and calcareous belt of North Bihar in particular is lacking. In this study, the aim is to determine Zn absorption situations in the calcareous soil where cereals are densely cultivated and to examine its compatibility with Langmuir and Freundlich isotherms and to avoid unnecessary fertilizer applications by accurately determining Zn fertilizer amount to be given to the soils with help of the isotherms.

MATERIAL AND METHODS

A long-term field experiment was started in Kharif 2000 in light textured highly calcareous soil at RAU Research farm, Pusa. The experimental soil had pH 8.40, EC 0.32 dSm^{-1}, OC 3.80 g kg^{-1}, CEC 8.2 [cmol (p^+) kg^{-1}], Free $CaCO_3$ 34.40% and available Zn 0.73 mg kg^{-1}. The experiment was laid out in a RBD with following treatment details as T_1-control, T_2-Sunhemp every year, T_3-sunhemp alternate year, T_4-Dhaincha every year, T_5-Dhaincha alternate year, T_6- Green gram every year, T_7-Green gram + 2.5 t FYM ha^{-1} every year, T_8-Green gram + 5.0 t FYM ha^{-1} every year, T_9-10 t FYM ha^{-1} every year and T_{10}-10 kg Zn ha^{-1} alternate year. These were mixed thoroughly though out the respective experimental plot one week prior to transplanting of rice. After completion of 5^{th} cycle (2005) soil samples were collected and available Zn was extracted with DTPA solution[15] were determined using Atomic Absorption Spectrophotometer (Perkin Elmer A Analyst-100) To study the adsorption behavior of Zn, 40ml of 0.01 M $CaCl_2$ solution containing graded concentration of Zn (5, 7.5, 10, 15, 25, 50, 75 100, 150 and 200 ppm) were added to 2 g soil in each polypropylene bottle. The soil suspensions were equilibrated at 15 and 30 ± 2^0C for 48 hours within treatment shaking each time at least for 15 minutes. In the extract zinc was determined by AAS. The amount adsorbed was obtained from the difference between initial zinc added and that remaining after equilibration. The parameters of adsorption were calculated by fitting the experimental data into the linear forms of different adsorption isotherms models as described below:

(a) Langmuir adsorption isotherm[12]

$$\frac{\mathrm{Ce}}{\mathrm{x/m}} = \frac{1}{\mathrm{Kb}} + \frac{\mathrm{Ce}}{\mathrm{b}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

A plot of Ce/x/m Vs Ce yield a straight line, where

Ce = The equilibrium Zn concentration in solution (mg Zn L^{-1})

x/m = The amount of Zn adsorbed per gram soil (mg Zn kg^{-1})

K = Constant related to the bonding energy (mg L^{-1}) of adsorption as obtained by dividing the slope (1/b) by the intercept (1/Kb)

B = The adsorption maxima (mg kg^{-1}), which is reciprocal of the slope (1/b) of the regression equation.

(b) Freundlich adsorption isotherm[7]

The adsorption data were fitted into Freundlich adsorption isotherm as per equation below:

$x/m = K.Ce^{1/n}$ ....(2)

or linear expansion of this equation is:

log x/m = log K + 1/n log Ce ....(3)

A plot of log x/m Vs log Ce yields a straight line where,

x/m = amount of Zn adsorbed per unit mass (Soil) (mg kg^{-1})

Ce = The Zn concentration in equilibrium solution (mg L^{-1})

K and **n** are imperial constants where 1/n can be obtained from the slope and K from anti-logarithm value of intercept.

Desorption: A 10g sample of each soil was first equilibrated at 15 and 30 ± 2^0C for 48 hours with 20 ml solution of 10 ppm Zn. The soil samples were sequentially extracted with distilled water (DW), neutral normal ammonium acetate (1N NH_4OAc) and DTPA (pH 7.3). The amount of Zn in the extractants was determined on an Atomic Absorption Spectrophotometer Samples were sequentially extracted with distilled water, 1N NH_4OAc and DTPA, and Zn desorption was determined by AAS.

RESULTS AND DISCUSSION

Zinc Adsorption

When zinc is released from soil minerals or added through inorganic fertilizers, equilibrium reactions become operative between solution and exchangeable phase of soil. Zinc status in soil greatly influences the zinc chemistry. Adsorption reactions of Zinc in soils are important to understand the solid and solution phase interaction determining the release and fixation of applied zinc and thereby the efficiency of fertilization. The zinc concentration in equilibrium solution as results of solid and solution phase interaction at varying level of Zn-application for different treatments at 15^0C and 30^0C are presented in Table 1 and 2, respectively. There is a wide variation of Zn concentration in equilibrium solution in the soil under different treatments even at same level of Zn application. The equilibrium Zn concentration varied from 0.44 to 76.16 and 0.42 to 70.52 mg L^{-1} at 15 and 30^0C, respectively due to different treatments with varying levels of Zn-concentration from 5 to 200 mg L^{-1}. The amount of Zn adsorbed, calculated by subtracting the equilibrium Zn-concentration from the quantity of Zn-added, varied from 73.00 to 3286.40 and 74.40 to 3468.20 mg kg^{-1} in different treatments at 15^0C and 30^{0}C, respectively. The adsorption by soils increased with increasing levels of added zinc. At lower level of zinc concentration, the percentage of zinc adsorbed was more as compare to higher level of zinc addition (Fig 1).This revealed the higher affinity of zinc towards solid phase at lower concentration whereas; at higher Zn-concentration its affinity was more for solution phase. It is also apparently visible from the treatment mean (Fig 1) that per cent impact of different green manuring crops, FYM alone or conjoint with green gram and $ZnSO_4$ treatments varied from 69.95 to 88.01% at 15^{0}C temperature whereas, 72.94 to 89.75% at 30^{0}C temperature. The maximum amount of Zn adsorbed (3468.20 mg kg^{-1}) was noted at 30^{0}C temperature which may be due to the fact that free energy of zinc adsorption becomes increasingly negative with increase in temperature as reported by Adhikari and Rattan[1] and Kamini *et al*[10]. Among the green manure crops, green manuring with dhaincha provided almost similar trend with respect to Zn-adsorption at both 15 and 30^{0}C temperature.

The zinc adsorption isotherm curve (Fig 4 & 5) indicated that the soils produced L-type of adsorption isotherm indicating that at lower level of zinc concentration, the affinity of zinc to remain in the solution phase was less pronounced as compared to solid phase. As the concentration increases, the affinity of Zn becomes more for solution phase than solid phase. The nature of isotherm suggested that adsorption maxima are not obtained up to highest zinc level under study. The experimental data of zinc adsorption on different soils were tried to be fitted into different linear forms of adsorption isotherm equations (Freundlich and Langmuir adsorption isotherm) to explain the adsorption behavior of zinc. The plots of the data for all treatments on log x/m Vs log Ce was found to be the best fit in describing the Zn adsorption as (Freundlich equation) shown in Fig (6 & 7). Fitting of Zn-adsorption data to the linear form of Freundlich equation corroborates the findings of Krishnasamy and Krishnamoorthy[11], and Kamini *et al*[10]. A linear relationship was observed for all treatments as also evidenced by high R^2 values varying from 0.9909 to 0.9972 and 00.9888 to 0.9980 at 15 and 30^{0}C, respectively. The adsorption parameters as work out from Freundlich adsorption equation are presented in Table 3 and 4. The adsorption parameters '1/n' and 'K' values ranged from 0.7571 to 0.8922 and 0.7952 to 0.9056 at 15^{0}C and 0.2498 to 0.3593 and 0.2621 to 0.3636 at 30^{0}C, respectively due to different treatments. The value of 'K' is a measure of the adsorbability of the compound in the surface and the value of 'n' serves as the energy of adsorption. The values of 1/n in soil are less than unity indicating that the amount of zinc adsorbed increased less rapidly than the concentration in solution. The higher values of 'K' in green manuring as well as FYM, treatment as compare to control and $ZnSO_4$ application showed higher adsorbability of the compound in surface with low Zn-concentration. This might be due to the fact that high organic matter in treated soil probably generated the adsorbing sites exercised greater selectivity or preference for adsorption of Zn[1].

The data on Zn adsorption in soils were fitted into Langmiur adsorption isotherm model and have been depicted in (Fig 8 & 9). A linear relationship was observed for all treatments which were confirmed by high R^2 values varying from 0.9748 to 0.9955 at 15^{0}C and 0.9713 to 0.9912 at 30^{0}C due to different treatments as shown in Table 5 and 6. The langmuir adsorption parameters viz., adsosrption maxima (b) and bonding energy (k) for the treatments are presented in Table 5 and 6. Fitting of Zn adsorption data in the linear form of Langmuir equation corroborates the findings of many earlier workers[16,19,21]. Perusal of the data revealed that the adsorption maxima varied from 5000 to 10000 mg kg^{-1} at both 15^{0}C and 30^{0}C temperature whereas, the bonding energy ranged from 0.00980 to 0.03846 and 0.0111 to 0.04167 mg L^{-1} these were corroborates the findings of Kamini *et al*[10].

Zinc Desorption

All the soils for desorption studies were equilibrated with 20 μg g^{-1} Zn as $ZnSO_4$ for the preparation of Zinc saturated soil. The amount of Zn adsorbed by soils under different treatments (16.01 to 18.98 and 17.82 to 19.42 μg g^{-1} soil at two temperature, 15 and 30^0C, respectively) are presented in Table 7 and 8. This adsorbed Zn was utilized for calculating per cent of adsorbed Zn desorbed at 15 and 30^0C temperature for soils under different treatments. The concentration of Zn desorbed at 15^0C and 30^0C temperature widely varied by distilled water (0.45 to 0.82 and 0.50 to 0.95 μg g^{-1} soil), NNH_4OAc (1.64 to 2.90 and 1.80 to 3.21 μg g^{-1} soil) and DTPA (4.00 to 6.89 and 4.48 to 7.81 μg g^{-1} soil) as influenced with different treatments Table 7 and 8. The results showed that the amount of Zn extracted out of the amount retained by different soils under different treatments by distilled water, NNH_4OAc and DTPA ranged from 2.81-4.32, 10.27-15.36 and 25.02-36.34 per cent, respectively at 15^0C whereas, 2.82-4.87, 10.10-16.50 and 25.15-40.26 per cent, respectively at 30^0C temperature (Fig 2 & 3). This reveals that a major portion of adsorbed Zn is retained in the exchangeable form in these soils. The quantity of Zn extracted by these three extractants together varied from 38.10 to 55.94 % and 38.07 to 61.58% at 15 and 30^0C temperature, respectively of the adsorbed amount indicating that a portion of applied Zn is retained by the soils in forms, other than exchangeable or chelated and may, therefore, be unavailable to plants as reported by Chatterjee and Mandal[5]. In conclusions: The Zn adsorption-desorption capacity of soil are enhanced by every year green manuring or 10 t ha^{-1} FYM application which can enhance the efficiency of micronutrient fertilizers and maintain micronutrient nutrition to plants.

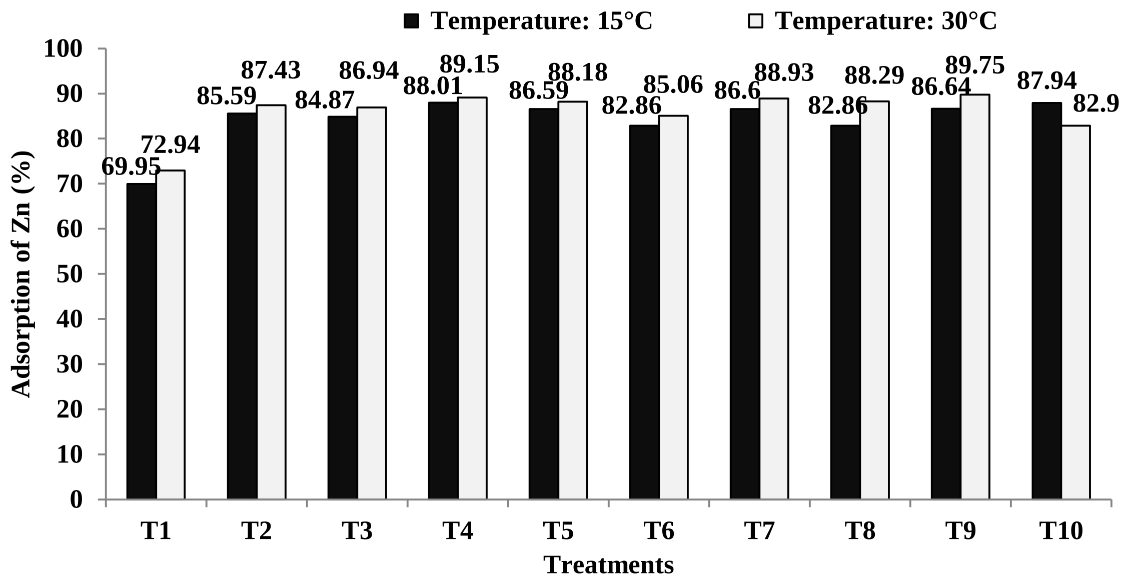

Fig. 1: Percentage of applied zinc adsorbed at equilibrium in different soil at 15^0C and 30^0C

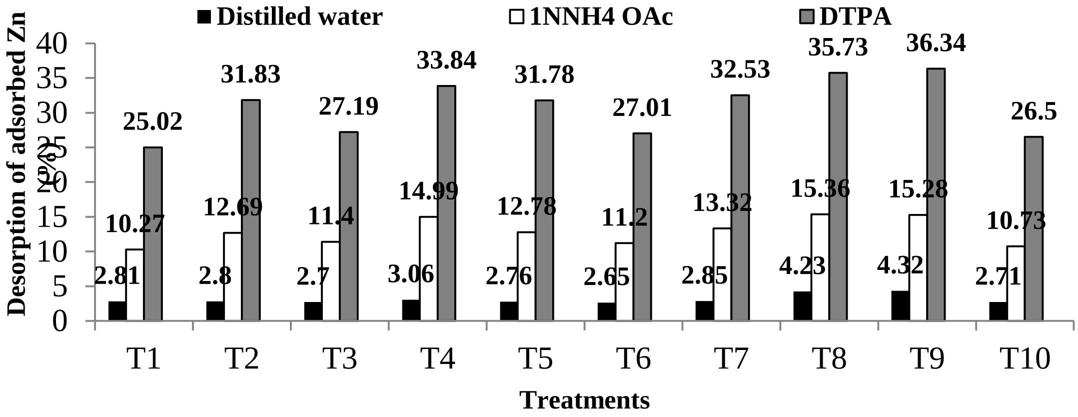

Fig. 2: Percent of adsorbed Zinc desorbed by different extractants at 15°C

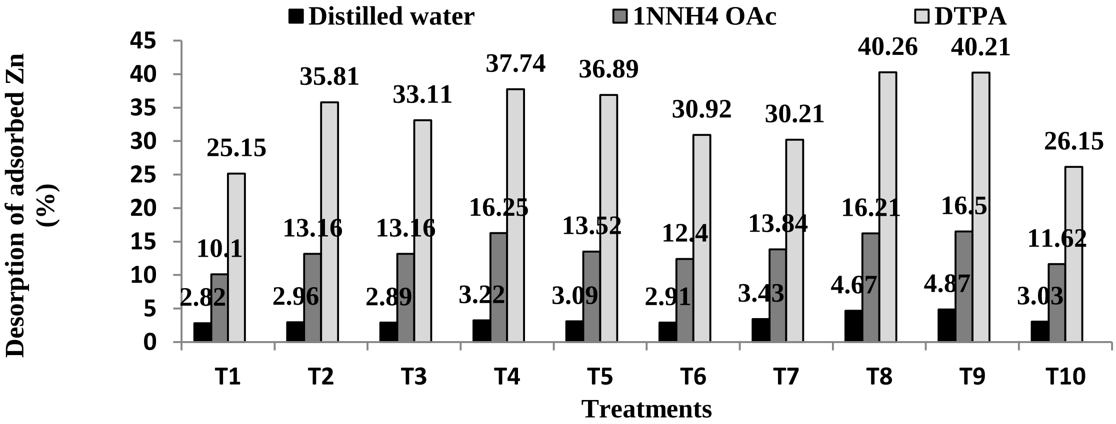

Fig. 3: Percent of adsorbed Zinc desorbed by different extractants at 30°C

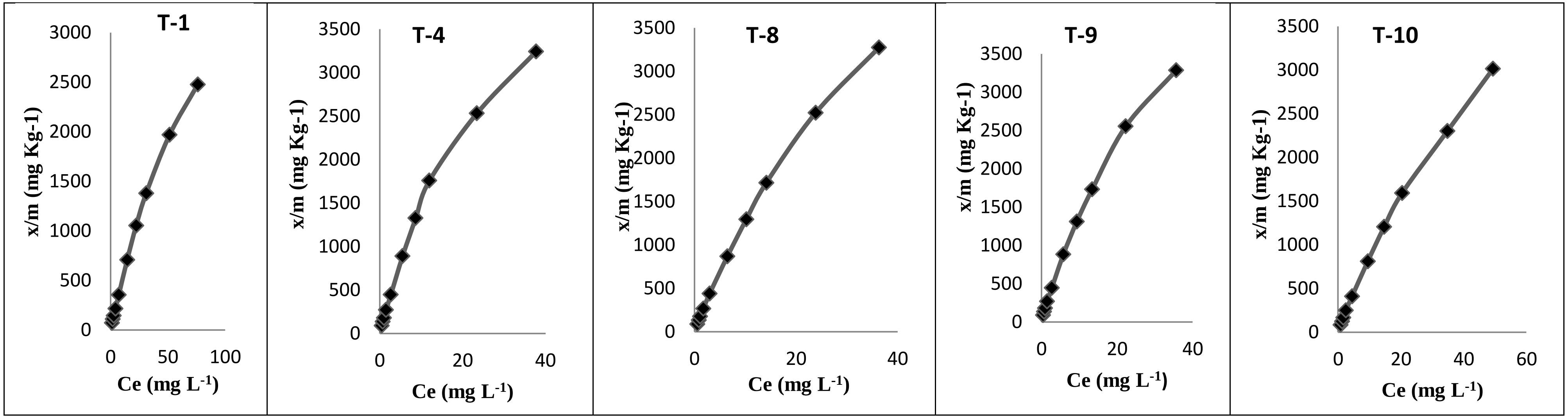

Fig. 4: Isotherm of Zinc Adsorption in soils of treatment no. T-1, T-4, T-8, T-9 and T-10 at 15^{0}C

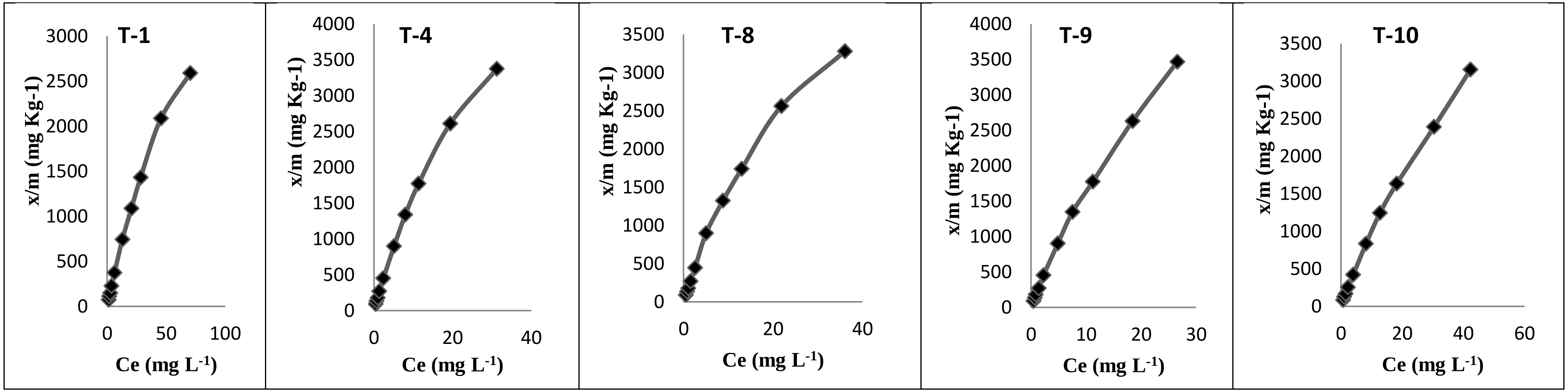

Fig. 5: Isotherm of Zinc Adsorption in soils of treatment no. T-1, T-4, T-8, T-9 and T-10 at 30^{0}C

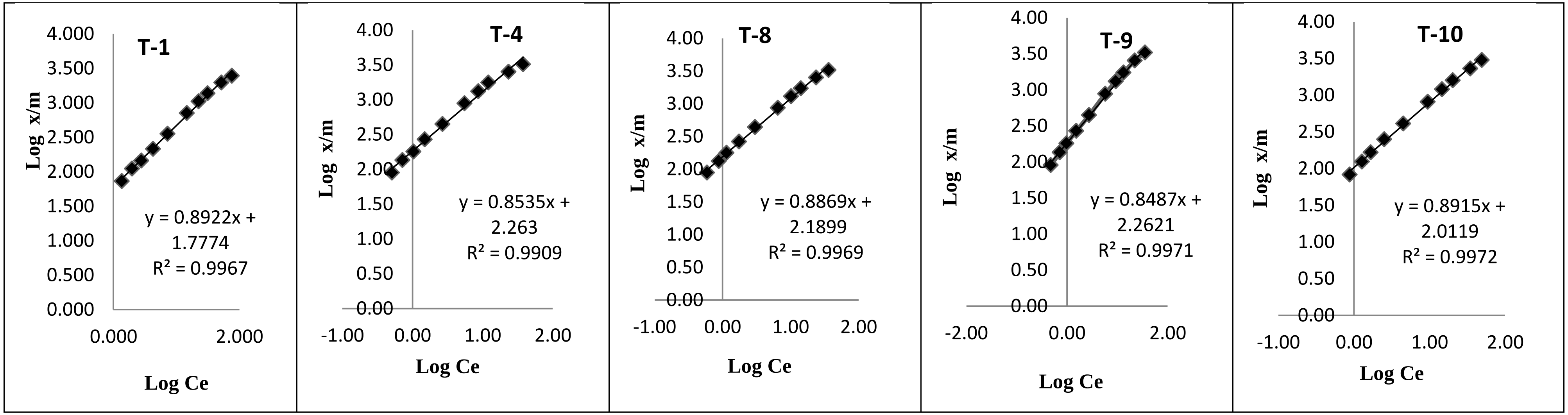

Fig. 6: Freundlich adsorption isotherm for Zinc in soils of treatment no.T-1, T-4, T-8, T-9 and T-10 at 15^{0}C

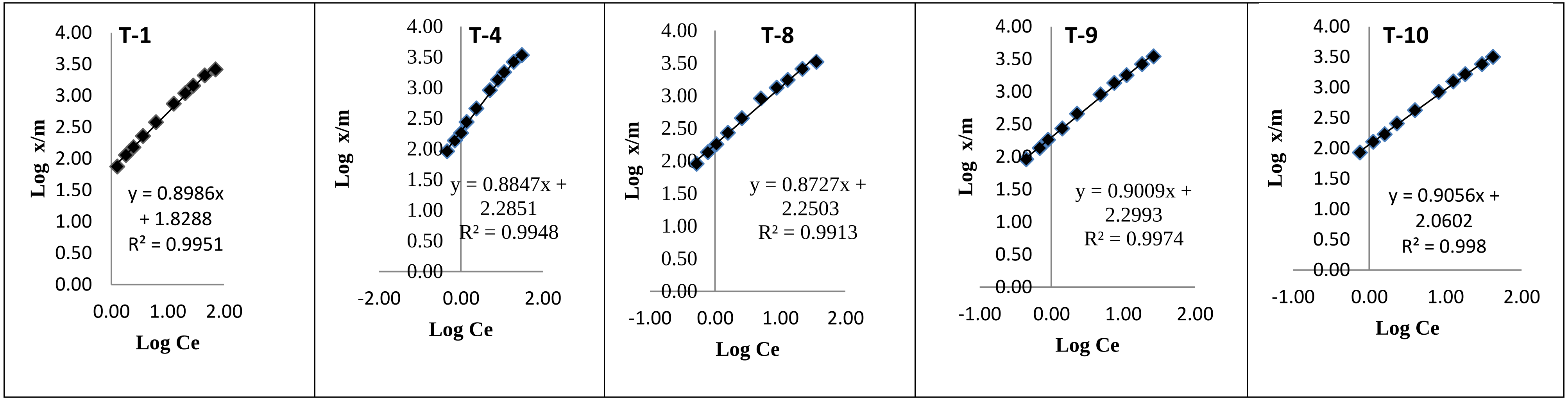

Fig. 7: Freundlich adsorption isotherm for Zinc in soils of treatment no.T-1, T-4, T-8, T-9 and T-10 at 30^{0}C

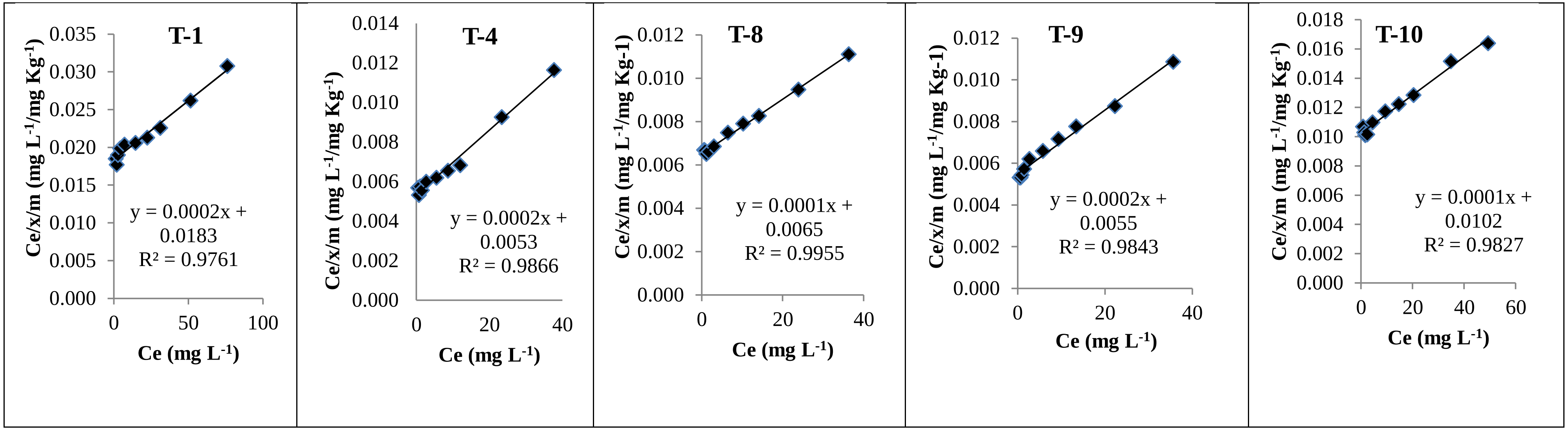

Fig. 8: Langmuir adsorption isotherm for Zinc in soils of treatment no.T-1, T-4, T-8, T-9 and T-10 at 15^{0}C

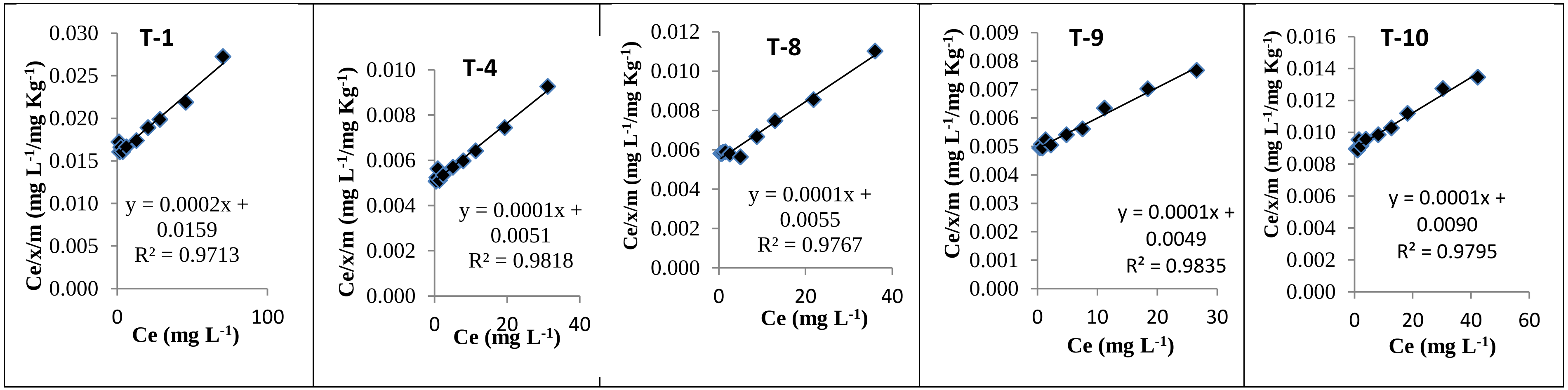

Fig. 9: Langmuir adsorption isotherm for Zinc in soils of treatment no.T-1, T-4, T-8, T-9 and T-10 at 30^{0}C

Table 1: Equilibrium zinc concentration (mg L^{-1}) at different Zinc levels (15^0C)

Treatments	Zinc Levels (mg L^{-1})									
	5	**7.5**	**10**	**15**	**25**	**50**	**75**	**100**	**150**	**200**
T_1 – Control	1.35	1.96	2.75	4.26	7.23	14.57	22.38	31.11	51.55	76.16
T_2 – Sunhemp (every year)	0.56	0.82	1.07	1.82	3.15	7.03	11.55	16.03	27.63	45.12
T_3 – Sunhemp (alternate year)	0.58	0.88	1.23	1.85	3.17	6.75	11.10	15.73	27.54	48.50
T_4 – Dhaincha (every year)	0.51	0.72	1.03	1.50	2.67	5.50	8.67	12.00	23.43	37.76
T_5 – Dhaincha (alternate year)	0.44	0.69	0.99	1.42	2.37	6.44	10.86	16.47	28.63	48.66
T_6 – Green gram (every year)	0.72	1.06	1.42	2.15	3.87	7.85	12.53	19.36	32.80	50.06
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	0.50	0.79	1.01	1.58	3.00	6.27	10.68	15.00	25.44	43.12
T_8 – Green gram + 5t FYM ha^{-1} (every year)	0.59	0.88	1.15	1.75	3.01	6.51	10.23	14.17	23.88	36.32
T_9 – 10.0 t FYM ha^{-1} (every year)	0.48	0.72	0.98	1.54	2.76	5.82	9.39	13.44	22.31	35.68
T_{10} – 10 kg Zn ha^{-1} (alternate year)	0.88	1.28	1.67	2.53	4.50	9.50	14.73	20.42	34.88	49.37

Table 2: Equilibrium zinc concentration (mg L^{-1}) at different Zinc levels (30^0C)

Treatments	Zinc Levels (mg L^{-1})									
	5	**7.5**	**10**	**15**	**25**	**50**	**75**	**100**	**150**	**200**
T_1 – Control	1.28	1.82	2.49	3.65	6.24	12.89	20.57	28.41	45.65	70.52
T_2 – Sunhemp (every year)	0.51	0.78	1.08	1.60	2.72	5.56	9.13	13.26	23.50	41.05
T_3 – Sunhemp (alternate year)	0.54	0.79	1.06	1.71	2.98	5.71	9.54	14.03	25.66	42.11
T_4 – Dhaincha (every year)	0.46	0.71	1.01	1.39	2.41	5.11	7.99	11.36	19.42	31.25
T_5 – Dhaincha (alternate year)	0.42	0.65	1.00	1.35	2.24	5.34	8.72	13.46	24.63	42.03
T_6 – Green gram (every year)	0.60	1.00	1.23	1.98	3.22	6.89	10.87	16.24	28.80	44.01
T_7– Green gram + 2.5t FYM ha^{-1} (every year)	0.48	0.68	0.92	1.52	2.02	4.87	7.72	10.73	19.80	32.33
T_8 – Green gram + 5t FYM ha^{-1} (every year)	0.52	0.78	1.05	1.58	2.59	5.06	8.82	13.00	21.90	36.08
T_9 – 10.0 t FYM ha^{-1} (every year)	0.45	0.69	0.90	1.42	2.29	4.88	7.56	11.25	18.47	26.59
T_{10} – 10 kg Zn ha^{-1} (alternate year)	0.76	1.13	1.60	2.32	4.01	8.22	12.77	18.26	30.45	42.36

Table 3: Freundlich adsorption parameters and regression equation of Zinc for soils at different treatments (15^0C)

Treatments	**1/n**	**K**	**Regression equation**			**R^2**
T_1 – Control	0.8922	0.2498	Y (log x/m)	=	1.7774 + 0.8922x	0.9967
T_2 – Sunhemp (every year)	0.8196	0.3438	Y (log x/m)	=	2.2072 + 0.8196x	0.9957
T_3 – Sunhemp (alternate year)	0.8315	0.3402	Y (log x/m)	=	2.1890 + 0.8315x	0.9914
T_4 – Dhaincha (every year)	0.8535	0.3547	Y (log x/m)	=	2.2630 + 0.8535x	0.9909
T_5 – Dhaincha (alternate year)	0.7571	0.3593	Y (log x/m)	=	2.2874 + 0.7571x	0.9913
T_6 – Green gram (every year)	0.8478	0.3237	Y (log x/m)	=	2.1073 + 0.8478x	0.9939
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	0.8171	0.3506	Y (log x/m)	=	2.242 + 0.8171x	0.9949
T_8 – Green gram + 5t FYM ha^{-1} (every year)	0.8873	0.3404	Y (log x/m)	=	2.1898 + 0.8873x	0.9969
T_9 – 10.0 t FYM ha^{-1} (every year)	0.8487	0.3545	Y (log x/m)	=	2.2621 + 0.8487x	0.9971
T_{10} – 10 kg Zn ha^{-1} (alternate year)	0.8910	0.3038	Y (log x/m)	=	2.0126 + 0.8910x	0.9972

Table 4: Freundlich adsorption parameters and regression equation of Zinc for soils at different treatments (30^0C)

Treatments	1/n	K	Regression equation			R^2
T_1 – Control	0.8986	0.2621	Y (log x/m)	=	1.8288 + 0.8986x	0.9951
T_2 – Sunhemp (every year)	0.8474	0.3515	Y (log x/m)	=	2.2467 + 0.8474x	0.9902
T_3 – Sunhemp (alternate year)	0.8411	0.3485	Y (log x/m)	=	2.2312 + 0.8411x	0.9902
T_4 – Dhaincha (every year)	0.8847	0.3589	Y (log x/m)	=	2.2851 + 0.8847x	0.9948
T_5 – Dhaincha (alternate year)	0.7952	0.3636	Y (log x/m)	=	2.3103 + 0.7952x	0.9888
T_6 – Green gram (every year)	0.8555	0.3351	Y (log x/m)	=	2.2831 + 0.8555x	0.9934
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	0.8444	0.3585	Y (log x/m)	=	2.3511 + 0.8444x	0.9931
T_8 – Green gram + 5t FYM ha^{-1} (every year)	0.9011	0.3502	Y (log x/m)	=	2.2400 + 0.9011x	0.9965
T_9 – 10.0 t FYM ha^{-1} (every year)	0.9009	0.3616	Y (log x/m)	=	2.2993 + 0.9009x	0.9974
T_{10} – 10 kg Zn ha^{-1} (alternate year)	0.9056	0.3139	Y (log x/m)	=	2.0602 + 0.9056x	0.9980

Table 5: Langmuir adsorption parameters and regression equation of Zinc for soils at different treatments (15^0C)

Treatments	Adsorption maxima (b) (mg kg^{-1})	Bonding energy (k) (mg L^{-1})	Regression equation			R^2
T_1 – Control	5000	0.01100	Y (Ce/ x/m)	=	0.0182 + 0.0002x	0.9748
T_2 – Sunhemp (every year)	5000	0.03125	Y (Ce/ x/m)	=	0.0064 + 0.0002x	0.9803
T_3 – Sunhemp (alternate year)	5000	0.03077	Y (Ce/ x/m)	=	0.0065 + 0.0002x	0.9938
T_4 – Dhaincha (every year)	5000	0.03774	Y (Ce/ x/m)	=	0.0053 + 0.0002x	0.9866
T_5 – Dhaincha (alternate year)	5000	0.03846	Y (Ce/ x/m)	=	0.0052 + 0.0002x	0.9790
T_6 – Green gram (every year)	5000	0.02439	Y (Ce/ x/m)	=	0.0082 + 0.0002x	0.9921
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	5000	0.03450	Y (Ce/ x/m)	=	0.0058 + 0.0002x	0.9818
T_8 – Green gram + 5t FYM ha^{-1} (every year)	10000	0.01538	Y (Ce/ x/m)	=	0.0065 + 0.0001x	0.9955
T_9 – 10.0 t FYM ha^{-1} (every year)	5000	0.03636	Y (Ce/ x/m)	=	0.0055 + 0.0002x	0.9843
T_{10} – 10 kg Zn ha^{-1} (alternate year)	10000	0.00980	Y (Ce/ x/m)	=	0.0102 + 0.0001x	0.9816

Table 6: Langmuir adsorption parameters and regression equation of Zinc for soils at different treatments (30^0C)

Treatments	Adsorption maxima (b) (mg kg^{-1})	Bonding energy (k) (mg L^{-1})	Regression equation			R^2
T_1 – Control	5000	0.01257	Y (Ce/ x/m)	=	0.0159 + 0.0002x	0.9713
T_2 – Sunhemp (every year)	5000	0.03571	Y (Ce/ x/m)	=	0.0056 + 0.0002x	0.9900
T_3 – Sunhemp (alternate year)	5000	0.03448	Y (Ce/ x/m)	=	0.0058 + 0.0002x	0.9900
T_4 – Dhaincha (every year)	10000	0.01961	Y (Ce/ x/m)	=	0.0051 + 0.0001x	0.9818
T_5 – Dhaincha (alternate year)	5000	0.04167	Y (Ce/ x/m)	=	0.0048 + 0.0002x	0.9912
T_6 – Green gram (every year)	5000	0.02857	Y (Ce/ x/m)	=	0.0070 + 0.0002x	0.9875
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	5000	0.03920	Y (Ce/ x/m)	=	0.0051 + 0.0002x	0.9871
T_8 – Green gram + 5t FYM ha^{-1} (every year)	10000	0.01754	Y (Ce/ x/m)	=	0.0057 + 0.0001x	0.9878
T_9 – 10.0 t FYM ha^{-1} (every year)	10000	0.02041	Y (Ce/ x/m)	=	0.0049 + 0.0001x	0.9835
T_{10} – 10 kg Zn ha^{-1} (alternate year)	10000	0.01111	Y (Ce/ x/m)	=	0.0090 + 0.0001x	0.9795

Table 7: Comparative desorption of adsorbed zinc by different extractants at 15^0C

Treatments	Adsorbed Zn (µg/g soil)	Desorption of Zn (µg/ml) by		
		Distilled water	1N N NH_4 OAC	DTPA
T_1 – Control	16.01	0.45	1.64	4.00
T_2 – Sunhemp (every year)	18.16	0.50	2.30	5.78
T_3 – Sunhemp (alternate year)	17.80	0.48	2.03	4.84
T_4 – Dhaincha (every year)	18.35	0.56	2.75	6.21
T_5 – Dhaincha (alternate year)	18.00	0.49	2.30	5.72
T_6 – Green gram (every year)	17.81	0.47	1.99	4.81
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	18.02	0.51	2.40	5.86
T_8 – Green gram + 5t FYM ha^{-1} (every year)	18.82	0.79	2.89	6.72
T_9 – 10.0 t FYM ha^{-1} (every year)	18.98	0.82	2.90	6.89
T_{10} – 10 kg Zn ha^{-1} (alternate year)	17.62	0.47	1.89	4.67

Table 8: Comparative desorption of adsorbed zinc by different extractants at 30^0C

Treatments	Adsorbed Zn (µg/g soil)	Desorption of Zn (µg/ml) by		
		Distilled water	1N NH_4 OAc	DTPA
T_1 – Control	17.82	0.50	1.80	4.48
T_2 – Sunhemp (every year)	18.99	0.56	2.50	6.80
T_3 – Sunhemp (alternate year)	18.16	0.53	2.39	6.01
T_4 – Dhaincha (every year)	19.08	0.62	3.10	7.20
T_5 – Dhaincha (alternate year)	18.42	0.57	2.49	6.80
T_6 – Green gram (every year)	18.15	0.53	2.25	5.61
T_7 – Green gram + 2.5t FYM ha^{-1} (every year)	18.78	0.65	2.60	6.80
T_8 – Green gram + 5t FYM ha^{-1} (every year)	19.28	0.90	3.13	7.76
T_9 – 10.0 t FYM ha^{-1} (every year)	19.42	0.95	3.21	7.81
T_{10} – 10 kg Zn ha^{-1} (alternate year)	18.12	0.55	2.11	5.28

Acknowledgements

The authors are thankful to the sir Dr. A. P. Singh, former Professor, Department of Soil Scienc, RAU, Pusa for their guidance and suggestions during course of investigation and also RAU, Puasa for providing financial assistance.

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