APPLICATION OF FREUNDLICH ADSORPTION ISOTHERM TO DETERMINE PHOSPHORUS REQUIREMENT OF COTTON CROP ON THREE DIFFERENT TEXTURED SOILS

M. Yasin*, A. M. Ranjha**, M. Yasin**, Rashid.A***
*Directorate General of Agriculture (Extension Wing)
**Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad
***Department of Crop Physiology

Cotton is an important cash crop in wheat-cotton cropping system of Pakistan. Most of the farmers apply phosphorus (P) fertilizer only to wheat and not to cotton crop which might be the main reason for low cotton yield. A field study was conducted to determine P requirements of three different textured calcareous soils viz. sandy loam, loam and clay loam. Sorption isotherms were constructed in the laboratory by equilibrating 2.5 g soil samples with 25 ml of 0.01 M $CaCl_2$ solution containing 0, 5, 10, 15, 20, 40, 60 and 80 mg P L^{-1} as KH_2PO_4. Sorption data were fitted to Freundlich model which were found significant at P = 0.05. P fertilizer doses for cotton crop were computed against theoretical soil solution P levels of 0.0, 0.10, 0.20, 0.25, 0.30, 0.35 and 0.40 mg P L^{-1}. It was noted that different P fertilizer doses were required for clay loam (0, 93, 132, 151, 155, 160 and 199 kg P ha^{-1}), loam (0, 49, 67, 80, 100, 117 and 135 kg P ha^{-1}) and sandy loam (0, 30, 54, 57, 63, 70 and 79 kg P ha^{-1}) soils to maintain the same soil solution P level. The maximum number of bolls was recorded at 0.30 mg P L^{-1} soil solution P level in sandy loam (28 vs. P rate of 63 kg ha^{-1}) and loam (35 vs. P rate of 100 kg ha^{-1}) soils. Statistically significant response of seed cotton yield (kg ha^{-1}) and lint % age were observed to the tune of 4419 and 35.65, respectively for sandy loam soil, while 4982 and 36.37, respectively for loam soil. Clay loam soil showed minor response to graded levels of applied P with respect to different cotton quality parameters.
Keywords: Phosphorus, sorption, isotherms, cotton, soil texture, Pakistan

INTRODUCTION

Phosphorus (P) is the most limiting nutrient element after nitrogen (N) for cotton (*Gossypium hirsutum* L.) production. More than 93 % soils in arid and semi arid regions of Pakistan are deficient in P (Memon *et al.,* 1992). General fertilizer recommendation may result excess application of fertilizer P on the soil where it may be required in less amount and insufficient quantity on some other soil where it may be needed in large amount. Owing to the high cost of P fertilizer, there is a need to apply it in the most efficient and economic ways.

Sorption isotherm technique has been suggested by many investigators to determine the amount of P required to bring the soil solution P to a level optimum for maximum plant growth (Fox and Kamprath, 1970., Holford, 1997). This technique is based on the assumption that a certain solution concentration of P is required to supply adequate P to plants at which most plants attain near maximum growth (Pena and Torrent, 1990., Chaudhry *et al.*, 2003). There is a general consensus that the residual P of that applied to wheat is adequate for cotton and that the requirements of cotton for P is less. That is why in wheat-cotton cropping system of Pakistan cotton yield is low as compared to many other countries of the world. Keeping in view the importance of P use for the most valuable crop, a study was conducted to determine optimum fertilizer P requirement for maximum cotton yield using adsorption isotherm.

MATERIALS AND METHODS

Three different textured soils were selected and composite soil samples were collected from 0-30 cm depths for the determination of physical and chemical characteristics (Table 1) following methods described by Bigham (1996).

Phosphorous adsorption isotherms

Phosphorus adsorption isotherms of the soils were constructed by equilibrating 2.5 g soils with 25 ml 0.01M $CaCl_2$ containing P concentrations of 0, 5, 10, 15, 20, 40, 60, 80, 120 and 160 mg P L^{-1} prepared from KH_2PO_4. The suspensions were shaken for 24 hours at 25±2°C. P concentration in the filtrate was measured using ascorbic acid method (Murphy and Riley, 1962). The amount of P adsorbed was calculated from the difference of P added and P in soil solution after P equilibrium was established. The sorption data were fitted to the Freundlich equation given as below:

Table 1. Physico-chemical properties of the selected soils

Parameters	Values		
EC (dS m^{-1})	1.3	1.4	0.8
pH	8.0	7.9	8.3
$CaCO_3$ (%)	6	8	10
O. M (%)	0.40	0.70	0.80
Olsen P (mg kg^{-1})	4.9	5.6	9.6
Extractable K (mg kg^{-1})	57	71	118
Sand (%)	75	58	36
Silt (%)	14	20	37
Clay (%)	11	22	27
Textural class	Sandy loam	Loam	Clay loam
Great group	Torripsamments	Torrifluvents	Camborthids

Table 2. P fertilizer doses applied to cotton crop*

Treatment	Target soil solution P level	Sandy loam	Loam	Clay loam
		P_2O_5		
	mg L^{-1}	kg ha^{-1}		
T_1	0.00	0	0	0
T_2	0.10	30	49	93
T_3	0.20	54	67	132
T_4	0.25	57	80	151
T_5	0.30	63	100	155
T_6	0.35	70	117	160
T_7	0.40	79	135	199

*Doses calculated with Freundlich model

$x/m = Kf\,(C)^{1/n}$

Where x/m is the amount of P adsorbed per unit weight of soil (mg kg^{-1})

C = Equilibrium P concentration in soil solution (mg L^{-1})

Kf and 1/n are constants which represent the intercept and slope of the regression equation, respectively. P fertilizer doses were computed to attain the soil solution levels of 0.00, 0.10, 0.20, 0.25, 0.30, 0.35 and 0.40 mg P L^{-1} by using the Freundlich adsorption isotherm (Table 2).

Field Experiment

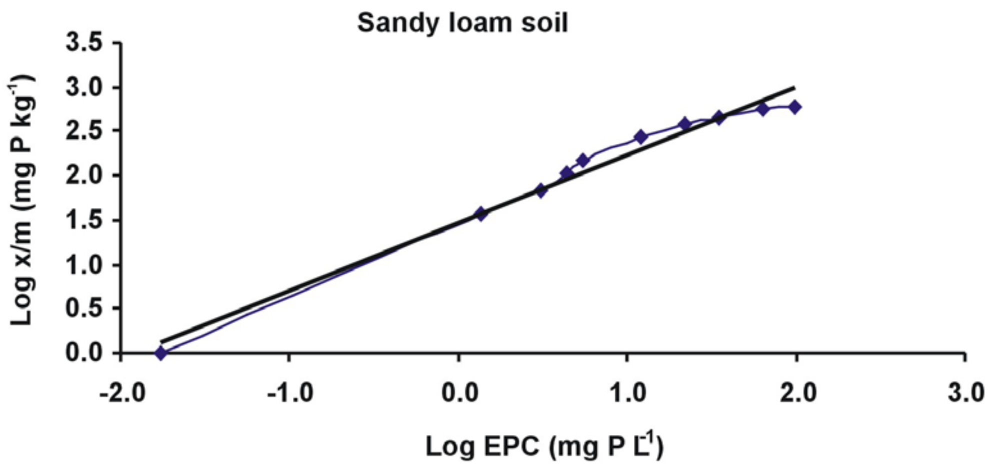
Cotton cultivar CIM-496 was sown in the first week of May, 2007 on beds through dibbling method with seed rate of 10 kg ha^{-1}. Row to row and plant to plant distance was maintained as 75 and 25 cm, respectively. Seven treatments repeated thrice were layed out according to Randomized Complete Block Design (RCBD). Recommended dose of K_2O (60 kg ha^{-1}) was broadcasted before making beds. N fertilizer was applied in four splits (First) - after 35 days of sowing at 50 kg ha^{-1}, (Second) - 2nd week of July at 50 kg ha^{-1}, (Third) - 1st week of August at 50 kg ha^{-1}, and (Fourth) - 3rd week of August at 50 kg ha^{-1} The sources of N, P and K were urea, TSP and SOP, respectively. For the control of weeds Pendimethaline was sprayed on wet sides of beds at 2.5 L ha^{-1} after first irrigation. Plant protection measures were adopted according to the recommendations of the Punjab agriculture department. No. of days required to reach at maturity were 182 days for sandy loam and 179 days each for loam and clay loam soils. Plant samples were collected at boll formation stage for P concentration. Following data were recorded:

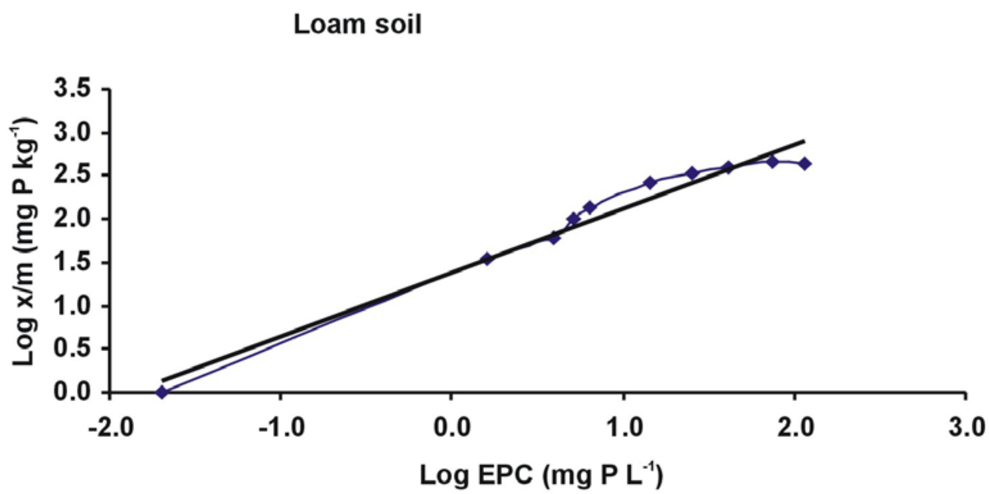
Number of bolls $plant^{-1}$ (before picking of cotton), average boll weight (g), seed cotton yield (kg ha^{-1}) and lint % age. The data were analyzed statistically (Steel and Torrie, 1980) and the comparisons among the treatment means were made by applying Duncan's Multiple Range (DMR) test at P = 0.05 (Duncan, 1955).

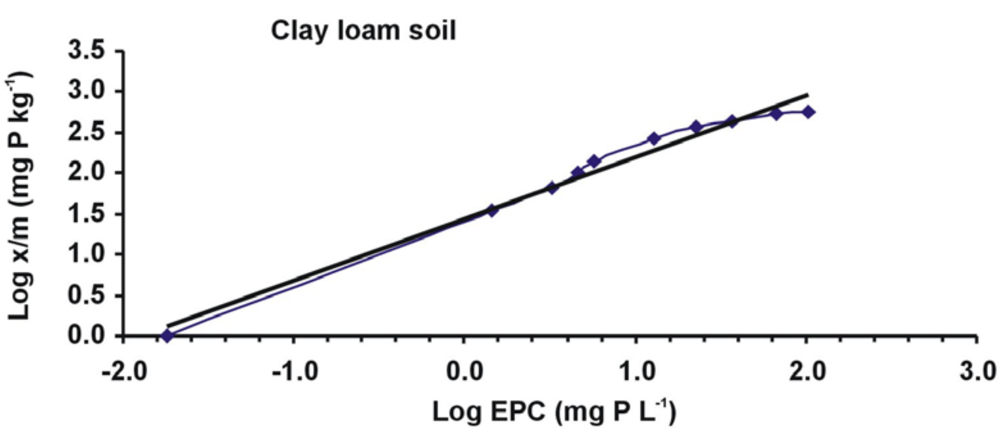
RESULTS AND DISCUSSION

Freundlich adsorption isotherm

The adsorption isotherms were examined according to the linear form of the Freundlich equation (Log x/m vs. Log EPC) which gave a linear fit and significant at P= 0.05 (Fig. 1). In the Freundlich model Kf indicates the adsorption capacity or buffering capacity of the soil. In


Sandy loam soil
Log x/m (mg P kg-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-2.0
-1.0
0.0
1.0
2.0
3.0
Log EPC (mg P L-1)


Loam soil
Log x/m (mg P kg-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-2.0
-1.0
0.0
1.0
2.0
3.0
Log EPC (mg P L-1)


Clay loam soil
Log x/m (mg P kg-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-2.0
-1.0
0.0
1.0
2.0
3.0
Log EPC (mg P L-1)

this study maximum buffering capacity (159.92 mg P kg^{-1}) was observed in clay loam soil followed by loam and sandy loam soils (Table 3). The values of exponent (1/n) represent the extent of adsorption and expressed as mg P kg^{-1} soil. In this study these values ranged from 0.579 to 0.718 L kg^{-1}. Similar values of exponent (1/n) were observed by a number of other researchers (Zhou and Li, 2001., Hussain *et al.*, 2006).

Table 3. Freundlich adsorption parameters for three soils

Soil	Amount adsorbed K_f (mg kg^{-1})	1/n (L kg^{-1})	(R^2)
Sandy loam	64.26	0.579	0.99**
Loam	77.47	0.718	0.95**
Clay loam	159.92	0.665	0.977**

n = 10 **Significant at P = 0.05

Number of bolls plant-1 and boll weight

Number of bolls $plant^{-1}$ (Table 4) increased with increasing soil solution P levels in all the three soils but the optimum level of fertilizer P for maximum no. of bolls $plant^{-1}$ was different in different textured soils. In the case of sandy loam soil the maximum no. of bolls $plant^{-1}$ (28) were noted with T_5, where P was applied at 62 kg P_2O_5 ha $^{-1}$ calculated against the soil solution P level of 0.30 mg L^{-1} and this treatment was statistically at par with T_6 and T_7. Minimum no. of bolls (16) were noted in controls. Similar trend was observed on loam soil except that the highest no. of bolls $plant^{-1}$ were 35 with T_5. On clay loam soil very small improvement was observed with respect to control as treatments were found non-significant from T_2 to T_7. This might be due to greater P supplying capacity of the soil as compared to other soils. Similar results were reported by Singh *et al.* (2000a & b).

Boll weight is an important yield parameter of cotton crop which was significantly affected by graded levels of applied P (Table 4). In sandy loam soil maximum boll weight observed was 3.89 g $boll^{-1}$ with T_4 where P was applied at 57 kg P_2O_5 ha^{-1} but this treatment was statistically at par with T_5, T_6 and T_7. The minimum boll weight (3.57g) was noted with T_1. In loam soil boll weight reached to the plateau point of 3.62 g with T_5 where P was applied at 100 kg P_2O_5 ha^{-1} calculated against the soil solution P level of 0.30 mg L^{-1} but non-significant effect was observed from T_6 to T_7. It is evident from the data that optimum soil solution P level for maximum boll weight in sandy loam and loam soils was 0.25 mg L^{-1} where as in case of clay loam soil only meager improvement was observed with respect to control which might be due to its high initial level of P (Table 1) leading to the better P supplying capacity of the soil. Gallardo *et al.* (1994) also reported that the average boll weight increased with increasing P rate and higher P buffering capacity of the soil.

Seed cotton yield and lint content

There was a gradual increase in seed cotton yield with increase in adjusted soil solution P levels. Significant increase in seed cotton yield (4191 kg ha^{-1}) was obtained with T_5 where P was applied at 63 kg P_2O_5 ha^{-1} calculated against the soil solution P level of 0.30 mg L^{-1} and minimum yield was found with T_1 in sandy loam soil (Table 5). Similar results were recorded in loam soil as well.i.e.T_5 performed statistically better (4982 kg ha^{-1}) than the rest of treatments as compared to control and P fertilizer rate to adjust the soil solution level of 0.25 mg L^{-1} was 100 kg ha^{-1}. Again minor improvement was recorded in clay loam soil as was observed in previous parameters. It is evident from the data that optimum soil solution P levels in case of sandy loam and loam soil was 0.25 mg L^{-1}. Singh and Sale (1998) also reported that seed cotton yield increased significantly with increasing P rate in coarse textured soils but the effects were small in their field trials conducted on heavy textured soils. Cotton lint %

Table 4. Effect of applied P on number of bolls $plant^{-1}$ and boll weight

Adjusted soil sol. P levels (mg L^{-1})	Sandy loam		Loam		Clay loam	
	No. of bolls $plant^{-1}$	Boll weight (g)	No. of bolls $plant^{-1}$	Boll weight (g)	No. of bolls $plant^{-1}$	Boll weight (g)
0.00	16d	3.52d	22d	2.91c	31b	3.26c
0.10	19c	3.60cd	25c	3.09c	33ab	3.45b
0.20	23b	3.77bc	30b	3.33b	32 b	3.69a
0.25	24b	3.89ab	31b	3.50ab	35a	3.71a
0.30	28a	3.90a	35a	3.62a	36a	3.70a
0.35	28a	3.91a	35a	3.62a	34a	3.71a
0.40	28a	3.88a	35a	3.57a	34a	3.73a

Means sharing same letters are statistically at par at 5 % level of probability.

Table 5. Effect of applied P on seed cotton yield and lint content

Adjusted soil sol. P levels (mg L^{-1})	Sandy loam		Loam		Clay loam	
	Seed cotton yield	Lint	Seed cotton yield	Lint	Seed cotton yield	Lint
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
0.00	2203d	34.46d	2517e	35.39d	4114c	36.43b
0.10	2700c	35.24c	3076d	36.04c	4615b	36.97ab
0.20	3419b	35.35b	3885c	36.28b	4899b	37.16a
0.25	3716b	35.65ab	4321b	36.37ab	5202a	37.30a
0.30	4119a	35.70a	4982a	36.42a	5296a	37.38a
0.35	4325a	35.71a	5126a	36.42a	5117a	36.94ab
0.40	4328a	35.74a	5042a	36.45a	5087a	37.21a

Means sharing same letters are statistically at par at 5 % level of probability

age responded positively to applied P in all the three soils and with T_5 more than 50 % yield was recorded with respect to control both in sandy loam and loam soils where as in clay loam soil only 19.31 % higher yield was recorded with T_3 (Table 5). Thus the optimum soil solution P level for maximizing lint % age in cotton was 0.25 mg L^{-1} in sandy loam and loam soils.

P uptake

The data regarding the P uptake depicted in Table 6 show that P uptake was increased with increasing P use in all the three soils. In the case of sandy loam soil the maximum P uptake (26.85 kg ha^{-1}) was noted with T_7 where P was applied at 79 kg P_2O_5 ha^{-1}. Minimum P uptake was noted from control plots. In loam soil P uptake was similar as in the case of sandy loam soil and maximum P uptake (28.04 kg ha^{-1}) was noted with T_7 where P was applied at 135 kg P_2O_5 ha $^{-1}$ calculated against the adjusted soil solution P level of 0.40 mg L^{-1}. In the case of clay loam soil the maximum P uptake (29.50 kg ha^{-1}) was noted with T_5 where P was applied at 155 kg P_2O_5 ha^{-1} but after that there was non-significant decrease up to T_7.

Table 6. Effect of applied P on Total P uptake (kg ha^{-1})

Adjusted Soil sol. P levels (mg L^{-1})	Sandy Loam	Loam	Clay Loam
0.00	13.96f	20.31f	24.40b
0.10	18.69e	21.74e	25.67ab
0.20	20.19d	23.06d	27.01ab
0.25	23.07c	25.19c	28.54ab
0.30	25.31b	26.64b	29.50a
0.35	26.27a	27.62a	27.86ab
0.40	26.85a	28.04a	28.63ab

Means sharing same letters are statistically at par at 5 % level of probability.

LITERATURE CITED

Bigham, J.M. 1996. Methods of Soil Analysis. Part 3, Chemical Methods. SSSA and ASA, Madison, WI, USA.

Chaudhry, E.H., A.M. Ranjha, M.A. Gill and S.M. Mehdi. 2003. Phosphorus requirement of maize in relation to soil characteristics. Int. J. Agric. Bio. 5 (4): 625-629.

Duncan, D.B. 1955.Multiple Range and Multiple F-Test. Biometrics.11:13-15.

Fox, R.L. and E.J. Kamprath. 1970. Phosphate sorption isotherm for evaluating the phosphate requirement of soils. Soil Sci. Soc. Am. Proc. 34: 902-907.

Gallardo, M., N.C. Turner and C. Ludwid. 1994. Water relations, gas exchange and abscisic acid content of Lupinus cosentini leaves in response to drying different proportions of the root system. J Exp Bot. 276:909–918.

Holford, I.C.R. 1997. Soil phosphorus: Its measurement, and its uptake by plants. Aust. J. Soil Res.35.227-239.

Hussain, A., A. Ghafoor and G. Murtaza. 2006. Use of models for phosphorus adsorption on some sodic soils of Punjab. Int.J.Agri.Biol.8:242-248.

Memon, K.S., A. Rashid and H.K. Puno. 1992. Phosphorus deficiency diagnosis and P soil test calibration in Pakistan. Tropical Soil Bulletin No.92-02, Phosphorus Decision Support System Workshop, March 11-12, 1992. College Station, Texas, University of Hawaii, Honolulu, USA.

Murphy, J. and H.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

Pena, F. and J. Torrent. 1990. Predicting phosphate sorption in soils of Mediterranean regions.Fertil.Res.23.173-179.

Singh, D.K., P.W.G. Sale, C.K. Pallaghy and V. Singh. 2000a. Role of proline and leaf expansion rate in the recovery of stressed white clover leaves with increased phosphorus concentration. New Phytol. 146:261–269.

Singh, D.K. and P.W.G. Sale. 1998. Phosphorus supply and the growth of frequently defoliated white clover (*Trifolum repens* L.) in dry soil. Plant Soil. 205:155–168.

Singh, D.K., P.W.G. Sale, C.K. Pallaghy and B.M. McKenzie. 200b. Phosphorus concentrations in the leaves of defoliated white clover affect abscisic acid formation and transpiration in drying soil. New Phytol. 147:249–259.

Steel, R.G.D. and J.H.T orrie. 1980. Principles and Procedures of Statistics. 2nd Ed. McGraw-Hill Book Corp. Inc., NY. USA.

Zhou, M. And Y.Li. 2001.Phosphorus sorption characteristics of calcareous soils and limestone from the southern everglades and adjacent farmlands. Soil Sci.Soc.Am.J.65:1404-1412.