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Grain yield and phosphorus uptake by wheat as influenced by long-term phosphorus fertilization

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Phosphate reactions in the soil have important implications for crop growth and its nutrition to plants. Using a 40 years old long-term fertility experiment, we studied the fate of different sources of applied P into its nutrition to wheat in calcareous soils in a pearl millet-wheat cropping system during *rabi* 2009 and 2010. Results showed that water soluble sources of phosphatic fertilizers (Single super phosphate, Diammonium phosphate, Urea ammonium phosphate) were found superior over partially water soluble (nitrophosphate) and mineral acid soluble (RP) sources in terms of grain yield and P uptake. With increasing levels of P from 60 to 120 kg P₂O₅ ha⁻¹, grain yield and P uptake increased significantly. Cumulative mode of P application was found the best for grain yield and P uptake as compared to direct and residual mode. The available P, saloid-P and AI-P were positively and significantly correlated with grain yield ($r = 0.829^{**}$ to 0.894^{**}), straw yield ($r = 0.833^{**}$ to 0.890^{**}), P concentration in grain ($r = 0.666^*$ to 0.749^*), and total P uptake ($r = 0.860^{**}$ to 0.928^{**}). Multiple regression equations between yield and P uptake and various inorganic P fraction of soil also indicated that saloid-P and AI-P were the important forms of inorganic P and contributed mainly towards grain and straw yield and total P uptake.

Key words: Phosphatic fertilizers, wheat grain yield, phosphorus uptake.

INTRODUCTION

Phosphorus is one of the major elements; the essentiality of which as a nutrient for plant growth is well established as it plays a vital role in the metabolism of plants. After nitrogen stress, P is the second most widely occurring nutrient deficiency in cereal systems around the world (Balemi and Negisho, 2012). It is also a structural component of metabolically active compounds present in plants. However, its concentration and solubility in soils is low due to its interacting nature, and consequently P is a critical nutrient limiting plant growth (Tekchand and Tomar, 1993; Tomar, 2000; Setia and Sharma, 2007).

Thus, phosphate reactions in the soil have important implications for crop growth and fertilizer use efficiency. Due to its low solubility and interacting nature in soil, the efficiency of P fertilizers is quite low (Fohse et al., 1991). Eighty percent of Indian soils are either low or medium in available P (Motsara, 2002). Availability of P to plants also varies with the nature of soil, fertilizers and reaction products, the solubility of which largely depends upon the ionic form of P present in the added fertilizer (Khurana et al., 2003). Thus, the response of fertilizer having 100% water soluble P is at variance to those having fully or

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partially citrate soluble forms.

Long-term experiments reflect not only the crop response to current fertilizer application of varying solubilities but also the response to residual fertility from previous application (Tang et al., 2008; Ma et al., 2009). In addition, such experiments also make it possible to determine the long-term effects of soil fertility and nutrient balances between amount applied and those removed by crops over a long period which could not be obtained in a single crop experiment. Therefore, knowledge of the rate of increase or decrease of available P and the fate of residual P resulting from fertilization and crop removal is essential for long-term planning of fertilization strategies to sustain crop production (Ma et al., 2009; Huang et al., 2011). The P utilization by crop plants, its residual effects and accumulation in the soil have been studied extensively mostly from short-term or medium-term studies. There are very few reports on the effect of a long-term application of phosphatic fertilizers on grain yields, nutrient uptake and their effects on the same soil. Therefore, the present study was undertaken to study the effect of long-term P fertilization on grain yield and nutrient uptake by wheat.

MATERIALS AND METHODS

A long-term field experiment on pearl-millet-wheat rotation on the use of different levels of various phosphatic fertilizers applied under three modes was initiated in *rabi* 1968 at Soil Research Farm (Typic Haplustepts), Chaudhary Charan Singh Haryana Agricultural University, Haryana, India. The field experiment was conducted with a fixed layout plan using split-plot design with two replications in 10×3.33 m² plots. Weather conditions like rainfall, T_{max}, T_{min}, and relative humidity during November to April were 23.7 mm, 27.0°C, 7.3°C and 72.5% during 2008-2009 and 21.6 mm, 28.2°C, 10.9°C and 61.6% during 2009-2010 respectively prevailed over the location during the crop growing period. There were eleven treatment combinations related to sources (five) and three levels of P including one control (P₀) which were in main plots and three modes of P application were in sub-plots. Phosphorus was applied at the rate of 0, 60 and 120 kg P₂O₅ ha⁻¹ through nitrophosphate (20% N + 20% P₂O₅), single superphosphate (16% P₂O₅), diammonium phosphate (18% N + 46% P₂O₅), urea ammonium phosphate (28% N + 28% P₂O₅) and rock phosphate which is mineral acid soluble (20% P₂O₅) introduced later on in *rabi* 1978-1979. There were three modes of P application, that is, M₁ – applied to *kharif* crop only (Pearl millet – *Pennisetum typhoides*), M₂ – to *rabi* crop only (wheat – *Triticum aestivum*) and M₃ – to both *kharif* and *rabi* crops.

Nitrogen at 150 kg ha⁻¹ through urea after compensating the N added through the N containing phosphatic fertilizers and Potassium at 60 kg K₂O ha⁻¹ through muriate of potash (MOP) and 25 kg ZnSO₄·7H₂O ha⁻¹ were applied as basal dose. All the P, K, Zn and half of N were applied at the time of sowing of wheat and remaining half of N was top dressed at the time of first irrigation after 21 days of sowing. Wheat variety UP-2338 was sown. The crop was harvested at the time of maturity. Threshing was done plot-wise and yields of grains and straw were recorded. Initial physico-chemical properties of the experimental soil and P content in grains and straw were analyzed by following the standard procedures as outlined by Jackson (1973).

The data were analyzed statistically by applying the analysis of

variance (ANOVA) technique as suggested by Cochran and Cox (1950). The critical differences were obtained at 5% level of significance as described by Panse and Sukhatme (1961). Analysed data of the aforesaid experimental trial was also pooled for the consecutive two years, that is, 2009 and 2010 and presented using statistical software SPSS 16.0.

RESULTS AND DISCUSSION

Soil properties

The soil of the field at the start of the experiment was calcareous, sandy loam having pH 8.2 using Beckman pH meter, EC 0.67 dSm⁻¹, organic carbon 0.34% (Walkley and Black's rapid titration method), CaCO₃ 1.7% (Puri's method), CEC 9.1 cmol(p⁺)kg⁻¹ as outlined by Jackson (1973), alkaline hydrolysable N-173 kg ha⁻¹ and Olsen's available P-13.2 kg ha⁻¹. The soil of the field before sowing of wheat crop in 2009-2010 was calcareous, sandy loam in texture having pH 7.6, EC 0.49 dSm⁻¹, organic carbon 0.39%, CaCO₃ 1.9%, CEC 12.4 cmol(p⁺)kg⁻¹, available N 196 kg ha⁻¹ and available P 19.4 kg ha⁻¹. It was observed that pH of the soil decreased from 8.2 to 7.6 and available P status of the soil increased from 13.2 to 38.8 kg ha⁻¹ with the application of P for 40 years where highest dose of P (120 kg P₂O₅ ha⁻¹) was applied. However, the CaCO₃, organic carbon, CEC, available N increased and EC slightly decreased. Available P content of the soil decreased from its original level of 13.2 to 4.8 kg ha⁻¹ where no P was added over the last 40 years. Similar trend of the depletion of available P in soil after continuous cultivation was also reported by Ma et al. (2009).

Grain and straw yield

Grain yield of wheat increased, irrespective of sources, levels and modes with P application over control except in case of RP (Table 1). However, the grain yield of wheat was obtained relatively lower than the previous years due to late sowing of wheat. Highest grain yield of 27.5 and 29.3 q ha⁻¹ were obtained at 60 and 120 kg P₂O₅ ha⁻¹, respectively, when P was applied in both seasons through SSP. On an average, SSP produced maximum grain yield which was followed by Diammonium phosphate (DAP), urea ammonium phosphate (UAP), nitrophosphate and Phosphate rock (RP). However, except RP there was no significant difference among these sources but all these sources were highly superior over RP. In case of RP the grain yield was even lower than control (14.4 q ha⁻¹). Singh et al. (1982) also reported that RP itself could fix a significant amount of soluble P. On the basis of adsorption isotherm drawn, they also reported that 1.0 g RP could fix 28.0 mg P. Mehdi et al. (2003) reported that SSP, DAP, TSP and nitrophosphate applied at the rate of

Table 1. Effect of sources, levels and modes of P application on grain and straw yield (q ha⁻¹) of wheat.

Treatment	Modes						Mean	
	Direct		Residual		Cumulative			
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control	14.40	29.67						
RP-60	12.15	26.37	9.87	24.20	12.91	28.81	11.64	26.46
RP-120	13.34	26.51	11.05	24.48	13.95	28.95	12.78	26.65
Mean	12.75	26.44	10.46	24.34	13.43	28.88	12.21	26.55
N Phos-60	24.42	44.92	22.66	39.29	25.65	46.42	24.24	43.54
N Phos-120	25.52	48.04	23.54	44.68	27.31	50.48	25.46	47.73
Mean	24.97	46.48	23.10	41.98	26.48	48.45	24.85	45.64
SSP-60	24.99	46.37	22.98	42.75	27.50	48.33	25.16	45.82
SSP-120	27.32	52.73	24.51	44.32	29.30	54.34	27.04	50.46
Mean	26.15	49.55	23.74	43.53	28.40	51.33	26.10	48.14
DAP-60	24.36	44.76	22.87	42.38	26.10	46.23	24.44	44.46
DAP-120	26.44	49.89	24.04	43.77	28.05	52.74	26.18	48.80
Mean	25.40	47.32	23.45	43.07	27.08	49.48	25.31	46.63
UAP-60	24.18	44.85	21.67	39.30	25.93	47.43	23.93	43.86
UAP-120	26.42	47.34	23.63	43.26	27.79	50.86	25.95	47.15
Mean	25.30	46.09	22.65	41.28	26.86	49.14	24.93	45.50
Overall mean	22.91	43.18	20.68	38.84	24.45	45.46	22.68	42.49

C.D. (0.05): Grain yield: Sources-1.81, Levels-1.15 and Modes-0.84; Straw yield: Sources 3.32, Levels 2.10 and Modes 1.27.

110 kg P₂O₅ ha⁻¹ along with recommended N and K doses significantly improved grain and straw yield of wheat.

Application of phosphatic fertilizers invariably increased the grain yield with higher P levels over the lower levels as well as control (Table 1). The increase over control was approximately 7.5 and 8.9 q ha⁻¹ with the application of 60 and 120 kg P₂O₅ ha⁻¹, respectively. The earlier observations of Meelu et al. (1977) and Chaudhary et al. (1979) from the same experiment indicated superiority of water soluble sources (SSP, DAP and UAP) over nitrophosphate of 30% water soluble P in calcareous soils of Haryana, at lower levels of P application but at higher levels, that is, 120 kg P₂O₅ ha⁻¹ the differences were non-significant. But in the present case, effectiveness of nitrophosphate was at par with water soluble sources because of comparable available P in soils which is supported by the data of the present investigation on available P status of soil under the influence of different phosphatic fertilizers (Saha et al., 2013). However, SSP was superior to all other sources when applied both at 60 and 120 kg P₂O₅ ha⁻¹.

As regards the effect of different modes of P application, grain yield was significantly higher under cumulative mode of application than that on alternate fertilization in *rabi* or *khariif* season except in case of RP (Table 1). On an average, the highest grain yield of wheat was observed with SSP applied at the rate 120 kg P₂O₅

ha⁻¹ under cumulative mode (29.3 q ha⁻¹) and the lowest was in case of RP at the rate 60 kg P₂O₅ ha⁻¹ under residual mode (9.87 q ha⁻¹).

Straw yield of wheat followed almost similar trend as grain yield with respect to different P fertilizers, modes and levels of P application (Table 1). Highest straw yield of 54.34 q ha⁻¹ was recorded with 120 kg P₂O₅ ha⁻¹ applied through SSP in cumulative mode and lowest yield of 24.20 q ha⁻¹ was recorded with 60 kg P₂O₅ ha⁻¹ applied through RP in residual mode. Water soluble sources were definitely superior to RP. All the water soluble sources were found to be at par but significantly superior than RP. In case of RP, the straw yield of wheat was even lower than that of control. This behavior of RP on yield performance of crop has already been explained.

P uptake

Results revealed that all the P sources increased total P uptake by wheat over control and RP. The total P uptake was maximum with water soluble sources (SSP, DAP and UAP) followed by partially water soluble nitrophosphate and the least effective was insoluble RP (Table 2). The trend of yield with respect to P sources also reflected in the total P uptake by wheat. Such a trend might be explained on the basis of availability of P and solubility of fertilizer in the soil system. Highly water

Table 2. Effect of different phosphatic fertilizers, their levels and modes of application on P uptake (kg ha^{-1}) by wheat.

Treatment	Modes			Mean
	Direct	Residual	Cumulative	
Control	4.17			
RP-60	4.71	3.83	5.99	4.84
RP-120	5.63	4.63	6.91	5.72
Mean	5.17	4.23	6.45	5.28
N Phos-60	9.24	8.12	10.26	9.21
N Phos-120	10.34	9.07	12.79	10.73
Mean	9.79	8.59	11.53	9.97
SSP-60	10.08	8.66	12.70	10.48
SSP-120	11.98	9.88	15.20	12.35
Mean	11.03	9.27	13.95	11.42
DAP-60	9.83	8.28	12.25	10.12
DAP-120	12.39	9.87	14.29	12.18
Mean	11.11	9.08	13.28	11.15
UAP-60	10.32	8.64	12.73	10.56
UAP-120	12.07	10.11	14.30	12.16
Mean	11.20	9.38	13.52	11.36
Overall mean	9.66	8.11	11.74	9.84

C.D. (0.05): Sources-0.64, Levels-0.40 and Modes-0.50.

soluble P sources added continuously on long-term basis to maintain available P levels in the soil system are able to maintain effective concentration of P in soil solution which might ultimately lead to its uptake by plants. In case of RP (water insoluble source) such concentration in soil solution phase might not be expected and hence very low uptake by the crop. The maximum total P uptake was recorded in case of SSP which was followed by UAP, DAP, nitrophosphate and RP. Sulphur containing P source SSP was found significantly superior over nitrophosphate and RP, but remained at par with UAP and DAP. Dhillon and Dev (1993) reported that increasing level of P through single super phosphate increased P uptake significantly. It is evident from the results that in calcareous sandy loam soil, the effectiveness of phosphatic fertilizers decreased with decrease in their water soluble P content. Rishi and Goswami (1977) also reported increased plant utilization of added P by wheat with increasing water solubility. All these sources of phosphatic fertilizers resulted into highly significant total P retained in Ca-P fraction which contributed negatively towards yield and total P uptake. This is further conformed from multiple regression equations presented in Table 4.

Increasing P levels significantly increased total P uptake by wheat. The increase of 4.9 and 6.5 kg ha^{-1} P uptake was observed with the application of 60 and 120 $\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$ phosphatic fertilizers, respectively, over

control. These results are in conformity with the results obtained by Setia and Sharma (2007). Cumulative mode (11.74 kg ha^{-1}) of P application was significantly superior over direct (9.66 kg ha^{-1}) or residual mode (8.11 kg ha^{-1}) of P application in increasing P uptake by wheat. The maximum uptake was recorded at 120 $\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$ level with SSP application in cumulative mode (15.20 kg ha^{-1}) and the minimum at 60 $\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$ when RP was applied in residual mode (3.83 kg ha^{-1}). The residual effects of P fertilizers on total P uptake by wheat were also reported by Ryan et al. (2008).

Correlation between P fractions and yield attributing characters

All the inorganic P fractions in soil were significantly correlated with grain and straw yield, P concentration in grain and straw and total P uptake by wheat crop. The values of coefficients of correlations (r) are presented in Table 3. The available P, saloid P and Al-P were positively and significantly correlated with grain yield ($r = 0.829^{**}$ to 0.894^{**}), straw yield ($r = 0.833^{**}$ to 0.890^{**}), P concentration in grain ($r = 0.666^*$ to 0.749^*), and total P uptake ($r = 0.860^{**}$ to 0.928^{**}) by wheat. All these inorganic P fractions except Al-P did not show significant relationship with P concentration in straw. This might be because of dilution effect and translocation of P from

Table 3. Coefficients of correlation (r) between P fractions and yield attributing characters.

P Fraction	Grain yield	Straw yield	Grain P	Straw P	P uptake
Available P	0.894**	0.890**	0.749*	0.494	0.928**
Saloid-P	0.829**	0.833**	0.666*	0.479	0.860**
Al-P	0.861**	0.880**	0.680*	0.648*	0.925**
Fe-P	0.392	0.383	0.755*	0.498	0.510
Ca-P	-0.405	-0.399	0.279	0.061	-0.300

**,* Significance at 1 and 5% level, respectively.

Table 4. Relative contribution of inorganic P fractions to the yield and P uptake by wheat.

Plant parameter	Regression equation	R ²
Grain yield (q ha ⁻¹) =	17.482 + 2.260** X ₁ - 0.043 X ₂ - 0.004 X ₃ - 0.075** X ₄	0.98**
Straw yield (q ha ⁻¹) =	25.906 + 3.135** X ₁ + 0.199 X ₂ - 0.026 X ₃ - 0.108** X ₄	0.98**
P uptake (kg ha ⁻¹) =	-4.284 + 0.399 X ₁ + 0.320* X ₂ + 0.078 X ₃ - 0.026** X ₄	0.97**

Where, X₁ = Saloid P (mg kg⁻¹), X₂ = Al-P (mg kg⁻¹), X₃ = Fe-P (mg kg⁻¹), X₄ = Ca-P (mg kg⁻¹) and R²=Coefficient of determination; **, * Significance at 1 and 5% level, respectively.

straw to grain during grain formation stage. Calcium-P, on the other hand, was negatively correlated with grain and straw yield and P uptake, but the relationship in this regard was non-significant. As it is a calcareous soil, and there was more Ca-Phosphate formation that would lead to negative relationship with P uptake. The results are in conformity with the findings of Vig et al. (2000) and Setia and Sharma (2007). Patil et al. (1995) reported that the Al-P fraction was the most important for the wheat yield and total phosphorus uptake. The saloid-P and Al-P fractions seemed to be important as these correlated significantly with Olsen's available P and various yield and phosphorus uptake parameters in calcareous soils. Sharma and Verma (2000) and Takahashi and Anwar (2007) also reported that among different P fractions, Fe-P and Al-P were the most important P fractions contributing to phosphorus nutrition of rice and wheat grown in a sequence.

Relative contribution of inorganic P fractions to the yield and P uptake

On the basis of regression equation in case of grain yield, it is noted that contribution of saloid-P was positive and significant but Ca-P had a significantly negative effect. The coefficient of determination (R²= 0.98**) for this equation was significant meaning thereby that more than 98% variation in grain yield could be accounted by this regression equation. Similarly, contribution by saloid-P was significant and positive, whereas that of Ca-P was significantly negative towards straw yield (Table 4). The equation for straw was also significant (R²= 0.98**) showing its applicability in 98% cases. Multiple

regression equation between total P uptake by wheat and various inorganic P fractions of soil was found highly significant (R²= 0.97**). However, there was low significant contribution of individual fractions. The significant coefficient of determination, thus indicated collective contribution of all these fractions, positive and significant being in case of saloid-P and Al-P and significantly negative due to Ca-P. Thus, saloid P mainly contributed towards P uptake by wheat and Ca-P gave the negative effect. Sharma and Verma (2000) also studied similar regression equations and concluded that among different P fractions, Fe-P and Al-P were the most important P fractions contributing to phosphorus uptake by wheat.

Conclusion

All the water soluble sources were significantly superior to water insoluble source (RP). Effectiveness of nitrophosphate reached statistically at par with water soluble phosphatic fertilizers after 40 years of P fertilization. With increasing levels of P from 60 kg P₂O₅ ha⁻¹ to 120 kg P₂O₅ ha⁻¹, grain yield and phosphorus uptake increased significantly. Cumulative mode of P application resulted into significantly higher N, P and K uptake by wheat. The available P, saloid-P and Al-P were positively and significantly correlated with grain yield, straw yield, P concentration in grain and total P uptake by wheat. Multiple regression equations between yield and P uptake and various inorganic P fractions of soil indicated that saloid-P and Al-P were the important forms of inorganic P and contributed mainly towards grain and straw yield and total P uptake by wheat. Highly significant

values for coefficient of determination ($R^2= 0.97^{**}$ to 0.98^{**}) for yield and P uptake indicated that validity of multiple regression equation in more than 90% cases.

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