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Phosphorus management in field pea (*Pisum sativum*) ˘rice (*Oryza sativa*) cropping system under temperate conditions

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ABSTRACT

A field study conducted during 2005–07 at Sapore, Jammu and Kashmir revealed that application of single super phosphate (SSP) and inoculation of phosphate-solubilizing bacteria (PSB) recorded highest nodulation, yield attributes and yield, net returns, B:C ratio, protein content, N, P uptake and available-soil P than that of DAP and arbuscular mycorrhizal fungi (AMF). Inoculation of PSB increased grain yield (1.70 tonnes/ha) of field pea by 6.92% over AMF (1.59 tonnes/ha). Application of 100% P as basal (M_1) being at par with 50% P as basal + 50% P as top dressing (TD) at branching initiation (BI) stage (M_3) recorded significantly higher yield attributes, yield, protein content, N, P uptake and available-soil P over 100% P as TD at BI (M_2) and 50% P as basal + 25% P as TD at BI + 25% P as TD at before flowering (BF) stage (M_4) and enhanced seed yield by 30.4 and 8.4% respectively. Rice grain yield and P uptake was significantly improved with the residual effect of SSP and DAP over control but SSP had significantly higher residual effect over DAP. Inoculation of AMF in field pea showed apparent residual effect over PSB. Method M_1 and M_3 showed highest direct and residual effect on available-soil P which was 22.5, 19.8, 15.7 and 13.5% higher over M_2, respectively.

Key words: Available-soil P, Pea-rice sequence, P sources, Solubilizers, Uptake, Yield

Rice (*Oryza sativa* L.) is the most important and extensively growing crop in entire Kashmir valley during rainy (*kharif*) season but due to prolonged severe low temperate in entire valley, rice–wheat cropping system is not feasible. At this situation, farmers are generally used sarson–rice, oat (fodder)–rice and pea–rice sequence during winter season. The nutrient-use efficiency especially for phosphorous is the major concern in winter season crop due to prolong winter (*rabi*) season. Pea (*Pisum sativum*) is grown as vegetable as well as field crop in large area of Kashmir valley in winter season and phosphorus, a key nutrient which improves nitrogen fixation, quality and quantity of legumes and rice (Baired *et al.* 2010) but due to several constraints, viz prices of phosphatic fertilizers are increasing day-by-day, lack of supply of fertilizers at proper time and soil properties which restricts the application of full dose of phosphorus at proper time. Under such situations, marginal farmers are not able to utilize full recommended dose of P fertilizers at the time of sowing (Verma *et al*. 2002). Phosphatic fertilizers are well known to have a carry-over effect on the succeeding crops due to utilization efficiency of applied phosphatic fertilizers seldom exceeds to 15% by the first crop and a substantial amount of P is left as residue for the next crop. Studies on legume-based cropping system in temperate conditions have shown that utilization efficiency of applied P fertilizers is low due to long spell of winter season. The basal application of P is recommended in all the crops including field pea and rice in Jammu and Kashmir but due to severe temperate conditions, crops come under dormant stage for three months immediately after germination. So under dormant stage, most of the P applied as basal is converted into fixed P which is not available to the existing crop but available to the succeeding crops as residual effect. A lot of research works have been conducted on inoculation of phosphate-solubilizing microorganism (PSM) with many crops which increased the availability of phosphorus in tropical condition (Thakuria *et al.* 2008 and Ding *et al.* 2012) but little information is available in temperate conditions. Application of low and high grade P fertilizers like single super phosphate (SSP) and diammonium phosphate (DAP) with different mode of application and P solubilizers is not carried out in field pea–rice sequence in temperate conditions. Therefore, split application of P fertilizers accompany phosphate-solubilizing micro-organisms may be one of the best alternatives for improving P fertilizers-use efficiency in

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Table 1 Effect of P sources, solubilizers and methods of application on nodulation, yield, uptake and fertilizers-use efficiency of field pea (pooled data of two years)

Treatment	Nodules/plant at flowering		Yield (tonnes/ha)		Protein content (%)	Protein yield (kg/ha)	Total N uptake (kg/ha)	Total P uptake (kg/ha)	Available P after field pea harvest	AE (kg grain/kg P applied)	RE (%) (kg/ha)
	Numbers	Dry weight (mg)	Grain	Stover							
P. sources											
SSP	48.9	115.5	1.67	2.69	21.6	361.9	68.8	6.2	16.9	24.8	11.7
DAP	46.3	112.8	1.62	2.63	21.2	342.9	67.0	5.9	16.7	22.5	10.8
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS		
P solubilizers											
PSB	48.9	116.5	1.70	2.74	22.0	375.2	70.4	6.2	17.4	26.1	11.7
AMF	46.2	111.7	1.59	2.57	20.8	329.0	65.4	5.8	16.2	21.1	10.3
CD (*P*=0.05)	2.38	4.12	0.09	0.14	0.99	31.09	3.31	0.28	1.02		
Methods of P application											
M_1-100% basal	49.7	116.9	1.80	2.88	22.3	393.6	72.4	6.5	18.0	30.7	13.5
M_2-100% TD at BI	43.9	109.9	1.38	2.29	19.8	273.1	62.2	5.1	14.7	11.5	6.9
M_3-50% basal + 50% TP at BI	48.7	115.3	1.74	2.79	22.3	382.5	69.6	6.3	17.6	28.0	12.2
M_4-50% basal + 25% TD at BI +25% TD at BF	47.9	114.4	1.66	2.69	21.5	359.1	67.4	6.0	16.8	24.3	11.1
CD (*P* = 0.05)	2.16	3.87	0.09	0.13	0.94	30.01	3.23	0.24	0.87		
Control vs others											
Control	38.8	91.0	1.13	1.88	18.1	204.8	56.6	3.6	13.6		
Others	47.6	114.1	1.65	2.66	21.4	352.1	67.9	5.6	16.8	23.9	9.4
CD (*P* = 0.05)	3.32	5.46	0.12	0.18	1.29	40.65	4.38	0.32	1.28		
Initial P									14.2		

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temperate conditions. An attempt was therefore made to evaluate different sources, solubilizers and methods of P application on direct and residual effect on field pea–rice cropping sequence.

MATERIALS AND METHODS

A field experiment was conducted at Faculty of Agriculture, SKUAST-K, Wadura, Sopore, Jammu and Kashmir under temperate conditions during 2005–07. The soil was silty-clay loam, neutral in reaction (*p*H 7.1) having organic C 0.89%, available N 282 kg/ha, available P 14.2 kg/ha and available K 215 kg/ha. The two P sources, viz SSP and DAP, two P solubilizers, viz *Pseudomonas striata* (PSB) and arbuscular mycorrhizal fungi (AMF) and four methods of P application, viz 100% P as basal (M_1), 100% P as top dressing (TD) at branching initiation (BI) stage (M_2), 50% P as basal + 50% P as TD at BI (M_3) and 50% P as basal + 25% P as TD at BI + 25% P as TD at before flowering (BF) stage (M_4). One absolute control was also maintained, thereby forming 17 treatment combinations, were laid out in randomized block design with three replications.

Field pea cultivar Rachna was sown on 2 and 7 October, 2005 and 2006 and harvested on 2 and 6 May, 2006 and 2007 respectively. After harvesting of field pea, rice cultivar Shalimar rice 1 was sown on 15 and 19 June, 2006 and 2007 and harvested on 26 and 30 September, 2006 and 2007 respectively. Rice was grown on residual fertility (without fertilizers application) in the undisturbed plots of different sources, solubilizers and methods of P fertilizers applied to field pea. A uniform recommended dose of N and K @ 20 and 40 kg/ha, respectively was applied to field pea in the form of urea (after deduction of N content in DAP treated plots) and muriate of potash as basal. Phosphorus was applied @ 21.8 kg P/ha as per treatment with single super phosphate granule (SSP) and diammonium phosphate (DAP). Gypsum was applied in DAP treated plot to compensate the sulphure and calcium effect in SSP. Pea seeds were inoculated as per standard procedure with charcoal-based inoculants of *P. striata* (PSB) and *Rhizobium leguminosarum* (bv. v*iceae*) @ 500 g/ha and soil: sand-based AMF culture @ 2 kg/ha. The grains and stover/straw of field pea and rice were analyzed for N and P concentration following standard procedure. Soil samples (0-15 cm) were collected after harvest of the each crop and analyzed for available-soil P as per standard methods. Agronomical efficiency (AE) and apparent recovery efficiency (RE) of added fertilizer P were calculated as:

$$\text{AE (kg grains/kg P applied)} = \frac{\text{Grain yield in P fertilized plot–grain yield in control plot}}{\text{Quantity of fertilized P applied}} \times 100$$

$$\text{RE (\%)} = \frac{\text{Total P uptake in P fertilized plot–total P in control plot}}{\text{Quantity of fertilized P applied}} \times 100$$

RESULTS AND DISCUSSION

Direct effect on field pea

Number and dry weight of nodules improved significantly with the application of P sources, solubilizers and methods of application over control (Table 1). Application of SSP remain at par with DAP in respect of nodules/plant and dry weight of nodules. Inoculation of *P. striata* recorded significantly higher nodules/plant and dry weight of nodules over AMF might be due to *P. striata* (PSB) has more synergistic effect with *Rhizobium* association than AMF which accelerate the proliferation and development of nodules in pea (Singh and Srivastava 2007). Basal application of P fertilizers (M_1) had significant effect on nodule formation over M_2, being at par with M_3. The maximum nodulation were recorded with 100% P as basal (M_1) could be attributed to increased availability of P at initial stage of root development which improve the nodule initiation, multiplication and proliferation. However, method M_1 and M_2 being at par with each other in respect of nodulation at flowering which might be due to continued supply of P due to splitting of P which have favourable effect on continuous nodule formation and development (Agarwal *et al*. 2007).

Application of sources, solubilizers and methods of P application significantly affected grain and stover yield of field pea over control (Table 1). Inoculation of PSB observed significantly higher yield and yield attributes of field pea over AMF but application of SSP was at par with DAP. Inoculation of *P. striata* increased grain yield of field pea in the tune of 6.92% over AMF inoculation. The higher value for yield attributes may be due to the effect of P on root development, energy transformation and metabolic processes of plant, which resulted in greater translocation of photosynthates towards the sink development due to higher activity of phosphate-solubilizing bacteria increased very rapidly with rising of temperature which solubilize more phosphorous over AMF (Agarwal *et al*. 2007). Application of 100% P as basal (M_1) significantly enhanced grain and stover yield of field pea over M_2 and M_4 but remained at par with method M_3. The mode of P application responded in the order: $M_1 > M_3 > M_4 > M_2$. This might be due to split application of P at right stage and place (50% P as basal + 50% P as TD at BI) reduced the P fixation and improved P-use efficiency. However, later application of P had little effect on plant growth and development owing to lack of starter dose of P which affect root proliferation and development resultant restricted the nutrient uptake (Rautaray *et al*. 2008).

Protein content, protein yield and N uptake were recorded significantly higher over control. However, application of SSP and DAP was at par to each other (Table 2). The increase in protein content and N uptake might be due to application of adequate amount of phosphorous which stimulated the activity of nitrogenase enzyme which accelerates the biological N_2 fixation resultant increase in concentration and uptake of N (Ding *et al*. 2012). The increase in P uptake, available-soil P, agronomic efficiency and apparent recovery efficiency by SSP and DAP over control owing to proper supply of P in SSP and DAP treated plot (Agarwal *et al.* 2007). Inoculation of PSB significantly improved protein content, uptake, available-soil P, AE and RE over AMF inoculation might be due to higher activity of phosphate-solubilizing bacteria which accelerate their activity very rapidly in the organic rich soil after increasing of temperature but in case of AMF inoculation their root colonization activity was slow and required some times for infectivity. Application of 100% P as basal (M_1) recorded significantly higher protein content, protein yield, N, P uptake, available-soil P, AE and RE of field pea over M_2 and M_4 methods but remained at par with M_3. Application of 100% P as basal (M_1) and M_3 recorded an increase of 22.5 and 19.8% available-soil P over M_2 respectively. The maximum P uptake, available-soil P, AE and RE due to 100% P applied as basal (M_1) and least with 100% TD at BI stage (M_2) might be attributed to its relatively immobile characters in soil and accumulation on soil surface due to top dressing which remained beyond the reach of lower root system (Majumdar *et al*. 2007).

Residual effect on rice

Application of SSP and DAP to field pea had significant residual effect on growth and development of rice over control. The residual effect of SSP was significantly pronounced and increased grain yield by 9.8% over DAP (Table 3). The improved soil-P status following field pea crop fertilized with SSP and DAP resulted in increased effective tillers, grain and straw yield of the succeeding rice crop. The increase in these parameters might be due to greater biological N fixation and rhizosphere benefits of legume inclusion in the cropping system, besides better P availability (Rautaray 2008). Inoculation of P solubilizers also had significant residual effect on growth, yield attributes, straw and grain yield of rice over control. Similar findings were also reported by Thakuria *et al.* (2008). Inoculation of field pea with PSB and AMF increased grain yield of rice by 15.6 and 21.2% over control. However, residual effect of AMF was more pronounced than that of PSB. This might be due to the fact that AMF produced zygospores and clamydospores are re-germinate after getting suitable atmosphere and liable to work well under submerged condition, whereas phosphate-solubilizing bacteria (*P. striata)* are less resistance to submerged condition which improved availability of P over PSB (Maiti *et al*. 2011). Among the methods of P application, the residual effect of 100% P applied as TD at BI (M_2) recorded significantly higher yield and yield attributes of rice over M_1 and M_3 remained at par with M_4 (Table 3). Application of P to the field pea through different methods, viz M_1, M_2, M_3 and M_4 registered 9.2,

Table 2 Residual effect of P sources, solubilizers and methods of application on yield, P balance and fertilizers-use efficiency of rice under field pea–rice sequence (pooled data of two years)

Treatment	Yield (tonnes/ha) Straw	Yield (tonnes/ha) Grain	Total P uptake (kg/ha)	Available P after rice (kg/ha)	AE (kg grain/kg P) field pea–rice sequence	RE (%) field pea–rice sequence	Net gain (+) or loss (–) after field pea–rice sequence (kg/ha)
P sources							
SSP	5.55	4.04	17.1	14.3	60.6	20.2	1.6
DAP	5.31	3.68	16.5	14.3	41.7	16.1	0.7
CD (*P*=0.05)	NS	0.18	0.67	NS			
P solubilizers							
PSB	5.23	3.77	16.5	14.2	49.5	17.4	0.9
AMF	5.63	3.95	17.2	14.4	52.8	18.8	1.4
CD (*P*=0.05)	0.26	0.18	0.67	NS			
Methods of P application							
M_1-100% basal	4.83	3.56	16.1	15.4	44.5	17.0	2.0
M_2-100% TD at BI	6.07	4.20	17.5	13.3	54.6	17.0	–0.1
M_3-50% basal + 50% TP at BI	4.99	3.61	16.5	15.1	44.0	18.9	1.9
M_4-50% basal + 25% TD at BI +25% TD at BF	5.84	4.07	17.3	13.4	61.5	20.2	0.7
CD (*P*=0.05)	0.32	0.20	0.62	0.61			
Control vs others							
Control	4.36	3.26	15.3	12.2			
Others	5.43	3.86	16.8	14.3	51.8	16.06	0.7
CD (*P*=0.05)	0.38	0.28	0.85	0.69			

Table 3 Direct and residual effect of various treatments on economic evaluation under field pea–rice cropping sequence

Treatment	Direct effect on field pea			Residual effect on rice			Cumulative effect on field pea–rice cropping sequence			
	Cost of cultivation (₹ /ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
P sources										
SSP	16 569	27 230	10 661	20 000	25 803	5 803	36 569	53 033	16 464	1.45
DAP	17 831	26 425	8 594	20 000	23 631	3 631	37 831	50 056	12 225	1.32
P solubilizers										
PSB	15 020	27 720	12 700	20 000	24 104	4 104	35 060	51 824	16 804	1.48
AMF	15 050	25 930	10 880	20 000	25 330	5 330	35 100	51 260	16 210	1.46
Methods of P application										
M_1-100% basal	17 200	29 340	12 140	20 000	22 707	2 707	37 200	52 047	14 847	1.40
M_2-100% TD at BI	17 200	22 535	5 335	20 000	26 975	6 975	37 200	49 510	12 310	1.33
M_3-50% basal + 50% TP at BI	17 200	28 365	11 165	20 000	23 072	3 072	37 200	51 437	14 237	1.38
M_4-50% basal + 25% TD at BI +25% TD at BF	17 200	27 075	9 875	20 000	26 119	6 119	37 200	53 194	15 994	1.43
Control vs others										
Control	15 270	18 455	3 185	20 000	20 762	762	35 270	39 217	3 947	1.11
Others	15 000	26 905	11 905	20 000	24 717	4 717	35 000	51 622	16 622	1.47

28.8, 10.7 and 24.8% higher grain yield of rice over control, respectively. However, method M_2 enhanced grain yield by 17.9% over 100% P applied as basal (M_1). This attributed to more efficient utilization of fixed amount of P by increasing plant density of rice when root system come into direct contact with fixed amount of P in soil with preceding crop of field pea (Verma *et al.* 2002).

Residual effect of single super phosphate recorded significantly more P uptake and apparent P recovery over DAP owing to substantially higher concentration of P in grain and straw as well as greater grain and straw yield of rice (Table 3). Inoculation of field pea with AMF also had significant residual effect on enhancement of P uptake and apparent P recovery of rice than that of PSB. This could be attributed to the fact that AM fungal spores lying in the soil cause infection whenever obtained proper temperature and moisture, spread fungal hyphae covering bulk volume of soil that have high content of un-diffused P which diffused the fixed P by AMF hyphae (increased absorbing surface) towards deficient zone created around rhizosphere of rice (Baired *et al*. 2010). Among the methods of P application, M_2 being at par with M_4 significantly recorded higher P uptake over M_1 and M_3. This might be due to high crop density of rice that covers larger surface area by roots and enhanced utilization of unavailable form of P efficiently thus increased yield attributes, straw and grain yield and resulted in enhanced P uptake (Singh and Verma 2006). Application of 100% P as basal (M_1) and 50% P as basal + 50% P as top-dressing at branching initiation (M_3) showed highest residual effect on available-soil P which was 15.7 and 13.5% higher over M_2 and 8.4 and 6.4% over initial level of available-soil P after completion of field pea–rice sequence, respectively. Application of 100% P as top dressing at BI stage (M_2) recorded lowest available-soil P being decreased 6.3% over initial level of available-soil P might be due to higher P uptake by rice which resulted in decreased available-soil P after rice. Application of P through SSP and AMF inoculation showed highest gain of P over DAP and PSB. The highest net gain of P was recorded in M_1, followed by M_3 after completion of field pea-rice sequence. Agronomic efficiency (AE) and apparent recovery efficiency (AE) recorded highest with residual effect of SSP and AMF inoculation over DAP and PSB after field pea–rice sequence, respectively. Method M_4 recorded highest AE (61.5 kg/kg) and RE (20.2%), followed by M_2 after field pea–rice sequence indicated that split and delayed application of P fertilizers could be beneficial in legume-based cropping sequence whereas method M_1 and M_3 profitable for single cropping.

Economics

Direct and residual effect of sources, solubilizers and methods of P application had more pronounced effect on net returns (₹ 16 622/ha) and B: C ratio (1.47) over control (Table 3). Cumulative net returns (₹ 16 464/ha) and B: C ratio (1.45) was higher due to application of SSP than DAP whereas inoculation of PSB had similar effect like AMF inoculation on net returns and B: C ratio. Application of 50% P as basal + 25% TD at BI + 25% TD at BF (M_4) markedly enhanced net returns (₹ 15 994/ha) and B:C ratio (1.43) followed by 100% P as basal (M_1) due to residual effect of P applied in field pea.

It is concluded that higher productivity, net returns, soil fertility and phosphorus-use efficiency of field pea and its residual effect on rice could achieved with the application of 100% P as basal or 50% P as basal + 50% P as top-dressing at branching initiation stage through single super phosphate (SSP) and inoculation of phosphate-solubilizing microorganisms in temperate conditions of Kashmir valley.

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