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EXTERNAL AND INTERNAL PHOSPHORUS REQUIREMENT OF WHEAT IN BHALIKE SOIL SERIES OF PAKISTAN

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Abstract

A field experiment was conducted during Rabi 2004-05 in Bhalike soil series (Typic Camborthid) to determine the phosphorus (P) requirement of wheat for obtaining 95 % relative yield. Site selection was based on calcareousness and P deficiency. Phosphorus sorption isotherms were constructed to study the behavior of soil to phosphate application by adding 0, 5, 10, 15, 20, 40, 60 and 80 µg P mL^{-1} and were examined by the modified Freundlich equation. The parameters **a** (amount adsorbed ug g^{-1}) and **b** (buffer capacity mL g^{-1}) were estimated by regression of the logarithmic form of the data obtained from the adsorption isotherms. Theoretical doses of P (mg kg^{-1} soil) were calculated from this equation to develop P levels in the soil solution under field conditions which were 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 and 1.00 mg L^{-1} with native solution P level as control with and without nitrogen and potash. Maximum wheat grain (4.36 Mg ha^{-1}) and straw yield (4.45 Mg ha^{-1}) was recorded with 0.30 mg P L^{-1} developed by adding 54.10 mg P kg^{-1}. The maximum phosphorus concentration in wheat grain and straw was 0.318 and 0.118 % with P level of 0.50 mg L^{-1}, respectively. External soil solution P requirement was 0.273 mg P L^{-1} and internal P requirement was found 0.276 % for obtaining 95 % relative yield of wheat.

Introduction

Soils of Pakistan are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0%) in nature. When phosphatic fertilizers are added, part of it goes to soil solution and taken up by plants while rest goes to exchange sites and is either adsorbed or precipitated. Soil solution P is an immediate source for plant P uptake (Halford, 1989). Ahmad *et al*., (2003) conducted a survey on evaluation of nutrient status in the rice growing area of Punjab and observed that the available phosphorus ranged from 0.3-12.6 mg kg^{-1} with an average of 5.89 mg kg^{-1} soil.

Soils vary greatly in the amount of P required to provide an adequate supply of available P for plant and plants also vary in their P requirement for optimal growth (Vanderzaag *et al*., 1979). Standard solution P concentration (0.2 mg L^{-1}) provides P adequately for many crops if it is continuously maintained in the medium (Beckwith, 1965). The Freundlich equation is often considered to be purely empirical in nature but has been used extensively to describe the adsorption of phosphate by soils (Aslam *et al*., 2000; Arshad *et al.,* 2000; Javid Rowell, 2003; Chaudhry *et al.,* 2003). Using P sorption approach, P requirement of several crops has been determined under a variety of soil and climatic conditions (Fox, 1981; Vanderzaag *et al.,* 1979; Memon *et al*., 1992, Hassan *et al*., 1993). Chaudhry *et al.,* (2003) determined P requirement for maize by using sorption isotherm and fitted data in Langmuir and modified Freundlich equations and found that 22-67 mg P kg^{-1} was required to maintain 0.2 mg P L^{-1} soil solution in different soil series. According to the scale given by Juo & Fox (1977) the data from P sorption studies indicated that the soils of Pakistan had a low P sorption capacity. The addition of 50-100 kg P_2O_5 ha^{-1} in many cases increased the level of solution P to the desired level for optimal production. Nisar (1988) reported the result of wheat grown at four locations in Hafizabad, Gujranwala, Lyallpur and Sultanpur soil series. Phosphorus in soil solution at 95% maximum yield varied significantly among these soils. The phosphorus in solution for Lyallpur, Gujranwala, Hafizabad and Sultanpur series were found to be 0.09, 0.05, 0.26 and 0.90 ug mL^{-1}, respectively and the corresponding P requirement for 95% of maximum yield were 75, 92, and 150 kg P_2O_5 ha^{-1} for these soil series, respectively.

Memon *et al.,* (1991) reported that the P requirement of wheat grown on calcareous soils of Pakistan was 0.032 mg L^{-1} for 95% yield as determined from a composite yield response curve. The term "internal nutrients requirement" may delineate the minimum uptake of nutrient (a quantity factor) or the concentration of nutrient in the plant (an intensity factors) that is associated with near maximum yield usually named as the "critical concentration" (Fox, 1981). Similarly external phosphorus requirement of crop is the minimum concentration of P in soil solution equilibrated with soil associated with near maximum attainable yield of crop. Fox (1981) demonstrated that the external P requirement is not a single valued constant that holds for all conditions and suggested that the concentration of P in dilute salt solution is a useful indicator of the P nutrition of crops and that the external P requirement might be widely applied in conjunction with P sorption curves to estimate P fertilizer requirement. The phosphorus sorption approach provides a possible mean and has been advocated as a rational basis for estimating both the need for P and amount for a given soil crop combination (Vanderzaag *et al.,* 1979; Fox *et al.,* 1989). Keeping all this in view, a study was planned in the Bhalike soil series to determine phosphorus adsorption capacity of the soil and then computing P doses for field application to determine external and internal P requirement of wheat.

Materials and Methods

A field experiment was conducted during 2004-05 in Bhalike soil series at Farmer field in district Sheikhupura, Pakistan which is a rice tract of the Punjab province. Representative composite soil samples were collected from 0-20 cm depth with the help of auger. Soil physical and chemical properties were determined using methods described in Handbook No. 60 (U.S. Salinity Lab. Staff, 1954). Lime and particle size analyses were determined by the method of Moodie *et al.,* (1959) and available phosphorus was measured by the procedure as given by Watanabe & Olsen (1965). Phosphorus sorption isotherms were constructed by the methodology of Rowell (1994). To 2.5 g sample of soil, 25 ml of 10 mM $CaCl_2$ solution containing a series of phosphate concentrations was added. The initial concentration of P in solution ranged from 0-80 ug P mL^{-1} (0, 5, 10, 15, 20, 40, 60 and 80), with close intervals between the low concentrations. The soils were shaken on end over end shaker for 24 h. These samples were filtered through a Whatman No. 42 filter paper. The phosphate concentration in the final solution was determined by the method of Murphy & Riley (1962). The difference between amount of P in solution before and after equilibrium was taken as the amount of P sorbed (Nair *et al*., 1994). The sorption isotherms were examined by modified Freundlich equation and the simplest form of the Freundlich model was proposed by Le Mare (1982) as follows:

$$\mathbf{P = a\ C^{b}}$$

where **a** is the amount of P adsorbed (ug g^{-1}) when the concentration C is 1 ug mL^{-1} and b (mL g^{-1}) is the buffer power defined by the slope of the sorption curve at the point where P / C = 1 (mL g^{-1}). The value of P = C at which this point occurs varies between soils. The modified Freundlich model used to describe the soils in this work is as follows:

$$\mathbf{P = a\ C^{b/a}}$$

Table 1. Computed P doses to be applied in the field.

Sr. No.	P in soil solution (mg L^{-1})	P (mg kg^{-1} soil) to be added	P_2O_5 (kg ha^{-1}) to be added
1.	Native (0 NK)	0	0
2.	Native (+ NK)	0	0
3.	0.05	21.86	112.13
4.	0.10	31.04	159.12
5.	0.15	38.11	195.48
6.	0.20	44.07	226.06
7.	0.25	49.34	253.09
8.	0.30	54.10	277.51
9.	0.40	62.57	320.95
10.	0.50	70.05	359.32
11.	1.00	99.45	510.13

The main advantage of this equation is that **a** and **b** are the amount and the buffer capacities, respectively at the same point on the curve where **C** = 1 ug mL^{-1} and this point is the same for all the soils. The parameters **a** and **b** were estimated by regression of the logarithmic form of the data obtained from adsorption isotherms. Theoretical doses of phosphatic fertilizers to develop P levels in soil solutions (0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 and 1.0 mg L^{-1} with native solution P level as control with and without nitrogen and potash) under field conditions were calculated from this equation (Table 1).

Field experiment: Wheat (*Triticum aestivum* L.) crop cv. Inqulab-91 was sown during 2004-2005 at farmer field in District Sheikhupura with seed rate of 125 kg ha^{-1} after treating the seed with benlate @ 100 g per 40 kg wheat seed. Half of the recommended nitrogen (70 kg ha^{-1}) and potassium (K_2O) @ 70 kg ha^{-1} along with phosphorus (P_2O_5) doses calculated from modified Freundlich model for developing soil solution P were applied at sowing time in the form of urea, potassium sulphate and triple super phosphate, respectively. Second half of nitrogen was applied at first irrigation. The system of lay out was randomized complete block design with three replications. The plot size was 6m x 4m. All the cultural practices were applied to mature the crop successfully. Canal water was used for irrigation purpose. The crop was harvested at maturity. Grain and straw yield data were recorded. Grain and straw samples were dried at 70 ºC, ground and analyzed for P concentration.

The yield representing each phosphorus level was expressed as percentage of maximum yield of the experiment. The percentage yield, also termed as relative yield, was expressed as the yield with test nutrient added as percentage of maximum yield. The relative yield is a measure of the yield response to a single nutrient when other nutrients are supplied adequately but not in excessive amount. It was calculated as:

$$\text{Relative yield} = \frac{\text{Threshold yield for x}}{\text{Plateau yield for x}} \text{ X } 100$$

where

Threshold yield = Yield at zero level of x

Plateau yield = Point of maximum response to x

X = Rate of nutrient (P) applied.

Table 2. Original soil analysis.

Determinant	Units	Values
Sand	%	39
Silt	%	28
Clay	%	33
Textural class	-	Clay Loam
Sub group	-	Typic Camborthid
Series		Bhalike
pHs	-	8.22
ECe	dS m^{-1}	1.22
TSS	me L^{-1}	12.2
Ca^{2+}+ Mg^{2+}	me L^{-1}	7.6
Na^{+}	me L^{-1}	3.98
SAR	(m mol $L^{-1})^{0.5}$	1.02
CO_3^{2-}	me L^{-1}	-
HCO_3^{-}	me L^{-1}	1.8
Cl^{-}	me L^{-1}	1.9
SO_4^{2-}	me L^{-1}	8.5
$CaCO_3$	%	7.85
Organic matter	%	0.76
Olsen P	mg kg^{-1}	5.20
Extractable K	mg kg^{-1}	142

Relative yield (%) was plotted against soil solution P level and P concentration (%) in grain to determine the external and internal P requirement of wheat from the regression equation. All the parameters (grain, straw, P concentration) were statistically analyzed using method as described in Steel & Torrie (1980).

Results and Discussion

All the physical and chemical characteristics of the soil used in this study are given in Table 2. The soil used was non-saline, alkaline in nature, having clay content of 33 % and was clay loam in texture. Calcium carbonate content was 7.85 % indicating that soil was calcareous in nature. The soil was deficient in organic matter and available phosphorus but medium in extractable potassium.

Freundlich plot of sorption data: The adsorption curve presented in Fig. 1 exhibits that maximum P was fixed at low P concentrations in the isotherm. The data were fitted to examine modified Freundlich equation. The linear plot of the modified Freundlich equation presented in Fig. 2 and parameters of the equation [amount adsorbed (**a**), buffer capacity (**b**) mL g^{-1} and correlation coefficient (r^2)] are presented in Table 3. The buffer capacities (**b**) of the soil was 50.29 mL g^{-1} and the amount of P adsorbed (**a**) was 99.45 µg g^{-1}. The goodness of the fit of the model was ascertained by looking at the r^2 value (0.93) indicate high conformity of the adsorption data with the modified Freundlich model. The linearization transformation of data showed that the plot was linear.

Table 3. Phosphorus sorption parameters of the Freundlich model.

Soil	Amount adsorbed **(a)** ug g^{-1}	Buffer capacity **(b)** mL g^{-1}	Correlation coefficient (**r^2**)	No. of values (**n**)
Bhalike	99.45	50.29	0.93	8

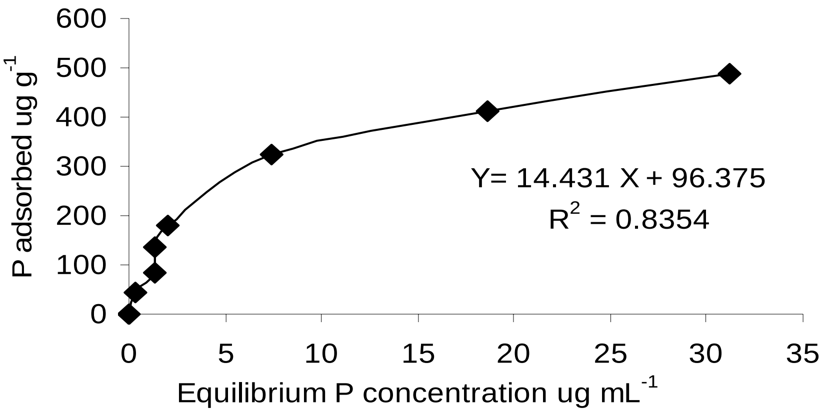

Fig. 1. Phosphorus Adsorption isotherms.

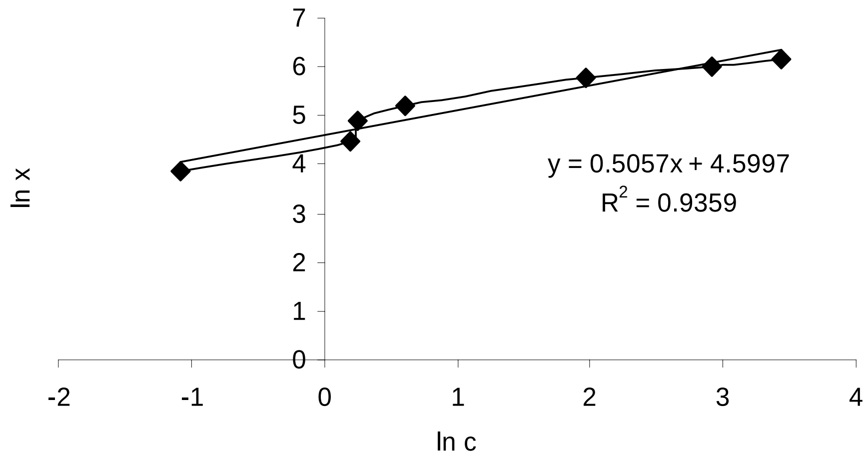

Fig. 2. Fitted modified Freundlich equation on P sorption data.

Generally the Freundlich model seemed fit at medium and high equilibrium concentrations. The value of the exponent was found < 1 (Table 3) which relates to the characteristics of the adsorbent (soil or $CaCO_3$). The findings are in agreement with those of Kuo & Lotse (1974) and Chaudhry *et al*., (2003) who reported that exponent of the Freundlich equation was independent of the time and temperature and the values depended on solution P concentration.

Since the Freundlich adsorption equation was derived empirically, its parameters **a** and **b** have been considered meaningless. Despite this, it was proposed that **a** could be considered as a capacity factor implying that a soil having a larger **a** value has larger adsorbing capacity than a soil having smaller **a** value. For practical purposes, the **a** value estimated in Table 3 may be used to differentiate soils having different P adsorption capacities. The larger **b** values have larger curvature of the adsorption isotherm and for **b** = 1, the isotherms would be a straight line. Using the P adsorption parameters, the Freundlich plot equation was formulated (Table 4) on the basis of these values. Fitter & Sutton (1975) and Rathowsky (1986) reported similar observations.

Table 4. Modified Freundlich model.

Soil	Modified Freundlich equation	
	Model form $P = a\ C^{b/a}$	Linear form
Bhalike	$P = 99.4544\ C^{0.5057}$	$Y = 0.5057\ x + 4.5997$

In the present study, the Freundlich model conformed to the observed adsorption data over medium range of equilibrium concentration. The Freundlich parameter **a** was used to be a practically useful parameter in summarizing the adsorption properties of the soil over wide range of equilibrium concentrations. Linear form of modified Freundlich model was used for computing P fertilizer quantities to develop the soil solution P level up to 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 and 1.00 mg L^{-1} i.e.,

$$\mathbf{P = a\ C^{b/a}}$$
$$\mathbf{Log\ P = log\ a + b/a\ log\ C}$$

The P quantities computed as mg P kg^{-1} soil will be multiplied with 2.24 x 2.29 to get kg P_2O_5 ha^{-1} as described in Table1.

Wheat grain and straw yield (Mg ha^{-1}): Results regarding wheat grain and straw yield are presented in Table 5. The data show that the maximum wheat grain yield (4.36 Mg ha^{-1}) was obtained at solution P level of 0.30 mg P L^{-1} which was developed by adding 277.51 kg P_2O_5 ha^{-1}. There was a progressive increase in yield with P application at lower or medium levels but at the higher levels of solution P, the yields were at par. This means that wheat responded differently to the solution P but response to the higher doses (> 0.30 mg P L^{-1}) was not observed. Similar results were also obtained by Amrani *et al*., (1999), Patel *et al.,* (1997), Saeed *et al*., (1992), Sharma & Singh (1998) and Rashid (1992).

Similarly straw yield also increased at the same soil solution P levels and the trend was almost same as was seen in the case of grain yield. Maximum straw yield of 4.45 Mg ha^{-1} was noted at soil solution P level of 0.30 mg L^{-1} (277.51 kg P_2O_5 ha^{-1}). Minimum straw yield was recorded in the control plots where no fertilizer was added. The reason for this might be poor tillering in control plots which increased significantly with the application of P fertilizer and building solution P levels. Khattak & Iqbal (1992) also found similar results for maize crop.

Phosphorus concentration (%) in wheat grain and straw: Data regarding P concentration of wheat grain (Table 5) reveal that maximum P concentration (0.318%) was observed at solution P level of 0.50 mg L^{-1} which was developed by adding 70.05 mg P kg^{-1} soil. This means that the soil was heavy textured and maximum P concentration was observed at the highest solution P level. This might be due to that wheat translocated P to the grain less efficiently in this soil. Minimum P concentration of 0.082% was determined in control plots. Duivenbooden *et al*., (1996) also reported P concentration in wheat grain between 0.25 – 0.49 percent. Similarly, the data also show that maximum P concentration of 0.118% was recorded in straw (like P concentration in grain) at solution P level of 0.50 mg L^{-1} which was obtained by adding 70.05 mg P kg^{-1} soil. However, minimum P concentration 0.010% was observed in plots receiving no fertilizer. Low P concentration in straw than grain might be due to more P translocation to the grain in the reproductive stage. Duivenbooden *et al*., (1996) also reported P concentration in wheat straw between 0.03 - 0.08%.

Table 5. Wheat grain, straw yield and P concentration in grain and straw.

Solution P (mg L^{-1})	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	P Conc. grain (%)	P Conc. in straw (%)
Native (0 NK)	1.05 H	1.19 H	0.082 G	0.010 H
Native (+ NK)	1.72 G	1.84 G	0.104 F	0.016 H
0.05	2.74 F	2.87 F	0.197 E	0.049 G
0.10	3.52 E	3.63 E	0.239 D	0.064 F
0.15	3.68 D	3.82 D	0.246 D	0.072 E
0.20	3.85 C	3.98 C	0.254 CD	0.083 D
0.25	4.10 B	4.23 B	0.272 BC	0.095 C
0.30	4.36 A	4.45 A	0.274 BC	0.098 BC
0.40	4.30 A	4.38 A	0.283 B	0.104 B
0.50	4.34 A	4.42 A	0.318 A	0.118 A
1.00	4.32 A	4.40 A	0.316 A	0.116 A
LSD	0.05	0.09	0.04	0.0

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

Phosphorus requirement of wheat: The phosphorus requirement of wheat crop was determined on the basis of near maximum (95% of the attainable maximum yield) crop yield. The fertilizer requirements are crop specific and site specific and can be estimated as external and internal P requirements. Fox (1981) reported that phosphorus requirement, both external and internal, of most crops were greater during early stage of growth than for crops approaching to maturity.

External (solution) phosphorus requirement of wheat: The solution levels developed for wheat growth were plotted against 95% relative yield of wheat for the determination of P requirement by the Boundary Line Technique (Webb, 1972) as shown in the Fig. 3. The graph revealed that solution P requirement of 0.273 mg L^{-1} was found in Bhalike soil series for near maximum yield of wheat (95%). This value elucidated that near maximum yield of wheat (95%) was obtained at medium solution P level and the P requirement is high in heavy textured soil with respect to yield and the reason might be that in heavy textured soils, P availability is very low due to P fixation. Memon *et al*., (1991) found that 18-29 kg P ha^{-1} is required to develop a solution level of 0.032 mg P L^{-1} in calcareous soils. The concentration at the root surface of young plants need about 0.03-0.3 mg P L^{-1} and older plants require about 0.03 mg P L^{-1} or less but the concentrations which have been shown by many workers to be required in bulk soil solution are little higher (0.06-0.68 mg P L^{-1}) and this would be expected because uptake reduces the phosphate concentration at the root surface when plants are grown in static systems e.g., soils (Kamprath & Watson, 1980). Similarly, Beckwith (1965) suggested a standard concentration of 0.2 ug P mL^{-1} as adequate for most plant species. Similar results were found Hassan *et al*., (1994), Memon *et al*., (1991) and Nisar (1988).

Internal phosphorus requirement of wheat: Internal requirement of wheat was determined by making graph of P concentration in grain and maximum attainable 95 % relative yield as shown in Fig. 4. The value obtained was 0.276%. This means that as the crop passed through reproductive phase, the phosphorus which is highly mobile within the plant was shifted to the seed and this transfer of P was very rapid and highest in this heavy textured soil. Critical P concentration in wheat grains for near maximum grain yield normally range from 0.19% to 0.25% and Rashid (1992) found critical P concentration in wheat grain as 0.22% and in maize grain as 0.27% under green house conditions.

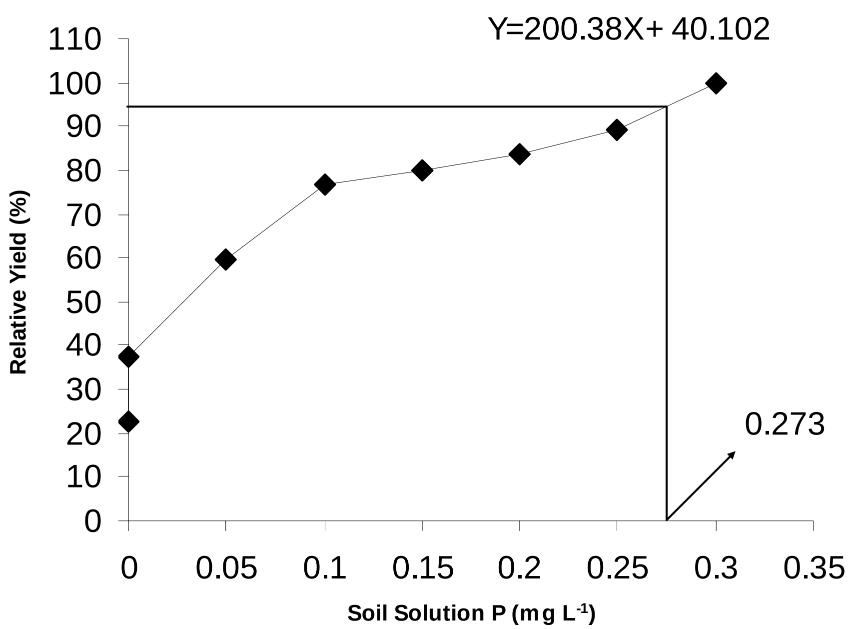

Fig. 3. External phosphorus requirement of wheat.

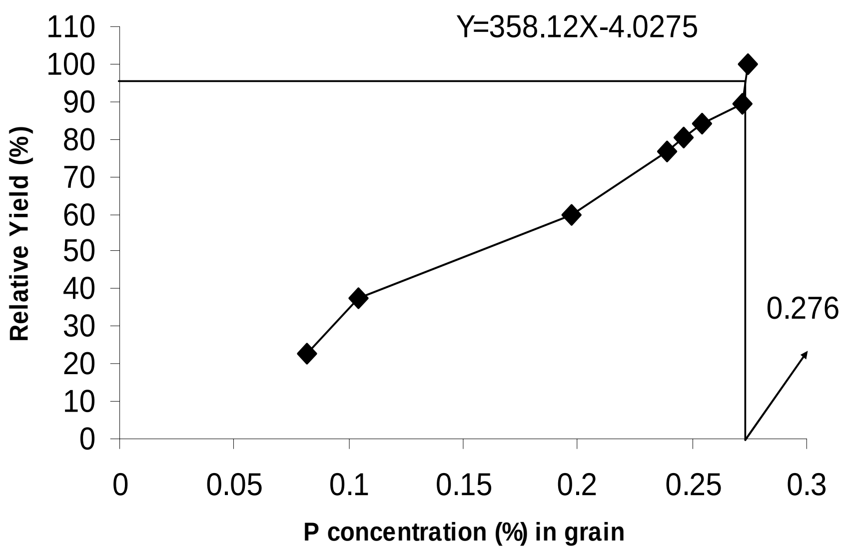

Fig. 4. Internal phosphorus requirement of wheat.

It can be concluded from this study that application of adsorption isotherm in Freundlich model was quite effective in determining the phosphorus requirement of wheat. External solution P requirement was 0.273 mg P L^{-1} and internal P requirement was found 0.276% for obtaining 95% relative yield of wheat. Further research is still needed on this aspect to formulate some concrete fertilizer recommendation by using the model approach.

References

Ahmad, N., M. Abid, K. Hussain, M. Akram and M. Yousaf. 2003. Evaluation of nutrient status in rice growing areas of the Punjab. *Asian J. Plant Sci*., 2(5): 449-453.

Amrani, M., D.G. Westfall and L. Mustafa. 1999. Improving the soil test phosphorus calibration for calcareous soils. *Commun. Soil Sci. Plant Anal*., 30(1-2): 129-144.

Anonymous. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Salinity Lab. Staff. USDA Handbook No. 60, Washington, DC, USA.

Arshad, M., Rahmatullah, M. Salim and M. Yousaf. 2000. Soil properties related to phosphorus sorption as described by modified Freundlich equation in some soils. *Int. J. Agri. Biol*., 2: 290-292.

Aslam, M., M. Sharif, Rahmatullah, M. Salim and M. Yasin. 2000. Application of Freundlich isotherm to determine phosphorus requirement of several rice soils. *Int. J. Agri. Biol*., 2: 286-288.

Beckwith, R.S. 1965. Sorbed phosphate at standard supernatant concentration as an estimate of the phosphate needs of soils. *Aust. J. Exp. Agri. and Anl. Hus*. 5:52-58.

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.

Duivenbooden, N. Van, C.T. deWit and H. vanKeulen. 1996. Nitrogen, Phosphorus and Potassium relation in five major cereals reviewed in respect to fertilizer recommendations using simulation modeling. *Fert. Res*., 44: 37-49.

Fitter, A. H. and C. D. Sutton. 1975. The use of the Freundlich isotherm for soil P sorption data. *J. Soil Sci*., 26: 241-246.

Fox, R.L. 1981. External Phosphorus requirement of crops. In: *Chemistry in the soil environment*. (Eds.): M. Shelly *et al*. American Soc. of Agron. Madison, WI, USA. p. 223-239.

Fox, R.L., R.P. Bossbart, D. Somponge and M.L. Lin. 1989. Phosphorus requirements and management of sugarcane, pineapple and bananas. In: *Proc. "P requirements for Suitable Agriculture in Asia and Ocean*". March 5-10. Los Banos, Philippines.

Hassan, M.M., A. Rashid and M.S. Akhtar. 1993. Phosphorus requirement of corn and sunflower grown on calcareous soils of Pakistan. *Commun. Soil Sci. Plant Anal*., 24: 1529-1541.

Hassan, M.M., A. Rashid and M.S. Akhtar. 1994. Phosphorus requirement of maize and sunflower on selected bench mark soils of Pakistan. *In Proc. 4th Nat. Cong. Soil Sci*., May 24-26, 1992 at NARC, Islamabad. p. 327-332.

Holford, I. 1989. Phosphorous behavior in soils. *Agri. Sci*., 12: 15-20.

Javid, S. and D.L. Rowell. 2003. Effect of soil properties on Phosphate adsorption in calcareous soils of Pakistan. *Pak. J. Soil Sci*., 21(4): 47-55.

Juo, A.S.R. and R.L. Fox. 1977. Phosphate Sorption Capacity of some benchmark soils in West Africa. *Soil Sci*., 143: 370-376.

Kamprath, E.J. and M.E. Watson. 1980. Conventional soil and tissue test for assessing the phosphorus status of soils. In: *The role of Phosphorus in Agriculture*". (Ed.): F.E. Khawsaneh et al., "Soil Sci. Soc. Am. Madison, WI., USA. p. 433-469.

Khattak, J.K. and J. Iqbal. 1992. Calibration of phosphorus on calcareous soils by $NaHCO_3$ and NH_4HCO_3- DTPA extracting using maize as a test crop. In: "*Role of Phosphorus in Crop Production*." NFDC, Islamabad, Pakistan. p. 311-320.

Kuo, S. and E.G. Lotse. 1974. Kinetics of phosphate adsorption and desorption by lake sediments. *Soil Sci. Soc. Am. Proc*., 38: 50-54.

Le Mare, P.H. 1982. Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Colombia and Brazil, and comparisons with soils of southern Nigeria. *J. Soil Sci*., 33: 691-707.

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

Memon, K.S., H.K. Puno and R.L. Fox. 1991. Phosphate sorption approach for determining phosphorus requirements of wheat in calcareous soils. *Fert. Res.,* 28(1): 67- 72.

Moodie, C.D., H.W. Smith and R.A. Mcreery. 1959. *Laboratory manual for soil fertility*. State college of Washington, Mimeograph, Pullman Washington, D.C. USA. p. 31-39.

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.

Nair, P.S., T.J. Logan, A.N. Sharpley, L.E. Somers, M.A. Tabatabai and T.L. Yuan. 1994. Inter laboratory Comparison of a Standardized Phosphorus Adsorption Procedure. *J. Environ. Qual*., 13(4): 591-595.

Nisar, A. 1988. Phosphorus use efficiency and soil test crop response correlation. Ph.D. Thesis. Dept. Soil Sci., Uni. Agri., Faisalabad, Pakistan.

Patel, N.M., R.P. Sahlawat and R.B. Ardeshna. 1997. Direct and residual effect of Phosphorus in rice-wheat sequence under south Gujrat conditions. *Ind. J. Agron*., 42(1): 18-21.

Rashid, A. 1992. Internal P requirement of crops and use of universal soil test for evaluating P fertility of Pakistani soils. In: Role of Phosphorus in Crop Production. July 15-17, 1990. NFDC, Islamabad, Pakistan. p. 147-173.

Rathowsky, D.S. 1986. A statistical study of seven of curves for describing the sorption of phosphate by soil. *J. Soil Sci*., 37: 183- 189.

Rowell, D.L. 1994. *Soil Science. Methods and Applications*. Longman Scientific and Technical, Harlow, Essex, UK.

Saeed, M., Z.A. Ahmad and M.Y. Nadeem. 1992. Residual effect of Phosphorus applied to rice on wheat and vice versa. In: Role of Phosphorus in Crop Production." July 15-17, 1990. NFDC, Islamabad, Pakistan. p. 415-423.

Sharma, R.D. and T.A. Singh. 1998. Direct and residual affects of liquid ammonium poly phosphate as a phosphorus source in wheat (*Triticum aestivum*) – maize (*Zea mays*) cropping systems in an Entisol of western Utter pardesh. *Ind. J. Agron*., 43(2): 223-230.

Steel, R.G.D. and J.H. Torrie. 1980. *Principles and Procedures of Statistics*. 2nd Ed. Mc Graw-Hill Book Corp. Inc., NY, USA.

Vander Zaag, P., R.L. Fox, R.S. Delapena, W.M. Laughlin, A. Ryskamp, S. Villa-gracia and D.T. Westermann. 1979. The utility of phosphate sorption curves for transferring soil management information. *Trop. Agri*., 56: 153-160.

Watanabe, F.S. and S.R. Olsen. 1965. Test of an Ascorbic acid method for determining phosphorus in water and $NaHCO_3$ Extracts from soil. *Soil Sci. Soc. Am. Proc*., 29: 677-678.

Webb, R.A. 1972. Use of boundary line technique in the analysis of biology data. *J. Hort. Sci*., 47: 309-319.

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