DETERMINING INTERNAL AND EXTERNAL P REQUIREMENT OF WHEAT ON CALCAREOUS SOILS BY ADSOPTION ISOTHERMS

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Among factors that influence wheat yield, phosphorus (P) plays an important role and plants require adequate P from the very early stages of growth for optimum crop production. Currently, no site-specific fertilizer recommendations are available for Pakistani soils. The P sorption isotherms were used to determine internal and external P requirements of wheat cv. Inqalab 91. Three field experiments were conducted on three different textured soils during Rabi (winter) 2004. Taxonomically, these soils were classified as: i) Chromusterts known as Kotli series that has clay texture (S_1), ii) Haplargids known as Hafizabad series that has sandy clay loam texture (S_2) and iii) Torripsamments known as Thal series that has sandy loam texture (S_3). Eleven P treatments (4 to 96 mg P kg^{-1} soil) were arranged following a randomized complete block design with three replications. Adsorption studies were conducted and isotherms were constructed by plotting the amount of P added (mg kg^{-1}) vs. P in soil solution (mg L^{-1}) at equilibrium. The soil solution-P levels were determined against different quantities of fertilizer P for S_1, S_2 and S_3 soils. Internal P requirements associated with 95 % relative yield were 0.355 % (S_1 soil), 0.385 % (S_2 soil) and 0.350 % (S_3 soil) at booting stage or 0.108 % (S_1 soil), 0.066 % (S_2 soil) and 0.100 % (S_3 soil) in straw or 0.295 % (S_1 soil), 0.215 % (S_2 soil) and 0.315 % (S_3 soil) in grain. It ranged from 0.215-0.315 % at booting stage or 0.066-0.108 % in straw or 0.350-0.385 % in grain. External solution P requirement (EPR; mg L^{-1}) of wheat for its 95 % maximum yield was 0.23 (S_1 soil), 0.25 (S_2 soil), and 0.28 (S_3 soil). Corresponding amounts of fertilizer P (mg kg^{-1}) required for these EPR levels were 38 (S_1 soil), 26 (S_2 soil) and 13 (S_3 soil). Soil texture affected the P rates to obtain 95 % of maximum wheat grain yield. It was concluded that P recommendations in future should be made keeping in view soil texture to make the P application.

Keywords: Internal and external P; wheat; adsorption isotherms

INTRODUCTION

Plants require adequate phosphorus (P) from the very early stages of growth for optimum crop production (Grant *et al.*, 2005), root development and for later phenological stages since it is a constituent of cell nucleus and essential for cell division as well as for the development of meristematic tissues (Blevins, 1999 and Havlin *et al.*, 1996).

Among factors that influence wheat yield, P fertilizer application plays an important role (Alam *et al.*, 2003) and management of P is considered as critical under native crop-environment conditions for good crop yield. As P is an expensive nutrient compared to N and wheat also commonly suffers from P deficiency while grown on alkaline calcareous soils (Malik *et al.*, 1992). Moreover, soils of Pakistan are alkaline (pH > 7.0) and mostly alluvial calcareous ($CaCO_3$ > 3.0 %) in nature (Saleem, 1992). Over 90 % soils are low in available P (Nisar *et al.*, 1992) and suffer from moderate to severe P deficiency. When P fertilizer is added to calcareous soils, a series of fixation reactions occur that gradually decreased its solubility and eventually its availability to plants. Phosphorus "fixation" is a combination of surface adsorption on both clay and lime surface, and precipitation of various Ca-P mineral (Leytem and Mikkelsen, 2005). With time this adsorbed P becomes more firmly adsorbed and release of which into soil solution is relatively slower (Huang, 1998). Consequently efficiency of fertilizer P in calcareous soils remains low (Delgado *et al.*, 2002).

Fertilizer recommendations need to be tailored to specific soil and crop situations on scientifically sound basis. Particularly about the quantities of P fertilizer needed to increase the soil solution P to a level desired for optimal or targeted crop yield (Bhuiyan and Sedberry, 1995). Phosphorus sorption isotherms could relate P concentration in soil solution with P sorbed. Use of the P sorption isotherms have been suggested by many investigators to determine the amount of P required to bring the soil solution P to a level which is optimum for maximum plant growth. Moreover, it is a rapid and accurate method for assessing P requirement (Fox and Kamprath, 1970). But a little information is available on the use of this technique for alkaline and alluvial calcareous soils. So keeping this in view, a study was conducted to assess the amount of fertilizer P required to achieve 95 % of maximum wheat (*Triticum aestivum* L.) yield on three different textured alluvial calcareous soils and to find out external and internal P requirement of wheat.

MATERIALS AND METHODS

Three field studies were conducted during Rabi (winter) 2004 at i) University of Agriculture, Faisalabad (S_1), ii) near town Sheikh Rajada, District Gujranwala (S_2), and iii) Thal near town Azam colony, District Khushab (S_3).Taxonomically, the soils were classified as Chromusterts known as Kotli series that had clay texture (S_1), Haplargids known as Hafizabad series that had sandy clay loam texture (S_2) and Torripsamments known as Thal series that had sandy loam texture (S_3). All the soils were non-saline and non-sodic (EC 0.80 to 1.50 dS m^{-1}), low in organic matter (0.4 to 0.9 %) while had low to medium Olsen-P (9.20 to 13.90 mg kg^{-1} soil; Table 1). Wheat crop cv. Inqalab-91 was sown after treating with benlate @ 2.5 g kg^{-1} seed. Seed rate was 124 kg ha^{-1}. Half of the N (60 kg ha^{-1}) and full doses of K (60 kg ha^{-1}) as well as of P (Table 1) were applied at sowing. The remaining N was applied at the time of first irrigation. Nitrogen as urea, P as triple super-phosphate (TSP) and K as sulphate of potash were applied. All the P fertilizer was banded 3-5 cm to the side and 2-5 cm below the seed with the help of drill at the time of seeding. Row to row distance of wheat crop was maintained at 22.5 cm. Eleven P treatments (Table 2) were arranged according to randomized complete block design with three replications having plot size of 22.28 m^2 (S_1), 40.50 m^2 (S_2) and 24.50 m^2 (S_3). Agronomic and recommended cultural practices were followed as and when required for the normal growth of crop. Whole plant samples without root (whole shoots) were obtained at booting stage as well as at maturity. The latter included both the straw and grain samples. At harvest, plants were harvested at the base from the whole plot, and total biomass and grain yield was measured. Straw yield was calculated by deducting grain yield from the total biomass yield. Plant samples were oven-dried at 60-70°C to a constant weight. The oven-dried plant samples were ground with electric grinding machine. Sub-portion of the ground plant material, i.e. samples collected at booting stage as well as of straw and grain were digested in diacid mixture (HNO_3: $HClO_4$, 2:1) following the method No. 54a of U.S. Salinity Lab. Staff (1954). Phosphorus concentration (%) in the digested material was determined by vanadomolybdate yellow color method (Chapman and Pratt, 1961) and then internal P requirements at 95 % of relative yield were computed

Table 1. Basic analysis of the soils under investigation

Soil characteristics	Unit	Soil		
		S_1	S_2	S_3
pH_s		7.4	7.4	7.7
EC_e	dS m^{-1}	0.8	1.4	1.5
SAR		2.3	1.4	2.8
Olsen-P	mg kg^{-1}	9.2	13.9	10.3
Extractable K^+	"	195	156	105
$CaCO_3$	%	9.1	7.1	6.1
OM	"	0.9	0.4	0.5
SP	"	49	34	27
Sand	"	39	55	80
Silt	"	16	16	04
Clay	"	45	29	16
Textural class		Clay	Sandy clay loam	Sandy loam

Table 2. Phosphorus added and soil solution P achieved as determined by sorption isotherms

Treatment	Soil					
	S_1		S_2		S_3	
	P-added (mg P kg^{-1})	SSPA* (mg L^{-1})	P-added (mg P kg^{-1})	SSPA (mg L^{-1})	P-added (mg P kg^{-1})	SSPA (mg L^{-1})
P_0	Native	-	Native	-	Native	-
P_1	16	0.07	14	0.13	4	0.08
P_2	24	0.14	19	0.17	6	0.12
P_3	31	0.17	24	0.23	8	0.17
P_4	37	0.22	28	0.27	10	0.22
P_5	43	0.27	31	0.31	12	0.24
P_6	48	0.32	34	0.33	14	0.3
P_7	57	0.43	40	0.39	17	0.37
P_8	74	0.62	50	0.54	23	0.57
P_9	89	0.83	58	0.68	28	0.78
P_{10}	96	0.93	62	0.77	31	0.94

*SSPA denotes soil solution P concentration achieved, mg L^{-1}

by Boundary Line Technique (Webb, 1972). Soil samples were collected at booting stage and at maturity for the determination of external P requirements of crop at 95 % relative yield following the technique of Webb (1972). The results obtained were subjected to statistical analysis following ANOVA technique (Steel and Torrie, 1993) and the differences among the treatments were compared by DMR test using MSTATC software.

Phosphorus sorption

Phosphorus sorption isotherms (Fig. 1) were constructed by equilibrating 10 g processed sample of soil with 100 mL 0.01 *M* $CaCl_2$ solution containing different concentrations of P (0, 2.26, 5.65, 11.14, 36.88, 45.25, 91.25, 112.21, 173.28, 223.58 mg L^{-1}) and equilibrated for seven days at 25 ± 2°C by shaking for 30 min. twice daily (Fox and Kamprath, 1970).

RESULTS AND DISCUSSION

Grain and straw yields

The grain yield increased significantly up to 6.8 Mg ha^{-1} with P_5 on S_1 or 5.9 Mg ha^{-1} with P_4 on S_2 or 4.8 Mg ha^{-1} with P_6 on S_3 soil with application of P (mg kg^{-1} soil) up to 43 on S_1 or 28 on S_2 or 14 on S_3 soil. Soil solution P concentration (mg L^{-1}) at these corresponding levels were 0.27 in S_1, again 0.27 in S_2 and 0.30 in S_3 soil. Similarly, straw yield significantly increased up to 7.4 Mg ha^{-1} with P_2 on S_1 or 10.3 Mg ha^{-1} with P_3 on S_2 or 8.60 Mg ha^{-1} again with P_3 on S_3 soil with made up level of 24 mg P kg^{-1}soil on S_1 or again 24 mg kg^{-1} soil on S_2 or 8 mg kg^{-1} soil on S_3 soil. Soil solution P concentration (mg L^{-1}) at respective levels were 0.14 in S_1, again 0.23 in S_2 and 0.17 in S_3 soil. Thereafter, increase in yield (grain as well as straw) was either non-significant or yield further turned down (Table 3).

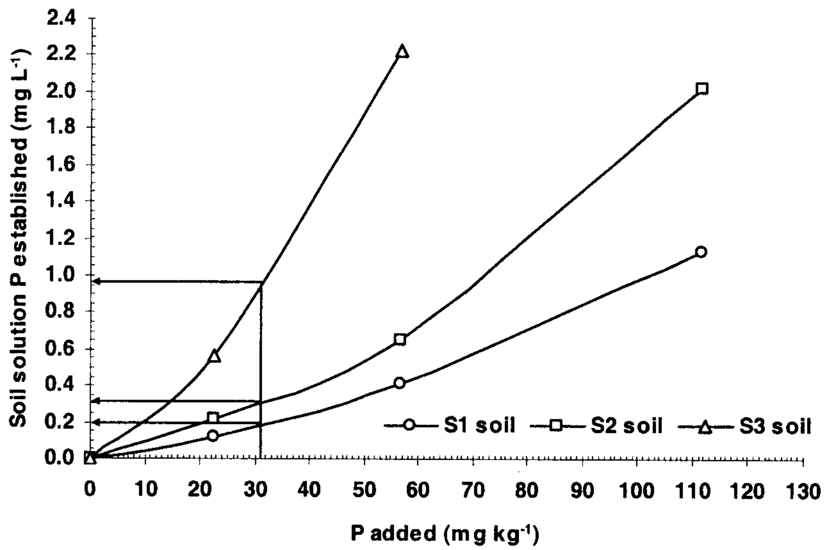

Fig. 1. Equilibration isotherms indicating dynamics of solution P in soils with incremental addition of P, an example at 31 mg P kg^{-1}soil added (a common value)

A few drops of toluene were added to avoid the microbial growth during storage of solutions. After filtration, the P contents of the supernatant were determined with the help of spectrophotometer (Nicolet 100) at 882 nm using ascorbic acid molybdenum-blue color method (Watanabe and Olsen, 1965). The sorption isotherms were constructed (Fig. 1) by plotting the amount of P added (mg P kg^{-1}) vs. P in soil solution (mg L^{-1}) at equilibrium. The soil solution P levels (mg L^{-1}) were determined against amount of P added following the method of Memon and Fox (1983) and designated them as treatments for S_1, S_2 and S_3 soil (Table 2).

The maximum grain yield (Mg ha^{-1}) was 6.8 with P_5 on S_1 soil at SSPA level of 0.27 mg L^{-1} or 6.0 with P_5 on S_2 soil at SSPA level of 0.31 mg L^{-1} or 5.0 with P_7 on S_3 soil at SSPA level of 0.37 mg L^{-1}. While maximum straw yield (Mg ha^{-1}) was 7.8 with P_4 on S_1 soil at SSPA level of 0.22 mg L^{-1} or 10.5 with P_5 on S_2 soil at SSPA level of 0.31 mg L^{-1} or 9.2 with P_7 on S_3 soil at SSPA level of 0.37 mg L^{-1}. Minimum yields (straw and grain) were obtained in the control plots (P_0). Rehman *et al.* (2005) reported an increase in wheat grain and straw yields with increasing soil solution P levels up to

0.15 mg L^{-1}. However, grain and straw yields were obtained at higher soil solution P concentrations in our study as compared to those reported by Rehman *et al.* (2005) probably due to different textured and $CaCO_3$ contents of the soils under studies. Sanchez and Uehara (1980) stated that the soil solution P concentration required for maximum plant growth differs between species, growth stages and growth rate, and with soil properties related to the diffusion of P to plant roots. Lopez-Hernandez *et al.* (1987) stated that variety differences may be the factor that can influence external P requirements of the crops.

Phosphorus concentration (%) in wheat at booting stage, straw and grain

Nutrients uptake is a result of its concentration in the rooting medium and biomass produced. Where maximum P was applied (P_{10}), maximum internal P (%) was recorded, i.e. 0.340 % (booting stage), 0.165 % (straw) and 0.402 % (grain) on S_1 soil or 0.288 % (booting stage), 0.163 % (straw) and 0.520 % (grain) on S_2 soil or 0.361 % (booting stage), 0.181 % (straw) and 0.438 % (grain) on S_3 soil. Minimum P concentration (%) was recorded in the control plants (P_0), i.e. 0.221 % (booting stage), 0.084 % (straw) and 0.243 % (grain) on S_1 soil or 0.129 % (booting stage), 0.024 % (straw) and 0.245 % (grain) on S_2 soil or

Table 3. Effect of different P levels on grain and straw yields of wheat

Treatment	Grain yield (Mg ha^{-1})			Straw yield (Mg ha^{-1})		
	Soil			Soil		
	S_1	S_2	S_3	S_1	S_2	S_3
P_0	3.7F	2.9	3.5F	5.5E	6.1D	7.7D
P_1	4.9E	3.9D	3.7E	6.7CD	8.4C	8.09CD
P_2	5.4D	5.2C	4.0D	7.4ABC	9.6B	8.4BCD
P_3	5.9C	5.5B	4.3C	7.5AB	10.3A	8.6ABC
P_4	6.3B	5.9A	4.4C	7.8A	10.4A	8.6ABC
P_5	6.8A	6.0A	4.6B	7.7A	10.5A	8.7ABC
P_6	6.8A	5.9A	4.8AB	7.3BC	10.3A	9.0AB
P_7	6.8A	5.9A	5.0A	7.0BC	10.5A	9.2A
P_8	6.7AB	5.9A	4.8A	6.7CD	10.5A	9.2A
P_9	6.8A	5.8A	4.9A	6.3D	10.3A	9.2A
P_{10}	6.8A	5.9A	4.9A	6.12DE	10.3A	9.1A
Mean	6.1	5.3	4.4	6.9	9.8	8.7
LSD (0.05)	0.35*	0.20*	0.19*	0.62*	0.60*	0.64*

*Means followed by different letters in the same column differed significantly from each others.

Table 4. Range of P concentration in wheat at booting stage, straw and grain

Soil	Range of P concentration (%) at/in		
	Booting stage	Straw	Wheat grain
S_1	0.221G – 0.340A	0.084H– 0.165A	0.243F – 0.402A
Mean	0.290	0.120	0.340
LSD (0.05)	0.026*	0.011*	0.040*
S_2	0.129I – 0.288A	0.024J – 0.163A	0.245G – 0.520A
Mean	0.220	0.09	0.410
LSD (0.05)	0.009*	0.009*	0.058*
S_3	0.245H – 0.361A	0.079E – 0.181A	0.249I – 0.438A
Mean	0.310	0.110	0.340
LSD (0.05)	0.017*	0.021*	0.021*

*Means followed by different letters in the same column differed significantly from each others.

0.245 % (booting stage), 0.079 % (straw) and 0.249 % (grain) on S_3 soil (Table 4). Low P concentration in straw than grain may be due to translocation of P to grains at the reproductive stage (Rӧmber and Schilling, 1986). During the late stages of plant reproductive growth when young seeds are being formed, P is remobilized from older leaves and moves into developing seeds because seeds contained important genetic information in the form of DNA. In seed, P stores in form of phytic acid molecules. Each molecule of phytic acid contained 6 C atoms and 6 P atoms, and each of the P atoms has a negative charge, which attracts K^+, Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+} and Fe^{2+}. Consequently, this is an effective way for seeds to store P and important cations for the next generation of plants (Blevins, 1999). Nisar (1988) reported that P concentration in wheat straw was significantly higher (0.03 %) with P @ 8.50 mg kg^{-1} soil than that of the control plant (0.029 %). Similarly, Memon and Fox (1983) reported that P (%) in two wheat varieties increased from 0.248 to 0.304 % (Pak-70), 0.200 to 0.220 % (Pavan) at flag leaf stage, 0.253 to 0.269 % (Pak-70) and 0.250 to 0.273 % (Pavan) in grain as the P (mg L^{-1}) in the soil solution increased from 0.010 to 0.115 mg L^{-1}. Imtiaz *et al.* (2003) reported that P concentration in wheat plants varied according to the quantity of P applied onto soil. They concluded that plants managed to translocate more P into grains (0.305 %) and straw (0.037 %) at 29.50 mg P kg^{-1} soil applied level as compared to other lower P rates, i.e. 0.148 % in grain or 0.011 % in straw in control plots.

Internal and external P requirement

Phosphorus concentration (%) in wheat at booting stage, straw and grain were plotted against 95 % relative yield to determine internal P requirements (Fig. 2). Similarly, the soil solution P concentration achieved with the addition of different quantities of P fertilizer (Table 2) for wheat growth were plotted against 95 % relative yield of wheat (Fig. 3) for the determination of external P requirement by Boundary Line Technique (Webb, 1972).

Internal P requirement (%) associated with 95 % relative yield were 0.295 (S_1), 0.215 (S_2) and 0.315 (S_3) at booting stage or 0.108 (S_1), 0.066 (S_2) and 0.100 (S_3) in straw or 0.355 (S_1), 0.385 (S_2) and 0.350 (S_3) in wheat grain (Fig. 2).

Rashid and Bughio (1993) reported that 0.28 % internal P concentration in whole shoots of wheat was associated with 95 % grain yield. Smith and Loneragan (1997) believed that the critical concentration is not a single value, but a narrow range of nutrient element concentration above which a plant is adequately supplied with the nutrient element and below which the plant is 'deficient'. Such a range would, therefore, cover the different critical values derived under

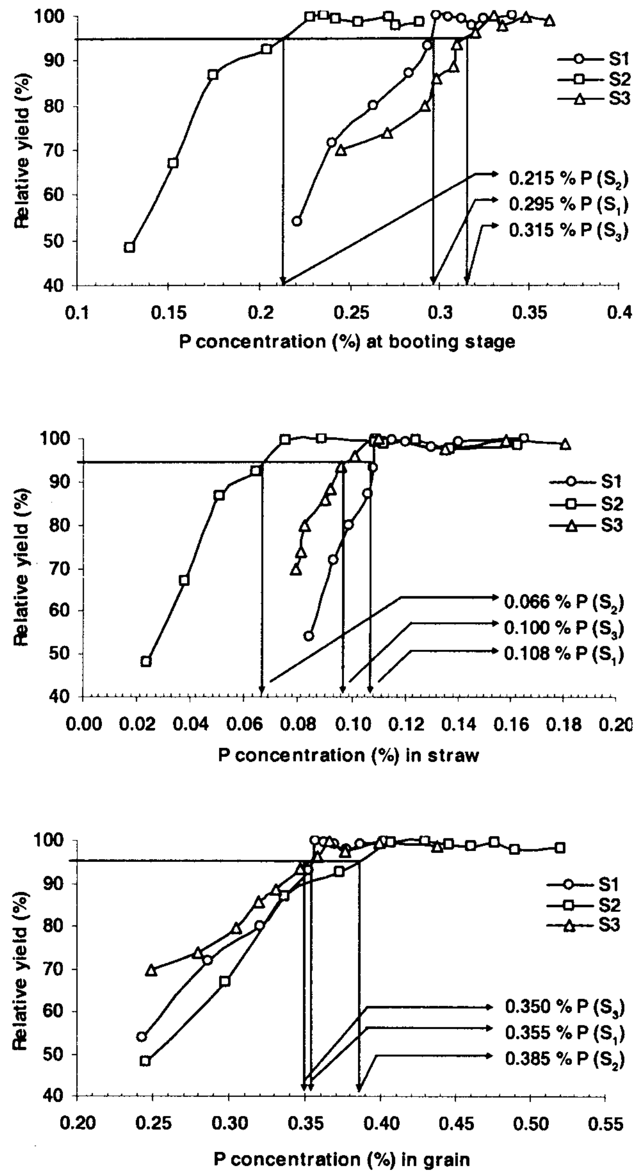

Fig. 2. Internal P requirement of wheat at booting stage, straw and grain associated with 95 % relative wheat grain yield.

different physical, environmental, and biological conditions that influence plant nutrient element levels. Consequently, critical P for wheat ranged from 0.215-0.315 % at booting stage or 0.066-0.108 % in straw or 0.350-0.385 % in grain. Reuter *et al.* (1997) estimated critical P (%) values for spring wheat grain between 0.19 and 0.23 % for maximum grain yield. Rashid *et al.* (2005) proposed critical P concentration ranges for spring wheat in Pakistan as 0.13-0.28 % in young whole shoots or 0.27-0.36 % in recently matured leaves or 0.13-0.27 % in mature grain.

External solution P requirement (EPR; mg L^{-1}) was 0.23 (S_1), 0.25 (S_2), and 0.28 (S_3; Fig. 3) and corresponding amount of fertilizer P (mg kg^{-1}) required to achieve these EPR levels were 38 (S_1), 26 (S_2) and 13 (S_3; Fig. 4). Memon *et al.* (1991) found that 4-6 mg recommending P fertilizer required to obtain 95 % of maximum yield. It is concluded that P recommendations in future should be made keeping in view the texture of soils by using the sorption isotherms. Such doses will be cost-effective.

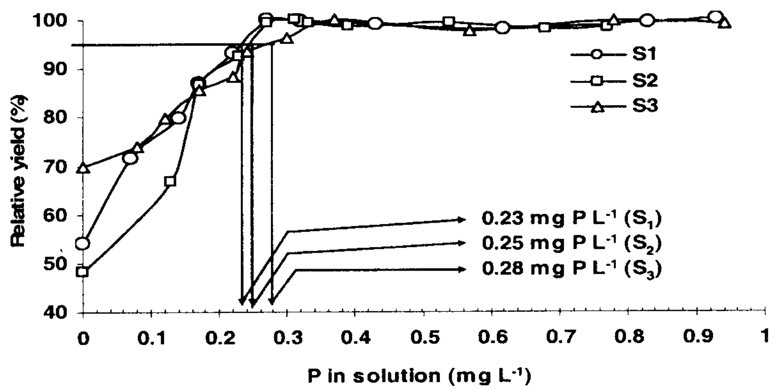

Fig. 3. External P requirement associated with 95 % relative wheat grain yield.

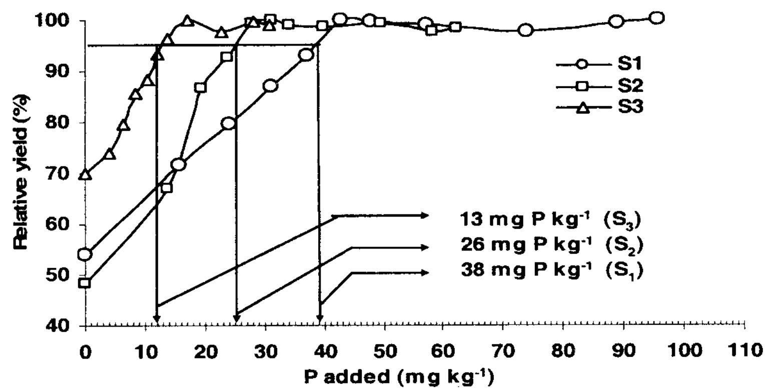

Fig. 4. External fertilizer P requirement associated with 95 % relative wheat grain yield.

P kg^{-1} was required for establishing a solution level of 0.032 mg P L^{-1} in calcareous soils. It is notable that value of fertilizer P (26 mg P kg^{-1}) associated with 95 % relative yield on S_2 soil (sandy clay loam) was equivalent to the generalized recommendations of 25 mg P kg^{-1} (NFDC, 1997) for wheat in Pakistan. However, P requirements for wheat were higher (38 mg P kg^{-1}) on clay textured soil (S_1) and lower (13 mg P kg^{-1}) on sandy textured soil (S_3) as compared to generalized P recommendations of 25 mg P kg^{-1} (NFDC, 1997).

CONCLUSIONS

The results of this study suggest that a close relation exists between yields and the levels of P in solution as predicted by P sorption isotherms. Thus, knowledge of external P requirement of crops used in conjunction with P sorption isotherms provides a rational basis for recommending P fertilizer required to obtain 95 % of maximum yield. It is concluded that P recommendations in future should be made keeping in view the texture of soils by using the sorption isotherms. Such doses will be cost-effective.

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