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# Phosphorus Requirement of Wheat using Modified Freundlich Model in Sultanpur (Pakistan) Soil Series

OBAID-UR-REHMAN, A.M. RANJHA†, S.M. MEHDI AND A.A. KHAN
*Soil Salinity Research Institute, Pindi Bhattian–Pakistan*
†*Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad–38040, Pakistan*

## ABSTRACT

A field experiment was conducted on Sultanpur soil series (Typic Camborthid) to determine the phosphorus requirement of wheat for obtaining 95% relative yield. Phosphorus sorption isotherms were constructed by adding 0, 5, 10, 15, 20, 40, 60 and 80 µg P $mL^{-1}$ and were examined by the modified Freundlich equation. The amount of P adsorbed (µg $g^{-1}$ soil) and buffer capacity (mL $g^{-1}$ soil) 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 0.01, 0.02, 0.03, 0.04, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40 and 0.50 mg $L^{-1}$ with native solution P level as control with and without nitrogen and potash. Maximum wheat grain (4.22 Mg $ha^{-1}$) and straw yield (4.35 Mg $ha^{-1}$) was recorded with 0.15 mg P $L^{-1}$ developed by adding 37.12 mg P $kg^{-1}$. The maximum phosphorus concentration in wheat grain and straw was 0.41 and 0.16% with P level of 0.50 mg $L^{-1}$, respectively. External soil solution P requirement was 0.12 mg P $L^{-1}$ and internal P requirement found 0.27% for obtaining 95% relative yield of wheat.

**Key Words:** Phosphorus; Sorption isotherms; Modified Freundlich model; Wheat yield; P concentration

## 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 P uptake by plants (Holford, 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 level of P for its adequate availability to plants, although they vary greatly in their P requirement for optimum growth (Vanderzaag *et al*., 1979). Soil solution P concentration of 0.2 mg $L^{-1}$ is adequate for many crops if continuously maintained in the medium (Beckwith, 1965). Chaudhry *et al*. (2003) determined P requirement of maize by using sorption isotherm and fitted data in Langmuir and modified Freundlich equations. They found that 22-67 mg P $kg^{-1}$ was required to maintain 0.2 mg P $L^{-1}$ soil solution in different soil series. Phosphorus in solution for Lyallpur, Gujranwala, Hafizabad and Sultanpur series were 0.09, 0.052, 0.26 and 0.90 µg $mL^{-1}$, respectively and the corresponding P requirement for 95% of maximum yield was 75, 92, 114 and 150 kg $P_2O_5$ $ha^{-1}$, respectively for these soil series (Nisar, 1988). Similarly, Memon *et al*. (1991) reported that the P requirement for 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 phosphorus sorption approach provides a possible means and has been advocated on 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 on the Sultanpur 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 for wheat.

## MATERIALS AND METHODS

A field experiment was conducted on Sultanpur soil series in the rice tract of the Punjab. 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-P was estimated by the procedure given by Watanabe and Olsen (1965). Phosphorus sorption isotherms were constructed by the method of Rowell (1994). For this purpose, 2.5 g sample of soil was added to 25 mL of 10 mM $CaCl_2$ solution containing 0, 5, 10, 15, 20, 40, 60 and 80 µg P $mL^{-1}$. The soils were shaken on end over end shaker for 24 h and filtered through a Whatman No. 42 filter paper. Phosphate concentration in the final solution was determined by the method of Murphy and Riley (1962). Sorption isotherms were examined by modified Freundlich equations as proposed by Le Mare (1982), described in Fig.1. Theoretical doses of phosphatic fertilizers to develop desired P levels in soil solution under field conditions were calculated from this equation (Table I).

**Table I. 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 | 0.01 | 8.04 | 36.82 |
| 4 | 0.02 | 11.29 | 51.71 |
| 5 | 0.03 | 13.76 | 63.02 |
| 6 | 0.04 | 15.84 | 72.54 |
| 7 | 0.05 | 17.67 | 80.93 |
| 8 | 0.10 | 24.80 | 113.58 |
| 9 | 0.15 | 30.24 | 138.50 |
| 10 | 0.20 | 34.80 | 159.38 |
| 11 | 0.25 | 38.81 | 177.75 |
| 12 | 0.30 | 42.43 | 194.33 |
| 13 | 0.40 | 48.84 | 223.69 |
| 14 | 0.50 | 54.48 | 249.52 |

**Field trial.** Wheat (*Triticum aestivum* L.) crop cv. Inqulab-91 was sown 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 in the form of urea, potassium sulphate and single super phosphate, respectively. Second half of nitrogen was applied at first irrigation. The crop was harvested at ground level at maturity. Grain and straw yield data were recorded by harvesting the whole plot. Grain and straw samples were 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 is calculated as

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

Where
Threshold yield = Yield at zero level of x
Plateau yield = Point of maximum response to x
x = Rate of nutrient (P) applied.

Relative yield (%) was plotted against soil solution P level and P concentration (%) in the 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 methods as described by Steel and Torrie (1980).

## RESULTS AND DISCUSSION

The soil used was non-saline, alkaline in reaction, loam in texture, moderately calcareous in nature (6.48% $CaCO_3$), deficient in organic matter and available phosphorus but medium in extractable potassium (Table II).

**Freundlich plot of sorption data.** The linear plot of the modified Freundlich equation is 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 III. The buffer capacities (**b**) of the soil was 37.38 mL $g^{-1}$ and the amount of P adsorbed (**a**) was 76.45 µg $g^{-1}$. The goodness of the fit of the model was ascertained from the $r^2$ value (0.95), which indicated high conformity of the adsorption data with the modified Freundlich model. The linearization transformation of data showed that the plot was linear. Generally, the Freundlich model seemed fit at medium and high equilibrium concentrations. The value of the exponent was found < 1 (Table III) 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.

Using the P adsorption parameters, the Freundlich plot equation was formulated (Table IV) on the basis of these

**Fig. 1. Phosphorus Adsorption isotherms**

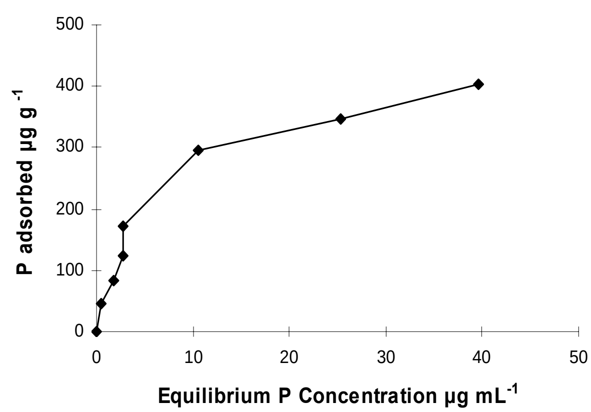
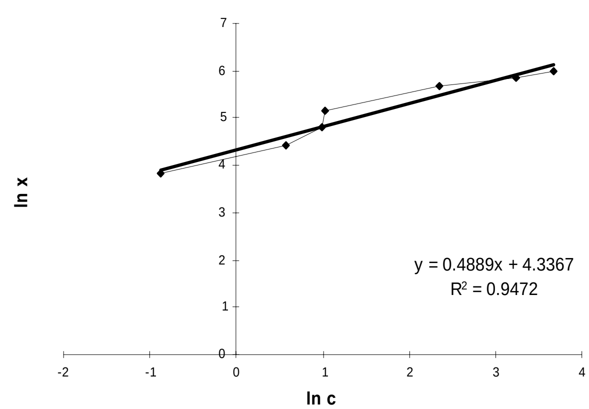



**Fig. 2. Fitted modified Freundlich equation on P sorption data**



values. Fitter and Sutton (1975) and Rathowsky (1986) reported similar observations.

**Wheat grain and straw yield.** Results regarding wheat grain and straw yield are given in Table V. The data show that the maximum wheat grain yield (4.22 Mg $ha^{-1}$) was obtained at solution P level of 0.15 mg P $L^{-1}$ which was developed by adding 138.50 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 implies that wheat responded differently to the solution P; however, response to the higher doses (> 0.15 mg P $L^{-1}$) was not observed. Similar results were reported by others (Saeed *et al*., 1992; Patel *et al*., 1997; Sharma & Singh, 1998; Amrani *et al*., 1999; Tomar *et al*., 1999). Similarly, straw yield also increased at the same soil solution P levels and the trend was almost same as seen in case of grain yield. Maximum straw yield of 4.35 Mg $ha^{-1}$ was noted at soil solution P level of 0.15 mg P $L^{-1}$ (153.11 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.

**Phosphorus concentration (%) in wheat grain and straw.** Data regarding P concentration of wheat grain revealed that maximum P concentration (0.407%) was observed at solution P level of 0.50 mg $L^{-1}$ which was developed by adding 54.48 mg P $kg^{-1}$ soil (Table V). This means that the soil was medium textured and maximum P concentration was observed at low solution P level. This might be due to the reason that wheat translocated P to the grain more efficiently in this soil series. Minimum P concentration of 0.103% was determined from control plots. Duivenbooden *et al*. (1996) also reported P concentration in wheat grain between 0.25 – 0.49%. Similarly, the data also revealed that maximum P concentration of (0.157%) was recorded in straw (like P concentration in grain) at solution P level of 0.50 mg $L^{-1}$, which was obtained by adding 54.48 mg P $kg^{-1}$ soil. However, minimum P concentration (0.021%) was observed in plots receiving no fertilizer. Low P concentration in straw than grain might be due to more P translocation to the grain at the reproductive stage, which corroborated the findings of Duivenbooden *et al*. (1996).

**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). Data revealed that solution P requirement of 0.121 mg $L^{-1}$ was found in Sultanpur soil series for near maximum yield of wheat (95%) (Fig. 3). This means that near maximum yield of wheat (95%) was obtained at lower solution P level and that P requirement is very low in medium textured soil with respect to yield. This might mean that P availability is greater in these soils. 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

**Table II. Original soil analysis**

| Determinant | Units | Values |
|---|---|---|
| Sand | % | 45 |
| Silt | % | 33 |
| Clay | % | 22 |
| Textural class | - | Loam |
| Sub group | - | Typic Camborthid |
| Series | | Sultanpur |
| pHs | - | 8.16 |
| ECe | $dSm^{-1}$ | 0.87 |
| TSS | $meL^{-1}$ | 8.7 |
| $Ca^{2+}$+ $Mg^{2+}$ | $meL^{-1}$ | 4.28 |
| $Na^{+}$ | $meL^{-1}$ | 3.62 |
| SAR | $(m\ mol\ L^{-1})^{0.5}$ | 1.30 |
| $CO_3^{2-}$ | $meL^{-1}$ | - |
| $HCO_3^{-}$ | $meL^{-1}$ | 1.4 |
| $Cl^{-}$ | $meL^{-1}$ | 2.4 |
| $SO_4^{2-}$ | $meL^{-1}$ | 4.9 |
| $CaCO_3$ | % | 6.48 |
| Organic matter | % | 0.62 |
| Olsen P | mg $kg^{-1}$ | 4.95 |
| Extractable K | mg $kg^{-1}$ | 126 |

**Table III. Phosphorus sorption parameters of the Freundlich model**

| Soil | Amount adsorbed (a) µg $g^{-1}$ | Buffer capacity (b) mL $g^{-1}$ | Correlation coefficient ($r^2$) | No. of values (n) |
|---|---|---|---|---|
| Sultanpur | 76.45 | 37.38 | 0.95 | 8 |

**Table IV. Modified Freundlich model**

| Soil | Modified Freundlich equation | |
|---|---|---|
| | Model form $P= a\ C^{b/a}$ | Linear form |
| Sultanpur | $P = 76.45\ C^{0.489}$ | Y = 0.4889 x + 4.3367 |

**Table V. Wheat grain, straw yield (Mg $ha^{-1}$) and P concentration (%) in grain and straw**

| Solution P (mg $L^{-1}$) | Grain yield | Straw yield | P (%) in grain | P (%) in straw |
|---|---|---|---|---|
| Native(0 NK ) | 0.94F | 1.07F | 0.103I | 0.021I |
| Native(+ NK ) | 2.18E | 2.30E | 0.117HI | 0.027H |
| 0.01 | 3.12D | 3.26D | 0.130H | 0.040H |
| 0.02 | 3.44C | 3.57C | 0.173G | 0.053G |
| 0.03 | 3.61BC | 3.74BC | 0.187G | 0.063G |
| 0.04 | 3.80B | 3.93B | 0.207F | 0.077F |
| 0.05 | 3.76B | 3.90B | 0.250E | 0.087EF |
| 0.10 | 3.79B | 3.94B | 0.263E | 0.097E |
| 0.15 | 4.22A | 4.35A | 0.290D | 0.113D |
| 0.20 | 4.20A | 4.32A | 0.323C | 0.117CD |
| 0.25 | 4.26A | 4.40A | 0.327C | 0.127C |
| 0.30 | 4.31A | 4.44A | 0.370B | 0.123CD |
| 0.40 | 4.36A | 4.50A | 0.377B | 0.140B |
| 0.50 | 4.35A | 4.47A | 0.407A | 0.157A |

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

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

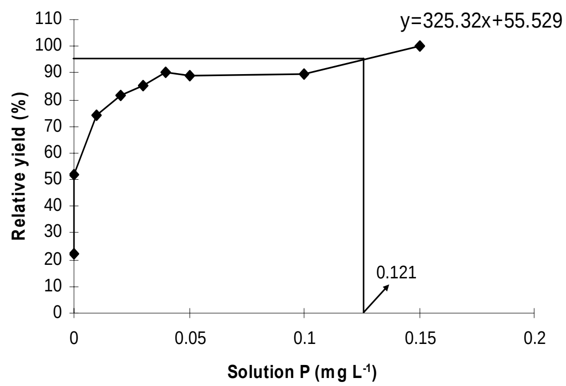
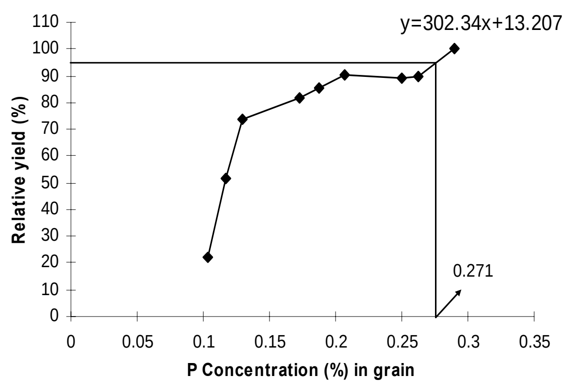



**Fig. 4. Internal phosphorus requirement of wheat**




been shown by many workers to be required in bulk soil solution are a little higher (0.06-0.68 mg P $L^{-1}$). This is 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 µg P $mL^{-1}$ as adequate for most plant species. Similar results were found by Nisar (1988), Memon *et al.* (1991) and Hassan *et al.* (1994).

**Internal phosphorus requirement for wheat.** The term "internal P requirement" can be defined as the concentration of phosphorus in the diagnostic plant parts associated with near maximum (95%) yield. The internal requirement generally parallels, but is not identical with the "critical concentration" and is reflective of available nutrient status of soil. Internal P requirement of wheat was determined at crop maturity (in grain) by making graph of P concentration in grain and maximum attainable 95% relative yield (Fig. 4) and the value obtained was 0.271%. This means that at reproductive phase, the phosphorus which is highly mobile within the plant was rapidly translocated to the seed. Critical P concentration in wheat grains for near maximum grain yield normally ranged 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.

It can be concluded from this study that application of adsorption isotherm in Freundlich model was quite effective to determine the phosphorus requirement of wheat. External solution P requirement was 0.121 mg $L^{-1}$ and internal requirement was 0.271% 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.

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