PHOSPHORUS SORPTION CAPACITY AS A GUIDE FOR PHOSPHORUS AVAILABILITY OF SELECTED SUDANESE SOIL SERIES

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ABSTRACT

Crop response to phosphorus application is often erratic in most soil types in Sudan. This inconsistent response is believed to be due to the alkaline nature of most soils in the country. Phosphorus adsorption isotherms and buffering capacity are powerful tools for predicting response of different soil types to apply P fertilisers. This study was carried out to investigate the degree of P adsorption capacity in some soils in Sudan and the consequential effect on P availability. A laboratory experiment was conducted on six soil samples of selected soil series from different sites in Sudan. Samples were equilibrated with different P concentrations, prior to evaluating the sorption potential and binding intensity. Results indicated that at any specific P concentration, the amount of P sorbed by the *Entisols* was higher than for the other soils. The order of soils according to their adsorption capacities using Freundlich equation were 917, 330, 315, 269, 214 and 80 mg P kg^{-1} soil for River Nile banks (*Entisols*), Dongola 2 (*Aridisols*), Permanent Fallow (Virgin *Vertisols*), Remitab (Cultivated *Vertisols*), Khashm elgirba (*Vertisols*) and Dongola1 (*Aridisols*), respectively. The soil's ability to sorb added P increases due to increase in affinity sites of clay and iron content.

Key Words: *Aridisols, Entisol*, sorption isotherm, *Vertisols*

RÉSUMÉ

La réponse des cultures à l'application du phosphore est souvent imprédictible dans beaucoup de types de sols du Sudan suite à la nature alkaline de laplupart des sols dans ce pays. Les isothermes d'adsorption du phosphore et la capacité tampon sont des outils les plus efficaces pour prédire la réponse de différents types de sols à l'application des engrais phosphatés. Cette étude était conduite pour évaluer la capacité d'adsorption du phosphore dans quelques sols du Sudan et ses effets sur le phosphore disponible. Un essai au laboratoire était conduit sur six échantillons de sol sélectionnés des séries de différent sites au Sudan. Ces échantillons étaient équilibrés avec différentes concentrations de P avant l'évaluation du potentiel d'adsorption et l'intensité d'adhésion. Les résultats ont indiqué qu'à une certaine concentration spécifique de P, la quantité de P fixé par les Entisols était plus élevée que celle des autres sols. Sur base de l'Equation de Freundlich, l'ordre de sols en rapport avec leur capacité d'adsorption était de 917, 330, 315, 269, 214 et 80 mg P kg^{-1} de soil pour les bordures de la rivière Nile (*Entisol*s), Dongola 2 (*Aridisols*), la jachère permanente (*Vertisols* vierge), Remitab (*Vertisols* cultivés), Khashm elgirba (*Vertisols*) et Dongola 1 (*Aridisols*), respectivement. La capacité du sol à fixer P augmente suite à l'augmentation des sites d'affinité d'argile et de la teneur en fer.

Mots Clés: *Aridisols, Entisol*, Isotherm d'adsorption , *Vertisols*

INTRODUCTION

The challenge for agriculture over the coming decades will be to meet the world increasing demand for food in a sustainable way. Declining soil fertility and mismanagement of plant nutrients have made this task more difficult (Gruhn *et al*., 2000). Phosphorous is an essential macronutrient

for plant growth and it is generally added to soil as a fertiliser and, thereby, increases the physiological efficiency of crops.

When phosphate fertiliser is applied to soil and dissolved by the soil water, various reactions occur between phosphate and soil constituents which remove P from the solution phase and render it less variable. This phenomenon is called P fixation or sorption (the two terms are frequently used interchangeably).

Phosphorus deficiency is very common on alkaline calcareous soils due to formation of insoluble calcium phosphate compounds. Bechwith (1965) suggested phosphorus sorption as one of the promising technique for measuring both the intensity and capacity factor of soil for phosphorus. He suggested standard concentration of 0.2 mg kg^{-1} phosphorus in solution to compare P sorption by soils because it is the adequate concentration of P in solution for most crop species.

Elmahi and Mustafa (1980) stated that P retention increased with increase in concentration of electrolyte or decreased in sodium adsorption ratio (SAR); this effect should be considered when appraising phosphorus fertiliser application to salt affected soils.

Paini et al. (1999) stated that soils differed markedly in their ability to hold P, though P adsorption was high in all observed soil when P was held by Fe oxides and Al oxides contents dissolved, reactive P could be found in percolating water in consequence of Fe solubility enhanced by reducing condition. A relationship between the iron content in high reactivity form and the adsorption of P resulting from a decreased P in solution was found. Therefore, after flooding- drained condition, P availability to plants decreased due to adsorption of P with recently precipitated high reactivity forms of irons oxides (Hernandez and Meurer, 2000). Singh and Singpuri (1986) reported that oxides of Fe and Al were correlated significantly with P adsorption maxima (r =0.405). Higher value of P adsorption maxima in case of soil containing higher content of oxides of Fe and Al might be due to formation of their respective metal phosphates (Maida, 1980).

Numerous studies show that alumino-silicate clay minerals play an important role in P sorption by soils. Generally, those clay minerals that possess greater anion exchange capacity (due to a positive surface charge) have a greater affinity for phosphate ions. The surface charge of clay minerals (and oxides) is partly pH dependent, so that anion exchange capacity increases as pH decreases. Among the layer silicate clays, 1:1 type clays have a greater phosphate retention capacity than 2:1 type clays. Soils containing large amounts of kaolinite group clay minerals will retain larger quantities of added phosphate than those containing the 2:1 type clay minerals.

The main objective of this research was to measure soil sorption capacity of different soil series in Sudan for the purpose of making P management recommendations.

MATERIALS AND METHODS

The study was conducted in laboratory with bulk surface samples (0-30) collected from six selected soil series Dongola1 (Kerma), Dongola 2 (Akked), permanent fallow (Remitab), Remitab soil, Entisol, kashm elgirba soil). The samples were characterised for pertinent physiochemical properties according to standard procedures (Richards,1954).

Soil collection. Soil samples were collected from the top soil (0-30 cm) from different locations as fallow:

1. Dongola 1 Kerma series: Deep, excessively drained, light yellowish brown, loamy sand to sand, non-calcareous non-saline and non-sodic.

2. Dongola 2 Akked series: Deep, dark grayish brown, clay loam to clay; calcareous, strongly saline and moderately sodic.

3. Permanent Fallow of (Gezira Research Farm): the soil was under permanent fallow since establishment of Gezira Research Station. The nature of the parent material is Blue Nile sediment. According to the land evaluation system adopted in Sudan (Kevie and Eltom, 2004), these soils are evaluated as S2vaf (Moderately suitable land with *Vertisolic*,

sodicity and with fertility limitations), classified as sodic *Haplotorerts.*

4. Remitab Series Soil sample was collected from agricultural Research Corporation field (located between lat 14° 23´ N, longitude 33° 29´ E altitude, 405 m above mean sea level). The soil was developed on Blue Nile alluvium, classified as Typic Haplusterts fine, smectitic, isohyperthermic, USDA (1999).

5. *Entisol* soil from the Blue Nile river bank.

6. Khashm algebra soil series; generally found in the lower lying area at 15° 46´ N, and 32° 23° 45´ E. The nature of parent material origin is River Atbara alluvium, current land is moderately suitable land due to sodicity *Vertisolic* and chemical fertility limitation (S2avf). USDA (1999) classified as sodic Haplustets, very fine, smect, isohyperthermic.

Phosphorus sorption. The sorption study was carried out on the six soils according to standard procedure recommended by Nair *et al.* (1984). One gram air dried soil was weighed into series of 50 ml plastic bottles. Twenty five millilitres of solution containing 0, 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 ppm P were added to these bottles. Three to four drops from toluene was added to inhibit microbial activity. All phosphorus solutions were made in 100 ml and each soil series replicated three times.

Volumetric flasks from 500 ppm P stock solutions of oven dried KH_2PO_4 and the volume was made up with distilled water. The bottles were capped tightly. The soil and phosphorus solution in bottles were equilibrated by shaking for 24 hours. After filtering the soil suspension through whatman No. 2 filter paper, the clear filtrate was analysed for P by using the method of Murphy and Riley (1962). Absorbance was determined at a wavelength of 882 nm using spectrometer (spectronic 21).The concentration of original P solution was also measured. The difference between the quantity of phosphate in solution after shaking with soil and the quantity initially present was calculated as the quantity of P sorbed by the soil in $\mu g\ g^{-1}$. The data obtained from the phosphate adsorption experiment were fitted to the Freundlich equation;

$$X = a\ C^n$$

Where X is the amount of P sorbed per unit weight of soil (mg P kg^{-1} soil), C the concentration of P in equilibrium solution (mg l^{-1}), a is a constant related to sorption capacity, n is phosphate sorption energy.

Statistical analysis. Data collected were statistically analysed using ANOVA of MStatc statistical package programme.

RESULTS AND DISCUSSION

Properties of soils. The physical and chemical characteristics of the soils used in the present study are depicted in Table 1. The pH, electrical conductivity (ECe) of saturation extract and exchangeable Sodium Percentage (ESP) indicated that all soils were non-saline and non-sodic, except Dongola2 (Akked series) which was saline-sodic soil. The calcium carbonate percent ranged from 4.3 to 5%, showing that the soils were calcareous in nature. All the soil samples were very low in organic matter and available phosphorus, except the *Entisol,* which had

TABLE 1. The adsorption capacity by different soils arranged in ascending order along with clay and iron (Fe) content

Name of soil series	Clay content (%)	Fe (ppm)	Sorption capacity (mg kg^{-1})
Dongola 1 (Kerma series)	18	5	80
Dongola 2 (Akked series)	39	2.7	269
Permanent Fallow (Remitab series)	53	11.4	330
(Remitab series) cultivated	55	8	315
Khashm elgirba series	59	11.2	214
Entisols	65	31.8	917

satisfactory level of organic matter and medium level in available phosphorus.

It was also noted that all soils had high clay (54%) content, except Dongola1 soil (Kerma series) which was sandy loam. Also, Soil 5 (*Entisol*) had high levels of Fe and Zn.

The relationships between the amounts of phosphorus sorbed *versus* phosphorus concentrations of these soil samples are shown in Figure 1. As the concentration of phosphorus was increased the phosphorus sorbed by the soil generally increased. This is consistent with previous reports by Barrow (1978). The result showed that at any specific P-concentration, the amount of P sorbed by the *Entisols* was higher than that of other soils.

Phosphate adsorption isotherm. The graphic representation of adsorption isotherms of six soils series used in the study is shown in Figures 1 - 3. It is evident from these isotherms that each soil exhibited different adsorption characteristics.
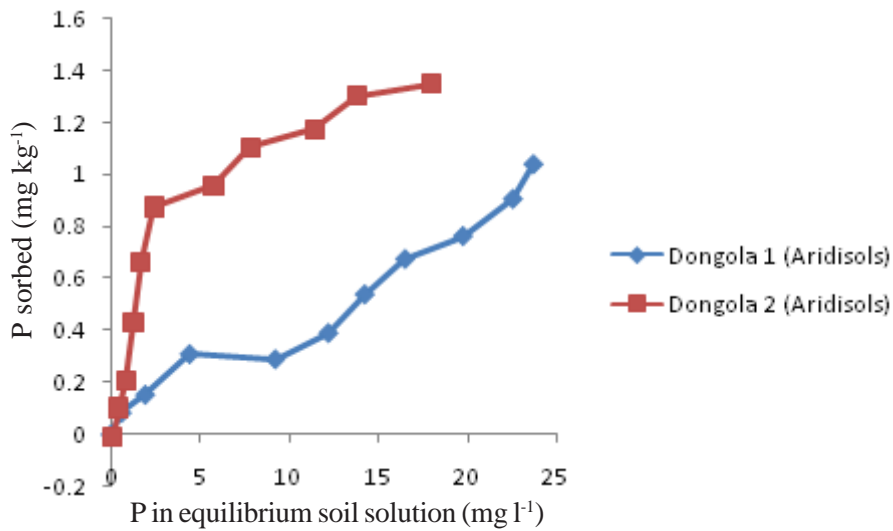

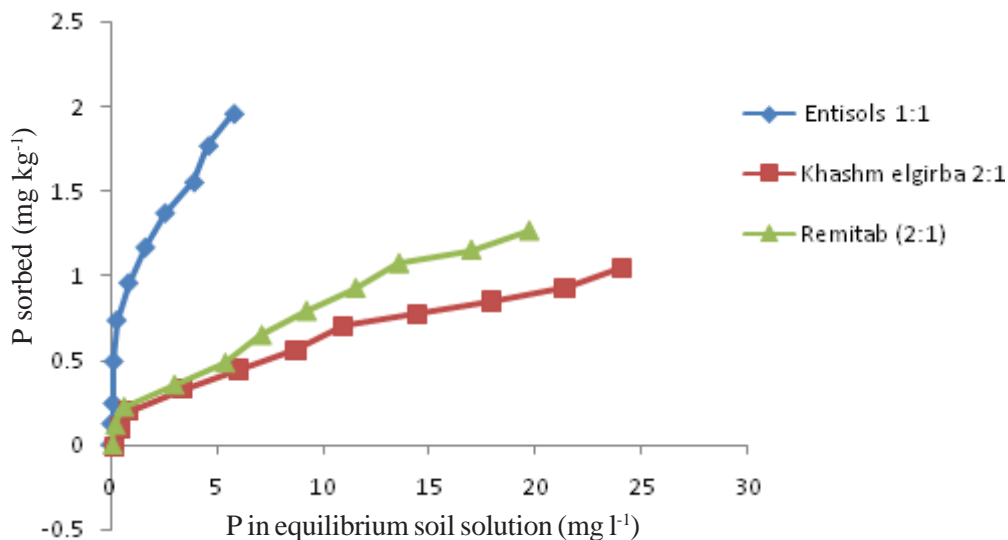Figure 1. Phosphorus sorption isotherm of Dongola1 and Dongola 2 soils from Sudan.

Figure 2. Phosphorus sorption isotherm of different soil series from Sudan.
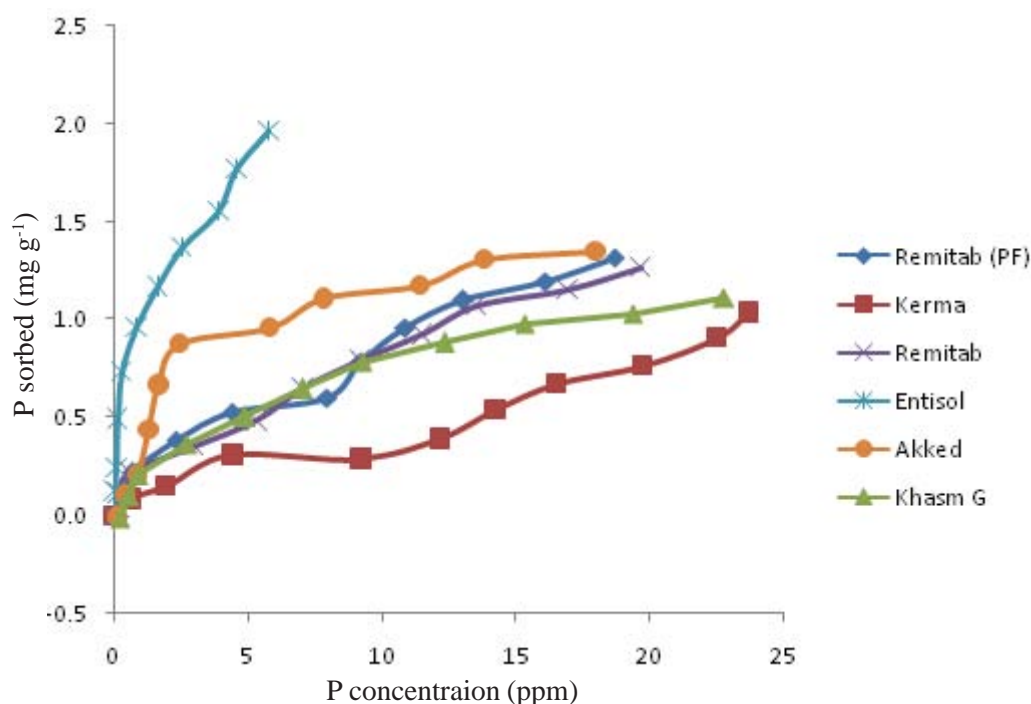
Figure 3. Phosphorus sorption isotherm of different soil series from Sudan.

Phosphorus sorption capacity of 917 g kg^{-1} soil was found in *Entisols* with 65% clay and 31.8 ppm Fe. Soil low in clay content adsorbed very small quantity of P. Dongola1 (Kerma) soil with 18% clay and 5 ppm Fe adsorbed minimum quantity of P (80 g kg^{-1} soil). Figures 1-3 show phosphorus adsorption isotherms for selected soils. P-sorption and equilibrium P-concentrations tended to increase with increasing levels of added P in all the soils. The slopes of the sorption curves showed that the amount of P sorbed by the soil differed among various soil series. The possible major factors affecting the P-sorption of these soils can be ascribed as some physicochemical properties of soils such as clay type and clay content (*Entisols* containing high amount of 1:1 clay type of clay. This result was in conformity with Soils and Torrent (1989) and Pena and Torrent (1990).

Figure 1 show the phosphorus adsorption isotherm for two *Aridisols* soils (Dongola1 Kerma series (18%) and Dongola 2 Akked series (39%) containing relatively small amount of clay content compared with the vertisols soils (Remitab, Kashm elgirba and Permanent Fallow). The high

sorption by P in Dongola 2 (Akked) was attributed to high level of salinity (electrolyte concentration). This result is similar to that of Elmahi and Mustafa (1980).

Freundlich model. The Freundlich parameter, i.e., sorption capacity (a) and P sorption energy (n); and correlation coefficient values computed from the data plotted according to P sorbed *vs*. P in equilibration solution. The goodness of fit of the model was ascertained by looking at the r^2 values. All the plots were highly correlated with r^2 values > 0.95, indicating apparent high conformity of the adsorption data to the Freundlich model. Generally, the Freundlich model seemed fit at all equilibrium concentrations. For all the soils, the values of sorption capacity (a) and P sorption energy (n) ranged from 80 to 917 mg kg^{-1} and 0.461 to 0.754 L kg^{-1}, respectively (Table 2).

Since the Freundlich adsorption equation was derived empirically, its parameters (a) and (n) have been considered physically meaningless. Despite this, it was proposed that (a) could be considered as capacity factor (Shayan and Davey, 1978)

TABLE 2. Phosphorus sorption parameters of the Freundlich model after 24 hr equilibration

Soil	Freundlich equation	Sorption capacity (a) (mg kg^{-1})	P sorption energy (n) (L kg^{-1})	Correlation coefficient (r^2)
Dongola 1	$X = 0.08\ C^{\,0.754}$	80	0.754	0.975
Dongola 2	$X = 0.269\ C^{\,0.708}$	269	0.708	0.879
P Fallow	$X = 0.33\ C^{\,0.487}$	330	0.487	0.97
Remitab	$X = 0.315 C^{\,0.461}$	315	0.461	0.971
Entisol	$X = 0.917 C^{\,0.547}$	917	0.547	0.905
Khashm elgirba	$X = 0.214\ C^{\,0.594}$	214	0.594	0.959

implying that a soil having a larger (a) value has a larger adsorbing capacity than a soil having a smaller (a) value. For practical purpose the (a) values estimated in (Table 2) may be used to differentiate soils having different P adsorption capacities. Thus, in this study, the *Entisols* (Soil 5) has the highest (a) value, followed by the Dongola 2, Permanent Fallow, Remitab, Khashm elgirba and Dongola 1.

The Freundlich parameter (a) was found to be practically useful parameter in summarising the adsorption properties of soil over wide range of equilibrium concentration. The order of soils according to their adsorption capacities was:

The *Entisols* > Dongola2 (Akked) > Permanent Fallow (Remitab) > Remitab > Khashm elgirba >Dongola1 (Kerma).

CONCLUSION

The results suggest a significant role of clay and iron content in phosphorus sorption by different selected soil series. The *Entisol* soil sorbed more phosphorus than other soil series, indicating that this soil needs more phosphorus fertilisation to attain optimum phosphorus concentration in the soil solution.

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