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Effect of phosphorus fertilization and microbial inoculants on yield, phosphorus use-efficiency and available phosphorus in maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted between 2012-14 to investigate the effect of different phosphorus levels (control-no P, 33% P, 50% P, 100% P and 100% P in 3-splits of the recommended dose of P) and microbial inoculants (un-inoculated control, arbuscular mycorrhizal fungi, AM phosphate solubilising bacteria, PSB and AM+PSB) in maize-wheat system. The study revealed that the maize and wheat grain yields were increased by 20% and 40%, respectively, under 100% P which were significantly higher over control. The total P uptake by maize and wheat varies from 11.7–20.7 kg/ha and 17.7–32.4 kg/ha, respectively. The highest apparent recovery (AR) in both the crops was recorded when 50% P was added with AM+PSB inoculation whereas, a significant reduction in AR was recorded with increase in fertilizer P beyond 50% of recommended P. Agronomic efficiency was highest under 50% P averaged across microbial inoculants in both maize (32.5 kg grain/kg P) and wheat (78.5 kg grain/kg P). Grain yield of both maize and wheat was significantly and positively correlated with Olsen P content at tasseling (r = 0.30*) and panicle emergence (r = 0.35**). The higher P use-efficiency under 50% recommended P along with microbial inoculants suggests applying lower doses of P fertilizer along with microbial inoculants to achieve optimum yield in maize-wheat system without any adverse impact on soil fertility.

Key words: Apparent recovery, Maize-wheat system, Microbial inoculants, Phosphorus use-efficiency

Phosphorus (P), plays many important roles in cell division and development, photosynthesis, breakdown of sugars, energy and nutrient transfer the plant, and gene expression. It is one of the most immobile, inaccessible and unavailable nutrients, and its deficiency is one of the yield limiting factors. Most soils contain large reserves of total P, but their low solubility causes P deficiency. The available form of P in soil solution is only a little fraction of total P (Lungmuana *et al.* 2012). This suggests the importance of maintaining its sufficient quantities in the soil solution through P fertilizers to achieve maximum production (Sharma *et al.* 2011; Meena *et al.* 2017). When water soluble P fertilizers are added to the soil, P reacts rapidly with different soil components and becomes unavailable to plants by conversion into less soluble inorganic P fractions through fixation and retention (Sanyal and de Datta, 1991) which reduces the P use-efficiency (PUE) and causes significant economic loss. The low use efficiencies of applied P (15-20%) pose a major challenge for sustainable agriculture which leaves room for improvement PUE by using several strategies (Dwivedi *et al.* 2017).

Diverse group of bacteria and fungi available in soil are involved in P solubilization through which insoluble forms of P get converted into soluble form (Sharma *et al.* 2012). *Pseudomonas*, *Bacillus, Rhizobium, Enterobacter, Aspergillus* and *Penicillium* are reported to be efficient in P solubilization (Whitelaw 2000) through organic acid production, enzyme secretion, chelation and ion-exchange reactions. Mycorrhizae, known as prominent P mobilizers, facilitate mobilization of soluble P from distant places in soil where plant roots cannot reach, and could be used to improve PUE in agricultural ecosystems (Brahmaprakash and Sahu 2012). Keeping in mind the importance of P fertilization and microbial inoculants uptake pattern and improving PUE, the present study was undertaken to examine the combined effect of P fertilization and microbial inoculations on yield and P use-efficiency under maize-wheat cropping system.

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MATERIALS AND METHODS

The experiment was conducted at ICAR-Indian Agricultural Research Institute Research Farm for two years (2012-14). The experimental soil was sandy loam (Typic Haplustept), alkaline (pH 8.5), non-saline (EC 0.19 dS/m), low in organic carbon (0.42%) and medium in available P (12.4 kg/ha) content. Twenty treatments combinations comprising five P fertilizer levels (No P, 33% P, 50% P, 100% P, 100% P in 3-splits of the recommended dose) as main plot and four microbial inoculations (un-inoculated control, arbuscular mycorrhizal fungi, phosphate solubilizing bacteria, AM+PSB) as sub-plot were evaluated in a split-plot design, and replicated thrice. Soil test-based recommended dose of NPK (120-26-33 kg/ha) for both maize and wheat, were applied through urea, diammonium phosphate and muriate of potash, respectively. Fertilizer N and K were applied uniformly to all the plots, whereas P was applied as per treatments. Full dose of P (except 100% P in 3-splits) and K was applied as basal at the time of sowing. N and P (100% in 3-splits) were applied in 3 equal splits at sowing, V4 and V8 stage in maize, and sowing, tillering and panicle emergence stage in wheat. For microbial inoculation, AM culture (25 kg/ha) was applied in furrows at the time of sowing. Seeds were treated with PSB culture, and dried in shade before sowing in the respective treatments. Maize (*cv.* PEEHM 5) and wheat (*cv.* HD 2967) were grown in sequence in a gross plot size of 6 × 5 m, and a net plot of 5 × 3 m was harvested for measuring yield that was converted to t/ha using necessary factor.

Soil samples were collected from rhizosphere (0-15 cm) at tasseling and harvest stage of maize, at and panicle emergence and harvesting in wheat. After processing, samples were analysed for soil $pH_{1:2}$ (Jackson, 1973). Available P (Olsen P) was extracted using 0.5 M $NaHCO_3$ (pH 8.5) according to Olsen *et al*. (1954). The representative plant samples (grain and straw) collected from each plot during the second crop cycle were processed as per standard procedures. The processed plant samples were digested in a di-acid mixture (HNO_3: $HClO_4$ in ratio of 4:1) and total P in the digested extracts was determined colorimetrically by vanadomolybdo-phosphate yellow color method. Phosphorus uptake, apparent recovery (AR) and agronomic efficiency (AE) were computed as:

$$\text{P Uptake} = \text{yield} \times \text{P content (\%)} \times 10$$

$$\text{Agronomic Efficiency (AE)} = \frac{\text{Grain yield under P} - \text{Grain yield under no P}}{\text{Rate of P application}}$$

$$\text{Apparent Recovery (AR)} = \frac{\text{Total P uptake under P} - \text{Total P uptake under no P}}{\text{Rate of P application}}$$

where, P uptake is in kg/ha, AR is in %, AE is in kg grain/kg P, Yield is in t/ha and rate of P application in kg/ha.

The field and laboratory data were analyzed statistically as per standard procedures of split-plot design using SAS Version 9.2.

RESULTS AND DISCUSSION

Grain and straw yield

Maize: Grain and straw yield of both maize and wheat crops (Table 1) revealed a significant positive effect due to different P levels. Increasing P levels increased both grain and straw yield of maize and wheat significantly. The yield gain with 100% recommended P was higher by 0.60 t/ha or 20% compared with no P control (3.37 t/ha). Nziguheba *et al.* (2002) reported that the addition of P fertilizers even at a low rate (10 kg P/ha) increased maize yields slightly while yield doubled with addition of 25 kg P/ha or more compared to no P. Inoculation with AM+PSB or PSB alone resulted in improvement in grain yield to the extent of 11 to 14% over un-inoculated control. However, use of AM alone as inoculants was not significant in improving grain yield. Sial *et al.* (2018) also reported that inoculation with PSB alone produced a similar yield to that of 25 kg P_2O_5/ha. The effects of main- and sub-plot treatments on straw yield were similar to grain yield, though the magnitude of increase was relatively less. The average increase in straw yield with 100% P fertilizer over no-P was 10%, however, inoculation with AM+PSB over un-inoculated control was 5.3% only. Similar result was reported by Fletcher *et al.* (2006) where sweet corn yield increased from 9.7 t/ha with no P to 15.9 t/ha with 200 kg P/ha. Patil *et al.* (2012) showed that maize seed inoculated with P solubilizing fungi along with different P levels also significantly influenced dry matter production, grain yield and total P uptake at harvest. Higher growth and yield were achieved with inoculations of P-solubilizing

Table 1 Effect of P fertilization and microbial inoculants on grain and straw yield (t/ha) of maize and wheat

Treatment	Maize		Wheat	
	Grain	Straw	Grain	Straw
*Phosphorus levels**				
No P	3.37	4.00	4.00	5.26
33% P	3.53	4.18	4.30	5.50
50% P	3.79	4.36	5.01	6.24
100% P	3.91	4.40	5.25	6.29
100% P (3-splits)	3.92	4.37	5.24	6.31
LSD (p = 0.05)	0.14	0.10	0.30	0.25
Microbial inoculants				
Control	3.55	4.15	4.46	5.66
AM	3.60	4.22	4.62	5.74
PSB	3.95	4.13	4.84	6.04
AM+PSB	4.06	4.37	5.11	6.25
LSD (p=0.05)	0.16	0.18	0.31	0.27
M×P	NS	NS	NS	NS
P×M	NS	NS	NS	NS

*100% P indicates 26 kg P/ha, AM-Arbuscular mycorrhiza; PSB-Phosphate solubilizing bacteria; M×P=M at same P, P×M=P at same M fungi along with 100% recommended P compared to 50% recommended P alone. Inoculation along with P-fertilizer gave 20-23% higher maize yield over control.

Wheat: From the data given in Table 1 it is observed that the grain and straw yield of wheat under different P fertilizer levels and microbial inoculants was more as compared to maize. With increasing fertilizer P levels to 33%, 50% and 100% of recommended rate wheat grain yield increased by 10, 30 and 40%, respectively, over control (no P). Split application of P fertilizer could not bring further increase in grain yield. A significant increase in wheat grain yield with the application of P over no P on a calcareous sandy loam soil was reported by Saha *et al.* (2014). Singh *et al*. (2009) also reported that P application rates significantly influenced the yield of maize and wheat. Among microbial inoculation options, highest increase in grain yield (20%) was recorded under AM+PSB over control, but the difference between AM+PSB and PSB were not statistically significant. Almost similar trend was observed in enhancing straw yield under different treatments, and the magnitude of such increase was 19.6% due to 100% P over no P and 10.4% due to AM+PSB over un-inoculated control. Inoculation with AM alone failed to give a significantl increase the grain or straw yields over control. The interaction between P fertilizer levels and microbial inoculants was not significant. Sharma *et al.* (2011) reported that the dry matter production increased from 0.42 to 0.59 t/ha, 2.67 to 3.37 t/ha, and 8.56 to 9.51 t/ha at tillering, ear emergence, and harvest respectively in case of wheat seed inoculated with *Aspergillus.* Dual inoculation with PSB and AM resulted in higher grain and straw yields than the inoculation with single organisms suggesting the synergistic effect of solubilizers and mobilizers. Inoculating with both PSB and AM further improved P uptake as compared to inoculation with either PSB or AM alone. The significance of PSB in enhancing straw and biological yield of wheat was also reported by Agrawal and Pathak (2010).

Phosphorus uptake

The P uptake by both grain and straw of maize with application of different levels of P fertilizer and microbial inoculants is given in Table 2. Increasing levels of P fertilizer and use of microbial inoculants significantly and progressively increased the P uptake. Across P application levels, average enhancement in P uptake with microbial inoculants varied from 12% with AM to as high as 41% with AM+PSB. Similarly increase in grain P uptake due to fertilizer P ranged from 11 to 33% across microbial inoculants. The interaction between P levels and microbial inoculants was found significant, where P uptake due to P levels was lowest under un-inoculated control, and maximum under AM+PSB. Phosphorus uptake in maize straw was much less than that of P uptake by grain and varied from 3.08 kg/ha (no-P uninoculated control) to 4.95 kg/ha (50% P with AM+PSB). Though P uptake increased significantly with combined use of P and microbial inoculants, but split application of P did not show any effect on grain and straw P uptake. Total P uptake ranged between 11.7 kg/ha (no P un-inoculated control) and 20.6 kg/ha (100% P 3-splits with AM+PSB inoculation). There was no significant difference in total P uptake by crops between 50% P with AM+PSB and 100% P with AM+PSB. This corroborated the findings of Shafiq and Tahir (2015) where the use of AM and PSB in combination with different P levels enhanced plant P uptake over control. Data also showed a significant ($P<0.05$) interaction between P fertilizer levels and microbial inoculation treatments as compared to un-inoculated control. The significance of seed inoculation with P solubilizing fungi along with different P levels in increasing total P uptake was also reported by Patil *et al.* (2012). Singh and Reddy (2012) reported that P uptake by maize grain was significantly higher under rock phosphate amended soil inoculated with *Aspergillus* spp. compared to non-amended soils while the greatest increase was observed in rock phosphate added plots.

Results also revealed that the P uptake by wheat grain varied from 11.1 (control) to 16.6 kg P/ha (100% P) and by straw it ranged from 8.7 (control) to 11.4 kg P/ha (100% P-3 splits) (Table 3). But, it was at par with 50% of recommended P, and thereafter no significant change was noticed. Sharma *et al.* (2012) has also reported an increase in grain P uptake by 38.2, 62.1, and 71.2% and straw by 47.2, 84.4, and 93.8% with increasing levels of 30, 60, and

Table 2 Effect of P fertilization and microbial inoculants on P uptake (kg/ha) by maize

Phosphorus rates	Grain					Straw				
	Microbial inoculants				Mean	Microbial inoculants				Mean
	Control	AM	PSB	AM + PSB		Control	AM	PSB	AM + PSB	
No P	8.6	9.4	10.4	11.4	10.0	3.08	4.23	3.94	3.96	3.80
33% P	9.4	10.2	11.5	13.2	11.1	3.28	4.42	4.29	4.86	4.21
50% P	10.1	11.8	13.1	15.4	12.6	3.80	4.91	4.86	4.95	4.63
100% P	11.3	12.0	14.0	14.6	13.0	3.94	4.97	4.81	4.86	4.65
100% P (3-splits)	10.7	12.3	14.2	15.8	13.3	3.53	4.23	4.82	4.85	4.36
Mean	10.0	11.2	12.7	14.1		3.53	4.55	4.59	4.85	
LSD (P= 0.05)	P	M	M×P	P×M		P	M	M×P	P×M	
	1.39	0.87	1.94	2.17		0.29	0.21	0.48	0.51	

90 kg P_2O_5/ ha, respectively. Among microbial inoculants, the performance in increasing P uptake was in the order: AM+PSB>PSB>AM which indicated that use of AM+PSB had a better effect on mobilization and solubilization of native and applied P in the soil leading to increased absorption of P by plant roots. Phosphorus uptake by wheat grain was significantly increased under the application of P over control, same has also been reported by Saha *et al.* (2014) where the total P uptake by wheat inoculated with *Aspergillus* spp. was 21.1% higher over un-inoculated seeds. Ademoseye *et al.* (2009) reported that supplementing 75% of the recommended fertilizer rate with inoculants produced higher yield and P uptake which was statistically equivalent to the full fertilizer rate without inoculants.

Phosphorus use-efficiency

Phosphorus use-efficiency is computed as apparent recovery (AR) and agronomic efficiency (AE). The AR of P fertilizer ranged from 9.8 to 38.3% in maize and 15.9 to 45.8% in wheat with different P levels and microbial inoculants (Table 4). Highest apparent recovery was recorded under 50% P with AM+PSB inoculation in both maize and wheat crops. This may be due to solubilization and mobilization of native and applied P by AM and PSB, thus resulting in higher P uptake by both crops. With increase in P fertilizer levels beyond 50% of recommended P, there was significant decrease in AR in both maize and wheat. It shows that low rate of P application resulted in a relatively higher P recovery and agronomic efficiency compared to higher dose of P application which is similar to the findings of Kumawat *et al*. (2018). Sundara *et al.* (2002) also reported that PSB used in conjunction with P fertilizers reduced the required dose of P by 25%. The agronomic efficiency (AE) followed a similar trend as AR and ranged from 15.0 to 34.6 kg grain/kg P in maize, and 25.4 to 84.6 kg grain/kg P in wheat with different treatment combinations (Table 5). The highest AE of both maize and wheat was 32.5 and 78.5 kg grain/kg P applied, respectively, with 50% recommended P across microbial inoculation. When microbial inoculants compared at same P levels, the agronomic efficiency (AE) was 24.1, 20.3 and 23.9 kg grain/kg P in maize and 54.7, 51.8 and 49.2 kg grain/kg P in wheat under AM, PSB and AM+PSB, respectively. The study suggested that application of microbial inoculants could help in enhancing the AR but not AE of P. Aulakh and Pasricha (1999) reported an increase in AR of P from 17 to 32% and 39 to 44% by groundnut and mustard, respectively, but AE increased to 70% (by two crops grown in a rotation) when groundnut was grown on left over fertilizer P in soil from the preceding mustard in an irrigated groundnut-mustard rotation. Kumawat *et al.* (2018) also reported that 50% of recommended dose of P with AM+PSB gave the highest total P uptake (26.6), apparent recovery (28.2%) and agronomic efficiency (51.2 kg grain/kg P) in maize.

Table 3 Effect of P fertilization and microbial inoculants on P uptake (kg/ha) by wheat

Phosphorus rates	Grain					Straw				
	Microbial inoculants				Mean	Microbial inoculants				Mean
	Control	AM	PSB	AM + PSB		Control	AM	PSB	AM + PSB	
No P	10.3	11.4	12.7	14.1	12.1	7.37	8.06	9.22	10.2	8.7
33% P	11.3	12.3	14.2	15.3	13.3	7.83	8.54	9.69	11.0	9.3
50% P	12.9	14.0	15.1	18.2	15.0	8.87	10.3	12.0	12.7	11.0
100% P	13.8	15.1	18.7	18.9	16.6	9.15	10.5	11.4	13.1	11.0
100% P (3-splits)	14.6	15.5	16.8	18.7	16.4	9.86	10.5	11.5	13.7	11.4
Mean	12.6	13.7	15.5	17.0		8.6	9.6	10.8	12.1	
LSD (P= 0.05)	P	M	M×P	P×M		P	M	M×P	P×M	
	1.58	1.75	NS	NS		1.04	1.16	NS	NS	

Table 4 Effect of P fertilization and microbial inoculants on apparent recovery (%) in maize and wheat

Phosphorus rates	Maize					Wheat				
	Microbial inoculants				Mean	Microbial inoculants				Mean
	Control	AM	PSB	AM + PSB		Control	AM	PSB	AM + PSB	
33% P	11.1	10.6	17.5	30.2	17.4	17.4	15.9	22.8	26.3	20.6
50% P	16.5	23.2	28.3	38.3	26.6	27.3	31.6	39.5	45.8	36.1
100% P	13.8	14.8	23.4	15.8	17.0	20.2	23.6	28.0	28.6	25.1
100% P (3-splits)	9.8	11.0	18.2	20.2	14.8	22.4	25.3	24.6	29.4	25.4
Mean	12.8	14.9	21.9	26.1		21.8	24.1	28.7	32.5	
LSD (P= 0.05)	P	M	M×P	P×M		P	M	M×P	P×M	
	1.17	0.76	1.51	1.75		0.93	1.58	3.16	2.89	

Available phosphorus

The available P (Olsen-P) at tasseling and harvesting stage of maize and panicle emergence and harvest stage of wheat under different treatments is shown in Fig 1. Olsen-P increased from 18.1 kg/ha in unamended soil to 24.7 kg/ha in 100% P. Across inoculation treatments at tasseling stage, it increased from 10.5 kg/ha in no P-control to 19.6 kg/ha with 100% P, the latter being at par with 100% P (3-splits) treatment at harvest. Dwivedi *et al.* (2004) also reported that regular P application resulted in a build-up of P in soil. Inoculation with AM+PSB improved the Olsen-P content by 20% at tasseling and by 16.9% at harvest over un-inoculated control, but inoculation with PSB or AM alone did not have significant effect at harvesting stage.

Both fertilizer P as well as microbial treatments enhanced Olsen-P in soil at panicle emergence stage of wheat and harvest. Phosphorous contents were higher at panicle emergence irrespective of treatments. The Olsen-P content was highest in 100% P which was at par with 100% P (3-splits). Lower doses of P application generally failed to increase Olsen-P content in soil, but application of 50% or 100% of recommended P brought significant change and increase P content at both stages. Lang *et al*. (2018) also reported that P addition increased Olsen-P by 4-6 times when P was applied at the rate of 44 kg/ha and by 10-20 times at 131 kg/ha. Split application of P was statistically at par with basal application of 100% P which suggested that split application of P does not have any advantage over full basal application. Among microbial inoculants, conjoint use of AM+PSB enhanced Olsen-P content in soil followed by PSB whereas inoculation with AM alone could bring significant improvement in Olsen-P at panicle emergence only. Sundara *et al.* (2002) also reported that PSB application increased the plant available P status in the soil. The Olsen-P observed at tasseling and panicle emergence stages was higher which could be due to the fact that rhizosphere soil had a slightly lower pH than most of the bulk soil, and the soil was biologically more active at this stage as compared to harvest when the rhizosphere effect ceased completely. Setia and Sharma (2007) also observed a decline in Olsen-P content with advancing growth of wheat till maturity. Jun *et al.* (2010) found a similar increase in Olsen-P where applications of P increased the levels of soil Olsen-P as compared to no P application, and PSB alone or in combination with AM improved P availability over un-inoculated control or AM alone. Yousefi *et al.* (2011) also observed greater amount of Olsen-P under AM+PSB inoculation than AM or PSB alone under same level of applied P. Addition of P fertilizer is known to enhance availability of P in the soil, which was apparent in present case despite high P demands of maize crop. PSB could be used to make use of the accumulated insoluble P compounds in soil thus the total dependence on chemical fertilizers could be reduced (Dwivedi *et al*. 2004, Kumawat *et al.* 2018). The microbial inoculation seems to have added to the P availability through solubilizing the otherwise sparingly soluble P forms as evident from P fractionation studies.

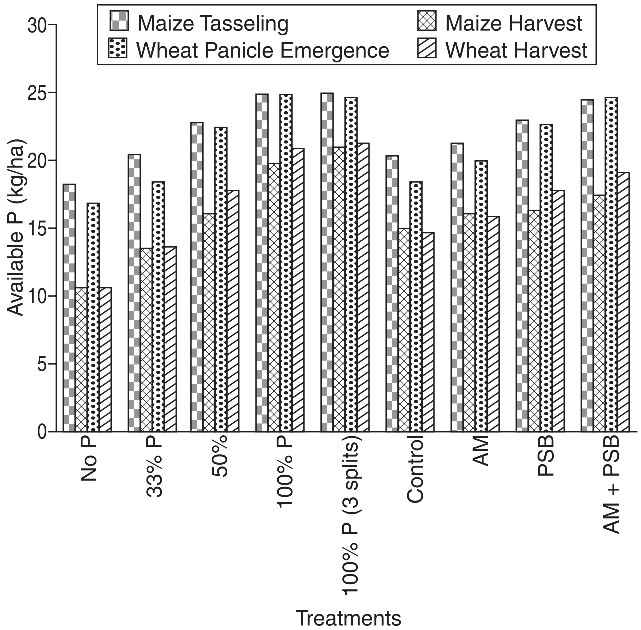

Fig 1 Effect of phosphorus fertilization and microbial inoculants on Olsen-P content (kg ha-1) at different stages in maize and wheat

Soil pH

The pH of rhizosphere soil at tasseling (maize), panicle emergence (wheat) and harvest (maize and wheat) declined

Table 5 Effect of P fertilization and microbial inoculants on agronomic efficiency of P (kg grain/kg P) in maize and wheat

Phosphorus rates	Maize					Wheat				
	Microbial inoculants				Mean	Microbial inoculants				Mean
	Control	AM	PSB	AM + PSB		Control	AM	PSB	AM + PSB	
33% P	19.6	17.3	15.0	21.9	18.5	42.7	33.4	38.1	25.4	34.9
50% P	31.5	33.9	30.0	34.6	32.5	72.3	78.5	78.5	84.6	78.5
100% P	23.1	22.3	17.7	20.4	20.9	47.7	53.8	46.5	44.2	48.0
100% P (3-splits)	25.0	23.1	18.5	18.9	21.3	51.9	53.1	44.2	42.3	47.9
Mean	24.8	24.1	20.3	23.9	24.8	53.6	54.7	51.8	49.2	53.6
LSD (P= 0.05)	P	M	M×P	P×M		P	M	M×P	P×M	
	1.01	0.36	0.72	1.18		2.02	2.10	4.20	4.15	

Table 6 Effect of P application and microbial inoculants on rhizosphere soil pH during different growth stages

Treatment	Maize		Wheat	
	Tasseling	Harvest	Panicle emergence	Harvest
Phosphorus rates				
No P	8.47	8.60	8.39	8.59
33% P	8.54	8.54	8.38	8.57
50% P	8.50	8.58	8.38	8.61
100% P*	8.51	8.58	8.39	8.59
100% P (3-splits)	8.52	8.58	8.37	8.58
LSD (P = 0.05)	NS	NS	NS	NS
Microbial inoculants				
Control	8.54	8.62	8.43	8.64
AM	8.51	8.59	8.43	8.61
PSB	8.49	8.55	8.35	8.57
AM+PSB	8.48	8.53	8.31	8.51
LSD (P = 0.05)	NS	0.05	0.06	0.08
M×P	NS	NS	NS	NS
P×M	NS	NS	NS	NS

consistently by 0.2 to 0.3 units under PSB and AM+PSB inoculation compared with uninoculated-control (Table 6). Although such small change in rhizosphere soil pH was not statistically significant, this may be due to the organic acids synthesized by PSB which results in acidification of the microbial cell and its surroundings (FNCA, 2006).

Relationship between Olsen-P soil and crop parameters

The grain yield of both maize and wheat was significantly ($P \leq 0.01$) and positively correlated with Olsen-P content at tasseling ($r=0.30^*$) and panicle emergence ($r=0.35^{**}$) (Table 7). Total P uptake, which played an important role in enhancing maize and wheat yield, was highly and positively correlated with Olsen-P at both tasseling and harvest stages, suggesting available P as an important criteria for total productivity of the cropping system.

Conclusion

From the study, it may be concluded that recommended dose of P fertilizer could be reduced by 50% with the use of AM+PSB or PSB alone in irrigated maize-wheat system on soils having medium P status. The study also provided a direct evidence of substantially higher apparent P recovery and agronomic efficiency under curtailed doses of fertilizer P along with microbial inoculants.

Table 7 Simple correlation between Olsen-P and crop parameters

Olsen-P at different stages	Grain yield	Stover yield	Total P uptake
Tasselling of maize	0.30*	0.24	0.75**
Harvest of maize	0.21	0.15	0.66**
Panicle emergence of wheat	0.35**	0.85**	0.36**
Harvest of wheat	0.28*	0.78**	0.31*

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