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Research Paper

Effect of phosphorus levels and sources on productivity, nutrient uptake and soil fertility of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted for two years (2006-07 and 2007-08) at New Delhi during the *kharif* and *rabi* seasons on sandy loam soil to assess the effect of single super phosphate and rock phosphate with different levels of phosphorus and biofertilizer on maize (*Zea mays* L.)–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol} cropping system. The results revealed with application of 90 kg P_2O_5/ha through single super phosphate and biofertilizers, maize recorded higher mean yield attributes, grain yield, straw yield, and N and P uptake over no phosphorus, 90 kg P_2O_5/ha through rock phosphate and 45 kg P_2O_5/ha through single super phosphate or rock phosphate and no inoculation. Residual effect of 90 kg P_2O_5/ha through single super phosphate or 90 kg P_2O_5/ha through rock phosphate applied to maize being on par, recorded higher mean yield attributes, grain yield (4.29 t/ha), straw yield, and N and P uptake in wheat over lower levels of phosphorus irrespective of sources. Direct application of phosphorus to wheat up to 90 kg P_2O_5/ha enhanced the mean yield attributes, grain yield (4.04 t/ha) and N and P uptake. Application of biofertilizer recorded higher yield attributes, yield (grain and straw) and N and P uptake in wheat crop over no biofertilizer. Phosphorus balance in soil increased with increase in P fertilization to the system.

Key words : Biofertilizers, Maize, Rock phosphate, Single super phosphate, Wheat

In any maize–wheat based cropping system, both the crops in sequence require liberal supply of P for exploiting their yield potential. In India, most of the soils are either deficient or marginal in P status. Among the different inorganic P sources, single super phosphate (SSP) is widely used as phosphatic fertilizer. Currently P fertilizer is very expensive as they are being totally imported. Therefore, there is a need to find out eco-friendly, feasible and cheaper options to meet the P needs of the crops grown in cropping system. With the discovery of several deposits of rock phosphate in the country, interest in the use of this material as an alternative source of phosphatic fertilizer has increased greatly. In view of the above, it was thought appropriate to test some of the locally available P sources like rock phosphate along with commonly used source single super phosphate. Since solubility of rock phosphate is relatively low as compared to single super phosphate, use of P solubilizing bacteria (PSB) and arbuscular mycorrhiza (AM) are useful in enhancing the availability of native as well as applied P to the crops.

Based on part of Ph.D. Thesis of first author submitted to IARI, New Delhi during 2009.

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MATERIALS AND METHODS

A field experiment was carried out at Division of Agronomy, Indian Agricultural Research Institute, New Delhi during rainy and winter seasons of 2006-07 and 2007-08. The soil was sandy loam with pH 8.1, 7.7 (1:2.5 soil to water), organic carbon 0.40, 0.42%, available N 123.9, 124.2 kg/ha and available P 12.9, 13.5 kg/ha at the start of the experiment in 0–30 cm soil layer during 2006-07 and 2007-08, respectively. The total rainfall received during the experimental period was 629.5 mm in 2006-07 and 527.6 mm in 2007-08. In maize crop, treatments were laid out in split plot design replicated thrice. In main plots, five combination of sources (SSP and RP) and levels (0, 45, 90 kg P_2O_5/ha) of phosphorus were applied. In maize crop, main plots were divided into two sub-plots to apply two treatments of biofertilizers *viz.* B_0 (control) and B_1 (AM + PSB). The sub-plots of maize crop were further divided into 3 sub-sub plots during *rabi* season to apply 3 levels of phosphorus *viz.*, control, 45 kg P_2O_5/ha and 90 kg P_2O_5/ha. Thus, the trial was laid out in split-split plot design in wheat. The recommended dose of 120 kg N/ha to maize was applied in three equal splits as basal, knee heigh and tasselling stages. In wheat, 120 kg N/ha, was applied in two splits, half at sowing and the remaining half at first irrigation at 21 days coinciding with crown root initiation (CRI stage). Variable doses of phosphorus, as per treatments (0, 45, 90 kg P_2O_5/ha) in the form of either single super phosphate or rock phosphate were applied and mixed with the soil at the time of sowing. Since single super phosphate, wherever required along with muriate of potash (60 kg K_2O/ha) were placed 3–5 cm below the seed with the help of metallic tube attached with plough. Phosphate solubilizing bacterial culture containing inoculum of *Pseudomonas striata* Chester and arbuscular mycorrhiza culture named 'Nutrilink' were used in maize crop. Maize was sown on second week of July and harvested in third week of October in both the years. Wheat crop was sown after maize on 3rd week of November. Maize 'Pratap' and wehat 'PBW-343' were sown at 60 and 22.5 cm interrows spacing respectively. In maize, plant to plant spacing of 20 cm was maintained after gap filling and final thinning. Other management practices were adopted as per recommendations of the crops under irrigated conditions.

RESULTS AND DISCUSSION

Yield and yield attributes

Effect of P on maize

Phosphorus application had significant influence on yield attributes *viz.*, number of cobs, number of grains/cob and test weight over no phosphorus (Table 1). Application of 90 kg P_2O_5/ha through SSP recorded significantly higher number of cobs/ha over no phosphorus, 90 kg P_2O_5/ha through RP and 45 kg P_2O_5/ha through SSP or RP. Further 90 kg P_2O_5/ha through RP, being on par, recorded significantly more number of cobs, number of grains/cob and test weight over no phosphorus and 45 kg P_2O_5 /ha through RP. All the phosphorus treatments were statistically at par with each other and recorded significantly more number of grains/cob over control. Phosphorus applied to maize failed to produce significant variation in test weight. The higher value for yield attributes were due to the effect on root development, energy transformation and metabolic processes of plant and resulted in more translocation of photosynthates towards the sink development.

Significant improvement in grain yield of maize was recorded due to phosphorus application (Table 2). In both the years, 90 kg P_2O_5/ha through SSP recorded significantly higher yield over no phosphorus and 90 kg P_2O_5/ha through RP and 45 kg P_2O_5/ha through SSP or RP. Application of 90 kg P_2O_5/ha through RP being at par with 45 kg P_2O_5/ha through SSP registered higher grain yield over no phosphorus and 45 kg P_2O_5/ha through RP. Thus, the increase in grain yield due to phosphorus was directly related to the vegetative and reproductive phases of the crop and attributes complex phenomenon of phosphorus utilization in plant metabolism. It also helped in the efficient absorption and utilization of the other required plant nutrients which ultimately increased the grain yield. The similar results and observations were also reported by Singaram and Kothandaraman (1991)

The inoculation with PSB and AM enhanced the yield attributes (number of cobs/ha, number of grains/cob and test weight), grain yield of maize to a level of significance as compared to non-inoculation. The increase in grain production was obviously due to biofertilizer inoculation, which resulted in increased availability of phosphorus (Table 1 and 2).

Residual effect of P on wheat

In wheat, residual effect of phosphorus applied to maize in respect of spikes/m^2, number of grains/spike and test weight was noticed in all the P treatments over control (Table 1). Application of 90 kg P_2O_5/ha through SSP to preceding maize recorded higher number of spikes/m^2 and number of grains/spike in wheat but remained at par with 90 kg P_2O_5/ha through RP. Phosphorus applied to maize failed to produce significant variation in test weight of wheat crop. Likewise, grain yield were increased in wheat crop with the application of 90 kg P_2O_5/ha through SSP being at par with 90 kg P_2O_5/ha through RP applied to preceding maize (Table 2). All these favourable effects were due to better supply of P from residual P derived from the fertilization of the preceding maize crop. Response of wheat to carry over effect of P applied to the preceding crop have also been reported earlier by Shivran *et al*. (2000) and Singh and Ahlawat (2006).

Application of biofertilizers (AM + PSB) had also beneficial effect on yield attributing characters (number of spikes/m^2, grains/spike and test weight) and grain yield as compared to no biofertilizer (Table 1 and 2). It thus seems plausible that AM plant roots could efficiently absorb solubilized P over a period of time and that the increase could be equivalent to that observed from addition of phosphatic fertilizers (Kucey *et al*., 1989).

Direct effect P on wheat

The application of phosphorus to wheat had a significant effect on yield attributes *viz.*, spikes/m^2, grains/spike and test weight and yield (Table 1 and 2). Application of phosphorus both at 45 and 90 kg P_2O_5/ha to wheat improved yield attributes and grain yield over no phosphorus. This might be possibly due to continued and balanced supply of nutrients enhancing their availability for the active involvement in shoot and root growth, which finally translated into higher yield attributes and yield of wheat. The similar responses have also been documented by Singh

Table 1. Effect of treatments on yield attributes of maize and wheat crop

Treatment	Maize						Wheat					
	No. of cobs ($\times10^3$ /ha)		No. of grains/cob		Test weight (g)		No. of spikes/m^2		Grains/spike		Test weight (g)	
	2006	2007	2006	2007	2006	2007	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
P to maize												
Control	53.1	52.9	250	245	205.4	206.1	280.1	286.2	39.2	40.1	39.0	39.9
45 through SSP	72.1	71.8	288	290	217.1	214.9	302.1	304.1	41.3	43.2	40.9	40.8
90 through SSP	79.3	77.9	295	296	218.1	219.6	325.1	327.1	44.9	46.9	42.2	42.8
45 through RP	65.6	62.7	287	288	216.1	215.8	295.1	298.1	40.7	41.4	40.0	40.0
90 through RP	72.3	70.0	292	293	217.9	218.8	319.1	324.2	44.4	45.3	40.4	41.1
SEm ±	1.7	1.7	7.6	7.6	5.5	5.7	6.7	6.9	0.9	0.9	0.9	0.9
CD (P=0.05)	5.8	5.7	24.7	24.8	NS	NS	21.7	22.5	3.0	3.1	NS	NS
Biofertilizer												
No biofertilizer	65.2	64.4	269.8	271.1	204.3	206.4	297.6	301.8	41.2	42.5	39.5	39.8
AM + PSB	71.8	69.8	295.0	293.7	225.5	223.6	311.1	314.1	42.9	44.2	41.4	42.0
SEm±	0.7	1.0	3.8	4.3	2.5	3.3	4.0	3.7	0.5	0.5	0.5	0.5
CD (P=0.05)	2.2	3.3	11.9	13.5	7.8	10.5	12.8	11.8	1.6	1.7	1.7	1.6
P to wheat												
0							291.3	295.0	40.3	41.6	38.9	39.2
45							304.2	308.1	42.1	43.4	40.7	40.9
90							317.4	320.8	43.9	45.2	42.1	42.7
SEm±							3.5	3.9	0.5	0.5	0.4	0.4
CD (P=0.05)							9.9	11.0	1.5	1.6	1.2	1.3

SSP=single super phosphate; RP=rock phosphate

Table 2. Effect of treatment on grain yield (t/ha), net returns (₹/ha) and B:C ratio of maize and wheat crop

Treatment	Maize						Wheat					
	Grain yield (t/ha)		Net returns		B:C ratio		Grain yield (t/ha)		Net returns		B:C ratio	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
P to maize												
Control	2.99	2.42	7,616	4,599	0.69	0.49	3.44	3.52	24,173	24,739	1.80	1.77
45 through SSP	4.49	3.88	15,101	14,429	1.23	1.13	3.72	3.79	27,182	38,195	2.02	2.75
90 through SSP	5.08	4.47	17,492	17,105	1.30	1.21	4.23	4.35	32,729	41,351	2.43	2.98
45 through RP	4.13	3.50	13,835	12,736	1.22	1.08	3.64	3.71	26,278	38,789	1.95	2.43
90 through RP	4.58	4.02	16,252	15,868	1.40	1.30	4.17	4.26	32,039	40,075	2.38	2.88
SEm±	0.11	0.10					0.08	0.08				
CD (P=0.05)	0.35	0.32					0.27	0.28				
Biofertilizer												
No biofertilizer	3.98	3.35	12,363	11,129	1.03	0.89	3.76	3.85	25,909	30,989	1.94	2.23
VAM+PSB	4.56	3.97	15,756	15,166	1.30	1.20	3.92	4.00	29,320	38,719	2.18	2.79
SEm±	0.06	0.05					0.04	0.04				
CD (P=0.05)	0.18	0.14					0.14	0.15				
P to wheat												
0							3.68	3.76	27,958	32,328	1.96	2.53
45							3.84	3.93	28,498	36,001	2.11	2.59
90							4.00	4.09	28,992	38,561	2.27	2.57
SEm±							0.04	0.05				
CD (P=0.05)							0.13	0.19				

and Rai (2002).

Nutrient uptake

In both the years, application of 90 kg P_2O_5/ha through SSP recorded increased N and P uptake in maize over no phosphorus, 90 kg P_2O_5/ha through RP and 45 kg P_2O_5/ha through SSP or RP (Table 3). This could be attributed to the fact that added phosphorus increased N and P concentration in grain and stover by providing balanced nutritional environment inside the plant and higher photosynthetic efficiency, which favoured growth and crop yield. The increased N and P uptake with phosphorus fertilization are in line with those of Jat and Ahlawat (2001).

The biofertilizer inoculation also enhanced the N and P uptake in maize and wheat as compared to uninoculated plot during both the years. This could be possible due to higher biomass production as well as due to more plant accessible phosphate made available by solubilization (by PSB) and mobilization (by AM) from native and applied phosphorus. Similar results and views were also shared by Mala and Thongchai (1995).

N and P uptake by wheat increased due to application of phosphorus to preceding maize at 90 kg P_2O_5/ha irrespective of sources (Table 3). It indicated a beneficial residual effect of P applied to preceding maize at higher level of 90 kg P_2O_5/ha. As a major portion of the P applied to maize was left behind for use by the succeeding crop, it created a balanced nutritional environment inside the plant leading to higher photosynthetic efficiency favourably plant growth and crop yield. These results are in line with those of Modak *et al*. (1994).

Phosphorus applied to wheat at 45 and 90 kg P_2O_5/ha had a significant influence on N and P uptake by wheat. As examined earlier, the increased concentration of N and P in grain and straw of wheat through continuous and balanced nutrition of crop resulted in higher crop yield and consequently higher N and P uptake.

Phosphorus status in soil

All the phosphorus receiving treatment recorded a positive change in available phosphorus status of soil. It was observed that the status of soil available P after maize markedly improved with the increase in applied phosphorus to maize crop in both the seasons (Table 4). 90 kg P_2O_5/ha through SSP recorded significantly higher soil available P after maize over no phosphorus, 90 kg P_2O_5/ha through RP and 45 kg P_2O_5/ha through SSP and RP. Negative balance of phosphorus was observed in control plot only.

It was observed that soil available P after wheat improved significantly with successive increase in rate of applied phosphorus within each source of P to maize. Application of 90 kg P_2O_5/ha through SSP or RP, being on par, recorded higher soil available P after wheat over no phosphorus and lower levels of phosphorus irrespective of sources in both the years of study. Application of

Table 3. Effect of treatments on total N and P uptake (kg/ha) by maize and wheat crop

Treatment	Maize				Wheat			
	N uptake		P uptake		N uptake		P uptake	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
P to maize								
Control	67.1	54.6	16.9	13.2	75.0	77.8	13.0	13.5
45 through SSP	106.3	93.9	32.9	30.3	82.0	85.5	14.6	15.4
90 through SSP	124.4	112.3	44.6	39.8	97.0	102.7	18.1	19.0
45 through RP	95.0	82.1	28.4	25.5	79.3	82.0	14.0	14.6
90 through RP	108.5	97.6	34.2	31.5	92.4	99.2	16.5	17.9
SEm±	3.0	1.6	0.5	0.6	3.6	3.7	0.6	0.6
CD (P=0.05)	9.9	5.4	1.6	2.1	11.7	12.1	2.0	2.1
Biofertilizer								
No biofertilizer	87.6	76.3	28.1	24.9	82.0	86.1	14.6	15.5
AM+PSB	112.9	99.9	34.7	31.2	88.3	92.7	15.9	16.7
SEm±	1.9	1.3	0.4	0.3	1.9	1.9	0.3	0.3
CD (P=0.05)	6.0	4.3	1.3	1.1	6.0	6.2	1.1	1.1
P to wheat								
0	-	-	-	-	78.0	81.9	14.0	14.7
45	-	-	-	-	85.2	89.5	15.3	16.1
90	-	-	-	-	92.2	96.9	16.5	17.6
SEm±	-	-	-	-	2.1	2.2	0.3	0.3
CD (P=0.05)	-	-	-	-	6.2	6.4	1.0	1.0

SSP = single super phosphate; RP = rock phosphate

Table 4. Direct and residual effect of phosphorus on net change (net gain/loss) in available phosphorus status (kg P/ha) in soil

Treatment	After Maize				After Wheat			
	Available phosphorus (kg P/ha)		Net change		Available phosphorus (kg P/ha)		Net change	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
P to maize								
Control	12.15	12.30	-0.75	-1.2	12.12	12.24	-0.78	-1.24
45 through SSP	17.95	18.12	+5.05	+4.62	16.55	16.92	+3.65	+3.42
90 through SSP	20.82	21.75	+7.92	+8.25	17.93	18.27	+5.03	+4.47
45 through RP	16.31	17.33	+3.41	+3.83	16.38	16.01	+3.48	+2.51
90 through RP	18.05	19.85	+5.15	+6.35	17.11	17.77	+4.21	+4.27
SEm±	0.45	0.49			0.30	0.30		
CD (P=0.05)	1.48	1.60			0.96	0.98		
Biofertilizer								
No biofertilizer	16.37	17.16	+3.47	+3.66	15.70	15.93	+2.80	+2.43
AM+ PSB	17.74	18.58	+4.84	+5.08	16.34	16.58	+3.44	+3.08
SEm±	0.27	0.28			0.17	0.17		
CD (P=0.05)	0.85	0.87			0.54	0.55		
P to wheat								
0					12.04	13.41	-0.86	-0.09
45					17.12	16.26	+4.22	+2.76
90					18.89	19.10	+5.99	+5.60
SEm±					0.21	0.14		
CD (P=0.05)					0.59	0.41		

Initial available P (2006-07)–12.90 kg/ha; Initial available P (2007-08)–13.50 kg/ha

biofertilizer had also effect on available phosphorus after maize and wheat crop in both the years as compared to no biofertilizer. Application of phosphorus to wheat had favourable effect on available P after crop harvest during both the years. The highest net positive change was observed with 90 kg P_2O_5/ha over no phosphorus and 45 kg P_2O_5/ha. All this could be explained in terms of poor phosphorus utilization. Moreover, since the excessive dose of fertilizer P does not result in to luxury consumption, naturally the unutilized portion goes into soil system and becomes unavailable fraction of soil phosphorus mainly because of its inherent chemical nature of fast fixation in the soil. Similar results were observed by Singh and Ahlawat (2007).

Economics

In maize, the highest net returns was recorded with 90 kg P_2O_5-/ha through SSP and with biofertilizer in both the years (Table 2). This could be attributed to higher yields with these treatments. B:C ratio was the highest in 90 kg P_2O_5-/ha through RP with biofertilizer in both the years. The involvement of low cost inputs like RP and biofertilizer along with the greater compatibility between these two sources have made this treatment economically most viable. Thus, it suggested that use of phosphatic biofertilizers can bring economic saving also. The net returns and B: C ratio in wheat increased when preceding maize received 90 kg P_2O_5/ha through SSP, which was followed by 90 kg P_2O_5/ha through RP, 45 kg P_2O_5/ha, through SSP, 45 kg P_2O_5/ha through RP and no phosphorus in 2006-07 and 2007-08, respectively. This could be ascribed to the fact that substantial fraction of P applied to maize was utilized by succeeding wheat crop, resulting increased yield of wheat, which consequently reflected in net return accrued from wheat crop. Application of biofertilizer fetched the higher net returns and B:C ratio over no biofertilizer during both the years. Wheat receiving 90 kg P_2O_5/ha in both the years fetched the highest net returns (₹28,992 and ₹38,561) and B:C ratio (2.27 and 2.57) over no phosphorus and 45 kg P_2O_5/ha.

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