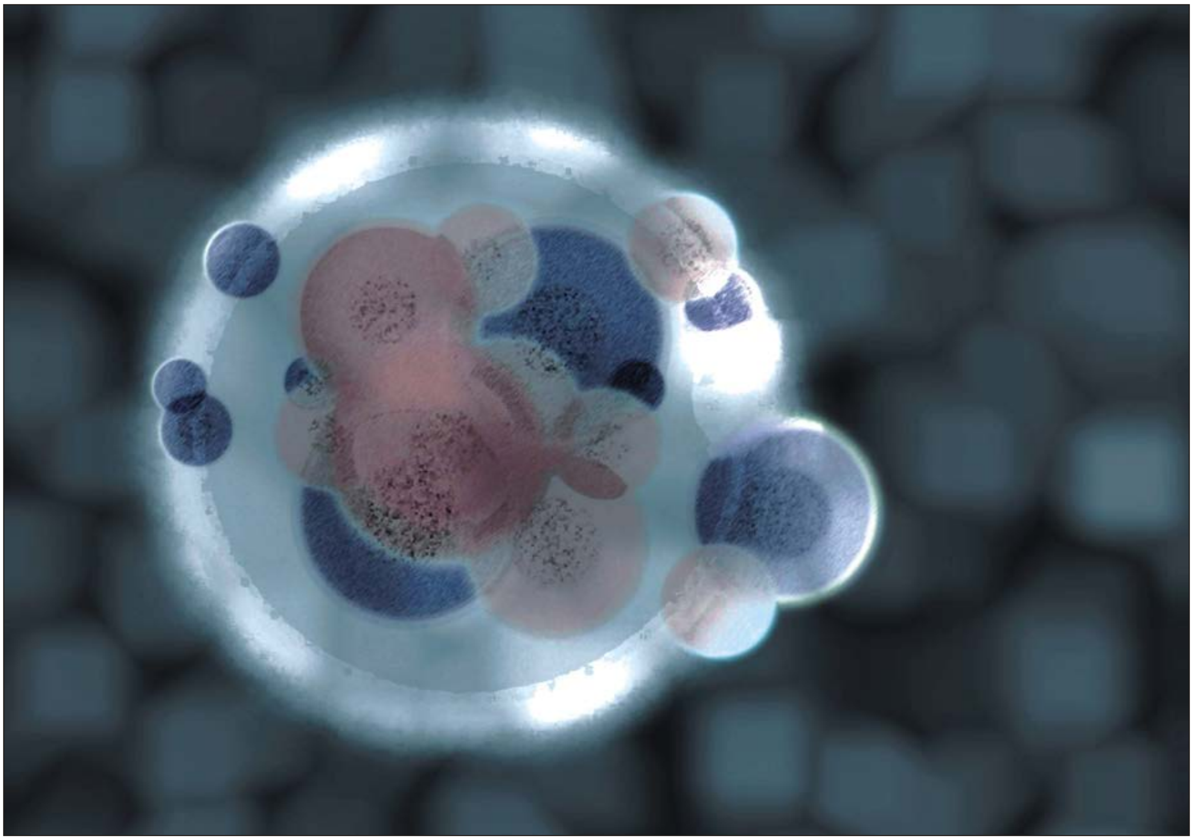

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Phosphorus Requirements of Cereal Crops and Fertility Build up Factor in a Typic Camborthid Soil

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Abstract: Field studies were conducted to arrest Phosphorus requirements of wheat, sorghum fodder and rice crops at 95% relative yield; Phosphorus Fertility Buildup Factor (PFBF) and level of phosphorus buildup in a Typic Camborthid (Sultanpur series) soil of rice tract of the Punjab, Pakistan. Sorption isotherms were constructed in the laboratory and data was fitted into linear form of modified Freundlich Model and doses were computed against soil solution P levels. Different theoretical P doses were applied in the field to develop soil solution P level 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 (native soil solution P). Phosphorus was also applied at the rate of 60 and 90 mg P_2O_5 kg^{-1} to subsequent sorghum fodder and rice crops, respectively. Wheat grain and straw, fresh sorghum fodder, rice paddy and straw yields were recorded at the harvest. Plant sampling was done at booting stage of wheat and rice and at the harvest of each crop. Soil sampling was also done at the harvest of each crop. The results indicated that maximum wheat grain yield was 4.05 Mg ha^{-1}; sorghum fresh fodder yield was 43.83 Mg ha^{-1} and rice paddy yield was 4.43 Mg ha^{-1}. Total P uptake by wheat, sorghum and rice was 22.73, 37.69 and 20.48 kg ha^{-1}, respectively. Mean phosphorus fertility build-up factor (mg P required to build 1 mg P kg^{-1} soil) was 16.23 and the level of P buildup (mg P kg^{-1} built-up in soil for each mg P kg^{-1} soil applied) was 0.062. Level of P depletion was 0.141 mg P kg^{-1} for NPK check plots while 0.162 mg P kg^{-1} for P check plots. Internal P requirement for wheat was 0.255% at booting stage and 0.281% for grain stage. For sorghum fodder, internal P requirement was 0.233% and for rice, it was 0.146% at booting stage and 0.266% for paddy stage.

Key words: wheat, sorghum fodder, rice, internal P requirement, PFBF

INTRODUCTION

The soils in the rice tract of the Punjab, Pakistan are deficient in available phosphorus (P) and the native P supply cannot cope with P mining due to continuous cropping. According to NFDC (2003), 93% of the soils of Pakistan contain less than 10 mg kg^{-1} Olsen extractable P and are thus deficient in plant available P. Soils of Pakistan are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0%) in nature. When phosphatic fertilizers are added, part of them go to soil solution and is taken up by plants, while rest goes to exchange sites and is either adsorbed or precipitated and is a serious problem (Sharif *et al*., 2000). Fox and Kamprath (1970) constructed phosphate sorption isotherms to describe the relationship between levels of P in solution established after fertilization in laboratory and the quantities of P sorbed at the end of equilibrium. This approach has an advantage over conventional method of soil testing in that it integrates P intensity, capacity and quantity aspect of the soil, all of 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. 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). Many equations e.g., Langmuir, modified Freundlich, Gunary, Tempkin and mechanistic models have been used to describe P adsorption in most recent study and have successfully confirmed P adsorption relationships (Huang, 1998). The Langmuir and the Freundlich equations described the adsorption phenomena satisfactorily (Boschetti *et al*., 1998).

The nutrient requirement of a crop can be expressed in several modes and channels. The internal requirement is defined as the 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). External P 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

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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.

Residual effect of P by the criteria of crop yield and soil analysis for P content showed a significant increase in the yield of subsequent wheat crop without P fertilizer application in the rice-wheat rotation (Saeed *et al*., 1992). Puno (1991) studied the P fertility build-up factor (PFBF) and Olsen P content in relation to P fertilization up to 32.8 mg kg^{-1} (150 kg P_2O_5 ha^{-1}) in a silt loam soil and found that PFBF ranged from 11.8-49.3 mg kg^{-1}. Firat and Gumus (2001) observed the residual effect and continuous application of P fertilizer in an alluvial soil increased the amount of available P in the soil solution and P concentration in plants. Keeping in view all the facts, present studies were planned in alluvial soils of rice tract with the following objectives:

- To determine the internal phosphorus requirement of wheat, sorghum (fodder) and rice.
- To see the level of P build-up and depletion following wheat-sorghum (fodder)-rice rotation.

MATERIALS AND METHODS

These investigations were carried out on a typic Camborthid (Sultanpur series) soil of the rice-growing tract of the Punjab, Pakistan during 2003-2004. Soil was selected on the basis of calcareousness and clay contents. A composite soil sample was collected from 0-20 cm depth, air-dried, sieved through a 2 mm sieve and stored for analyses. All basic analyses were performed for chemical characteristics of the soils 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), available phosphorus by Watanabe and Olsen (1965) and Murphy and Riley (1962), Organic matter by Walkley and Black (1934).

Adsorption isotherms were constructed by using modified Freundlich equations as proposed by Le Mare (1982). The simple form of the Freundlich model is as followed:

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

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 study is as follows:

$$\text{Model form } P = aC^{b/a} \quad P=76.45\,C^{0.489}$$

$$\text{Linear form } Y = 0.4889x+4.3367$$

Field experiments: The experiments were conducted in permanent lay out which included three crops i.e., wheat sorghum fodder and rice and fourteen treatments arranged in Randomized Complete Block Design (RCBD) with three replications having plot size of 6×4 m. All the agronomic and recommended cultural practices were followed for normal growth of the crops. Wheat crop cv. Inqalab-91 was sown during the second week of November. Half of the recommended nitrogen (70 kg ha^{-1}) and potassium (K_2O) at the rate of 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 and mixed in soil. 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 by harvesting the whole plot. The grain and straw samples were analysed to calculate the P uptake by the crop.

Post harvest soil sampling was also done immediately after harvest of wheat crop for the determination of Olsen P. After wheat harvest, sorghum cv. Hegari was raised to reap the benefits as animal fodder. The recommended dose of N (65 kg ha^{-1}) and P_2O_5 (60 kg ha^{-1}) was applied to sorghum. Fodder was harvested after 55 days of growth and fresh fodder yield was recorded. Plant samples were collected and oven dried at 70°C for analysis to measure oven-dried weight of fodder and P uptake. Post harvest soil samples were also collected for Olsen P analysis. 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

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

Treatments	P in soil solution (mg L^{-1})	P (mg kg^{-1} soil) to be added	P_2O_5 (kg ha^{-1}) to be added
T1	Native (0 NK)	0.00	0.00
T2	Native (+ NK)	0.00	0.00
T3	0.01	8.04	36.82
T4	0.02	11.29	51.71
T5	0.03	13.76	63.02
T6	0.04	15.84	72.54
T7	0.05	17.67	80.93
T8	0.10	24.80	113.58
T9	0.15	30.24	138.50
T10	0.20	34.80	159.38
T11	0.25	38.81	177.75
T12	0.30	42.43	194.33
T13	0.40	48.84	223.69
T14	0.50	54.48	249.52

(90 kg ha^{-1}) and K_2O (70 kg ha^{-1}) were applied as basal dose and remaining half N with $ZnSO_4$ at the rate of 12.5 kg ha^{-1} were applied after 30 days of transplanting. Plant sampling at booting stage was done from 25 above ground portion of rice plants. At maturity, paddy and straw yields were recorded and their respective samples were collected, oven dried and analysed for P contents. Soil samples were also taken at harvest for Olsen P determinations.

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 and was calculated by the formula

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

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

Phosphorus Fertility Build-up Factor (PFBF): PFBF was calculated by the total amount of P added (mg kg^{-1} soil) divided by Olsen-extractable P (mg kg^{-1} soil) after the last crop.

Level of phosphorus build-up: It was calculated by the net increase in Olsen P (mg kg^{-1} soil) after the third crop divided by the total P added (mg kg^{-1} soil).

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 solution P level after the harvest of each crop.

Statistical analysis: Analysis of variance (ANOVA) technique was used and Duncan's multiple range test (DMR) was applied to see the significance of difference among treatment means (Duncan, 1955). Regression and correlation was applied to compute build-up and depletion in soil P status in alluvial soils used in these investigations by the procedures as described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

The physical and chemical characteristics of the soil used in this study given in Table 2 indicated that the soil was non-saline and non-sodic, moderately calcareous in nature, deficient in organic matter and available phosphorus but medium in extractable Potassium.

Crop yields (Mg ha^{-1})

Wheat grain and straw yield: Wheat gain and straw (Table 3) yields increased with an increase in solution P level and maximum grain and straw yield was obtained at solution concentration of 0.20 and 0.30 mg P L^{-1} which were developed by adding 197.17 and 242.92 kg P_2O_5 ha^{-1}, respectively. The yields were significantly increased at lower level of solution P. The yields at native solution P level where only NK was applied were significantly higher than where no NK was applied. Memon (1982) 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.

Iqbal *et al*. (1998) observed a marked response to P in different soil series of Pakistan. Tandon (1987) also found 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. Brar *et al*. (2000) found similar wheat grain yield results in response to P application.

Sorghum fresh fodder yield: The maximum sorghum fodder yield of 48.95 Mg ha^{-1} was harvested from the plot hading 23 mg P ha^{-1} as residual P after the harvest of wheat crop and also supplied with 60 kg P_2O_5 ha^{-1}. The yield also increased significantly over native P solution (NK control). The yield in control plot (0 NPK) was 18.09 Mg ha^{-1}. The results are in line with those of Bhatti (1996) who obtained sorghum green fodder yield of 30.87 Mg ha^{-1} with traditional technology and 64.22 Mg ha^{-1} with improved technology and his data revealed that there was good compromise of fodder yield and fodder quality at 50% flowering stage of cutting. Khan *et al*. (1996) compared green fodder yield of sorghum varieties in India (44.41 Mg ha^{-1}) with Pakistan

Table 2: Original soil analysis of the selected soil series

Determinant	Units	Values
Textural class	-	Loam
Sub group	-	Typic Camborthid
pHs	-	8.16
ECe	dS m^{-1}	0.87
$CaCO_3$	%	6.48
Organic matter	%	0.62
Olsen P	mg kg^{-1}	4.95
Extractable K	mg kg^{-1}	126

Table 3: Crops yields (Mg ha^{-1})

	Wheat		Sorghum fodder		Rice	
Treatments	Grain	Straw	Fresh	Oven dried	Paddy	Straw
T1	0.99G	1.17F	14.54M	4.93M	1.34J	1.45K
T2	2.12F	2.45E	17.75L	6.02L	1.69I	1.52K
T3	3.11E	3.24D	20.58K	6.97K	1.83H	1.75J
T4	3.21E	3.32D	22.25J	7.54J	2.47G	2.01I
T5	3.21E	3.35D	26.09I	8.85I	2.65F	2.36H
T6	3.56D	3.70C	28.92H	9.80H	2.94E	2.56G
T7	3.68C	3.77C	31.29G	10.61G	3.32D	2.75F
T8	3.93B	4.07B	32.25G	10.94G	3.70C	3.22E
T9	3.95B	4.07B	33.79F	11.46F	4.20B	3.26E
T10	4.05AB	4.18AB	35.78E	12.13E	4.43A	3.46D
T11	4.13A	4.27A	37.42D	12.68D	4.40A	3.48D
T12	4.16A	4.29A	38.73C	13.13C	4.30AB	3.78C
T13	4.13A	4.25A	41.63B	14.11B	4.34A	4.08B
T14	4.13A	4.25A	43.83A	14.86A	4.38A	4.50A
LSD	0.1187	0.1187	1.093	0.3715	0.1300	0.1300

Means sharing same letter(s) are statistically at par at 5% level of probability

(42.59 Mg ha^{-1}). In Pakistan, sorghum is more responsive to fertilizer without lodging due to its medium height, thicker stem, more leaves per plant and leaf area. The results also commensurate with those of Akmal and Asim (2002) who emphasized adequate P fertilization to sorghum fodder on the basis of soil tests to get better yields. Phosphatic fertilizers are seldom applied to sorghum but it is an exhaustive crop and remove large amount of NPK.

Sorghum dry matter yield: The dry matter yield of sorghum is a good quality parameter as animal feed. The residual P after wheat harvest was not enough to increase yield which was enhanced with fertilizer P. The sorghum dry matter yield (Table 3) significantly increased in ascending order of treatments i.e. lowest in T1 and maximum in T14. The maximum dry fodder yield was 10.72 Mg ha^{-1}. Das *et al.* (1996) observed response of dry matter yield up to 80 kg P_2O_5 ha^{-1}. Akmal and Asim (2002) also obtained similar results regarding dry matter yield of sorghum.

Rice paddy and straw yield: The paddy and straw (Table 3) yields increased significantly from T3 to T14. Maximum response was obtained to T10 in case of paddy and T14 in case of straw. The yield at native P level (T1) was significantly low. Phosphorus application promoted plant growth through an adequate supply and helped in better development of roots. Intensive cropping has drastically reduced native soil fertility to such an extent that addition of fertilizers has become necessary to increase and maintain crop yields. These results are supported by the work of Nelson (1980) and Nadeem and Ibrahim (2002).

Phosphorus concentration (%) in crops

Wheat

Booting stage: The P concentration in a plant reflects the adequacy of P for plant growth. Phosphorus concentration in wheat plants at booting stage (Table 4) increased with increase in P solution level and maximum P concentration was observed at 0.10 mg P L^{-1} solution which was obtained by adding 137.95 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. 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. The results also correlates with the findings of Delong *et al.* (2001).

Wheat grain and straw: Different soil solution levels of P showed significant effect on P concentration in harvested wheat. Maximum P concentration was obtained at 0.50 mg P L^{-1} (developed by adding 316.02 kg P_2O_5 ha^{-1}) both in grain and straw. Minimum P concentration was observed in the treatment where no P was applied. Singh *et al.* (2002) observed grain yield and seasonal accumulation of P by wheat were higher for higher P rates. The results are supported by the findings of Brar (2000) and Delong *et al.* (2001).

Sorghum fodder: The phosphorus concentration of forage crops is important since low P content in the animal diet leads to aphosphorosis which is a serious disease in livestock. At less extreme levels of P deficiency, the fertility of livestock may be quite seriously affected

(FAO, 1984). The maximum P concentration (0.32%) was recorded at T13 (residual P 21.95+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 reported by Meelu *et al.* (2000).

Rice

Booting stage: The maximum level of P concentration was 0.23% in the rice plants in T14. Minimum P concentration (0.07%) was observed at native soil solution P level.

Paddy and straw: The maximum P concentration was examined in paddy and straw grown under T14 (residual P 13.75 mg kg^{-1} + 19.65 mg kg^{-1} added P). Minimum P concentration was found in the control plots where no NPK fertilizer was added. The data also revealed that sufficiency level of 0.20% was achieved in T9 (residual P 9.50+19.65 mg kg^{-1} added P), which leads to the conclusion that the crop roots extracted residual P in a better way. 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.

Phosphorus uptake (kg ha^{-1}) by different crops

Wheat grain and straw: The data of P uptake by wheat grain and straw is depicted in Table 5, which showed that maximum P uptake in grain and straw was noted at 0.50 mg P L^{-1} soil solution and this level was developed by adding P fertilizer at the rate of 316.25 kg P_2O_5 ha^{-1}. Minimum P uptake was seen in the control (without NPK) and each additional level of P had profound effect on its uptake. It is stated that the amount of P removed on an average yield of harvested grain varies from 7-15 kg P ha^{-1} (16-34 kg P_2O_5 ha^{-1}) and from this; 2-8 kg P ha^{-1} is returned back to the soil in the form of crop residues, which are left in the field (Hanway and Olsen, 1980). The present results are supported with the findings of Singh *et al.* (2002) and Delong *et al.* (2001).

Table 4: Phosphorus concentration (%) in plant

	Wheat			Sorghum	Rice		
Treatments	Booting	Grain	Straw	Fodder	Booting	Paddy	Straw
T1	0.09J	0.084L	0.010J	0.07K	0.07K	0.054J	0.024J
T2	0.09J	0.106K	0.016J	0.07K	0.08JK	0.064IJ	0.036IJ
T3	0.11I	0.151J	0.018J	0.10J	0.09IJ	0.074I	0.039HI
T4	0.12I	0.172I	0.028I	0.13I	0.10I	0.094H	0.049H
T5	0.14H	0.197GH	0.032I	0.15H	0.10HI	0.113GH	0.063G
T6	0.16G	0.190HI	0.042H	0.17G	0.12GH	0.121G	0.072FG
T7	0.18F	0.212G	0.051G	0.19F	0.13FG	0.147F	0.079F
T8	0.20E	0.246F	0.067F	0.22E	0.14EF	0.185E	0.099E
T9	0.21E	0.256EF	0.076E	0.24D	0.16DE	0.211D	0.106DE
T10	0.23D	0.277CD	0.087D	0.25C	0.17CD	0.242C	0.116CD
T11	0.25D	0.271DE	0.099C	0.29B	0.18C	0.255C	0.118BCD
T12	0.26C	0.293C	0.099C	0.31A	0.20B	0.259C	0.126BC
T13	0.32B	0.322B	0.108B	0.32A	0.21B	0.280B	0.130AB
T14	0.35A	0.348A	0.118A	0.32A	0.23A	0.301A	0.139A
LSD	0.014	0.019	0.008	0.008	0.019	0.020	0.012

Means sharing same letter(s) are statistically at par at 5% level of probability.

Table 5: P uptake (kg ha^{-1}) by crops

	Wheat			Sorghum	Rice		
Treatments	Grain	Straw	Total	Total	Paddy	Straw	Total
T1	1.30K	0.12J	1.42N	2.65M	0.93L	0.63J	1.56L
T2	2.55J	0.28J	2.82M	3.04LM	1.20L	0.72J	1.92L
T3	3.39I	0.38IJ	3.77L	4.46L	1.84K	0.94IJ	2.78K
T4	4.46H	0.73HI	5.19K	6.54K	2.60J	1.28I	3.88J
T5	5.74G	0.95H	6.66J	8.63J	3.53I	1.81H	5.34I
T6	6.37G	1.40G	7.77I	10.50I	4.11H	2.31G	6.42H
T7	7.56F	1.88F	9.44H	12.77H	5.39G	2.84F	8.23G
T8	9.14E	2.63E	11.76G	15.96G	7.09F	3.65E	10.74F
T9	9.73E	3.06D	12.79F	18.56F	8.74E	4.02E	12.76E
T10	10.73D	3.64C	14.38E	21.20E	10.60D	4.62D	15.22D
T11	11.23D	4.32B	15.56D	25.65D	11.37C	4.98D	16.35C
T12	12.41C	4.34B	16.76C	29.86C	12.58B	5.55C	17.08C
T13	13.83B	4.80A	18.63B	32.04B	12.43B	6.26B	18.69B
T14	14.79A	5.12A	19.91A	34.67A	13.39A	7.05A	20.44A
LSD	0.6920	0.3936	0.8656	1.499	0.5591	0.4179	0.7908

Means sharing same letter(s) are statistically at par at 5% level of probability

Sorghum fodder: Phosphorus uptake by sorghum fodder is product of fodder yield and concentration of phosphorus in fodder. The data regarding P uptake by sorghum fodder is given in Table 5. The maximum P uptake (34.67 kg ha^{-1}) was recorded at T14 (residual P 23.00 mg kg^{-1} + added P 13.65 mg kg^{-1}) and was significantly more than T13 (residual P 21.95 mg kg^{-1} + added P 13.65 mg kg^{-1}). This P uptake was found minimum in control plot (without NPK) and was 3.96 kg ha^{-1}. The data also showed that P uptake was progressively increased with increasing treatment numbers from T1 to T14.

Paddy and straw of rice: The data of P uptake by paddy and straw is given in Table 5, which showed that maximum P uptake was recorded at T14 (residual P 13.75 mg kg^{-1} + added P 19.65 mg kg^{-1}) and was significantly better than T13 (residual P 12.85 mg kg^{-1} + added P 19.65 mg kg^{-1}). This P uptake was found minimum in control plot (without NPK) and was 1.55 kg ha^{-1}. The increase in P uptake was increased with the increase in corresponding rates of P application.

Internal phosphorus requirement of crops under field conditions

Wheat

Booting stage: The phosphorus concentration in wheat plants at booting stage was plotted against relative yield of wheat grain by Boundary Line Technique (Webb, 1972) and is shown in Fig. 1a. The value of P concentration (%) for 95% relative yield was determined by regression equation and the value obtained was 0.249%, 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.

Maturity stage: Internal requirement of wheat was determined by making graph of P concentration in grain and maximum attainable 95% relative yield as shown in Fig. 1b). The value obtained was 0.277%. This means that as the crop passed through reproductive phase, P was shifted to the seed. 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.

Sorghum fodder: The internal requirement of P of sorghum fodder which is dependent on the P concentration at maximum growth (vegetative) was determined and plotted as shown in Fig. 2. The graph revealed that maximum internal P requirement of 0.326% was found for sorghum in this soil. Similar results were reported by Chaudhry *et al.* (2003).

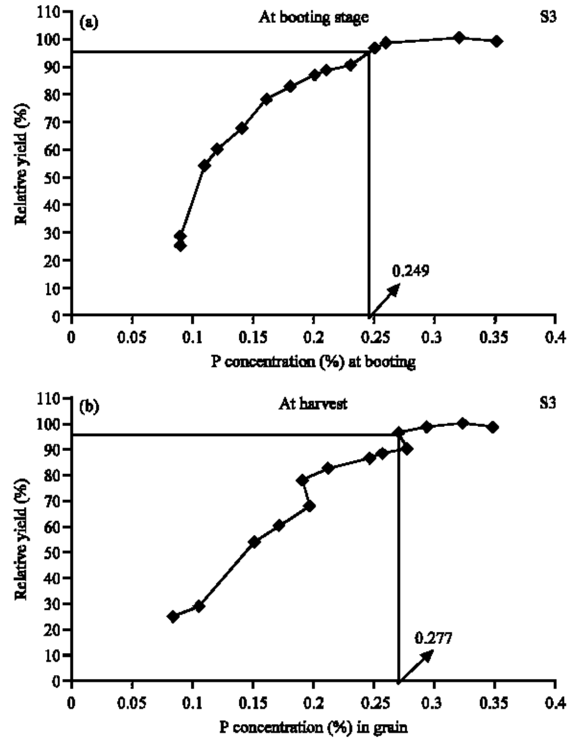

Fig. 1: Internal P requirement of wheat

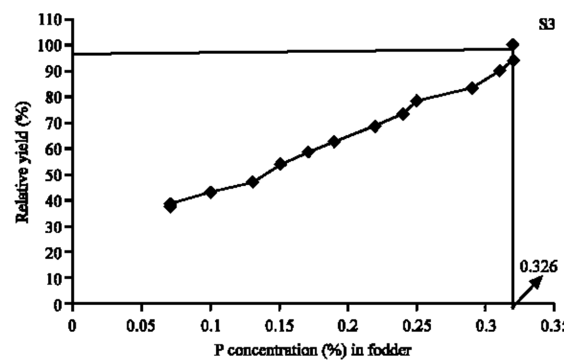

Fig. 2: Internal P requirement of sorghum fodder

Rice

Booting stage: Data regarding P concentration at booting stage of rice was plotted against 95% relative yield of rice as shown in Fig. 3a which illustrates that internal P requirement of rice was 0.165%.

Maturity stage: The plot of P concentration in paddy versus 95% relative paddy yield is shown in Fig. 3b

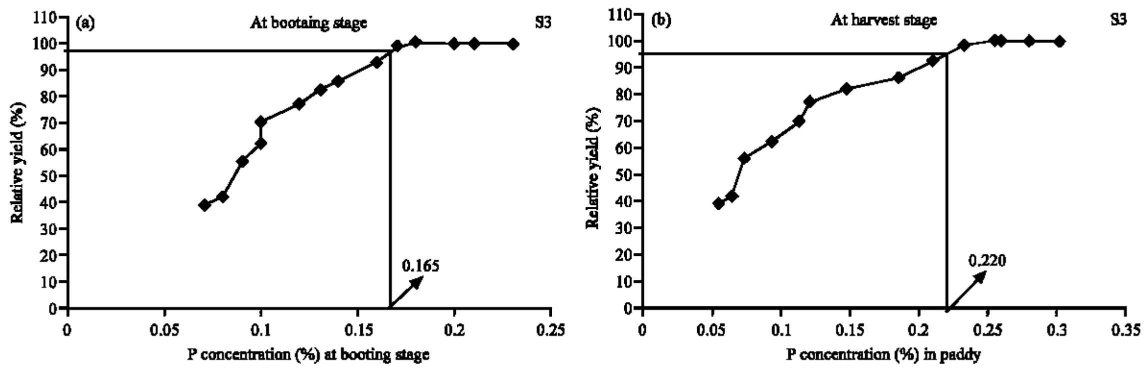

Fig. 3: Internal P requirement of rice I) Solution P (mg L^{-1})

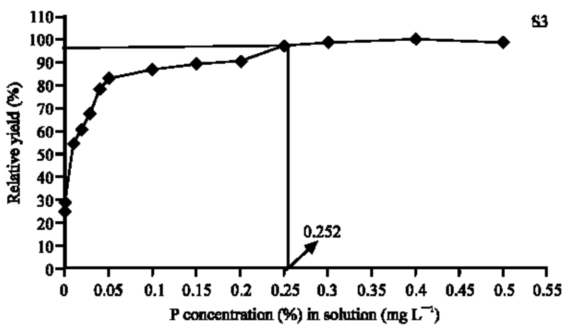

Fig. 4: External P requirement of wheat

which revealed that maximum internal P requirement of 0.220% was found for rice in this soil

External (solution) phosphorus requirement of wheat: The solution levels developed for wheat growth were plotted against 95% relative yield of wheat for the determination of P requirement by the Boundary Line Technique (Webb, 1972) as shown in the Fig. 4. The graph revealed that solution P requirement of 0.252 mg P L^{-1} was required for 95% yield in this soil. Memon *et al.* (1991) found that 18-29 kg P ha^{-1} is required to develop a solution level of 0.032 mg P L^{-1} in calcareous soils. The concentration at the root surface of young plants need about 0.03-0.3 mg P L^{-1} and older plants require about 0.03 mg P L^{-1} or less but the concentrations which have been shown by many workers to be required in bulk soil solution are little higher (0.06-0.68 mg P L^{-1}) and this would be expected because uptake reduces the phosphate concentration at the root surface when plants are grown in static systems e.g. soils (Kamprath and Watson, 1980). Similarly, Beckwith (1965) suggested a standard concentration of 0.2 ug P mL^{-1} as adequate for most plant species. Memon (1982) showed that P solution associated with 95% maximum yield of wheat was 0.025 μg mL^{-1}, particularly 0.029 μg mL^{-1} for Pak-70 and 0.023 μg mL^{-1} for pavon variety. Memon *et al.* (1991) determined external P requirement of wheat grain at near maximum yield as 0.032 mg L^{-1} as obtained from composite yield response curve.

Table 6: Olsen extractable P (mg kg^{-1} soil) after harvest

Treatments	Wheat	Sorghum	Rice
T1	5.10M	4.95H	4.65M
T2	5.00M	4.80I	4.45M
T3	5.90L	6.00H	6.15L
T4	6.45K	6.65H	6.85K
T5	6.85J	7.10GH	7.30J
T6	7.60I	7.95FG	8.20I
T7	8.05H	8.40F	8.75H
T8	8.45G	8.90EF	9.30G
T9	9.95F	9.50DE	9.90F
T10	10.60E	10.05CD	10.50E
T11	14.40D	10.90BC	11.35D
T12	18.10C	11.70B	12.25C
T13	21.95B	12.85A	13.40B
T14	23.00A	13.75A	14.50A
LSD	0.2123	1.041	0.2489

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

Phosphorus availability status in soils after wheat harvest: It is widely recognized that the efficiency of applied P increases if P application rates are tailored to the initial P fertility of the soil. After the harvest of wheat, soil samples were collected from all the plots and analyzed for Olsen P to determine the P status. The data presented in Table 6 reveal that P application rates significantly increased the available P status 5.90 to 23.00 mg kg^{-1} in the soil. However the native P status decreased in all the soils (5.20 to 5.10 mg kg^{-1} where no fertilizer was applied and where NK was applied, this native P further decreased to 5.00 mg kg^{-1}.

Decline in available P without P application is understandable because there is only P output without any input. Similarly Tandon (1987) summarized the results of 18 experiments and concluded that when half of the optimum rates of P were used, available P declined or showed little change at 60% sites and when applied

Table 7: Phosphorus fertility build-up factor (PFBF) and level of P build-up

Treatment No.	P added ($mg\ kg^{-1}$) Wheat	Sorghum	Rice	Total P ($mg\ kg^{-1}$)	Olsen P-Native P	Net available P	PFBF	Level of P build-up
T1	0	0	0	5.20	4.45-5.20	-0.75	0	-0.144
T2	0	0	0	5.20	4.35-5.20	-0.85	0	-0.164
T3	9.20	13.65	19.65	42.50	6.15-5.20	0.95	44.74	0.022
T4	13.15	13.65	19.65	46.45	6.85-5.20	1.65	28.15	0.036
T5	16.20	13.65	19.65	49.50	7.30-5.20	2.10	23.57	0.042
T6	18.79	13.65	19.65	52.09	8.20-5.20	3.00	17.36	0.058
T7	21.08	13.65	19.65	54.38	8.75-5.20	3.55	15.32	0.065
T8	30.12	13.65	19.65	63.43	9.30-5.20	4.10	15.47	0.065
T9	37.12	13.65	19.65	70.42	9.90-5.20	4.70	14.98	0.067
T10	43.05	13.65	19.65	76.35	10.50-5.20	5.30	14.41	0.069
T11	48.29	13.65	19.65	81.59	11.35-5.20	6.15	13.27	0.075
T12	53.04	13.65	19.65	86.34	12.25-5.20	7.05	12.25	0.082
T13	61.51	13.65	19.65	94.81	13.40-5.20	8.20	11.56	0.087
T14	69.00	13.65	19.65	102.30	14.50-5.20	9.30	11.00	0.091
Mean							18.51	0.054

optimum rates of P, a significant improvement in available P status was found. It was observed in the present study that to raise P fertility to a given level, different amounts of P are required. It was also noted that the higher P rates become uneconomical for resource constrained farmers.

Phosphorus availability status in soils after sorghum fodder harvest: Soil P status which was built after the wheat decreased to some extent with the passage of time and contributed to the P uptake by plants or adsorption on soil (Table 6). Native P of soils decreased to 4.65 $mg\ kg^{-1}$ in control plots of soil while in the plots receiving NK, Olsen P was further reduced to 4.80 $mg\ kg^{-1}$. However, the overall status of soil available P ranged from 6.00 to 13.75 $mg\ kg^{-1}$ in this soil. The results are in line with that of Tandon (1987) who described that the continuous application of recommended levels of P resulted in a significant increase in the soils available P status.

Phosphorus availability status in soils after rice harvest: Available phosphorus determined after harvesting of rice is depicted in Table 6 which revealed that soil P status was little bit improved after rice crop. The possible reason might be that the rice was grown under submerged conditions and more phosphorus became available for plant uptake and this P availability status reflected that wetting and drying conditions changed the available P status of soil i.e., after wheat it was built up due to high P application, after sorghum it decreased and after rice, it either maintained or slightly increased. The native P status decreased to 4.65 $mg\ kg^{-1}$ in the plot where no NK was applied and where NK was applied, it further reduced to 4.45 $mg\ kg^{-1}$ in the soil. These data confirmed that where no fertilizer was given, the rate of P depletion was less as compared to that where NK fertilizer was added. The application of NK improved the growth and increased root growth extracted more P from the native source. Tandon (1987) pointed out that soils which are medium to high in available P, when cropped using N alone become deficient in P within a couple of years and yields drop drastically unless P fertilizers are applied. Similar results were obtained with rice by Ittyarial (1979).

Phosphorus fertility build-up factor and level of phosphorus build-up: PFBF exhihibited that PFBF was maximum (44.74) in T3 (0.01 mg P L^{-1}) and minimum (11.00) in T14 (0.50 mg P L^{-1}) with a mean value of 18.51 (Table 7). As regards level of P build-up, the maximum value (0.091 $mg\ kg^{-1}$) was achieved in T14 (0.50 mg P L^{-1}) and minimum value (0.022 $mg\ kg^{-1}$) in T3 (0.01 mg P L^{-1}) with mean value of 0.054 $mg\ kg^{-1}$. There was a net decrease in control plots at the rate of 0.144 $mg\ kg^{-1}$ in NPK check and at the rate of 0.164 $mg\ kg^{-1}$ in P check plots, respectively. Similar results were obtained by Tandon (1987) and Puno (1991).

CONCLUSIONS

Main conclusions drawn from this piece of study are as under

- Olsen P can be built-up to nearly desired level in the soils considering the phosphorus fertility build-up factor (mg P required to build 1 mg P kg^{-1} soil).
- 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. However higher P rates needs to be tested for sorghum fodder for getting maximum yields.
- Taking plant samples at booting stage than at crop maturity for obtaining 95% relative yield better correlated with internal P requirements of crops.

- Soils are being mined per annum at the rate of 0.144 mg P kg^{-1} if no fertilizers are applied and at the rate of 0.164 mg P kg^{-1} if only NK are applied in fine textured soils, respectively. So balanced fertilization is a pre-requisite for harvesting maximum crop yields.

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