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Determination of Physical and Chemical Soil Parameters on Selenium Adsorption, Desorption by Rice Growing Soil

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ABSTRACT

Studies on Selenium adsorption was conducted in laboratory studies for some different rice growing soils of Malaysia at pH 4 and 7. Soils were equilibrated with 0.01 M CaCl₂ and Na₂SeO₃ solution to measure relative adsorption of Selenium as sodium Selenite ions. In general, the adsorption of Se on different soils at both pH, increased with increase in the level of Se added. Adsorption data were fitted well to Langmuir model. Maximum adsorption (Q_m) was correlated with organic carbon at both pH 4 (R = 0.77**) and pH 7 (R = 0.76**) and log K (R = 0.71** and R = 0.81**) at pH 4 and 7 respectively and also Q_m was correlated with percent of clay (R = 0.59*) and CEC (R = 0.58*) at pH 7. Desorption data showed the higher amount of desorbed Se was achieved at pH 7 than pH 4 in all type of soil except TIP2, KBK, Mb and UPM.

Key words: Adsorption, desorption, pH, selenium, soil

INTRODUCTION

Selenium (Se) is an essential microelement, for humans, animals and organisms functioning on one side and it can be toxic when the concentration is high (Cuvardic, 2003). Selenium in a food system depends chiefly on the levels of plant-available Se in soils used for agriculture production (Lyons *et al.*, 2008). The element is ample in different parts of the world but it is unevenly distributed and the amount of Se in soils differs with climatic conditions, vegetation cover and natural substrate. In most soils, it ranges from 0.1-2 g Se g⁻¹, but on the average, it is between 0.2-0.4 g⁻¹ (McNeal and Balistrieri, 1989). In England and Scotland, soils have very low amounts of Se (Hawkesford and Zhao, 2007). Data from geochemical survey of the UK showed a range of total Se in soils from 0.1-4 mg kg⁻¹, with >95% of the samples containing <1 mg kg⁻¹ (Broadley *et al.*, 2006). Although some soils have very little amounts of Se but some other regions in the world such as the Great Plains of the US and Canada, Enshi country of China, parts of Ireland, Colombia and Venezuela are seleniferous (Combs, 2001) with the soils having developed mainly from Se-enriched shales (Mayland *et al.*, 1991). Soils with vegetation containing more than 5 mg Se kg⁻¹, are seleniferous soils which have a danger

of Se poisoning for wild-life and livestock (Gupta and Gupta, 1998; Oldfield, 1999). The total Se concentrations in seleniferous soils are usually in the range from 5 up to 1200 mg kg⁻¹ (Mayland *et al.*, 1991). For regulating the Se entrance into the animal's food chain and humans, consideration of the process controlling the Se mobility and transport in the environment of the soil is vital. Many chemical and physical factors control the chemical form of Se and its concentration in drainage water or soils, such as mineralogical and chemical composition, pH, the status of oxidation-reduction and adsorbing surface. (Dhillon and Dhillon, 1999). Although Se may exist in four oxidation states, selenium-VI (as selenate, SeO₄⁻²) and selenium-IV (as selenite, SeO₃⁻²) are the major mobile forms, selenate and selenite competing with other anions, such as phosphate, sulfate, oxalate and molybdate for adsorption sites (Mayland *et al.*, 1991). Selenate is the overriding form in well-oxidised soils and high pH (pe+pH>15) while Se exists dominantly as selenite in well-drained mineral soils with pH from acidic to neutral (7.5<pe+pH<15). In powerfully reduced soil conditions (pe+pH<7.5), selenide becomes the dominant form. In comparison with selenate, selenite adsorbed much more powerfully on the surface of soil such as oxides, hydroxides of aluminium, iron and with increasing pH, both

adsorption decreased noticeably (Barrow and Whelan, 1989). It seems that the adsorption of selenite is similar to phosphate adsorption in which both are an inner sphere complexation while, selenate similar to the sulphate, adsorbed weakly through a nonspecific mechanism based on electrostatic forces. (Neal *et al.*, 1987; Barrow and Whelan, 1989). No Selenate adsorption was observed in some alluvial soils over the pH range of 5.5-9 from the San Joaquin Valley, California. Thus, Selenate is more soluble and more mobile in soil than selenite and therefore it is much more plants bioavailable but more ready to leaching (Neal and Sposito, 1989). The availability of special trace elements to plants is greatly depending on the portion related with the colloids of the soil and the presence in the soil solution. Swift and McLaren (1991) reported that the sorption and desorption phenomena controls trace metal ion bioavailability's in the soil which occur at the soil colloid soil solution interface. Understanding the nature of the sorption and desorption phenomenon for predicting and interpreting the behaviour of metals in soils under different environments is needed. These isotherms offer an appropriate ion retaining or releasing visual demonstration and a means of evaluating surface retention capacity (Harter and Luxmoore, 1991). Comparing the relative amounts of adsorbate which soils can hold or release under these situations is the most apparent use of the isotherms. Isotherm's shape offers info on the strength as well, by which the sorbate is held to the soil and an indication of bonding mechanism (Giles *et al.*, 1974). Selenite adsorption studies by minerals sample clarified the Se solubility's mechanistic features in soils. The adsorption of selenite on gibbsite and goethite was investigated and a rise at both the suspension's pH and negative surface charge on the oxide resulting from specific adsorption was reported (Hingston *et al.*, 1968). Moreover to the reaction of adsorptions, the reduction of selenite by Fe hydrous oxides might cause from the co-precipitation of ferric selenite with ferric oxide (Geering *et al.*, 1968). Neal *et al.* (1987) reported that selenite adsorption was highly pH dependent in alluvial soils, the maximum adsorption taking place under acidic situations. Selenite adsorption by soils can be small and lead leaching into drainage water or groundwater in neutral and high pH situations. The 1:1 minerals display more capacity of sorption for selenite than the 2:1 minerals

(Hamdy and Gissel Nielsen, 1977). The purpose of this study is to study the reaction of selenite adsorption, desorption and to determine some soil parameters on Se adsorption in some Malaysian soils under rice cultivation.

MATERIALS AND METHODS

Soil samples from the following rice growing areas in Malaysia were collected Tg. Karang (TGK), Teluk Intan I (TIP1), Teluk Intan II(TIP2), Bangan Serai (BSK), Guar Cempedak (GCK), Kangar I(KP1), Kangar II(KP2), Jertih, Kota Bharu (KBK), Machang (MB) and UPM (Fig. 1). The Soils were air dried and passes through a 2 mm sieve. Some physico-chemical characteristics of these soils their mineralogical properties are shown in Table 1. Soil pH was determined in deionized water using a 1:2.5 (w:v) soil/solution ratio after 24 h in equilibrium. Organic Matter content (OM) was determined by the Walkley-Black procedure (Nelson and Sommers, 1996). The particle size analysis was determined from the sieve-pipette method (Carter, 1993). Cation Exchange Capacity (CEC) was determined by leaching Tube and clay minerals were determined by X-Ray Diffraction. To derive Se sorption isotherms, Standard batch experiments were carried out at room temperature (25°C) in two different pH range as 4 and 7.

Soil samples (1 g) were equilibrated in 50 mL centrifuge tube, with 30 mL of 0.01 M calcium chloride (CaCl₂) having different Se rate 5, 10, 20, 40, 60, 80 and 100 mg mL⁻¹ in the form of Na₂SeO₃. Soil tubes were shaken for 24 h. then were centrifuged for 15 min, Supernatant was emptied and the sorption of Se was determined by ICP-EOS. The Se adsorbed amounts was determined from the (balance equation), difference between the initial and final concentration of Se, as described in Eq. 1:

$$S = \left(1 - \frac{cf}{ci}\right) V C_i / W \quad (1)$$

where, S is Se adsorbed amount (mg g⁻¹), V is volume of added solution (l), C_i is original concentration of Se (mg L⁻¹), C_f is final Se concentration equilibrium in solution (mg L⁻¹) and W is taken soil dry weight (g).

Table 1: Physico-chemical characteristic of experimental soils

Soil location	pH	EC (ds m ⁻¹)	OM (%)	CEC (cmol+/kg)	Clay (%)	Silt (%)	Soil texture
Tg. Karang (Tg. K)	5.16	0.80	2.31	23.14	65.67	33.79	Clay
Teluk Intan, Perak (TIP 1)	4.87	0.20	3.69	21.86	48.86	39.74	Clay
Teluk Intan, Perak (TIP 2)	7.22	0.58	1.00	4.48	39.61	14.96	Sandy loam
Bangan Serai, Perak (BSP)	6.40	1.40	1.91	17.79	72.33	27.05	Clay
Guar Cempedak, Kedah (GCK)	5.36	0.33	2.11	7.79	43.30	48.68	Silty clay
Kangar, Perlis (KP1)	6.50	0.35	1.51	6.32	29.01	48.30	Clay loam
Kangar Perlis (KP 2)	5.02	0.71	3.30	4.49	37.92	4.29	Clay loam
Jertih, Terengganu (Rotruck <i>et al.</i> , 1973)	6.92	0.50	1.32	9.71	30.59	50.18	Clay loam
Kota Bharu, Kelantan (KBK)	5.14	0.28	1.87	6.55	42.30	49.10	Silt clay
Machang Bandar (MB)	5.94	0.20	1.35	11.93	22.05	21.70	Sandy clay loam
University Putra Malaysia (UPM)	5.32	0.29	1.32	5.58	44.98	41.50	Silty clay



Fig. 1: Location of field studied

To study desorption of Se, soil residues from sorption extraction were used. Desorption extraction was performed by adding 20 mL of 0.01 M calcium chloride to each tube of the samples which contained the Se-sorbed soil residue, then the suspension was shaken for 24 h. The suspensions were centrifuged and the Se concentration in the desorbing solution was measured based on mass balance Eq. 2:

$$qd = v_i \left[ceq_2 - \left(ceq_1 * \frac{v_i - v_a}{v_i} \right) \right] / 1000 \times w \quad (2)$$

The Langmuir model (3) used to describe the soil in this study is as follows:

$$C / \left(\frac{x}{m} \right) = 1 / kQ_m + C / Q_m \quad (3)$$

where, x/m is amount of Se adsorbed per unit of soil ($mg\ kg^{-1}$), C is equilibrium Se concentration in soil solution ($mg\ L^{-1}$), k is a constant related to the bonding energy of Se to the soil, Q_m is the maximum soils adsorption capacity. The modified Freundlich model (4) used to describe the soil in this work in Eq. 4:

$$x = kC^{1/n} \quad (4)$$

where, x is amount of Se adsorbed per unit of soil ($mg\ kg^{-1}$), C is equilibrium Se concentration in soil solution ($mg\ L^{-1}$), $1/n$ and K is constants which represent the slope and the intercept of the sorption isotherms, respectively.

The sorption-desorption hysteresis for each sorbent-solute solution system was calculated by hysteresis index Eq. 5 (O'connor *et al.*, 1980; Barriuso *et al.*, 1994):

$$HI = \frac{n_{desorb}}{n_{sorb}} \quad (5)$$

where, the n_{sorb} and n_{desorb} are the exponent of the fitted Freundlich equation in the sorption and desorption branches, respectively. If there is no hysteresis n_{desorb} is equal to n_{sorb} , positive hysteresis would be characterized by n_{sorb} greater than n_{desorb} and K_{sorb} smaller than K_{desorb} and in case of negative hysteresis, n_{desorb} is greater than n_{sorb} and K_{desorb} is smaller than K_{sorb} , respectively.

Statistical analysis: The results are analysed by using one way ANOVA and results are significant at $p < 0.001$.

RESULTS AND DISCUSSION

Se Sorption at pH 7: The adsorption isotherm of Se in different Malaysian soils at pH 7.0 is shown in Fig. 2. The maximum amount of 1.56 mg Se g⁻¹ was adsorbed by the soil 2 (Teluk Intan) from the initial solution having 100 mg Se mL⁻¹. Soil 7 (Kangar) 1.352 mg g⁻¹, soil 1 (Tq.Karang) 1.314 mg g⁻¹, soil 11 (UPM) 1.19 mg g⁻¹, soil 4 (Bangan serai) 1.157 mg g⁻¹, soil 5 (Guar Cemepdak) 1.047 mg g⁻¹, soil 6 (Kangar) 1.017 mg g⁻¹, soil 9 (Kota Bharu) 0.963 mg g⁻¹, soil 10 (Machang) 0.68 mg g⁻¹, soil 8 (Jertih) 0.81 mg g⁻¹, soil 3 (Teluk Intan) 0.676 mg g⁻¹ adsorbed Se in the decreasing order.

The highest amount of 0.140, 0.270, 0.516, 1.111, 1.197 and 0.852 mg g⁻¹ was adsorbed by soil 2 and 4, respectively and the lowest amount 0.094, 0.175, 0.237, 0.3, 0.345 and 0.36 mg g⁻¹ was adsorbed by soil 3 from the initially solution of 5, 20, 40, 60 and 80 mg Se mL⁻¹.

Se sorption at pH 4: The maximum amount of 1.72 mg Se g⁻¹ was adsorbed by the soil 2 (Teluk Intan) from the initial solution having 100 mg Se mL⁻¹. Soils 7 (Kangar) 1.418 mg g⁻¹, soil 1 (Tq.Karang) 1.416 mg g⁻¹, soil 11 (UPM) 1.343 mg g⁻¹, soil 4 (Bangan serai) 1.2 mg g⁻¹, soil 5 (Guar Cemepdak) 1.09 mg g⁻¹, soil 6 (Kangar) 1.016 mg g⁻¹, soil 9 (Kota Bharu) 1.05 mg g⁻¹, soil 8 (Jertih) 0.81 mg g⁻¹, soil 10 (Machang) 0.68 mg g⁻¹, soil 3 (Teluk Intan) 0.67 mg g⁻¹ adsorbed Se in the declining order shown in Fig. 3. From the initial solution containing 5, 20, 40, 60 and 80 mg Se mL⁻¹ the highest amount of 0.143, 0.29, 0.561, 1.041, 1.343 and 1.527 mg g⁻¹ was adsorbed by soil 2 (TIP1) and the lowest amount of 0.089, 0.142, 0.231, 0.40, 0.530 and 0.5964 mg g⁻¹ was adsorbed by soil 3 (TIP3). The data of Se sorption fitted well to both the Langmuir adsorption equations. Intercept (k value) representing the Se adsorbed amount at unit concentration and $1/n$ (slope) indicating a concentration gradient in the Freundlich model and value of Q_m and K in the Langmuir model representing the maximum adsorption capacity of soil and the constant related to bonding energy, respectively are reported in Table 2 and 3.

Maximum adsorption value and bonding energy constant were calculated by applying the association between $1/q$ vs. $1/ceq$ as a single linear plot shown in Fig. 4 and the value for $\log K$ and n related to Freundlich model was calculated by applying the relationship between $\log q$ vs. $\log ceq$. Langmuir result showed that in pH 4, highest Q_m is equal to 1.632 mg g⁻¹ was related to soil 2 (TIP1) and the lowest Q_m is equal to 0.549 mg g⁻¹ was belonging to soil 3 (TIP2). At pH 7, the highest adsorption maxima ($Q_m = 1.196$ mg g⁻¹) was related to soil 1 (Tg.K) and the lowest one ($Q_m = 0.373$ mg g⁻¹) was belong to soil 3 (TIP2). The result obtained showed that the

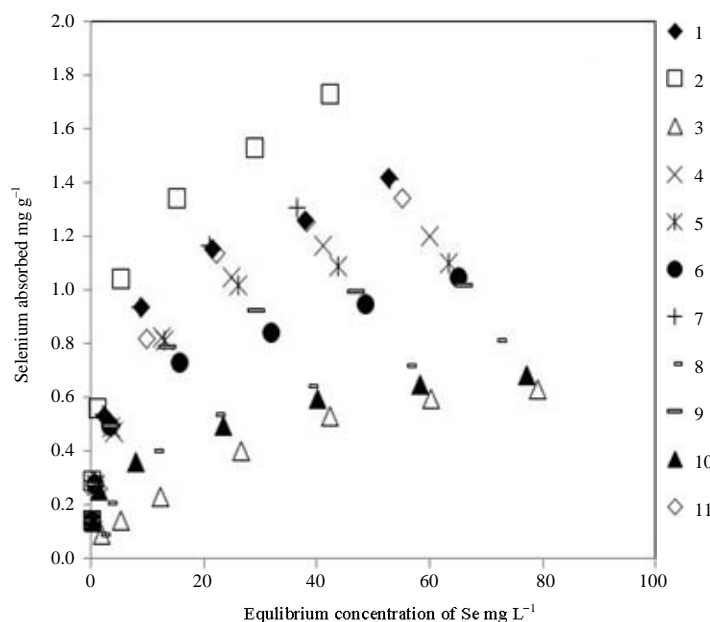


Fig. 2: Adsorption isotherms of Se in different Malaysian soils at pH 4

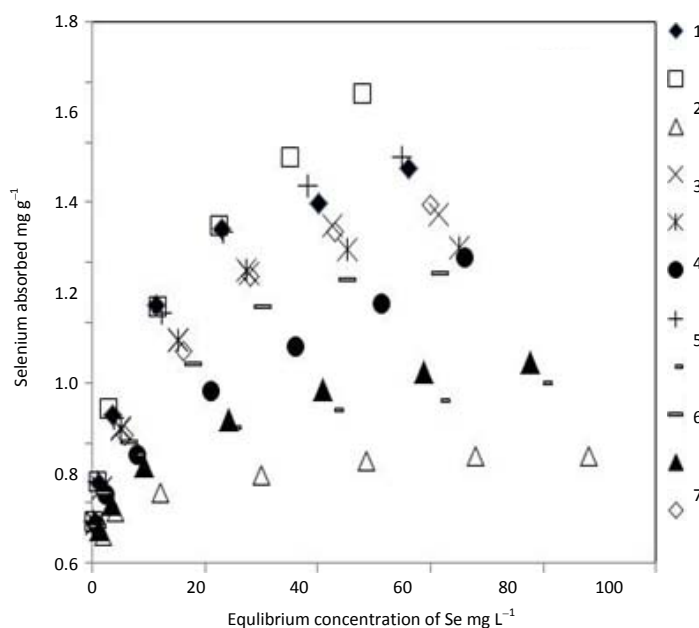


Fig. 3: Adsorption isotherms of Se in different Malaysian soils at pH 7

Table 2: Langmuir and Freundlich constants for Se adsorption in pH 4

Soil	Q_m (mg g ⁻¹)	Langmuir		Freundlich		
		K (mL mg ⁻¹)	R ²	K	n	R ²
1	1.220	0.459	0.995	0.308	2.39	0.960
2	1.632	0.511	0.968	0.405	2.34	0.946
3	0.549	0.090	0.953	0.057	1.73	0.995
4	0.901	0.602	0.973	0.260	2.45	0.984
5	0.841	0.947	0.969	0.290	2.78	0.979
6	0.853	0.658	0.993	0.267	2.92	0.963
7	1.268	0.555	0.962	0.339	2.54	0.953
8	1.121	0.050	0.938	0.087	1.83	0.935
9	0.892	0.598	0.992	0.268	2.80	0.958
10	0.544	0.720	0.964	0.193	3.33	0.983
11	1.141	0.260	0.986	0.224	2.03	0.969

*p<0.001 significant

Table 3: Langmuir and Freundlich constants for Se adsorption at pH7

Soil	Q_m (mg g ⁻¹)	Langmuir		Freundlich		
		K (mL mg ⁻¹)	R ²	K	n	R ²
1	1.196	0.261	0.996	0.235	2.142	0.968
2	1.088	0.433	0.981	0.267	2.139	0.988
3	0.373	0.189	0.953	0.094	3.084	0.936
4	0.857	0.355	0.962	0.197	2.166	0.991
5	0.944	0.260	0.990	0.193	2.212	0.971
6	0.698	0.270	0.963	0.145	2.206	0.996
7	0.946	0.544	0.969	0.258	2.272	0.992
8	0.490	0.585	0.968	0.171	3.405	0.976
9	0.903	0.174	0.992	0.149	2.045	0.982
10	0.602	0.174	0.985	0.112	2.311	0.985
11	0.769	0.432	0.926	0.189	2.142	0.997

*p<0.001 significant

amount of Se adsorbed was significantly correlated with the organic carbon content when all soils were considered at both pH4 and 7 (Table 4).

Selenium desorption: Selenium sorption and desorption in different soils are plotted in Fig. 5 and 6. The gap between sorption and desorption isotherms was assessed by the

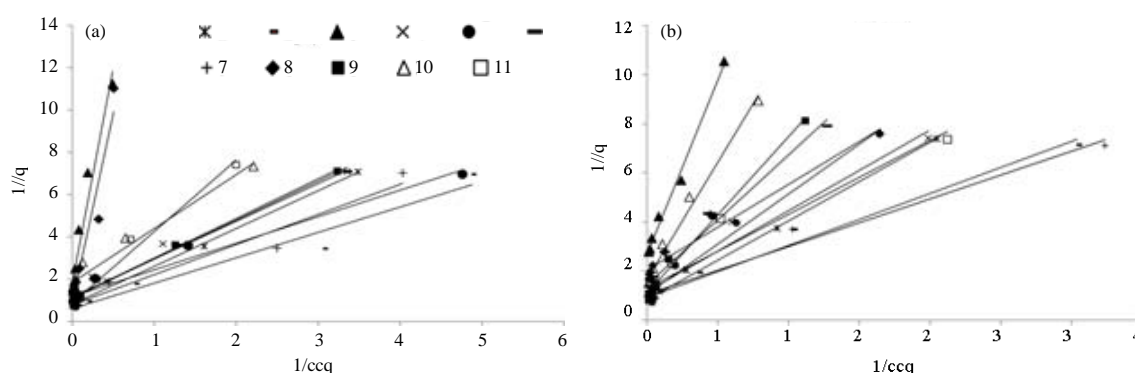


Fig. 4: Langmuir adsorption isotherms of Se at different soil locations with pH 4 and 7

Table 4: Coefficients of correlation between soil properties and adsorption parameters of Se

Soil characteristic	Adsorption parameters			
	Langmuir (pH 4)		Freundlich (pH 4)	
	Qm	K	Log k	n
EC	-0.008	-0.08	-0.01	-0.230
Organic carbon	0.77***	0.33	0.71***	0.130
CEC	0.46	0.11	0.39	0.030
Clay	0.34	0.03	0.33	-0.250
Silt	0.14	0.10	0.12	0.040
Soil characteristic	Langmuir (pH 7)		Freundlich (pH 7)	
	Qm	K	Log K	k
	EC	-0.008	0.210	0.220
Organic carbon	0.76***	-0.190	0.810***	-0.440
CEC	0.58*	0.015	0.470	-0.260
Clay	0.59*	0.017	0.510	-0.360
Silt	0.11	0.030	0.074	0.060

Table 5: Hysteresis index (HI) calculated for Se sorption and desorption isotherms

Soil location	HI (pH4)	HI (pH7)
Tg. Karang (Tg. K)	0.7499	0.869
Teluk Intan, Perak (TIP 1)	0.8591	0.919
Teluk Intan, Perak (TIP 2)	0.4767	0.687
Bangan Serai, Perak (BSP)	0.7419	0.759
Guar Cempedak, Kedah (GCK)	0.8111	0.843
Kangar, Perlis (KP1)	0.8744	0.769
Kangar Perlis (KP 2)	0.8181	0.884
Jertih, Terengganu (Rotruck <i>et al.</i> 1973)	0.5129	0.696
Kota Bharu, Kelantan (KBK)	0.8714	0.722
Machang Bandar (MB)	0.8567	0.796
University Putra Malaysia (UPM)	0.8064	0.752

Hysteresis Index (HI) shown in Table 5. Increasing the ratio of the sorbe to desorb, lead to higher index value which present the higher sorption affinity by soil.

The amount of desorbed Se at pH 7 was higher than pH 4 in all the soils tested but TIP2, KBK, MB and UPM. The results for all soils tested at both pH, showed positive hysteresis.

The result at both pH 4 and 7, showed that with increasing Se concentration from 5-100 mg Se mL⁻¹ in solution in all soils, the sorption of Se in the soil increased as well and the

adsorption isotherm can be described as L-shaped. This is a decreasing slope with increasing concentration because unoccupied adsorption sites reduce as the adsorbent sites are filled (Sparks, 2003). This adsorption behaviour is illustrated by the high affinity of the adsorbent for the adsorptive at low concentration that will decrease when concentration increases (Sparks, 2003). The comparison of the results at pH 4 and 7 showed that Se sorption in the different soils was higher at acidic pH than at pH 7. This result is in agreement with Neal *et al.* (1987) reports, that shows Se adsorption is powerfully pH dependent with the maximum adsorption occurring under acidic condition and also Balistrieri and Chao (1987) reported that SeO₃⁻² Adsorption is a function of pH, Particle concentration and composition, SeO₃⁻² concentration and the concentration of competing anions such as phosphate (PO₄³⁻). Geering *et al.* (1968) observed that at pH range of 4-7 Se⁴⁺ solubility in soil lowest while solubility increased with higher or lower pH values. Similarly, Hamdy and Gissel Nielsen (1977) reported that Se⁴⁺ adsorption by clays reached a maximum between pH 3 and 5 and then decreased with increasing pH. Many experiments also have shown the effect of soil pH on plants Se uptake. Cary and Allaway (1969) measured the accumulation of Se⁴⁺ by alfalfa grown in soils of

acid to neutral pH and found the highest Se concentration in plants grown on the highest pH soils. Besides being acidic, XRD result showed that TGK contained around 57% kaolinite which cause the great sorbed of Se and TIP2 having illite and smectite as dominant clay mineral affecting the least Se adsorption. Bar-Yosef and Meek (1987) observed less accessibility of anion to adsorption site than the negative electric field around kaolinite because of permanent negative electric field close to the surface of montmorillonite. Anion adsorption by soil clays controlled by the SiO_2 : R_2O_3 ratio as well, decreasing the ratio causing increase in adsorption of anion. Thus Kaolinite with a low SiO_2 : R_2O_3 ratio will hold further selenite ions than 2:1 type clay minerals. A significant positive correlation between $\log K$ and Q_m with OM at both pH 4 ($R = 0.004^{**}$, $R = 0.01^*$) and pH 7 ($R = 0.005^{**}$, $R = 0.0004^{**}$) showed that organic carbon presented more sites for Se adsorption through ligand exchange. That high organic matter soils can keep Se with greater strength. The results are in line with the studied of (John *et al.*, 1976) on Selenium Adsorption by New Zealand soil and (Dhillon and Dhillon,

1999) on Selenium adsorption by some Indian soils that showed that the amount of Se adsorbed was considerably correlated with the Organic Carbon. Also, there was a positive correlation between the CEC and the presence of clay at pH 7 (Table 4).

Hamdy and Gissel-Nielsen (1977) showed that clays and ferric oxide have the capacity to quickly remove Se^{4+} from solution. They found that 1:1 clays had more Se^{4+} fixation capacity than 2:1 clay minerals, vermiculite had more Se^{4+} adsorption capacity than montmorillonite but Fe_2O_3 adsorbed more Se^{4+} than all the minerals tested. Desorption result shows that selenite is not as mobile as Selenate which causes less availability of Se to plant (Bar-Yosef and Meek, 1987). Found that between pH 4 and 8, selenium solubility is governed by adsorption: the hydroxyl ions are more effective in modifying the selenium ion's adsorption capacity than in competing with selenium for common adsorption sites. Balistrieri and Chao (1987) found that selenium mobility, as opposed to adsorption on goethite is favoured by alkaline pH, high selenium concentrations, oxidizing conditions and high concentration of

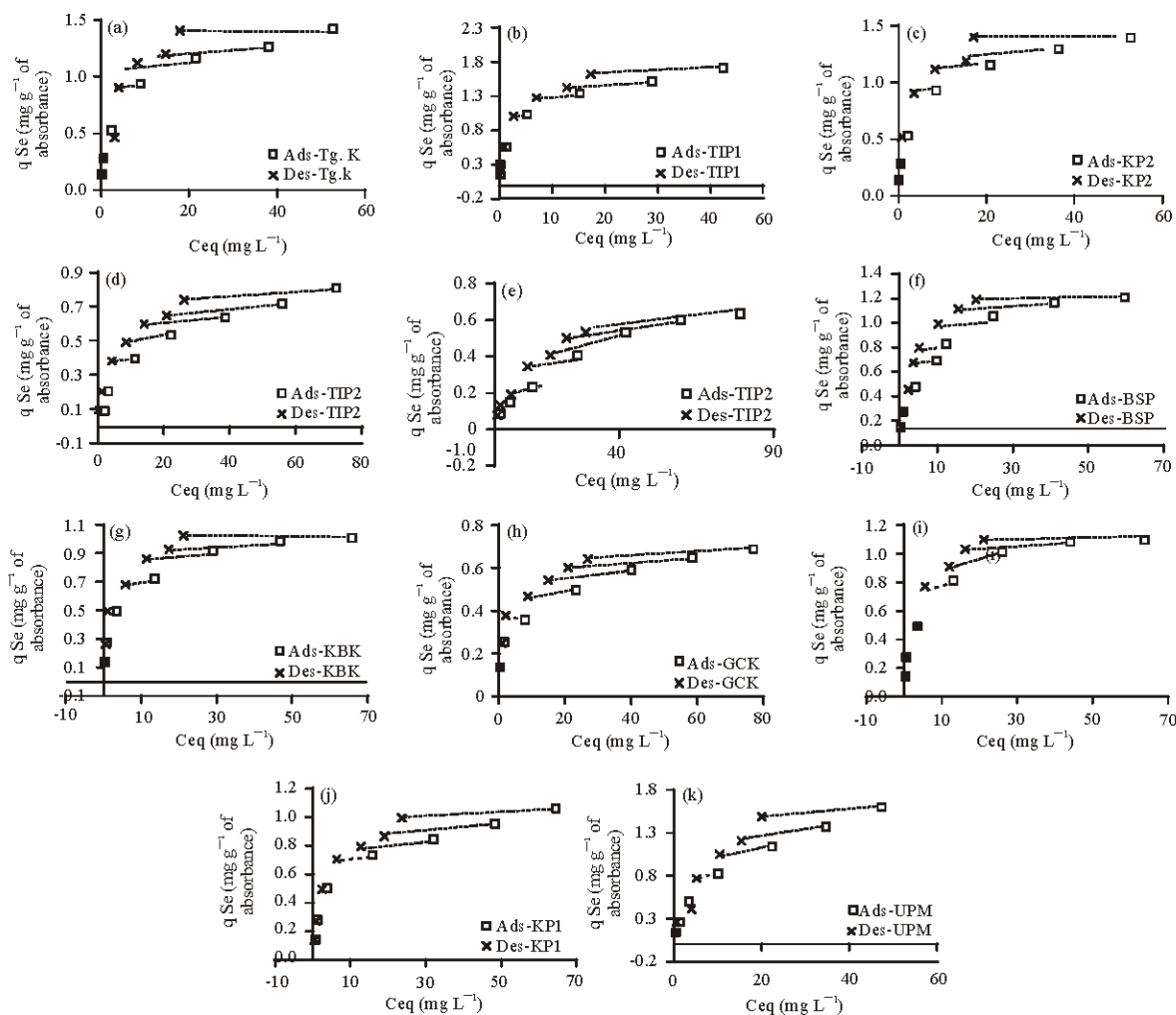


Fig. 5(a-k): Selenium sorption and desorption Isotherm in different soil at pH 7

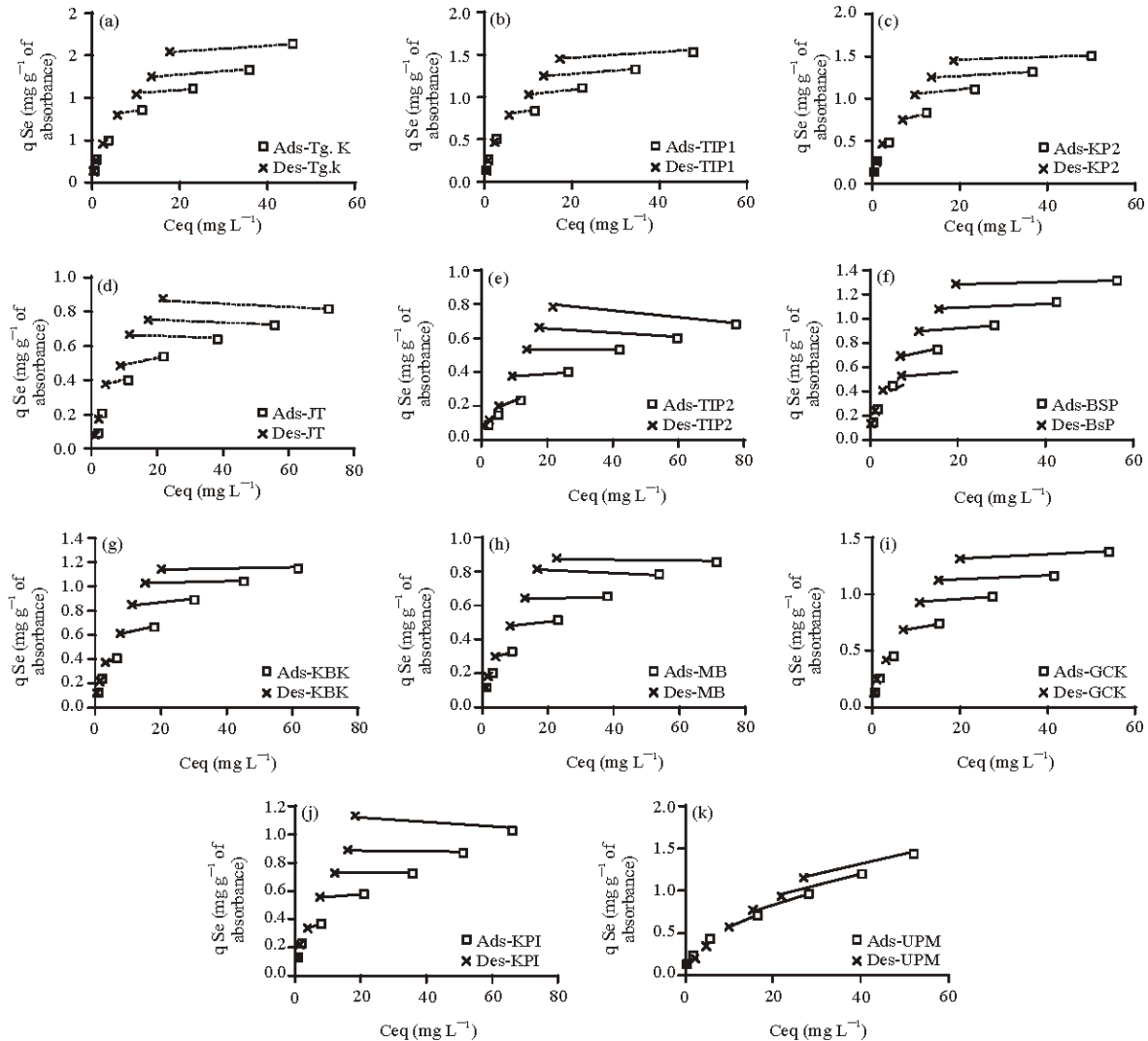


Fig. 6(a-k): Selenium sorption and desorption Isotherm in different soil at pH

other strongly adsorbed anions. The small amount of adsorption desorption hysteresis than hysteresis point (HI = 1) is obvious for the soil samples. It would seem that the Selenium desorption hysteresis by different soils is because of irreversible Se inner-Sphere binding to the mineral edge sites. In all soils the amounts of desorbed selenium were smaller than would be predicted from the adsorption isotherm this is because of positive hysteresis which suggests that a small portion of the adsorbed selenium is tightly bounded to the mineral surface; it is inner sphere adsorption that does not readily desorb. Increasing selenium desorption at pH 7 compared to pH 4 is cause acidic soils keep chiefly selenite on specific sites through ligand exchange mechanisms while the alkaline soils generally retain selenate in water soluble non-specifically sorbed forms (Geering *et al.*, 1968).

CONCLUSION

Selenium sorption and desorption isotherms of different soils were determined by the use of a batch method.

Freundlich and Langmuir equation were well fitted to the obtained sorption and desorption isotherms. Adsorption data in this study revealed L shape isotherm that could be describe by the high affinity of the soils for the Se sorption at low concentration which then decreases as the concentration increase. It is also concluded that Selenium availability to plant is affected by soil pH, organic matter and clay minerals. Sorption of Selenite increases with decreasing pH and increasing Organic Matter (OM). The result shown that the Se desorption hysteresis in different soils was due to irreversible Se inner sphere binding to the edge of the minerals.

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