*Soil & Environ. 28(1): 38-44, 2009*
*www.se.org.pk*

# External and internal phosphorus requirements of wheat in Rasulpur soil series of Pakistan

***M. Sarfraz*[1]*, M. Abid*[1] *and S.M. Mehdi*[2*]**
[1]University College of Agriculture, Bahauddin Zakirya University, Multan, Pakistan.
[2]Director, Soil Salinity Research Institute, Pindi Bhattian, Distt. Hafizabad, Pakistan.

## Abstract

*A field experiment was conducted in Rabi 2004-2005 on Rasulpur soil series (Typic Camborthid) to determine the 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 behaviour of soil to P application by adding 0, 5, 10, 15, 20, 40, 60 and 80 µg P* $mL^{-1}$ *and were examined by the Freundlich equation. The parameters* ***a*** *(amount adsorbed in µg* $g^{-1}$*) and* ***b*** *(buffer capacity in 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 adjust 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 and 1.00 mg P* $L^{-1}$ *with native solution P level as control with and without N and K fertilizer application. Wheat crop was grown according to randomized complete block design with three replications. Maximum wheat grain and straw yield of 3.52 and 3.67 Mg* $ha^{-1}$ *was recorded at solution P level of 0.20 mg P* $L^{-1}$*. Maximum phosphorus concentration in wheat grain and straw was 0.410 and 0.145% which was found at solution P level of 0.50 mg P* $L^{-1}$*, respectively. External solution P requirement was 0.172 mg P* $L^{-1}$ *and internal P requirement found was 0.302% for obtaining 95% relative yield of wheat.*

**Key words**: Freundlich model, P sorption isotherms, wheat, P concentration, external and internal P requirement

## Introduction

Balanced use of nutrients is essential for successful harvesting of crops on sustainable basis. The use of fertilizers has been mainly confined to the application of nitrogen while the use of phosphorus (P) is far below the needs of crops and soils in Pakistan.

Soils of Pakistan are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0%) in nature. When P fertilizer is added to the soil, part of it goes to soil solution and taken up by plants while remaining either adsorbed or precipitated. Ahmad *et al*. (2003) conducted a survey for 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. Plants also vary in their P requirement for optimal growth (Vanderzaag *et al*., 1979).The literature suggests that optimum 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 (Arshad *et al*., 2000; Aslam *et al*., 2000; Javid and 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 (Vanderzaag *et al*., 1979; Fox, 1981; Memon *et al.*, 1992 Hassan *et al.*, 1993). This approach has an advantage over conventional method of soil testing since it integrates P intensity, capacity and buffering capacity aspects of the soil which play important role in controlling the P flux to most of the growing plants. Moreover, fertilizer requirement can be estimated directly from P sorption curves. According to the scale given by Juo and 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. Ahmad (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 P in solution for Lyallpur, Gujranwala, Hafizabad and Sultanpur series were found to be 0.09, 0.052, 0.26 and 0.90 $\mu$g $mL^{-1}$, respectively and the corresponding P requirement for 95% of maximum yield were 75, 92, 114 and 150 kg $P_2O_5$ $ha^{-1}$ for these soil series, respectively. Similarly, 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 nutrient requirement of a crop can be expressed in several ways. The term "internal nutrients requirement" may delineate the minimum uptake of nutrient (a quantity factor in plant nutrition) that is associated with a specified yield. The internal requirement can also be defined as the concentration of nutrient in the plant (an intensity factors in

*Email: mehdi853@hotmail.com

plant nutrition) that is associated with near maximum yield usually named as the "Critical concentration" (Fox, 1981). Crops have external requirements too. External phosphorus requirement of crop may be defined as the maximum concentration of P in soil solutions equilibrated with soils associated with near maximum attainable yield of crop. The quantity of nutrient frequently taken up is of great significance if it is considered in relation to the capacity of the soil to hold nutrients; thus both the internal and the external requirement can be expressed in terms of P quantity, intensity and capacity factor. The P 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). Keeping all this in view, a study was planned in the Rasulpur 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.

## Material and Methods

### *Soil*

A field experiment was conducted in the rice tract, Distt. Hafiz Abad during 2004-05. Composite soil samples were collected from 0-20 cm depth with the help of an auger. Soil physical and chemical properties were determined using methods as described by U.S. Salinity Lab. Staff (1954). Lime ($CaCO_3$) and particle size (Soil texture) were determined by the method of Moodie *et al.* (1959) While available P by that of Watanabe and Olsen (1965).

### *P sorption isotherms*

Phosphorus sorption isotherms were constructed using the method of Rowell (1994). To a 2.5 g sample of soil, 25 mL of 10 mM $CaCl_2$ solution containing a series of P concentrations was added. The initial concentration of P in solution ranged from 0-80 µg $mL^{-1}$ (0, 5, 10, 15, 20, 40, 60 and 80). The soil samples were shaken on end over end shaker for 24 h. The samples were filtered through a Whatman No. 42 filter paper. The P concentration in the final solution was determined by the method of Murphy and 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 proposed by Le Mare (1982) as follows:

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

Where, **P** =Amount of P adsorbed per unit of soil (µg $g^{-1}$), **C**= Equilibrium P concentration in soil solution (µg $mL^{-1}$), **a** and **b** are constants which represent the intercept and slope of the sorption isotherm. When the concentration **C** is 1 µg $mL^{-1}$ 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 soil in this work is as follows:

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

The main advantage of this equation is that **a** and **b** are the amount of P adsorbed and the buffer capacities, respectively at the same point on the curve, where **C** = 1 µg $mL^{-1}$. 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 1.00 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 4).

**Table 4. Computed P doses to be applied in the field**

| P in soil solution (mg $L^{-1}$) | P to be added (mg $kg^{-1}$ soil) | $P_2O_5$ to be added (kg $ha^{-1}$) |
|---|---|---|
| Native ( 0 NK) | 0.00 | 0.00 |
| Native ( + NK) | 0.00 | 0.00 |
| 0.05 | 16.09 | 82.53 |
| 0.10 | 22.43 | 115.05 |
| 0.15 | 27.25 | 139.78 |
| 0.20 | 31.28 | 160.45 |
| 0.25 | 34.81 | 178.56 |
| 0.30 | 37.99 | 194.87 |
| 0.40 | 43.61 | 223.70 |
| 0.50 | 48.54 | 248.99 |
| 1.00 | 67.66 | 347.06 |

### *Field trial*

Wheat (*Triticum aestivum* L.) crop cv. Inqulab-91 was sown by using seed rate of 125 kg $ha^{-1}$ after treating the seed with benlate at 100 g per 40 kg wheat seed. Half of the recommended nitrogen (70 kg $ha^{-1}$) and potassium ($K_2O$) at 70 kg $ha^{-1}$ along with P doses calculated from modified Freundlich model 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 ground level 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 P level was expressed as percentage of maximum yield of the experiment, also termed as relative yield,was calculated as

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

Where

Threshold yield = Yield at zero level of x

Plateau yield = Point of maximum response to x

x = Rate of nutrient applied.

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 and Torrie (1980).

## Results and Discussion

The soil of the experimental site was non-saline, alkaline in reaction, calcareous, sandy loam in texture, deficient in organic matter and available P but medium in extractable K (Table 1).

**Table 1. Original soil analysis**

| Determination | Unit | Value |
|---|---|---|
| Textural class | - | Sandy Loam |
| Sub group | - | Typic Camborthid |
| Series | | Rasulpur |
| $pH_s$ | - | 7.96 |
| $EC_e$ | $dS\ m^{-1}$ | 0.92 |
| TSS | $meL^{-1}$ | 9.2 |
| SAR | $(m\ mol\ L^{-1})^{0.5}$ | 1.13 |
| $CaCO_3$ | % | 5.18 |
| Organic matter | " | 0.38 |
| Olsen P | $mg\ kg^{-1}$ | 4.35 |
| Extractable K | " | 98 |

### *Freundlich plot of sorption data*

After constructing the P adsorption isotherms (Figure 1), the data was subjected to examine the fitness of modified Freundlich equation. The linear plot of the modified Freundlich equation presented in Figure 2 and parameters of the equation [amount adsorbed (**a**), buffer capacity (**b**) mL $g^{-1}$ and correlation coefficient ($r^2$)] are presented in Table 2. The buffer capacities (**b**) of the soil was 32.43 mL $g^{-1}$ and the amount of P adsorbed (**a**) was 67.66 µg $g^{-1}$. The goodness of the fit of the model was ascertained by looking at the $r^2$ value (0.93) which indicated high conformity of the adsorption data with the Freundlich model. The linearization transformation of data showed that the plot was linear.

**Table 2. Phosphorus sorption parameters of the Freundlich model in Rasulpur soil series**

| Amount adsorbed (a) µg $g^{-1}$ | Buffer capacity (b) mL $g^{-1}$ | Correlation coefficient ($r^2$) | No. of values (n) |
|---|---|---|---|
| 67.66 | 32.43 | 0.93 | 8 |

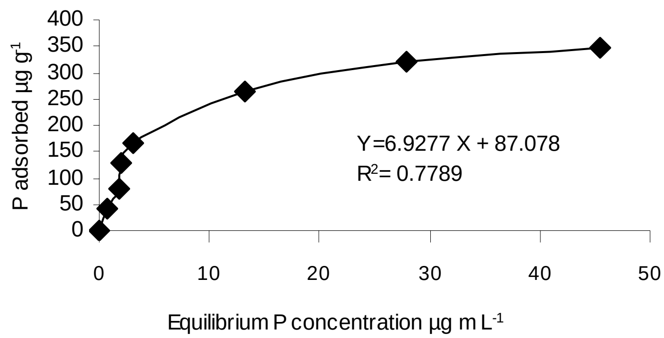


**Figure 1. Phosphorus Adsorption Isotherms**

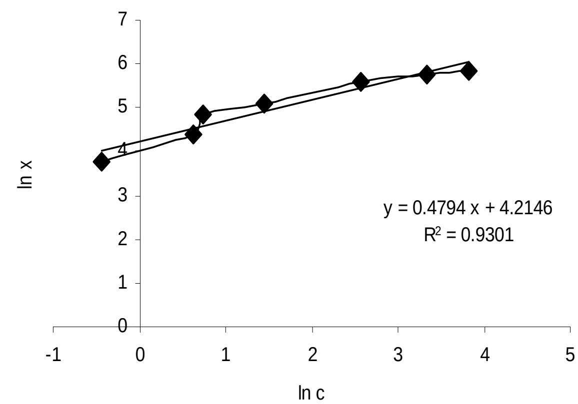


**Figure 2. Fitted Freundlich equation on P sorption data**

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 and 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 of no use for practical purposes. 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 2 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** equal to 1; the isotherms would be a straight line. Using the P adsorption parameters, the Freundlich plot equation was formulated (Table 3) on the basis of these values. Fitter and Sutton (1975) and Rathowsky (1986) reported similar observations.

**Table 3. Modified Freundlich model**

| Modified Freundlich equation | |
|---|---|
| Model form $P = a\,C^{b/a}$ | Linear form |
| $P = 67.6670\ C^{0.4794}$ | $Y = 0.4794\ x + 4.2146$ |

## Computed P doses to be applied in the field

Linear form of modified Freundlich model was used for computing P fertilizer quantities to adjust the soil solution P levels of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50 and 1.0 mg $L^{-1}$.

The P quantities computed as mg P $kg^{-1}$ soil was multiplied with 2.24 x 2.29 to get kg $P_2O_5$ $ha^{-1}$ as given in Table 4.

## Wheat grain and straw yield (Mg $ha^{-1}$)

Results regarding wheat grain and straw yield are depicted in Table 5. The data show that the maximum wheat grain yield (3.52 Mg $ha^{-1}$) was obtained at solution P level of 0.20 mg $L^{-1}$ which was adjusted by adding 160.45 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 (> 0.20 mg P $L^{-1}$) was not observed. Similar results were also obtained by Saeed *et al*. (1992), Patel *et al*. (1997), Sharma and Singh (1998), Amrani *et al.* (1999) and Tomar *et al*. *(*1999). 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 3.67 Mg $ha^{-1}$ was noted at soil solution P level of 0.20 (160.45 kg $P_2O_5$ $ha^{-1}$). Minimum straw yield was recorded in the control plots where no fertilizer was added. Khattak and Iqbal (1992) also found similar results for maize crop.

## Phosphorus concentration (%) in wheat grain and straw

Data regarding P concentration of wheat grain depicted in Table 5 revealed that maximum P concentration (0.410 %) was observed where solution P level of 0.50 mg $L^{-1}$ was adjusted by adding 248.99 kg $P_2O_5$ $ha^{-1}$ which remained non significant with higher level of 1.0 mg P $L^{-1}$. Minimum P concentration of 0.103% was determined in control plots. Duivenbooden *et al*. (1996) also reported P concentration in wheat grain between 0.25–0.49%. Similar results were obtained in straw regarding P concentration i.e. maximum P concentration (0.145%) was observed where solution P level of 0.50 mg $L^{-1}$ was adjusted by adding 248.99 kg $P_2O_5$ $ha^{-1}$ which remained non significant with higher level of 1.0 mg P $L^{-1}$. However, minimum P concentration of 0.014% was observed in plots receiving no fertilizer. It is an established fact that low P concentration in straw than grain is 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%.

## Phosphorus requirement of wheat

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

## External (solution) P 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 Figure 3.

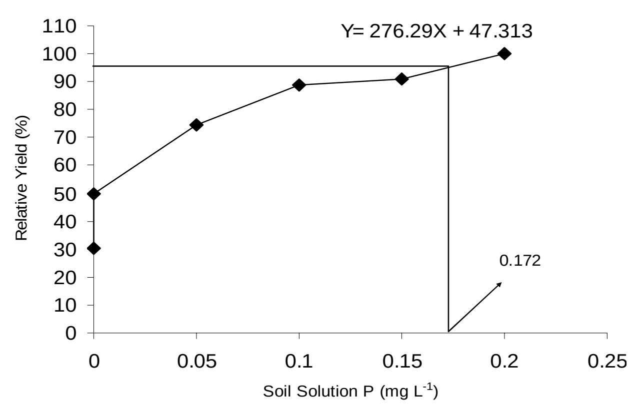


**Figure 3. External phosphorus requirement of wheat**

The graph revealed that solution P requirement of 0.172 mg $L^{-1}$ was found in Rasulpur soil series for near maximum yield of wheat (95%). This value elucidated that near maximum yield of wheat (95%) was obtained at lower solution P level. This means that P requirement is very low in coarse textured soil with respect to yield and the reason might be that coarse textured soil has a low P fixation capacity. 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. The concentrations which is 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 and Watson, 1980). Similarly, Beckwith (1965) suggested a standard concentration of 0.2 $\mu$g P mL$^{-1}$ as adequate for most plant species. Similar results were found by Ahmad (1988), Memon *et al*. (1991) and Hassan *et al*. (1993 &1994) under soil conditions in Pakistan.

**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. in grain (%) | P Conc. in straw(%) |
|---|---|---|---|---|
| Native ( 0 NK) | 1.12 F | 1.23 F | 0.103 H | 0.014 H |
| Native ( + NK) | 1.84 E | 1.96 E | 0.132 G | 0.019 H |
| 0.05 | 2.76 D | 2.87 D | 0.261 F | 0.058 G |
| 0.10 | 3.28 C | 3.42 C | 0.285 E | 0.076 F |
| 0.15 | 3.36 B | 3.50 BC | 0.291 E | 0.088 E |
| 0.20 | 3.52 A | 3.67 A | 0.315 D | 0.110 D |
| 0.25 | 3.47 A | 3.59 AB | 0.326 D | 0.118 C |
| 0.30 | 3.45A | 3.56 AB | 0.365 C | 0.125 B |
| 0.40 | 3.48 A | 3.61 AB | 0.379 B | 0.131 B |
| 0.50 | 3.44 A | 3.54 ABC | 0.410 A | 0.145 A |
| 1.00 | 3.46 A | 3.58 AB | 0.412 A | 0.147 A |
| LSD | 0.07617 | 0.1204 | 0.01177 | 0.006092 |

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

## *Internal P requirement of wheat*

Internal P requirement of wheat was determined at crop maturity i.e. in grain by making a graph of P concentration in grain and maximum attainable 95 % relative yield as shown in Figure 4. The value obtained for internal P requirement of wheat was 0.302% (Figure 4). This means that as the crop passed through reproductive phase, the P was translocated to the seed. Critical P concentration in wheat grains for near maximum grain yield normally ranges from 0.19 to 0.25%. Rashid (1992) found critical P concentration in wheat grain as 0.22% and in maize grain as 0.27% under green house conditions.

## *Conclusion*

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. Maximum grain and straw yield of 3.52 and 3.67 Mg ha$^{-1}$, respectively, was recorded at solution level of 0.20 mg P L$^{-1}$. Phosphorus concentration in grain and straw was 0.410 and 0.145%, respectively, which was found at solution P level of 0.50 mg L$^{-1}$. External P requirement was 0.172 mg P L$^{-1}$ and internal P requirement found was 0.302% 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.

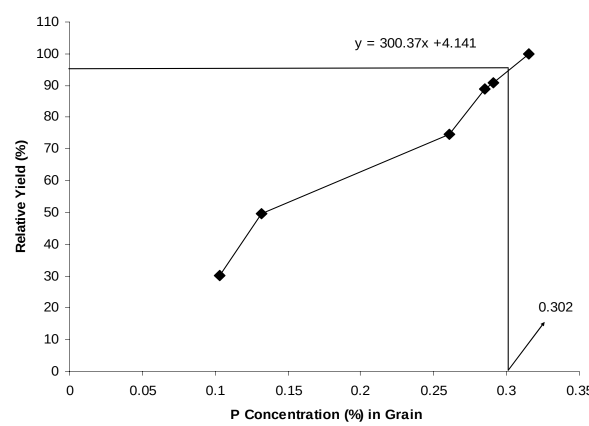


**Figure 4. Internal phosphorus requirement of wheat**

## References


Ahmad, N. 1988. Phosphorus use efficiency and soil test crop response correlation. Ph. D. Thesis. Department of Soil Science, University of Agriculture, Faisalabad, Pakistan.

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

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

Arshad, M., Rahmatullah, M. Salim and M. Yousaf. 2000. Soil properties related to phosphorus sorption as described by modified Freundlich equation in some soils. *International Journal of Agriculture and Biology* 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. *International Journal of Agriculture and Biology* 2: 286-288.

Beckwith, R.S. 1965. Sorbed phosphate at standard supernatant concentration as an estimate of the phosphate needs of soils. *Australian Journal of Experimental Agriculture and Animal Husbandry* 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. *International Journal of Agriculture and Biology* 5(4): 625-629.

Duivenbooden, N.V., C.T. de Wit and H. van Keulen. 1996. Nitrogen, Phosphorus and Potassium relation in five major cereals reviewed in respect to fertilizer recommendations using simulation modeling. *Fertilizer Research* 44: 37-49.

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

Fox, R.L. 1981. External Phosphorus requirement of crops. p. 223-239. In: Chemistry in the Soil Environment. R.H. Dowdy (ed.). American Society of Agronomy, Special publication 40, ASA., Madison, WI.

Hassan, M.M., A. Rashid and M.S. Akhtar. 1993. Phosphorus requirement of corn and sunflower grown on calcareous soils of Pakistan. *Communications in Soil Science and Plant Analysis* 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. p. 327-332. In: Proceeding 4$^{th}$ National Congress of Soil Science. May 24-26, 1992, NARC, Islamabad.

Holford, I. 1989. Phosphorous behavior in soils. *Agricultural Sciences* 12: 15- 20.

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

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

Kamprath, E.J. and M.E. Watson. 1980. Conventional soil and tissue test for assessing the phosphorus status of soils. p. 433-469. In: The role of Phosphorus in Agriculture. F.E. Khasawneh, E.C. Sample and E.J. Kamprath (eds.). Soil Science Society of America, Madison, WI., USA.

Khattak, J.K. and J. Iqbal. 1992. Calibration of phosphorus on calcareous soils by $NaHCO_3$ and $NH_4HCO_3$- DTPA extractants using maize as a test crop. p. 311-320. In: Proceeding of the symposium on the Role of Phosphorus in Crop Production, July 15-17, 1990, NFDC, Islamabad, Pakistan.

Kuo, S. and E.G. Lotse. 1974. Kinetics of phosphate adsorption and desorption by lake sediments. *Soil Science Society of America Proceedings* 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. *Journal of Soil Science* 33: 691-70

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.

Memon, K.S., H.K. Puno and R.L. Fox. 1991. Phosphate sorption approach for determining phosphorus requirements of wheat in calcareous soils. *Fertilizer Research* 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.

Murphy, J. and J.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. Shapely, L.E. Somers, M.A. Tabatabai and T.L. Yuan. 1994. Inter laboratory comparison of a standardized phosphorus adsorption procedure. *Journal of Environmental Quality* 13(4): 591-595.

Patel, N.M., R.P.S. Ahlawat and R.B. Ardeshna. 1997. Direct and residual effect of Phosphorus in rice-wheat sequence under south Gujrat conditions. *Indian Journal of Agronomy* 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. p. 147-173. In: Proceeding on Role of Phosphorus in Crop Production. July 15-17, 1990. NFDC, Islamabad, Pakistan.

Rathowsky, D.S. 1986. A statistical study of seven curves for describing the sorption of phosphate by soil. *Journal of Soil Science* 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. p. 415-423. In: Proceeding on Role of Phosphorus in Crop Production. July 15-17, 1990. NFDC, Islamabad, Pakistan.

Sharma, R.D. and T.A. Singh. 1998. Direct and residual effects 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. *Indian Journal of Agronomy* 43(2): 223-230.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2$^{nd}$ Ed., Mc Graw-Hill Book Corporation Inc., New York, USA.

Tomar, N.K. and R.S. Pundir. 1999. Effect of exchangeable sodium percentage on the efficiency of diammonium orthophosphate and ammonium polyphosphate in wheat. *Journal of the Indian Society of Soil Science* 45: 107-112.

U.S. Salinity Lab. Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Washington, DC, 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. *Tropical Agriculture* 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 Science Society of America Proceedings* 29: 677-678.

Webb, R.A. 1972. Use of boundary line technique in the analysis of biology data. *Journal of Horticultural Sciences* 47: 309-319.