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Phosphorus fertilizer recommendations for fodder based cereal crops

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Abstract

A field study was carried out to explore the phosphorus adsorption capacity of Rasulpur soil series of Pakistan for determination of P fertilizer doses, internal and external P requirements of the wheat, sorghum fodder and rice crops. Sorption isotherm was constructed in the laboratory and sorption data was fitted into modified Freundlich model and theoretical doses were computed for field application to develop soil solution P levels of 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} along with a control of native P soil solution. The studies were conducted in permanent layout in randomized complete block design (RCBD) with three replications. Phosphorus was also applied @ 13.65 and 19.65 mg P kg^{-1} to subsequent sorghum fodder and rice crops, respectively. All the data were analysed statistically by DMR test and simple regression and correlations were used for computing internal and external P requirements. Maximum wheat grain yield recorded was 3.30 t ha^{-1}; sorghum fresh fodder yield 38.33 t ha^{-1} and rice paddy yield 4.14 t ha^{-1}. Internal P requirement for wheat determined was 0.236 % at booting stage and 0.343% at harvest, for sorghum fodder, 0.175 % and for rice, 0.179% at booting stage and 0.234 % at harvest. External Olsen P requirement for wheat was 9.91, for sorghum fodder 15.33 and for rice, 10.24 mg kg^{-1} Olsen P, respectively.

Key words: Phosphorus, wheat, sorghum fodder, rice, internal/external P requirement

Introduction

The alluvial soils in Pakistan are mostly deficient in available phosphorus (P) and the native P supplying power cannot simulate with P uptake by continuous cropping. Thus, application of P fertilizer is necessary. The rate of P application is also much below the needs of crops. Soils have different P adsorption capacities, which are rarely taken into account while applying P fertilizers (Brinkman, 1998). Soil solution P is an immediate source for plant P uptake (Holford, 1989) and standard solution P concentration (0.2 mg L^{-1}) provides adequate P for many crops if it is continuously maintained in the medium (Beckwith, 1965). A number of mathematical equations e.g. Langmuir, modified Freundlich, Gunary, Tempkin and mechanistic models have been used for the description of P adsorption. Recent work done by many researchers has successfully confirmed the relationships of phosphorus adsorption with different equations (Huang, 1998; Zamuner and Culot, 1999). Using P sorption approach, P requirement of several crops has been determined under a variety of soil and climatic conditions (Hassan *et al*., 1993). Memon and Fox (1983) reported that P sorption curves were useful in determining the P requirement from a composite yield response curve. They reported that amount of P in soil solution was 0.025 µg mL^{-1} for 95% of the maximum yield. Phosphorus fertilizer estimations based on the P in soil solution requirement ranged from zero to 62 kg P ha^{-1}. 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 modes and channels. The term "internal nutrients requirement" may be defined as "the minimum uptake of nutrient (a quantity factor in plant nutrition) that is associated with a specified yield or concentration of nutrient in the plant (an intensity factors in 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.

So keeping in view all the facts, a study was conducted in alluvial soils of rice tract for the construction of P adsorption isotherms and fitting data to modified Freundlich equations for computing P fertilizer doses to raise soil solution P level for maximum yield and to determine the internal and external phosphorus requirement of wheat, sorghum (fodder) and rice.

Materials and Methods

An investigation was carried out on Rasulpur soil series of Pakistan. The site was selected with the technical assistance of Soil Survey of Pakistan. A composite soil sample was collected from 0-20 cm depth, thoroughly mixed, air dried, sieved through a 2 mm sieve and stored in plastic bottles for analyses. All analyses were performed for chemical characteristics of the soil based on methods described in Methods of Soil Analysis (Bigham, 1996) and U.S. Salinity Lab. Staff (1954) except texture by Moodie *et al*. (1959), phosphorus by Watanabe and Olsen (1965) and

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Murphy and Riley (1962). Plant samples were also analysed for phosphorus contents by the method given in Hand book No. 60 (U.S. Salinity Lab. Staff, 1954).

Construction of phosphorus adsorption isotherm and model application

In a 2.5 g soil sample, 25 mL of 10 mM $CaCl_2$ solution containing a series of phosphate concentrations ranging from 0, 5, 10, 15, 20, 40, 60 and 80 (µg P mL^{-1}) were added in triplicate. The samples were shaken on end over end shaker for 24 hours at 20 ºC. The amount of P sorbed was determined according to Nair *et al.* (1994). The sorption isotherms were examined by modified Freundlich equations proposed by Le Mare (1982) as follows:

$P = a C^{b}$ Where a is the amount of P adsorbed (µg g^{-1}), 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 soils in this work is as follows:

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

Theoretical doses of P to develop P levels in soil solutions under field conditions were calculated from this equation. Internal and external P requirement of crops were also determined. The experiment was conducted in permanent lay out which included three crops i.e. wheat, sorghum fodder and rice with fourteen treatments arranged in randomized complete block design (RCBD) with three replications having plot size of 6 m x 4 m.

Wheat crop cv. Inqalab-91 was sown and half of the recommended nitrogen (70 kg ha^{-1}) and potassium (K_2O) @ 70 kg ha^{-1} along with phosphorus (P_2O_5) doses (Table 1) were applied at sowing time in the form of urea, potassium sulphate and single super phosphate, respectively by broadcast method. Second half of nitrogen was applied at first irrigation. Plant sampling (20-25 above ground portion of plants) at booting stage was done to observe the P concentration (Jones *et al*., 1991). The crop was harvested at maturity. Grain and straw yields were recorded.

After wheat harvest, sorghum cv. Hegari was raised to reap the benefits as animal fodder with recommended dose of N and P_2O_5 @ 62.5 kg ha^{-1} each. Fodder was harvested after 55 days of growth and fresh and oven dried yield data were recorded. After sorghum fodder, fine rice cv. Super Basmati was transplanted in the second week of July. Half of recommended N (55 kg ha^{-1}), all P_2O_5 (90 kg ha^{-1} and all K_2O @ 70 kg ha^{-1} were applied as basal dose and remaining half N were applied after 30 days of transplanting by broadcast method. Plant sampling at booting stage was done from 25 above ground portion of rice plants. At maturity, paddy and straw yields were recorded. Plant samples of wheat, rice and sorghum were analysed for phosphorus.

Relative 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

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

Where

Threshold yield = Yield at zero level of x

Plateau yield = Point of maximum response to x

x = Rate of nutrient (P) applied.

Internal phosphorus requirement of crops

Internal P requirement of each crop was determined from the regression equation by plotting the relative yield (95%) against the P concentration (%) in the respective plant part.

External phosphorus requirement of crops

External Olsen and solution P requirement of crop was determined from the regression equation by plotting the graph between 95% relative yield and the Olsen P or solution P level after the harvest of each crop.

Results and Discussion

The physical and chemical characteristics of the soil used in this study indicated that the soil was non-saline and non-sodic. Calcium carbonate content was 5.15% indicating that it was moderately calcareous in nature. It was deficient in organic matter and available phosphorus but medium in extractable Potassium (Table 2).

Construction of modified Freundlich isotherms

Sorption isotherm was constructed and adsorption curve presented in Figure 1 revealed that maximum P was sorbed more at low P concentrations. The soil was calcareous in nature but did not show any precipitation upto the P application level of 80 µg mL^{-1}.

Freundlich plot of sorption data

The sorption isotherm of modified Freundlich equation and linear plot of this model for soil is 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 3.

The amount adsorbed (a) was 71.91 µg g^{-1} and the buffering capacity (b) of the soil was 33.65 mL g^{-1}. The goodness of the fit of the model was ascertained by looking at the r^2 value (0.91) indicating high conformity of the adsorption data with the Freundlich model.

The transformation of data showed that the plot was linear. Generally the Freundlich model seemed fit at medium and high equilibrium concentrations. The value of

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

Treatment	P in soil solution ($mg\ L^{-1}$)	P to be added ($mg\ kg^{-1}$ soil)	P_2O_5 to be added ($kg\ ha^{-1}$)
T1	Native (0 NK)	00.00	00.00
T2	Native (+ NK)	00.00	00.00
T3	0.01	8.23	37.69
T4	0.02	11.38	52.12
T5	0.03	13.76	63.02
T6	0.04	15.74	72.09
T7	0.05	17.48	80.06
T8	0.10	24.17	110.70
T9	0.15	29.22	133.83
T10	0.20	33.43	153.11
T11	0.25	37.11	169.96
T12	0.30	40.42	185.12
T13	0.40	46.25	211.83
T14	0.50	51.34	235.14

Table 2. Basic soil analysis

Determinant	Units	Values
Textural class	-	Sandy Loam
Sub group	-	Typic Camborthid
pHs	-	7.91
ECe	$d\ Sm^{-1}$	0.92
SAR	$(mmol\ L^{-1})^{1/2}$	1.13
$CaCO_3$	%	5.15
Organic matter	%	0.44
Olsen P	$mg\ kg^{-1}$	4.35
Extractable K	$mg\ kg^{-1}$	99.00

Table 3. Phosphorus sorption parameters of the Freundlich model

Amount adsorbed (a) $\mu g\ g^{-1}$	Buffer capacity (b) $mL\ g^{-1}$	Correlation coefficient (r^2)	No. of values (n)
71.91	33.65	0.91	8

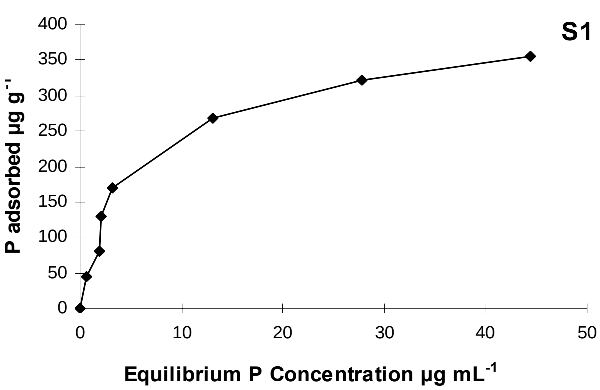


Figure 1. Phosphorus sorption isotherm of the soil

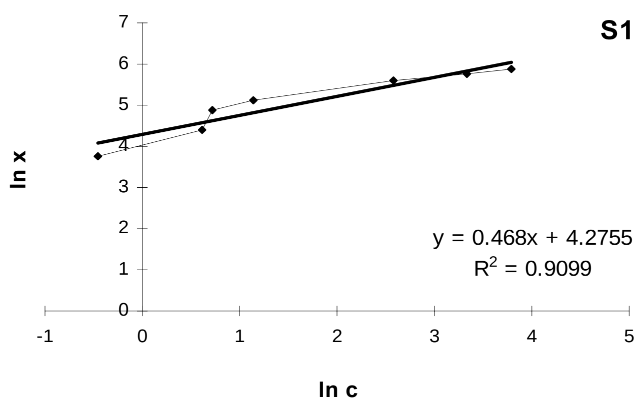


Figure 2. Fitted modified freundloch equation on P sorption data

the exponent was found < 1 (Table 4), which relates to the characteristics of the adsorbent (soil or $CaCO_3$). The findings are in agreement with those of Kuo and Lotse (1974) 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 for the soil was formulated (Table 4) on the basis of these values which was computed as $P = 71.00C^{0.468}$. Although the Freundlich equation is empirical yet it implies that sorption decreased exponentially with increasing saturation of exchange sites. This scenario seems close to the reality than assumption of constant bonding energy inherent in Langmuir plot. Rathowsky (1986) reported similar observations.

Table 4. Linear and model forms of Freundlich Equation

Model form	Linear form
$P= aC^{b/a}$	
$P=71.00C^{0.468}$	$Y=0.468x + 4.2755$

Wheat grain and straw yield (t ha^{-1})

The data of wheat gain and straw yield is given in Table 5. It is evident from the data that yield increased with an increase in solution P levels. The statistical analysis indicated that maximum grain and straw yield was obtained at solution concentration of 0.10 mg P L^{-1} that was developed by adding 110.70 kg P_2O_5 ha^{-1}. The yield was significantly increased at lower level of solution and was at par at all higher levels upto 0.50 mg P L^{-1}. The yield at native solution P level where only NK applied was significantly higher than where no NK applied. The results are in line with those of Memon (1982) who described a solution level of 0.009 mg P L^{-1} for 75% of maximum yield of wheat and 0.028 mg P L^{-1} for 95% of maximum yield.

Tandon (1987) and Brar *et al*. (2000) also found that wheat yield response to P were highest on low P alluvial soils and progressively lower on soil of higher soil fertility. Among major crops grown in sequence, wheat is more responsive to P application in low P soil and at lower level of P application.

Sorghum fresh fodder yield (t ha^{-1})

The sorghum fodder yield depicted in Table 5 exhibits a maximum green fodder yield (38.33 t ha^{-1}) at T_{14} (soil having residual phosphorus of 26.80 mg P kg^{-1} soil along with 13.65 mg P kg^{-1} added). The yield also increased significantly over native P solution (NK control). The reason for this might be that in comparing plant biomass systems for energy production, sweet sorghum is a leading contender due to its C_4 characteristics with a high photosynthetic rate and large biomass yield. The yield in control plot (0 NPK) was 17.60 (t ha^{-1}). The results are in line with those of Bhatti (1996) who obtained sorghum green fodder yield of 30.87 t ha^{-1} with traditional technology and 64.22 t ha^{-1} with improved technology. Khan *et al*. (1996) compared green fodder yield of sorghum varieties in India (44.41 t ha^{-1}) with Pakistan (42.59 t ha^{-1}). The results also commensurate with those of Anees and Hassan (1996) and Gill *et al*. (1995) who emphasized adequate P fertilization to sorghum fodder on the basis of soil tests to get better yields. Patidar and Mali (2001) and Akmal and Asim (2002) also obtained similar yield of the fodder.

Sorghum dry matter yield (t ha^{-1})

The sorghum dry matter yield data are depicted in Table 5 which indicates significant improvement in growth of sorghum plants in ascending order of treatments i.e. lowest in T_1 and maximum in T_{14} (10.85 t. ha^{-1}). The yield in treatment where only NK was applied have significantly higher yield over control (without NPK). These results are in line with those of Das *et al*. (1996) who observed that dry matter yield of sorghum increased with the application of P at all the stages of crop growth and boot leaf stage; response was observed up to 80 kg P_20_5 ha^{-1}. Akmal and Asim (2002) also obtained similar results regarding dry matter yield of sorghum.

Rice paddy and straw yield (t ha^{-1})

The data regarding paddy and straw yield are presented in Table 5. It is obvious from the data that paddy yield increased significantly in ascending order of treatments which were from T_3 to T_{10} (residual P in respective plots after sorghum as shown in Table 6 plus P @ 19.65 mg kg^{-1}). Maximum response was obtained at T_{10} and further response was non significant from T_{11} to T_{14}. This indicated that though soil was high P fixing but the residual response was achieved at T_{10} and it might be due to the reason that under submerged conditions, solubility of adsorbed / fixed P is increased. The yield at native P level (T_1) was 1.13 (t ha^{-1}). The straw yield like paddy yield was also increased significantly in ascending order of treatments from T_1 to T_{12}, and the trend was almost similar to that of the paddy yield. Maximum straw yield of 4.60 (t ha^{-1}) was recorded at T_{12} (residual P 13.65 + 19.65 mg P kg^{-1} soil). It was due to improvement in tillering when P was added to low P soils as the plants take most of the phosphorus from solution at tillering stage. Statistically least straw yield was seen in the control plot where no P was added. These results are supported by the work of Chandra *et al*. (2001), Nadeem and Ibrahim (2002), Slaton *et al*. (2000) and Singh *et al*. (2002).

Phosphorus concentration (%) in wheat plants at booting stage

Phosphorus concentration in wheat plants at booting stage is depicted in Table 7 which indicated that increase in P solution level raised the P concentration in plants significantly but considering the 0.2% P as sufficient, it was attained at 0.05 mg P L^{-1} solution that was obtained by adding 80.06 kg P_2O_5 ha^{-1}. However, the higher levels showed a luxury consumption of P at this stage. Tandon (1987) stated that modern high yielding grain varieties continue to absorb P till maturity and almost 70-80% of absorbed P ends up in the spikes or panicles. During early stages of plant growth, P accumulation can proceed faster than dry matter production indicating the need for higher P concentration for active vegetative growth and root proliferation, which is to follow setting of basic infrastructure for yield production. Phosphorus concentration below 0.05 mg P L^{-1} is in the deficient range indicating that wheat roots were unable to absorb sufficient P from soil solution below these levels for good crop growth. Similar results were obtained by Singh *et al*., (2002) and Delong *et al*. (2001).

Phosphorus concentration (%) in wheat grain and straw

The data regarding P concentration in grain and straw is shown in Table 7. The results revealed that different soil solution levels of P had significant effect on P concentration in wheat grain and straw and maximum concentration was obtained at 0.50 mg P L^{-1} (developed by adding 235.14 kg P_2O_5 ha^{-1}). Minimum P concentration was observed in the treatment where no P was applied. Each increment of P in soil solution progressively increased the P content of the grain and straw with few exceptions. The P concentration in wheat straw was much less than that in

Table 5. Yields (t ha^{-1})

Treatment	Wheat		Sorghum fodder		Rice	
	Grain	Straw	Fresh	Oven dried	Paddy	Straw
T1	1.11G*	1.23G	17.60J	4.97J	1.13K	1.47K
T2	1.91F	2.04F	22.58I	6.39I	1.54J	1.68J
T3	2.16E	2.29E	24.09HI	6.82HI	1.79I	1.94I
T4	2.62D	2.75D	24.79GH	7.02GH	2.34H	2.48H
T5	2.74CD	2.88CD	26.25FG	7.43FG	2.59G	2.73G
T6	2.85BC	2.99BC	26.58EF	7.52EF	2.85F	2.95F
T7	3.01B	3.14B	27.17EF	7.69EF	3.30E	3.34E
T8	3.30A	3.42A	28.08E	7.95E	3.54D	3.68D
T9	3.39A	3.53A	30.42D	8.61D	3.88C	4.00C
T10	3.50A	3.64A	30.83D	8.73D	4.14A	4.26B
T11	3.37A	3.50A	33.17C	9.39C	4.12AB	4.38B
T12	3.39A	3.53A	35.75B	10.12B	4.10AB	4.60A
T13	3.46A	3.60A	36.25B	10.26B	4.01B	4.63A
T14	3.44A	3.57A	38.33A	10.85A	4.05AB	4.66A
LSD	0.1914	0.1986	1.534	0.4377	0.1187	0.1404

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

Table 6. Residual phosphorus in soil after wheat, sorghum and rice harvest

Treatment	Residual P after wheat harvest (mg kg^{-1})	Residual P after sorghum (fodder) harvest (mg kg^{-1})	Residual P after rice harvest (mg kg^{-1})
T1	4.15	3.90	3.75
T2	4.10	3.85	3.70
T3	5.10	4.40	3.30
T4	5.60	5.00	3.90
T5	6.15	5.55	4.30
T6	6.65	6.30	4.80
T7	7.15	6.45	5.00
T8	8.30	7.20	5.50
T9	10.95	8.25	6.35
T10	13.90	8.30	6.85
T11	18.85	10.65	7.15
T12	20.40	11.25	8.20
T13	23.70	12.75	8.65
T14	25.15	13.10	8.70

grain due to the reason that phosphorus taken up by the plants by vegetative parts (straw) was shifted to the reproductive parts (grain) after fertilization. The results are supported by the findings of Brar *et al*. (2000) and Delong *et al*. (2001).

Phosphorus concentration (%) in sorghum fodder

The data regarding P concentration in sorghum fodder depicted in Table 7 showed that maximum P concentration (0.19%) was at T_{14} (residual P 24.05 mg kg^{-1} + 13.65 mg kg^{-1} added P). Minimum P concentration was observed in the control plot where no NPK were applied. As the sorghum is a C_4 plant and has extensive deep root system, which can explore larger volume of soil for P extraction. Similar results were found by Alvarez *et al*. (2000) and Niraj *et al*. (2001).

Phosphorus concentration (%) in rice at booting stage

The data regarding P concentration at booting stage depicted in Table 7 indicated that it was found maximum in T_{14}. The maximum level of P concentration was 0.26% in the rice plants. Minimum P concentration was observed at native soil solution level of P, which was 0.05% and being in deficient range (Olsen P 3.90 mg kg^{-1}) showing that soil was quite deficient in available P, although the diffusion rate is always greater under submerged conditions.

Phosphorus concentration (%) in paddy and straw

The data regarding P concentration in paddy & straw is depicted in Table 7 which showed it was noted maximum in T_{14}. Minimum P concentration was found in control plots where no NPK fertilizer was added. The data also revealed that sufficiency level of 0.20% P in paddy was achieved in T_7 (residual P 7.65 mg kg^{-1} + 19.65 mg kg^{-1} added P), which leads to the conclusion that the crop roots extracted residual P in a better way. There is no consistent relationship among P concentration in the various tissues of the rice plant. The aerial part of the plants are higher in P content than roots and during reproductive phase, the order is grain > leaves and stem > roots. Similar results were found by Singh *et al*. (2002) who found mean P content of rice grain from 20 soil series ranging from 0.41 to 0.55%, respectively. Slaton *et al*. (2000) found mean grain P concentration of 0.28% at Brooks -97, 0.33% at Davis-97, 0.29% at Wimpy-97, 0.26% at Davis-98 and 0.31% at Wimpy-98 and the concentration of P in the grain at 3 week after 50% heading or physiological maturity was about twice than that of the rice straw.

Phosphorus requirement of crops under field conditions

The phosphorus requirement of wheat, sorghum fodder and rice crops were 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 internal and external P requirements. Fox (1981) reported that phosphorus requirement, both internal and external, of most crops were greater during early stage of growth than for crops approaching to maturity.

Internal phosphorus requirement of wheat

The term "internal P requirement" can be defined as the concentration of phosphorus in the diagnostic plant part associated with near maximum (95%) yield. The internal requirement generally parallels, but is not identical with the "critical concentration" and is reflection of available

Table 7. Phosphorus concentration (%) in plant parts.

Treatment	Wheat			Sorghum	Rice		
	Booting	Grain	Straw	Fodder	Booting	Paddy	Straw
T1	0.07K*	0.101J	0.013I	0.07G	0.05I	0.102I	0.017K
T2	0.09J	0.139I	0.023I	0.08G	0.06I	0.122HI	0.024JK
T3	0.11I	0.197H	0.043H	0.11F	0.09H	0.141GH	0.033J
T4	0.13I	0.221H	0.048GH	0.11F	0.10H	0.137GH	0.045I
T5	0.15H	0.223H	0.062G	0.11EF	0.11G	0.158FG	0.059H
T6	0.18G	0.259G	0.090F	0.11EF	0.13G	0.178F	0.072G
T7	0.20G	0.302F	0.096EF	0.12EF	0.14F	0.200E	0.094F
T8	0.23F	0.318EF	0.111DE	0.12E	0.16E	0.213E	0.097EF
T9	0.25E	0.345DE	0.119CD	0.12E	0.18D	0.235D	0.101EF
T10	0.28D	0.375D	0.134BC	0.14D	0.19D	0.249D	0.106DE
T11	0.32C	0.409C	0.146B	0.15CD	0.21C	0.278C	0.113CD
T12	0.34C	0.449B	0.146B	0.17BC	0.23B	0.285C	0.122BC
T13	0.37B	0.479AB	0.173A	0.18AB	0.24B	0.322B	0.129B
T14	0.42A	0.505A	0.179A	0.19A	0.26A	0.357A	0.149A
LSD	0.0178	0.034	0.015	0.008	0.015	0.020	0.010

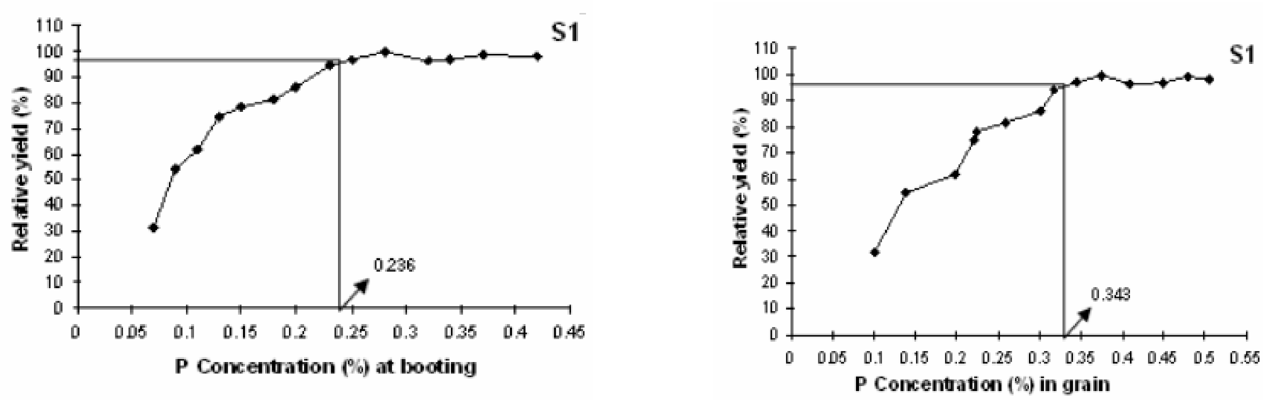
*Means sharing same letters are statistically at par at 5% level of probability nutrient status in soils. For wheat, internal P requirement was determined at two stages i.e. at booting stage and at crop maturity in grain.

The phosphorus concentration in wheat plants at booting stage was plotted against relative yield of wheat grain by Boundary Line Technique (Webb, 1992) and is shown in Fig. 3 (i). The value of P concentration (%) for 95% relative yield was determined by regression equation and the value obtained was 0.236%, which was critical phosphorus concentration for 95% of maximum wheat yield at booting stage. The results are in line with those of Memon and Fox (1983) who demonstrated that phosphorus content of two wheat varieties (Pak-70 and Pavan) increased at flag leaf stage as the phosphorus concentration in the solution increased. Rashid *et al*. (1992) found internal P requirement of crops in whole shoots (< 30 cm tall) as 0.23% for maize, 0.26% for chickpea, 0.27% for mustard, 0.28% for wheat and lentil, 0.29% for sunflower and 0.30% for mungbean.

fodder which is dependent on the P concentration at maximum growth (vegetative) was determined and plotted as shown in Figure 4. The graph revealed that maximum internal P requirement of 0.175% was found for sorghum in this soil. Similar results were reported by Rehman *et al*. (1992) and Chaudhry *et al*. (2003). Rashid *et al*. (1992) also found internal P requirement of crops in whole shoots (< 30 cm tall) as 0.23% for maize, 0.26% for chickpea, 0.27% for mustard, 0.28% for wheat and lentil, 0.29% for sunflower and 0.30% for mungbean.

Internal phosphorus requirement of rice at booting stage

Data regarding P concentration at booting stage of rice was plotted against 95% relative yield of rice as shown in Fig. 5 (i) which illustrates that internal P requirement of rice was 0.179%. The reason for low critical P (%) in rice than that in wheat and sorghum might be due to greater solubility and diffusion of P under flooded conditions and



i) At booting stage **ii) At harvest**

Figure 3. Internal P requirement of wheat

Internal phosphorus requirement of wheat at maturity

Internal requirement of wheat was determined by making graph of P concentration in grain and maximum attainable 95% relative yield as shown in Figure 3 (ii). The value obtained was 0.343%. 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. In contradiction to this Rashid *et al.* (1992) found critical P concentration in wheat grain as 0.22% and in maize grain as 0.27% under green house conditions.

Internal phosphorus requirement of sorghum fodder

Sorghum is a C_4 plant whose photosynthetic efficiency is very high and the internal requirement of P of sorghum

plant at early stages upto booting stage absorbed P very efficiently from the soil solution.

Internal phosphorus requirement of rice at harvest

The plot of P concentration in paddy versus 95% relative paddy yield is shown in Figure 5 (ii) which revealed that maximum internal P requirement of 0.234% was found for rice in this soil.

External (Olsen) phosporus requirement of wheat

The data of 95% relative yield of wheat was plotted against Olsen P in the soil after wheat harvest (Table 6) is shown in Figure 6 (i). It was inferred from the graph that the external P requirement for wheat was 9.91 mg kg^{-1} in this soil. Rashid *et al*. (1990) also determined fertilizer requirement for near maximum wheat grain yield as 15 mg

P kg^{-1} soil. While Rehman *et al*. (1992) determined 16 mg P kg^{-1} soil as Olsen P a critical level for 95% relative yield of wheat in Malakand division. Nisar (1988) reported that for getting 95% relative yield, 75, 92, 114 and 150 kg P_2O_5 ha^{-1} was required for the Lyallpur, Gujranwala, Hafizabad and Sultanpur series, respectively. Khan and Rafiq (1992) also found 150 and 100 kg P_2O_5 ha^{-1} as optimal dose for wheat grain on the Rasulpur and Hafizabad soils which are moderately calcareous.

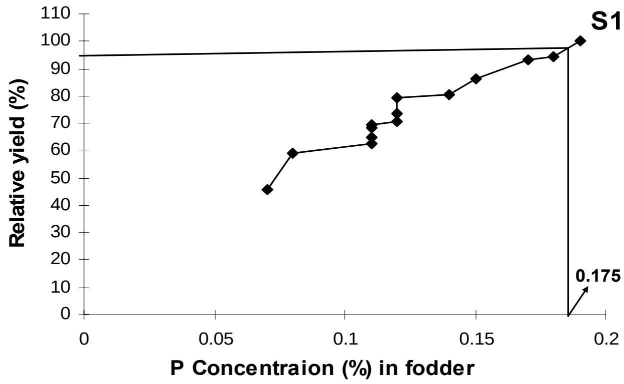
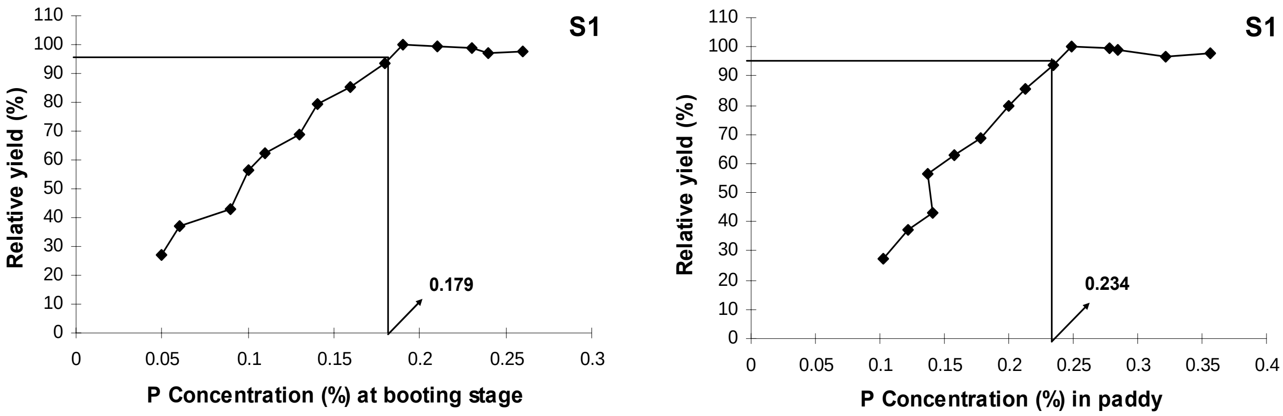


Figure 4. Internal P requirement of sorghum fodder



i) At booting stage **ii) At harvest stage**

Figure 5. Internal P requirement of rice

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, 1992) as shown in the Figure 6 (ii).

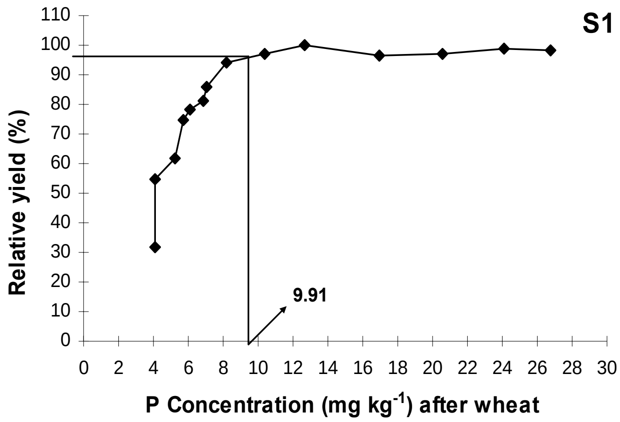
The graph revealed that solution P requirement of 0.120 mg P L^{-1} was required for 95% yield in this soil. Beckwith (1965) also suggested a standard concentration of 0.2 ug P mL^{-1} as adequate for most plant species. The concentration at the root surface of young plants need about 0.03-0.3 mg P L^{-1} 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 and Watson, 1980). Memon *et al*. (1991) determined external P requirement of wheat grain at near maximum yield as 0.32 mg L^{-1} as obtained from composite yield response curve.

External (Olsen) phosphorus requirement of sorghum fodder

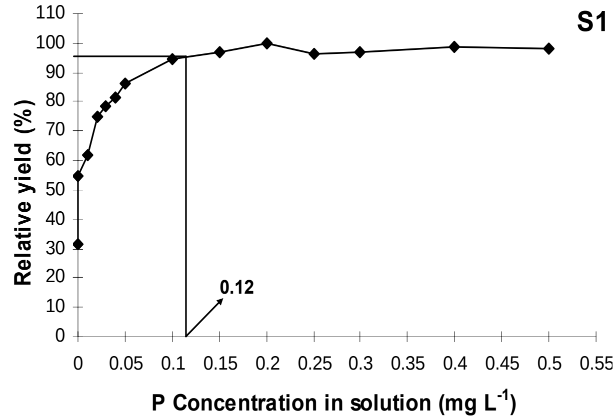
The phosphorus determined by Olsen method after harvesting sorghum fodder (Table 6) was plotted versus 95% relative yield to compute the external Olsen P requirement as shown in Figure 7. Maximum relative yield was obtained at Olsen P of 15.33 mg P kg^{-1} in this soil. The reason might be that growth of sorghum was quite rapid at early stages of growth and buffering capacity of the soil was very high, so higher P was replenished from solution (Quantity intensity factor) in this soil. Jones *et al*. (1991) showed that the relationship between percent P in leaves of corn at pre tasseling stage and P concentration of equilibrium soil extracts was linear.

External (Olsen) phosphorus requirement of rice

The data of Olsen P after rice (Table 6) was plotted against 95% relative yield to find out the external Olsen P requirement of rice and the graphs is presented in Figure 8. It was found that Olsen P requirement for near maximum yield of rice paddy was achieved at Olsen P of 10.24 mg P kg^{-1} in the soil. The reason might be the submerged soil conditions under which rice crop grow and the P availability remained at par as compared to the upland or oxidized conditions. Khan *et al*. (1996) found 16 mg kg^{-1} Olsen P as critical level for 95% relative yield of rice. Khan and Makhdum (1990) determined critical level of P for near maximum yield of rice as 7.19 mg kg^{-1}.

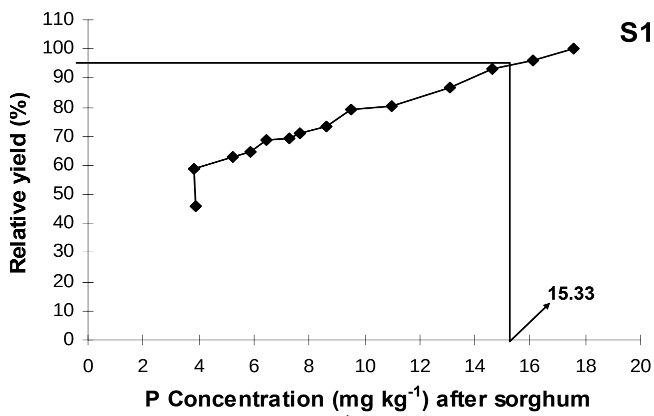


i) Olsen P (mg kg^{-1})



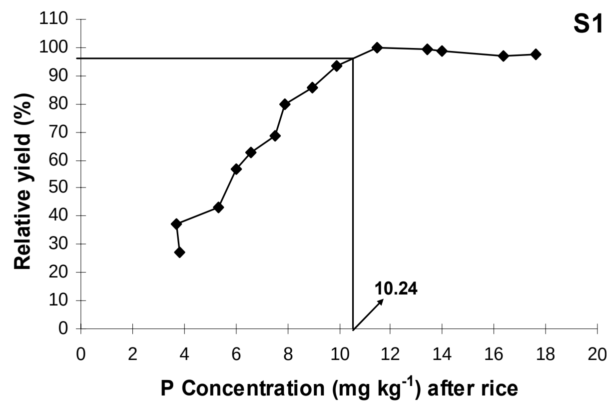
ii) Solution P (mg L^{-1})

Fig. 6 External P requirement of wheat



Olsen P (mg kg^{-1})

Fig. 7 External P requirement of sorghum fodder



Olsen P (mg kg^{-1})

Fig. 8 External P requirement of rice

Conclusions

1. Phosphatic fertilizers should be recommended and applied to the crops by taking P adsorption capacities into the account and P application should be soil and crop specific as the solution P and Olsen P vary for the soils and crops.
2. External P requirement was greater for sorghum fodder being heavy P feeder followed by rice and wheat. External P requirement showed significant correlation with 95% relative yield of wheat, sorghum fodder and rice.
3. Taking plant samples at booting stage than at crop maturity for obtaining 95% relative yield better correlated internal P requirement of crops.

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