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PHOSPHORUS DYNAMICS IN RASULPUR SOIL SERIES (TYPIC CAMBORTHID) UNDER RICE BASED CROPPING SYSTEM

O. U. Rehman, S. M. Mehdi [*], M. Sarfraz[*] M. A. Shakir[*], and G. Shabir[*]

[*]Soil and Water Conservation Research Station Fatehjang, Attock
[**]Soil Salinity Research Institute, Pindi Bhattian
Corresponding Author E-mail: drobaidtmn@yahoo.com

ABSTRACT

Phosphorus (P) nutrition of the rice cropping system is very important due to alternate wetting and drying cycles. A field experiment was conducted on a sandy loam soil (Typic Camborthid) to observe residual effect of P on succeeding crops and rate of P depletion after one crop rotation (wheat- sorghum fodder-rice). Rice was raised as second crop on the residual P after sorghum fodder, grown after wheat. Analysis of variance (ANOVA) technique under RCBD was used and Duncan's multiple range test (DMR) was applied to see the significance of difference among treatment means. Maximum residual P after sorghum fodder was 13.10 mg kg^{-1}, considered quite sufficient for rice crop. The significantly higher yield of paddy (2.83 Mg ha^{-1}) and straw (2.96 Mg ha^{-1}) was found where residual P was 10.65 mg kg^{-1} soil. Maximum P concentration (0.15 %) in paddy was found at highest residual P level while in straw it was maximum (0.10 %) where residual P was 10.65 mg kg^{-1} soil. Similar trend was found in case of P uptake i.e. it was significantly higher in paddy (4.22 Kg ha^{-1}) at highest residual P level and straw (3.05 Kg ha^{-1}) where residual P was 10.65 mg kg^{-1} while total P uptake was maximum (7.20 kg ha^{-1}) at highest residual P level. Maximum Olsen- P (8.70 mg kg^{-1}) was found after harvest of rice crop where maximum P was applied to wheat. Level of P depletion at the end of three crops was found to be 0.004 mg kg^{-1} $annum^{-1}$ where P was applied at 13.76 mg kg^{-1} soil and this depletion was promoted where no NPK was applied and further deterioration was noticed where only NK was applied without P. However at the higher rates of P application, there was no net P depletion It may be concluded from this study that phosphatic fertilizers 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 with varying soils and crops. The residual P upto 13.1 mg Kg^{-1} can support 2 to 3 succeeding crops in loose textured soils and soils are being mined $annum^{-1}$ @ 0.138 mg P kg^{-1} if no fertilizers are applied @ 0.149 mg P kg^{-1} if only NK are applied in light textured soils under rice cropping system.

Key words: P decline rate, phosphorus, residual effect, rice, Typic Camborthid.

INTRODUCTION

Judicious application of P-fertilizer is a key factor in the cereals based system of Pakistan for sustainable agriculture. Imbalanced fertilizer use, especially in terms of agricultural productivity and economic growth in Pakistan (NFDC, 2006). The application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application is the key to increased and sustained crop production (Cisse and Amar, 2000). Added P is not irreversibly fixed in forms that are unavailable to plants. Consequently, the efficiency of use of P added in fertilizers is often high (up to 90 percent) when considered over an adequate time scale and when evaluated using the balance method. Residual P contributes to the readily plant-available pool, but the rate of release may not be sufficient to maintain the critical value required to meet the P requirements of high-yielding cultivars. In such situations, P must be added in order to maintain the critical value to obtain optimal yields. (FAO, 2008). According to NFDC (2001), 93% of Pakistani soils contain less than 10 mg kg^{-1} Olsen-extractable P and are thus deficient. Phosphorus deficiency is invariably a common growth and yield limiting factor in unfertilized soils, especially in soils high in calcium carbonate which reduces P availability (Ibrikci *et al*., 2005). Application of phosphatic fertilizers is the common strategy to cope its deficiency, this option is not very much feasible because of low use efficiency of applied P, huge rise in its prices, environmental concerns and fear of depletion of non-renewable rock P reserves mined for production of P fertilizers (Vance *et al*., 2003). Because of the complexity of P chemistry in soil, only about 20 % of the total amount of P fertilizer is utilized by the first crop and the remaining 80 % is fixed in soil in unavailable form (Grotz and Guerinot, 2002). Soil fertility is continuously depleting due to the mining of essential nutrients from the soil under intensive cultivation and imbalance use of fertilizers. During 2011-12, the off take of phosphates (621000 tons) declined by 19 % as compared to previous year, widening the gap of N: P to 5:1 against desirable of 2:1. This decrease is attributed to their high prices, less farm profitability due to less commodity prices in the local market (Annual

Plan, 2012-13). Soil based P management requires a long term management strategy to maintain soil available P supply at an appropriate level through monitoring soil P fertility because of relative P stability within soil. By using this approach, the P fertilizer application can be generally reduced by 20 % compared to farmers practice for the high yielding cereal crops (Zheng *et al*., 2010). One unique characteristic of P is its low availability due to slow diffusion and high fixation in soils causing it a major limiting factor for plant growth. Phosphorus uptake and utilization by plants play a vital role in determination of final crop yield (Shen *et al*., 2011). Phosphorus fertilizer use efficiency in irrigated low land rice could be improved if fertilizer recommendations were based on the native soil fertility currently defined in field as plant P uptake (Anch and Phung, 2004). Numerous studies have been conducted for phosphorus fertility build up and depletion in different soil series of Pakistan using P sorption models (Sarfraz *et al*., 2009 and 2008, Mehdi *et al*., 2008, 2007 (a and b) and Rehman *et al*., 2007 (a and b) and observing their residual effect on different crops (Sukristiyonubowo and Tuherkih, 2009; Sahrawat, 2008; Khan *et al*., 2007; Rashid *et al*., 2007, Alam *et al*., 2005, Nadeem and Ibrahim, 2002 and Sahrawat(2001).

Rice ranks as second amongst the staple food grain crops after wheat in Pakistan and it accounts for 4.9 % value addition in agriculture and earns 1 % of GDP as Pakistan exports two third of its rice production. Area, production and yield of rice during 2011-12 remained 2571000 ha, 6160000 tons and 2396 kg ha^{-1}, respectively (Pakistan Economic Survey, 2011-12). Phosphorus is less commonly deficient for rice than upland crops because of its increased concentration in soil solution under flooded condition. The magnitude of residual effect depends upon the rate and kind of fertilizer used, the cropping and management system followed and to greater extent on the type of soil (Baskar *et al*., 2000). Khan *et al*., (2007) observed 47 % increases in paddy yields by residual application of 90 kg P_2O_5 ha^{-1} over control. The only plant available form of P is orthophosphate of which there are two types in typical aquatic system; HPO_4 predominates in alkaline condition while H_2PO_4 in acidic condition (Busman *et al*., 2002). Fertilisers are the most functional input to replace nutrient removal and the high yielding rice varieties require more mineral fertilizing to achieve their potential yields. Studies on the effect of rice production conducted in many rice producing areas have tremendously increased in line with the development of high yielding rice varieties (Sukristiyonubowo and Tuherkih, 2009; Cho *et al*., 2000). Alternate flooding and drying of soil can enhance the availability of water soluble phosphorus in the soil by 185-900 % (Turner and Haygarth, 2001). Crop rotation is important for phosphate fertilization, as crops differ in their response to applied P and their utilization of residual P. Pakistan has two principal cropping seasons i.e. kharif (summer) and rabi (winter). Major crop rotations followed are wheat-rice (irrigated), wheat-cotton, wheat–maize and some minor or fodder crops are adjusted in the intervening periods. A rice crop depletes about 7-8 kg ha^{-1} when P fertilizer is not used, while an application of about 20 kg ha^{-1} may cause an accretion of about 4-5 kg ha^{-1} (Dobermann *et al.,* 1996).

So keeping in view all the facts, a study was planned to monitor the residual effect of P on second crop after its application and rate of Olsen-P decline in an alluvial sandy loam soil of rice tract after wheat-sorghum fodder-rice rotation.

MATERIALS AND METHODS

The study was in continuation of experiments already conducted in Bhalike soil series (Rehman *et al*., 2007 a). Composite soil samples were collected from 0-20 cm depth of the restricted site with the help of a 5 cm diameter auger. Each soil sample was thoroughly mixed, air dried for seven days, sieved through a 2 mm sieve and stored in sealed plastic jars 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). 0.5 M $NaHCO_3$ solution adjusted to pH 8.5 by the addition of 50% w/w NaOH was used for extraction of 2.5 g soil (Watanabe and Olsen, 1965). P determination was made by the method as described by Murphy and Riley (1962). Original soil analysis is depicted in table 1.

Table 1. Original soil analysis

Determinant	Units	Values
Sand	%	70
Silt	%	18
Clay	%	12
Textural class	-	Sandy Loam
Sub group	-	Typic Camborthid
pHs	-	7.91
ECe	d Sm^{-1}	0.92
SAR	(m mol $L^{-1})^{0.5}$	1.13
$CaCO_3$	%	5.15
Organic matter	%	0.44
Olsen P	mg Kg^{-1}	4.35
Extractable K	mg Kg^{-1}	99

Theoretical doses of P and phosphatic fertilizers required to develop P levels in soil solutions under field conditions were calculated from the modified Freundlich model to develop soil solution P 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 P L^{-1} for wheat crop (Table 2). An overall check of NPK= 0 was also kept. No phosphatic fertilizer was added to sorghum and rice crops, which were grown only on the carryover effect of the P added to wheat. After sorghum fodder, fine rice cv. Super Basmati was transplanted in the second week of July. Half of the recommended N (55 kg ha^{-1}) with all K_2O i.e., 70 kg ha^{-1} was applied as basal dose. Remaining half N and $ZnSO_4$ at 12.5 kg ha^{-1} was applied after 15 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 and their respective samples were collected, oven dried and grinded for plant analysis. Soil samples were also taken at harvest for Olsen P determinations.

Table 2. Computed P doses to be applied.

Treat ments	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	0
T2	**Native (+ NK)**	0	0
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

Note:
Formula for converting P (mg kg^{-1} soil) to P_2O_5 (kg ha^{-1}) is P (mg kg^{-1}) x 2 = P (kg ha^{-1}) x 2.29 = P_2O_5 (kg ha^{-1}) i.e. mg kg^{-1} x 2 = kg ha^{-1} and P x 2.29 = P_2O_5

One gram oven dried rice plant material was digested in 20 mL concentrated HNO_3 and 10 mL of 72% $HC1O_4$, cooled the digest, transferred to 100 mL volumetric flask and made volume (U.S. Salinity Lab. Staff, 1954). From this digested material five mL aliquot was taken in 50 mL volumetric flask, added 5 mL each of ammonium vanadate (0.25%) and ammonium molybdate (5%), made volume and allowed to stand for 15-30 minutes. Reading was recorded on spectrophotometer. Then from the standard curve, P concentration (%) in plant was calculated.

The yield representing each phosphorus level was expressed as percentile 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

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

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

Level of phosphorus depletion was determined by the net decrease in Olsen P (mg kg^{-1} soil) after the third crop divided by the original native P or initial P (mg kg^{-1} soil) in the respective plots.

Two way analysis of variance (ANOVA) technique under randomized complete block design (RCBD) 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 *et al*., 1997.

RESULTS AND DISCUSSION

Rice paddy and straw yield (Mg ha^{-1}): Rice was the second crop grown in continuation on the carry over effect of phosphate fertilizer applied to wheat crop. Paddy and straw yield has been presented in table 3, which revealed that maximum response was observed with more P application. Maximum paddy and straw yield i. e. 2.83 Mg ha^{-1} and 2.96 Mg ha^{-1} was obtained in T11 (residual P 10.65 mg kg^{-1}) while at the higher levels, the yield decreased significantly. This might be due to the reason that under submerged soil conditions, response in coarse textured soil was attained at the lower P level. However, the minimum paddy and straw yield i. e. 1.38I Mg ha^{-1} and 1.52 Mg ha^{-1} was seen in the control plots where no NPK was applied. The reason might be due to less tillering and poor crop stand in the control plots. The results are in line with those of Sukristiyonubowo and Tuherkih, 2009; Sahrawat, 2008; Khan *et al*., 2007; Rashid *et al*., 2007, Alam *et al*., 2005, Nadeem and Ibrahim, 2002 and Sahrawat(2001).

Phosphorus concentration in rice paddy and straw: Data regarding P concentration in paddy (Table 4) exhibited that maximum P concentration 0.15% was observed in T14 (residual P 13.10 mg kg^{-1}) followed by T13, which was significantly less than T14. However the minimum P concentration (0.07 %) was seen in control plots. The results regarding P concentration of rice straw are also described in table 4. The data revealed that maximum P concentration (0.10) was observed in T11 (residual P 10.65 mg kg^{-1}). There was progressive increase in P concentration of rice straw from lower treatment P levels to higher treatment P levels but the higher levels (T12 to T14) had no significant effect on P concentration. The reason might be that due to submerged soil conditions, soils maintain solution P level and sufficiency range is attained at lower level in coarse textured soil. Minimum P concentration in straw (0.04 %) was observed in control plots. The results are in line with those obtained by Mehdi *et al*., 2008, 2007 (a and b) and Rehman *et al*., 2007 (a and b).

Table 3. Rice paddy yield (Mg ha^{-1}).

Treatments	Residual P after sorghum	Paddy yield	Straw yield	Residual P after rice
	mg Kg^{-1}	Mg ha^{-1}	Mg ha^{-1}	mg Kg^{-1}
T1	4.70J	1.34I	1.52I	3.75I
T2	4.60J	1.36H	1.66H	3.70I
T3	4.40I	1.61GH	1.74GH	3.30J
T4	5.00H	1.72G	1.84G	3.90HI
T5	5.55H	1.90F	2.01F	4.30GH
T6	6.30G	2.15E	2.26E	4.80FG
T7	6.45G	2.25DE	2.39D	5.00F
T8	7.20F	2.32CD	2.46CD	5.50E
T9	8.25E	2.44C	2.56C	6.35CD
T10	8.30E	2.61B	2.76B	6.85BC
T11	10.65D	2.83A	2.96A	7.15B
T12	11.25C	2.34CD	2.48CD	8.20A
T13	10.80B	2.33CD	2.46CD	8.65A
T14	10.90A	3.41B	3.53B	8.70A
LSD	**0.2706**	**0.1187**	**0.1187**	**0.7180**

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

Phosphorus uptake by rice paddy and straw: Phosphorus uptake by paddy is product of paddy yield and P concentration in paddy. The data regarding P uptake by rice paddy (Table 4) showed that maximum P uptake (4.22 kg ha^{-1}) was observed at T14 (residual P 13.10 mg kg^{-1}), which was significantly higher than T13 (residual P 12.75 mg kg^{-1}). The uptake of P by paddy was irregular in the middle order treatments. This P uptake was found minimum (0.97 kg ha^{-1}) in control plots (without NPK).

The data regarding P uptake by rice straw is also given in table 4. The data revealed that maximum P uptake by straw (3.05 kg ha^{-1}) was observed at T11 (residual P 10.65 mg kg^{-1}), which was significantly higher than T10 (residual P 8.30 mg kg^{-1}). The P uptake was found minimum (0.61 kg ha^{-1}) in control plots (without NPK) that was also at par with T2 and T3. The results are in line with those obtained by Mehdi *et al*., 2008, 2007 (a and b) and Rehman *et al*., 2007 (a and b).

Phosphorus uptake by rice: The results regarding total P uptake by rice depicted in table 4 revealed that maximum P uptake by rice crop (7.20 kg ha^{-1}) was observed at T14 (residual P 13.10 mg kg^{-1}), which was significantly higher than T13 being at par with T12 and T11. Minimum P uptake (1.58 and 2.04 kg ha^{-1}) was found in control plots without and with NPK fertilizer, respectively. The results are in line with those obtained by Mehdi *et al*., 2008, 2007 (a and b) and Rehman *et al*., 2007 (a and b).

Table 4. Phosphorus concentration (%) in rice paddy and straw and Phosphorus uptake (Kg ha^{-1})

Treatments	P concentration (%)		P uptake (Kg ha^{-1})		
	Paddy	Straw	Paddy	Straw	Total
T1	0.81J	0.05F	0.97I	0.61G	1.58H
T2	0.81IJ	0.04EF	1.32HI	0.72FG	2.04GH
T3	0.81HI	0.05EF	1.45H	0.82FG	2.27G
T4	0.81GHI	0.05EF	1.66GH	0.92EF	2.58FG
T5	0.10FGH	0.05EF	1.96G	1.01EF	2.97F
T6	0.11EFG	0.05DE	2.37F	1.21E	3.58E
T7	0.11EFG	0.06D	2.48EF	1.51D	4.00DE
T8	0.11DEF	0.08C	2.63EF	1.89C	4.52CD
T9	0.12CDEF	0.08C	2.85DE	2.14C	4.98C
T10	0.12CDE	0.10B	3.22BCD	2.66B	5.89B
T11	0.13BCD	0.10AB	3.60B	3.05A	6.65B
T12	0.13BC	0.11A	3.04CD	2.81AB	5.85B
T13	0.14B	0.11A	3.26BC	2.79AB	6.06B
T14	0.16A	0.12A	4.22A	2.99A	9.58A
LSD	**0.014**	**0.011**	**0.3677**	**0.2808**	**0.5838**

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

Available phosphorus status of soils after sorghum fodder harvest: As the sorghum fodder was raised on the residual phosphorus applied to previous wheat crop, so a marked reduction in Olsen P was observed (Table 3) and the values dropped to almost half after sorghum harvest. But still there was sufficient available P for raising an other crop after sorghum. Maximum value of 13.10 mg kg^{-1} was observed in T14 (residual P 25.15 mg kg^{-1} after wheat). Native Olsen P further dropped to 3.90 mg kg^{-1} where no NK was applied and 3.85 mg kg^{-1} where NK was applied. So imbalance application of fertilizers caused a great reduction in native P pool. The results also get support from Mehdi *et al*., 2008, 2007 (a and b); Rehman *et al*., 2007 (a and b) and Zhou *et al*. (2001),

Available phosphorus status of soils after rice harvest: Rice crop was also grown on carryover effect of P from the previous P application to wheat crop and sorghum was first crop raised on the residual P. A decrease in Olsen P was observed after rice harvest (Table 3) but not to that extent as was observed after sorghum fodder. Maximum value observed was 8.20 mg kg^{-1} at T12 (residual P 11.25 mg kg^{-1} after sorghum fodder). However after raising two crops on residual P, still there was considerable Olsen P in the soil which is quite higher than native soil P. Rehman *et al*. (1992) found Olsen P for 88% relative yield of rice at 10.90 mg kg^{-1}, 95% relative yield at 15.40 mg kg^{-1} and 99% relative yield at 23.75 mg kg^{-1}. Saeed *et al*. (1992) also found similar results. The results are in line with those obtained by Mehdi *et al*., 2008, 2007 (a nad b) and Rehman *et al*., 2007 (a and b).

Rate of Phosphorus depletion/annum in Soils: Data regarding annual level of P depletion is depicted in table 5. As regards level of P depletion, maximum level (0.138 mg kg^{-1}) was observed in the plots receiving no NPK fertilizers and it was further accentuated (0.149 mg kg^{-1}) with plots receiving N and K fertilizers without P. With the application of P fertilizers, the rate of P depletion was decreased and it was observed up to solution P level of 0.03 mg L^{-1} which was 0.004 mg kg^{-1} and above this level, no net P depletion was observed but P build up was noticed. The results are in line with those obtained by Mehdi *et al*., 2008, 2007 (a and b) and Rehman *et al*., 2007 (a and b).

Table 5. Rate of P depletion.

Solution P (mg L^{-1})	P added (mg kg^{-1})			Total P (mg kg^{-1})	Solution P – Native P	Net Available P	Annual Rate of P Depletion
	Wheat	Sorghum	Rice				
Native	0	0	0	0	3.75-4.35	-0.60	-0.138
Native	0	0	0	0	3.70-4.35	-0.65	-0.149
0.01	8.23	0	0	8.23	3.30-4.35	-1.05	-0.128
0.02	11.38	0	0	11.38	3.90-4.35	-0.45	-0.040
0.03	13.76	0	0	13.76	4.30-4.35	-0.05	-0.004
0.04	15.74	0	0	15.74	4.80-4.35	0.45	0.029
0.05	17.48	0	0	17.48	5.00-4.35	0.65	0.037
0.10	24.17	0	0	24.17	5.50-4.35	1.15	0.048
0.15	32.22	0	0	32.22	6.35-4.35	2.00	0.068
0.20	33.43	0	0	33.43	6.85-4.35	2.50	0.075
0.25	37.11	0	0	37.11	7.15-4.35	2.80	0.075
0.30	40.42	0	0	40.42	8.20-4.35	3.85	0.095
0.40	46.25	0	0	46.25	8.65-4.35	4.30	0.093
0.50	51.34	0	0	51.34	8.70-4.35	4.35	0.085

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 with varying soils and crops.
2. The residual P upto 13.1 mg Kg^{-1} can support 2 to 3 succeeding crops in loose textured soils.
3. Soils are being mined $annum^{-1}$ @ 0.138 mg P kg^{-1} if no fertilizers are applied @ 0.149 mg P kg^{-1} if only NK are applied in light textured soils under rice cropping system.

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