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Effect of combining poultry manure, inorganic phosphorus fertilizers and phosphate solublizing bacteria on growth, yield, protein content and P uptake in maize

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Abstract. Phosphorus (P) is a limited resource, and its efficient use is a main task in sustainable agriculture. Due to high costs of imported fertilizers, focus is now shifting to solutions that utilize local resources and biofertilizers. In a field experiment, the effect of combination of two inorganic phosphorus (P) fertilizer i. e. diammonium phosphate (DAP), single super phosphate (SSP), poultry manure (PM) and phosphate solublizing bacteria (PSB) on the on growth, yield, energy content and P utilization efficiency (PUE) of maize was evaluated in Typic Hapludolls acidic soil of Azad Jammu and Kashmir (AJK). Both inorganic P fertilizers when applied in combination with PM and inoculation with PSB significantly increased plant height, leaf area and chlorophyll content over control. Grain, dry matter, biomass yield and protein content increased by 48-99, 47-64, 48-75 and 61-104% over control. P uptake increased from 13 g kg^{-1} in control to 37 g kg^{-1} where DAP, PM and PSB was combined while increase in PUE was 7-24%. When applied in combination with PM, DAP+PM+PSB was the best treatment among P sources to be utilized.
Key words: phosphorus, yield, protein, P efficiency, PSB.

Introduction. The total P% in soil accounts approximately for 0.04–0.10%, only 1.00–2.50% of which can be absorbed by plants, as most of the phosphorus in soils exists in forms unavailable for uptake by plants (Lin 1990). The low availability of phosphorus nutrition in soils has become the ‘‘limiting factor’’ for plant and root growth (Borch et al 1999; Kanako et al 2004; Saneoka et al 1989) especially after plants have gained sufficient nitrogen nutrition (Liang 1994; Woolmanse & Duncan 1980). Some 17.5 million tonnes of P is processed annually from world reserves of rock phosphates, of which approximately 85% is used in the production of fertilizers (Cordell et al 2009a). However, reserves of rock-P are finite with an estimated depletion of quality sources expected to occur within the next 50–80 years (Isherwood 2000). Indeed world commodity markets have already faced rapid and sharp increase in the price of phosphate rock in recent years i.e. an approximately 7-fold increase in the period between March 2007 and 2008 (Cordell et al 2009b).

The need to use renewable forms of energy and reduce costs of fertilizing crops has revived the use of organic fertilizers worldwide. A possible way for recovering poor quality soils is to add manure and compost to improve soil health and quality, thereby enhancing biogeochemical nutrient cycles (Emmerling et al 2000; Niklasch & Joergensen 2001; Dutta et al 2003). To evaluate the full benefits of organic fertilization, more knowledge about its effect on nutrient avail-ability is required. This is complicated, since the transformation of organic compounds and nutrient release is a complex process, depending on many factors such as the stability of organic substances (Gutser et al 2005), climatic conditions (Dorado et al 2003), soil properties (Huffman et al 1996), type of cropping system (Van den Bossche et al 2005), and interaction with mineral fertilizers (Kaur et al 2005). Furthermore, the composition of organic fertilizers differs greatly, which influences the contents of organic and inorganic P as well (Traore et al 1999). Organic-matter supply to the soil is one of the most important factors for increasing the productivity in plant, with organic P as a significant part of the soil P cycle contributing to P nutrition of plants (Tarafdar & Claassen 2003; Richardson et al 2005; Eichler-Löbermann et al 2007). Organic fertilizers have equivalent or even better effects on crop yields than P from mineral sources (Sharpley 1996).

Amendment with organic residues may influence P dynamics in soils by means of competition between low-molecular-weight organic acids and phosphates for sorption sites that usually favors adsorption of organic acids and delays P adsorption (Violante & Gianfreda 1993; Staunton & Leprince 1996; Geelhoedet al 1999). On the other hand, the rate and form of phosphate precipitates can change in the presence of organic compounds. For example, Inskeep & Silvertooth (1988) reported that organic acids inhibit the precipitation of hydroxyapatite and favor the formation of thermodynamically less stable di-Ca-phosphate-dihydrate (Grossl & Inskeep 1991). Braschi et al (2003) reported that different rates of organic matter (OM) addition increased extractable P at different soil-moisture regimes by inhibiting P insolubilization whereas the adsorption process was not affected.

Phosphorus solubilizing bacteria (Phosphobacteria) are known to play a major role in mineralizing organic phosphorus, solubilization of unavailable forms of soil phosphorus and the uptake of its native and applied forms (Cao et al 1999; Khan 2005). Solubilization of insoluble compounds is due to the excretion of microbial metabolites including organic acids. Indeed the production of microbial metabolites including organic acids may result in a decrease in soil pH, which plays a major role in solubilization of some nutrients (Chen et al 2008). Phosphorus solubilizing rhizobacteria have also been reported c as possible alternative for chemical fertilizers (Vessey 2003).

Maize (*Zea mays* L.) is the single most important crop in the in the state of Azad Jammu and Kashmir, Pakistan with an area of 104911 hectares under cultivation, contributing more than 80% of the total production in the region (AJK at glance 2009), but its yield per unit area is very low. Though information is available on the conjunctive use of organic manures and inorganic fertilizers for improving soil fertility and crop yields, direct quantification of plant-available phosphorus tendered available to the crops from PSB is scant. The literature suggests that combined application of P fertilizer, poultry manure and PSB affect plant growth, grain yield, energy component and P efficiency parameters of maize. However, research information is lacking on the interactive effects of poultry manure, P fertilizer and PSB on maize growth and yield in the agro-ecological wheat-maize growing zones of AJK. This experiment was, therefore, performed with an objective to investigate the impacts of synergistic effect of P sources and PSB on the growth, yield, energy contents and P utilization efficiency of maize.

Materials and Methods

The study site. This study was carried out on an experimental field at the Research farm, Faculty of Agriculture, University of Azad Jammu and Kashmir (AJK) Rawalakot AJK (33–36^o N latitude and 73–75^{o}E longitude) during the year 2009. The study area (Rawalakot) lies between the altitude of 1800–2000 m above sea level in the north–east of Pakistan under the foothills of great Himalayas at Poonch district, AJK, Pakistan. The study area is characterized by annual rainfall ranging from 500−2000 mm (depending on season), most of which is irregular and falls as intense storms during the monsoon and sometimes in winter. Mean annual temperature is about 28 ^{0}C (maximum) in summer while winter is fairly cold with temperature ranging even below freezing point. The monthly precipitation and temperature of the experimental area are presented in Figure 1 and 2. Generally the soils are coarse silty, medium textured, mesic Typic Hapludolls acidic soil with mountain/hill land slopy relief and parent material residum-colluvium from shales (Ali et al 2006).

Field operation, experiment description and treatments. Before actual experiment, soil samples from the experimental field were collected for physical and chemical characteristics (Table 1). A field of 30 x 16 m^2 was selected where maize and wheat were grown previously since the last two years with addition of manures only. For proper seed bed preparation, field was ploughed thoroughly twice with tractor and left as such for next two weeks. The individual plots were prepared according to the treatments and the net plot size was 3 × 3 m^2 which was kept according to the size of the field. The plot was properly leveled for even and efficient fertilizer/water distribution. The experiment was laid out in a randomized complete block design (RCB) design with three replications. The treatments comprised of two different sources of P i.e. inorganic fertilizers as i) DAP (diammonium phosphate, $(NH_4)_2$ HPO_4, 46% P_2O_5 and 18% N); ii) SSP (single super phosphate, Ca $(H_2PO_4)_2$ $+CaSO_4{\cdot}2H_2O$, 18% P_2O_5) and an organic as Poultry manure (PM) respectively, and a control (no P); altogether a total of eight treatments with three replications were established in the experiment. Phosphorus was applied at recommended rate 90 kg ha^{-1} from either sources at or equivalent basis.

Table 1

Physical and chemical properties of soil before cultivation of maize

Soil parameter	Value
Organic C (g Kg^{-1})	4.5
Total N(g kg^{-1})	0. 28
Available P (mg kg^{-1})	7.14
K (mg kg^{-1})	123
ECe (dSm^{-1})	0.62
pH	6.63
CEC (C mol kg^{-1})	17.8
Sand (g kg^{-1})	265
Silt (g kg^{-1})	476
Clay (g kg^{-1})	259
Bulk density (mg m^{-3})	1.12
Porosity	51%

Table 2

Chemical characteristics of the poultry manure used

Nutrient elements	Values
C (%)	36.6
N (%)	2.21
P (%)	2.01
K (%)	2.84
Ca (%)	2.27
Mg (%)	0.29
Fe (mg kg^{-1})	927
Zn (mg kg^{-1})	107
Mn (mg kg^{-1})	216
pH	6.88
Dry matter (%)	48
Moisture (%)	52

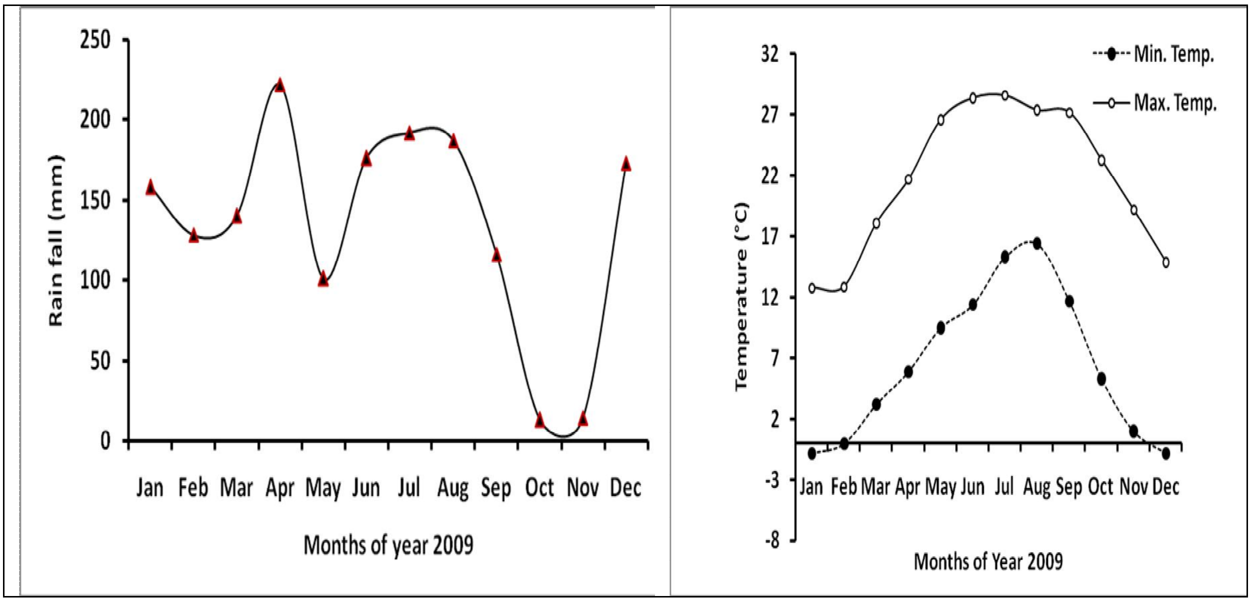


Figure 1. Mean annual rainfall, minimum and maximum temperature at Rawalakot during the study year 2009.

The treatments were, T_1 = without fertilization (P_0); T_2 = DAP @ 90 kg P_2O_5 ha^{-1}; T_3 = SSP @ 90 kg P_2O_5 ha^{-1}; T_4 = PM equivalent to 90 kg P_2O_5 ha^{-1}; T_5 = DAP × PM @ 90 kg P_2O_5 ha^{-1} (50:50 ratio); T_6 = SSP × PM @ 90 kg P_2O_5 ha^{-1} (50:50 ratio); T_7 = DAP × PM × PSB @ 90 kg P_2O_5 ha^{-1} (50:50 ratio + PSB inoculation) and T_8 = SSP × PM × PSB @ 90 kg P_2O_5 ha^{-1} (50:50 ratio + PSB inoculation).

Poultry manure was applied on the basis of P content 25 days before sowing. The chemical composition of PM is presented in Table 2. A promising PSB agrobacterium strain CA-18 was obtained from National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad, Pakistan and used as biofertilizer. Urea was used as N source and full dose of N fertilizer 120 kg ha^{-1} was applied by broadcast method at the time of sowing. Similarly, a basal dose of potassium was applied to all plots including control at the time of sowing at the rate of 60 kg K_2O ha^{-1} as sulphate of potash (SOP), by broadcast method. All the fertilizers were well mixed into the soil. Maize (*Zea mays* L) variety Jalal was used in the experiment. Seeds were collected from maize section, District Agriculture Office Rawalakot AJK. Maize was sown in lines on May 12, 2009 and seed were inoculated where required. After germination the distance between the plants was maintained at 25 cm, while the row to row distance was 50 cm and total of five rows per plot were established. All standard local cultural practices were followed when required throughout the growth period and was harvested on September 24, 2009.

Measurements. Morphological characteristics. Plant Height (cm): Plant height was taken from base to top of the plant for five selected plants per plot in all treatments and then averaged.

Average Leaf Area (cm^2): Five plants were randomly selected from each treatment and leaf area of all leaves of five plants was measured with the help of leaf area machine and averaged.

Chlorophyll content (mg cm^2): Chlorophyll content readings were taken with a handheld dual-wavelength meter (SPAD 502, Chlorophyll meter, Minolta Camera Co., Ltd., Japan). For each plot 30 younger fully expanded leaf blades per plot were used when the plants were at silking stage. The instrument stored and automatically averaged these readings to generate one reading per plot.

Yield and yield components. Dry matter Yield (kg ha^{-1}): For recording dry matter yield, the two middle rows from each plot at maturity were harvested after removing cobs, stacked for uniform drying, weighed and then converted to kg ha^{-1} by using the formula:

Dry matter yield (kg ha^{-1}) = kg dry matter yield m^{-2} × 10,000m^2

Shelling Percentage (%): Shelling percentage was calculated by using the following formula:

$$\text{Shelling percentage (\%)} = \frac{\text{Grains weight of five ears}}{\text{Total weight of five ears}} \times 100$$

Thousand Grain Weight (g): Thousand grain weight was taken at random from the grain lot of each plot using electronic balance. This was repeated three times and then average weight per 1000 grains was calculated and recorded.

Grain Yield (kg ha^{-1}): For recording grain yield data the two middle rows from each plot at maturity were harvested, husked, dried and threshed. Grain yield was recorded and converted to kg ha^{-1} by using the following formula:
Grain yield (kg ha^{-1}) = kg grain yield m^{-2} × 10,000m^2

Harvest Index (%): Harvest index was calculated using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Biological/biomass yield (kg ha}^{-1}\text{)}} \times 100$$

Biological Yield (kg ha^{-1}): At maturity four central rows in each plot were harvested, dried to constant weight and weighed. Biological yield, in kg ha^{-1}, was determined using the formula:

$$\text{Biological yield} = \frac{\text{biological yield per plot}}{\text{plot area harvested}} \times 10\,000.$$

Biochemical analysis of plant and grain. Plant material (shoot, leaves and grain) was dried in a forced-draft oven at about 70^0C until constant weight and ground to pass a 1mm sieve with an ED-5 Wiley mill (Arthur H. Thomas Co). The ground material was analyzed for N and P concentration. Protein concentration in the grain was determined from total N in the grain using the Kjeldhal digestion, distillation and titration method (Bremner & Mulvaney 1982). Grain protein concentration was determined using the formula: protein concentration = %N × 6.25 and then it was converted into g kg^{-1}. Phosphorus content in shoot was estimated by wet digestion with a 2:1 mixture of nitric acid (HNO_3) and Perchloric acid ($HClO_4$). The P content was then determined by the vanadomolybdate yellow color at 440nm using spectrophotometer (Murphy & Riley 1962). P accumulation (uptake) in plant was calculated from dry matter accumulation and P-concentration in shoot.

P efficiency parameters. The P data of samples were used for calculating the following P efficiency parameters following the methods used by Siddiqi & Glass (1981) and Sangakkara et al (2008).
Agronomic efficiency of applied fertilizer P (PAE) = (Grain yield in plots with fertilizer – grain yield of control plots) / Quantum of applied P fertilizer
P-use efficiency (PUE) = [(P uptake by the fertilized treatment – P uptake in the control)/ Quantum of applied P fertilizer] x100

Statistical analysis. For the determination of significant effect of treatments on the growth and yield of crop and on soil and plant characteristics, analysis of variance (ANOVA) and least significant difference (LSD) tests among means were conducted for each character separately using a MSTAT-C statistical analysis package. Comparison of means for the individual treatments was done at the 5% probability level based on the F-test of the analysis of variance (Steel et al 1996).

Results and Discussion

Morphological characteristics. Application of different P sources along with PGPR resulted in significant difference ($P \leq 0.05$) for all morphological parameters i. e. pant height, leaf area and chlorophyll content. Plant height was significantly increased for all the treatments with P addition and inoculation over control (Table 3). The relative increase in plant height was 35–51% over the control without P addition. Application of DAP+PM+PSB resulted in significantly taller plants 248 cm than the control with 164 cm. In rest of treatments the combination of inorganic P fertilizers with PM showed greater plant height than their sole application but less than where PSB was also applied. All the treatments showed significant increase in leaf surface area (LSA) compared with the control (Table 3). In general, at equivalent rates of application, DAP+PM+PSB resulted in higher LSA followed by plants treated with SSP+PM+PSB. The increase in LSA with the P fertilization was 34–49% compared with the control. Application of DAP and SSP in combination with PM significantly increased the chlorophyll content of maize plants as compared to control. Chlorophyll content was also significantly increased due to integration of P sources and PSB, ranging from 4.43 mg cm^2 in the control to 10.13 mg cm^2 DAP+PM+PSB. Average across treatments, the increase in chlorophyll content due to application of P fertilizers and manures was 52–131% compared with the control. Application of PSB in combine treatment of DAP and SSP with PM significantly increased the LSA as compared to their sole application. Ayoola & Adeniyan (2006) reported that application of poultry manure and P fertilizers influences plant growth and yield by providing more nutrients. Opala et al (2009) reported that integrated application organic and inorganic phosphorus sources had significant positive role in the growth characteristics of maize. As combine application of these sources significantly increasing the labile inorganic P pools and more effectively reducing the exchangeable Al. It appears that the ability of an OM to lower the exchangeable Al is more important in increasing maize yields than its ability to increase P availability. Pirdashti et al (2010) who also found that integrated use of half chemical P fertilizer and half organic source significantly increased plant height, leaf area and leaf chlorophyll content in soybean. The shoot and root growth, and nutrient uptake of peas and soybean were increased when seeds were inoculated (Groppa et al 1998; Egamberdiyeva & Hoflich 2004; Figueiredo et al 2008).

Yield and yield components. Analysis of Variance (ANOVA) for yield and yield components of maize indicated significant differences ($P \leq 0.05$) for inorganic P fertilizer, PM and their integration with PSB for all yield and yield components i. e. 1000-grain weight, shelling percentage, number of grains per cob, grain yield, dry matter yield, total biomass yield and harvest index (Table 4; Figure 3). Highest 1000 grain weight 326 g was recorded where combine application of DAP+PM+PSB was carried out, whereas 1000 grain weight in integrated treatments of DAP and SSP with PM were also higher than their sole application. Average across treatments, the increase in 1000 grain weight due to conjunctive use of P sources and PSB was 66–102% compared with the control. Addition of DAP+PM+PSB exhibited highest shelling percentage of 79, followed by SSP+PM+PSB with 77%. Average increase in shelling percentage following the application of different sources and PSB inoculation was up to 12% when compared to control. Grain yield recorded for different P treatments was significantly greater than the un-fertilized control (Table 4). Similar trend was observed for number of grains per cob with combine application of P sources and PSB and 3-29 % increase was recorded over control. Application of PSB significantly ($P \leq 0.05$) increased grain yield, dry matter yield and total biomass yield over the unfertilized control (Fig. 3). The relative increase in yield characteristics ranged from 48 to 99% for grain yield, from 47 to 64% for dry matter yield and 48 to 75 % for total biomass yield. Increments in yield attributes varied considerably among the different treatments and were, for example, extremely high in integrated treatments of PM with both inorganic p fertilizers when inoculated with PSB. With combine use of PSB and P sources harvest index was also increased up to 12%.

Dordas (2009) found that combine application of manure and inorganic fertilizers increased dry matter yield 22% than the control. Similarly, Valluru et al (2010) determined 50-105% increase in biomass yield of pear millet with P addition and Sholly et al (2010) recorded 29% yield increase with manure application in wheat. Egamberdiyeva (2008) reported that the bacterial strains independent from the origin increased the root, shoot, and dry weight of peas by more than 26% compared to the control.

Table 3

Effect of different P sources and PSB on the growth components of maize grown under field conditions at Rawalakot, Azad Jammu and Kashmir

Treatments	Plant height (cm)	Leaf area (cm^2)	Chlorophyll contents (mg cm^2)
T_1	163.8 f	594.6 e	4.4 e
T_2	231.1 cd	812.6 cd	8.8 bc
T_3	221.4 e	804.5 d	8.3 c
T_4	227.3 de	799.1 d	6.7 d
T_5	236.8 bc	826.0 c	9.2 abc
T_6	231.7 cd	815.1 cd	9.0 bc
T_7	248.2 a	884.2 a	10.1 a
T_8	238.4 b	857.7 b	9.4 ab
LSD ($P \leq 0.05$)	6.53	17.54	1.06

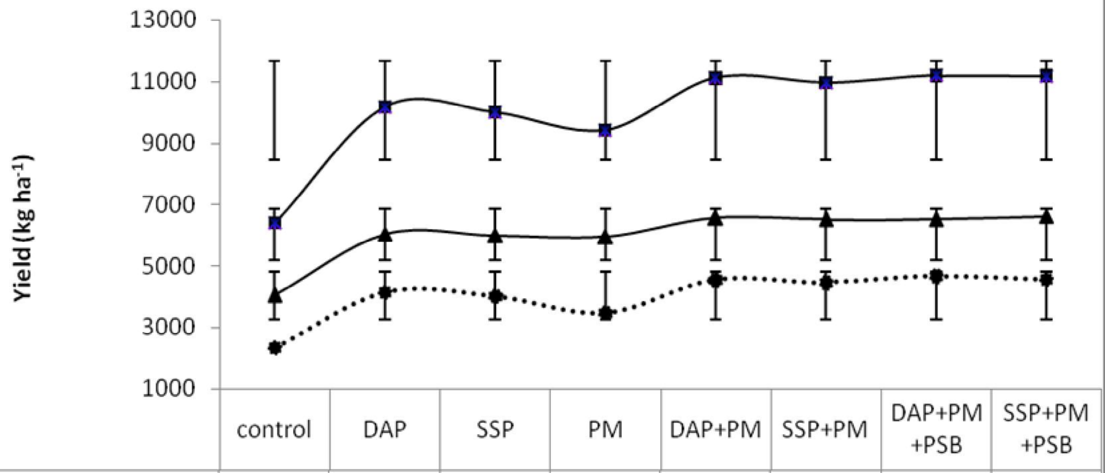
T_1 = without fertilization (P_0); T_2 = DAP @ 90 kg P_2O_5 ha^{-1}; T_3 = SSP @ 90 kg P_2O_5 ha^{-1}; T_4 = PM equivalent to 90 kg P_2O_5 ha^{-1}; T_5 = DAP × PM @ 90 kg P_2O_5 ha^{-1} (50:50 ratio); T_6 = SSP × PM @ 90 kg P_2O_5 ha^{-1} (50:50 ratio); T_7 = DAP × PM × PSB @ 90 kg P_2O_5 ha^{-1} (50:50 ratio + inoculated) and T_8 = SSP × PM × PSB @ 90 kg P_2O_5 ha^{-1} (50:50 ratio + inoculated). Means in the same column followed by the same letter do not differ significantly according to the LSD test ($P \leq 0.05$)

Table 4

Effect of different P sources and PSB on the yield and yield components of maize grown under field conditions at Rawalakot, Azad Jammu and Kashmir

Treatments*	1000 grain weight (g)	Shelling percentage	Number of grains per cob	Harvest Index (%)
T_1	161 e	70 d	417 f	37 d
T_2	292 bc	76 c	475 cd	41 bc
T_3	284 cd	71 d	467 d	40 c
T_4	267 d	71 d	430 e	37 d
T_5	310 ab	71 d	500 b	41 abc
T_6	297 bc	76 c	494 bc	41 bc
T_7	326 a	79 a	542 a	42 a
T_8	303 bc	77 b	512 b	41 abc
LSD ($P \leq 0.05$)	19.02	1.59	25.40	1.18

*Same as described in table 3. Means in the same column followed by the same letter do not differ significantly according to the LSD test ($P \leq 0.05$)



	control	DAP	SSP	PM	DAP+PM	SSP+PM	DAP+PM +PSB	SSP+PM +PSB
Grain yield	2348	4149	4019	3469	4548	4454	4677	4579
Dry matter yield	4041	6027	5980	5956	6563	6508	6520	6611
Total biomass yield	6389	10176	9999	9425	11111	10962	11197	11190

Figure 2. Effect of different P fertilizers, PM and PSB on grain, dry matter and total biomass yield in maize. Vertical bars show standard deviation (n = 3).

Grain protein content and P uptake in maize. Total N (protein content) and P uptake by maize in response to different P sources and PSB application is presented in Table 5. Protein content in grains of control treatment was 59 g kg^{-1} that significantly ($P≤0.05$) increased following integration of P sources and PSB application ranged between 90–114 g kg^{-1} demonstrating 61–104% increase over the control. Plant N increments varied significantly among different treatments and were, for example, extremely higher either with DAP+PM+PSB or SSP+PM+PSB. P-uptake by plants in control was 13.3 kg ha^{-1} that significantly ($P≤0.05$) increased to 20–34.7 kg ha^{-1} indicating 50–160% increase over the control. Plant P increments varied significantly among different treatments and were extremely higher where P sources and PSB was combined. Grains are most active sink for carbon and N assimilates in cereals. Whereas most of the carbohydrates are provided by current photosynthesis (Wardlaw 1990), the major portion of seed N is derived by mobilization of N accumulated in vegetative organs (Cartelle et al 2006). Similar to our results (Dordas 2009; Sholly et al 2010) reported that with the addition of inorganic P fertilizers and manure, N contents on whole plant level increased 33-48% over their respective controls. These P solublizers may increase the availability of phosphorus to plant by mineralizing organic phosphorus compounds and by converting inorganic phosphorus into more available form (Baryosef et al 1999). Generally, it has been found that the organisms isolated from the rhizosphere of legumes have been found to be more efficient in solubilizing phosphates than those from the non-rhizosphere or from the root zone of non-legumes (Gull et al 2004; Hameed et al 2004). The ability of PSB strains to solubilize insoluble P and convert it to plant available form is an important characteristic under conditions where P is a limiting factor for crop production. Chen et al 2008 reported that Phosphobacterium 9320-SD had significant effect ($p < 0.05$) on winter wheat total P and plant biomass under both pot and field conditions, although no obvious difference in plant height was found compared to the control. These results demonstrate that hosphobacterium 9320-SD has the ability to convert non-available forms of phosphorus into plant-available forms, and therefore holds great potential for development as a biofertilizer to enhance soil fertility and promote plant growth.

Table 5

Effect of different P sources and PSB on grain protein content and
P-uptake in maize grown under field conditions at Rawalakot, Azad Jammu and Kashmir

Treatments*	Grain protein content (g kg^{-1})	P-uptake (kg ha^{-1})
T_1	59 e	13.3 e
T_2	107 bc	26.3 c
T_3	100 c	21.3 d
T_4	90 d	20 d
T_5	107 ab	31.3 ab
T_6	106 ab	27.3 c
T_7	114 a	34.7 a
T_8	110 ab	28 bc
LSD (P≤0.05)	8.50	3.58

*Same as described in table 3. Means in the same column followed by the same letter do not differ significantly according to the LSD test ($P \leq 0.05$)

Phosphorus recovery and efficiency. Average over P inputs added, phosphorus agronomic efficiency (PAE), and phosphorus use efficiency (PUE) ranged between 12–26 and 7–24%, respectively (Figure 3). The highest recovery and utilization efficiency of P was recorded in the treatments where P was applied as DAP+PM+PSB. Dry matter yield of maize in the present study showed strong relationship with the agronomic efficiency and is confirmed by a strong positive correlation (r^2 = 0.98) between the two traits. Meena (2010) reported that the recovery of applied P by maize was 18-27% following the application of organic amendments along with inorganic P sources. Similar findings for PAE and PUE were obtained by Yaseen & Malhi (2010) and Sistani et al (2010).

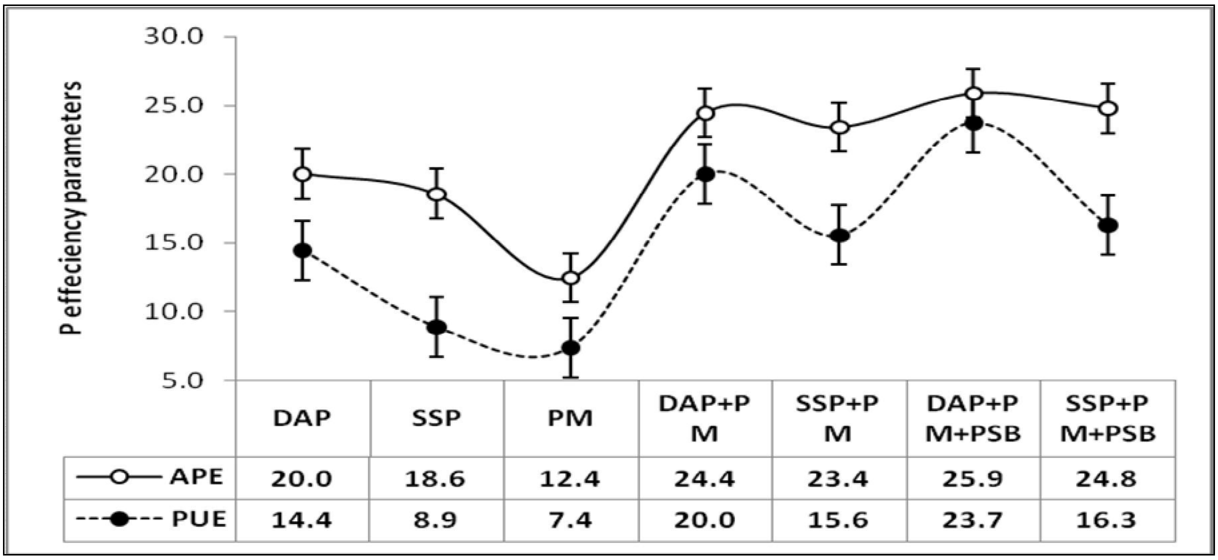


Figure 3. Effect of different P fertilizers, PM and PSB on phosphorus agronomic efficiency (PAE) and phosphorus use efficiency (PUE) in maize. Vertical bars show standard error.

P uptake and correlations. Many measurements in this study were significantly correlated with each other (Figure 4). Most of the parameters observed during the study have highly significant correlation (positive) with the P uptake. Leaf area, chlorophyll content, grain yield and protein content all were positively and significantly correlated with P uptake, i.e. r^2 = 0.74, 0.89, 0.87 and 0.82 respectively.

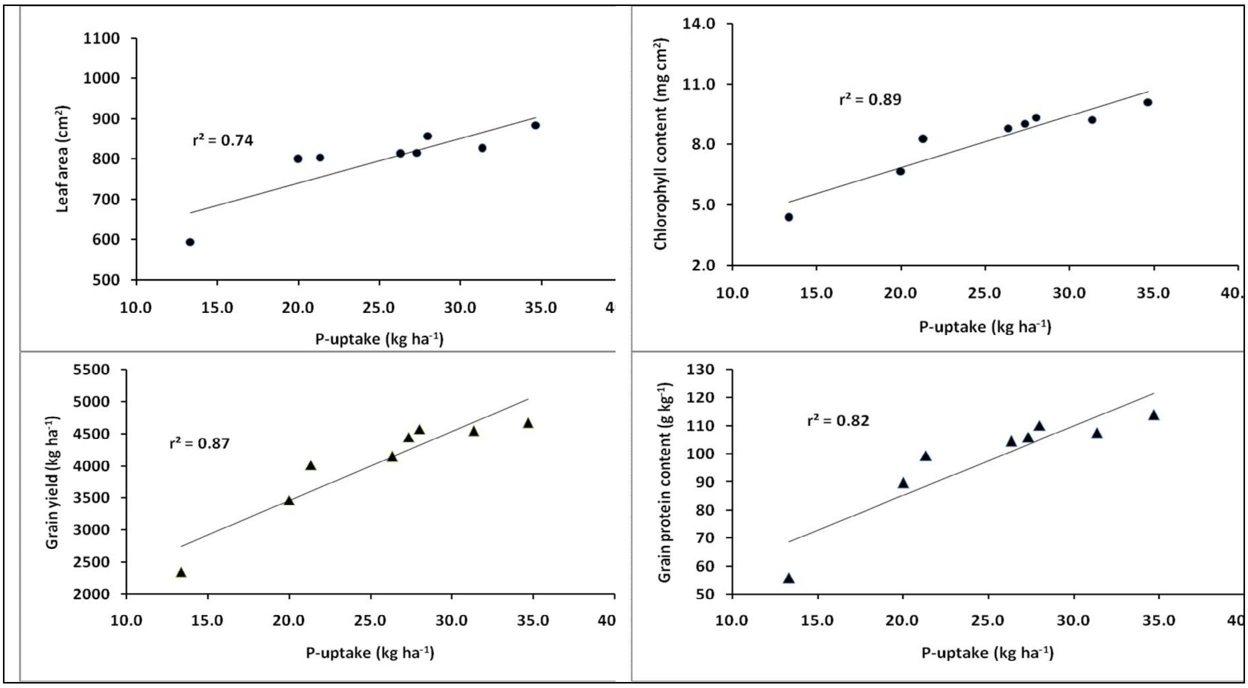


Figure 4. Correlation between total (shoot +seed) maize P-uptake vs. maize leaf area, total maize P-uptake vs. maize leaf chlorophyll content, total maize P-uptake vs. maize grain yield and total maize P-uptake vs. maize grain protein content.

Conclusions. The present study demonstrated that the beneficial bacterial greatly enhanced and mobilized P exhibited a substantial plant growth promoting abilities in addition to nutrient accumulation in maize. The results of our experiment indicated that PSB inoculation significantly increased the morphological characteristics (plant height, chlorophyll content), yield and yield attributes and NP uptake by plant. This study suggested that the tested PSB strain may be used as crop-enhancer for better P management practices to improve maize yield, phosphorus use efficiency and nutrient uptake. Also, further studies are needed to test the effect of PSB inoculation on soil quality over long term to get economic as well as biological benefits in the mountain region of Azad Jammu and Kashmir.

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References

Ali B., Hidayatullah M., Fida M., 2006 Integrated land resources survey and evaluation of AJK; Government of Pakistan Ministry of Food, Agriculture and livestock, Soil survey of Pakistan, Lahore.

Ayoola O. T., Adeniyan O.N., 2006 Influence of poultry manure and NPK fertilizer on yield and yield components of crops under different cropping systems in south west Nigeria. Afr J Biotech **5**:1386–1392.

Baryosef B., Rogers R. D., Wolfram J. H., Richman E., 1999 *Pseudomonas cepacia* mediated rock phosphate solubilization in kaolinite and montmorillomite suspension. Soil Sci Soc Am J **63**:1703–1708.

Borch K., Bouma T. J., Lynch J. P., Brown K. M., 1999 Ethylene: a regulator of root architectural responses to soil phosphorus availability. Plant Cell Environ **22**:425–431.

Braschi I., Ciavatta C., Giovannini C., Gessa C., 2003 Combined effect of water and organic matter on phosphorus availability in calcareous soils. Nutr Cycl Agroecosyst **67**:67–74.

Bremner J. M., Mulvaney C. S., 1982 Nitrogen-total. In Page et al. (eds) Methods of Soil Analysis. Part2: Chemical and Microbiological Properties. Madison, Wisconsin: ASA. pp. 595–624.

Cao G. M., Zhang J. X., Bao X. K., 1999 The phosphorus cycling in an alpine meadow. Acta Eco Sin **19**:514–518.

Cartelle J., Pedero A., Savin R., Slafer G. A., 2006 Grain weight response to post-anthesis spikelet-trimming in an old and modern wheat under Mediterranean conditions. Eur J Agron **25**:365–371.

Chen Z., Shengwu M., Lily L., 2008 Studies on phosphorus solubilizing activity of a strain of hosphobacteria isolated from chestnut type soil in China. Bio Tech **99**:6702–6707.

Cordell D., Drangert J.O., White S., 2009a The story of phosphorus: Global food security and food for thought. Glob Environ Change **19**:292–305.

Cordell D., Schmid-Neset T., White S., Drangert J. O., 2009b Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand. In: International conference on nutrient recovery from wastewater streams, IWA Publishing, London, UK. pp. 23–43.

Dorado J., Zancada M., Almendros G., López-Fando C., 2003 Changes in soil properties and humic substances after long-term amendments with manure and crop residues in dryland faming systems. J Plant Nutr Soil Sci **166**:31–38.

Dordas C., 2009 Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source-sink relations. Eur J Agron **30**:129–139.

Dutta S., Pal R., Chakraborty A., Chakrabarti K., 2003 Influence of integrated plant nutrient supply system on soil quality restoration in a red and laterite soil. Arc Agron Soil Sci **49**:631–637.

Egamberdieva D., 2008 Plant growth promoting properties of Rhizobacteria isolated from wheat and pea grown in loamy sand soil. Turkish J Biol **32**:9–15.

Egamberdiyeva D., Hoflich G., 2004 Effect of plant growth-promoting bacteria on growth and nutrient uptake of cotton and pea in a semi-arid region of Uzbekistan. J Arid Environ **56**:293-301.

Eichler-Löbermann B., Köhne S., Köppen D., 2007 Effect of organic, inorganic, and combined organic and inorganic P fertilization on plant P uptake and soil P pools. J Plant Nutr Soil Sci **170**:623–628.

Emmerling C., Liebner C., Haubold-Rosar M., Katzur J., Schröder D., 2000 Impact of application of organic waste materials on microbial and enzyme activities of mine soils in the Lusatian coal mining region. Plant Soil **220**:129–138.

Figueiredo M. V. B., Martinez C. R., Burity H. A., Chanway C. P., 2008 Plant growth-promoting rhizobacteria for improving nodulationand nitrogen fixation in the common bean (*Phaseolus vulgaris* L.). Word J Microb Biotech **24**:1187-1193.

Geelhoed J. S., van Riemsdijk W. H., Findenegg G. R., 1999 Simulation of the effect of citrate exudation from roots on the plant availability of phosphate adsorbed on goethite. Eur J Soil Sci **50**:379–390.

Government of Azad Jammu and Kashmir., 2009 Azad Kashmir at a glance. Department of Planning and Development Muzaffarabad, Pakistan. pp: 16.

Groppa M., Zawoznik M. S., Tomaro M. L., 1998 Effect of co-inoculation with Bradyrhizobium japanicum and Azospirillum brasilense on soybean plants. Eur J Soi Bio **34**:75-80.

Grossl P. R., Inskeep W.P., 1991 Precipitation of dicalcium phosphate dihydrate in the presence of organic acids. Soil Sci Soc Am J **55**:670–675.

Gull M., Hafeez F. Y., Saleem M., Malik K. A., 2004 Phosphate-uptake and growth promotion of chickpea (*Cicer arietinum* L.) by co-inoculation of mineral phosphate solubilizing bacteria and a mixed rhizobial culture. Aus J Exp Agri **44**:1-6.

Gutser R., Ebertseder T., Schraml M., Schmidhalter U., 2005 Short-term and residual availability of organic fertilizers on arable land. J Plant Nutr Soil Sci **168**:439–446.
Hameed S., Yasmin S., Malik K. A., Zafar Y., Hafeez F. Y., 2004 Rhizobium, Bradyrhizobium and Agrobacterium strains isolated from cultivated legumes. Bio Fer Soils **39**:179-185.
Huffman S. A., Cole C. V., Scott N. A., 1996 Soil texture and residue addition effects on soil phosphorus transformations. Soil Sci Soc Am J **60**:1095–1101.
Inskeep W. P., Silvertooth J. C., 1988 Inhibition of hydroxyapatite precipitation in the presence of fulvic, humic, and tannic acids. Soil Sci Soc Am J **52**:941 –946.
Isherwood K. F., 2000 Mineral fertilizer use and the environment. International Fertilizer Industry Association, United Nations Environment Programme, Paris.
Kanako O., Motohiko K., Ho A., Ken-ichi K., 2004 Phosphorus application affects root length distribution and water uptake of upland rice in a column experiment. J Soil Sci Plant Nutr **50**:257–261.
Kaur K., Kapoor K. K., Gupta A. P., 2005 Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical condition. J Plant Nutr Soil Sci **168**:117–122.
Khan A. G., 2005 Role of soil microbes in the rhizospheres of plants growing on trace metal contaminated soils in phytoremediation. J Trace Ele Med Bio **18**:355-364.
Liang S. F., 1994 Fuction and application of dissolving phosphorus microbial fertilizer. Soil Fertilizer **2**:46–48.
Lin C. G., 1990 Agricultural chemistry of soil. In: Lin, C.G. (ed.), The Holes, Structures and Cultivable Peculiarly of Field Soil. Agriculture Press, Beijing, pp. 56–65.
Meena S., 2010 Effect of different sources of phosphorus on yield and availability of phosphorus in maize-sunflower sequence in a typic Haplustalf-assessment using radio tracer technique. J Plant Nutr **33**:1229–1235.
Murphy J., Riley J. P., 1962 A modified single solution for determination of phosphate in natural waters. Ana Chim Acta **27**:35–36.
Niklasch H., Joergensen R. G., 2001 Decomposition of peat, biogenic municipal waste compost, and shrub/grass compost asses in different rates to a silt loam. J Plant Nutr Soil Sci **164**:365–368.
Opala P. A., Othieno C. O., Okalebo J.R., Kisinyo P. O., 2009 Effect of combining organic materials with inorganic phosphorus sources on maize yield and financial benefits in Western Kenya. Exp Agri **46**:23–34.
Pirdashti H., Motaghian A., Bahmanyar M. A., 2010 Effect of organic amendments application on grain yield, leaf chlorophyll content and some morphological characteristics in soybean cultivars. J Plant Nutr **33**:485–495.
Richardson A. E., George T. S., Hens M., Simpson R. J., 2005 Utilization of soil organic phosphorus by higher plants, In: Turner et al (eds) Organic Phosphorus in the Environment. CABI Publishing, Wallingford, Oxfordshire, UK. pp. 165–184.
Saneoka H., Fujita K., Ogata S., 1989 Effects of phosphorus fertilizer on drought tolerance in warm season forage. J Jpn Grassl Sci **35**:116–126.
Sangakkara R., Attanayake I. K. B., Stamp P., 2008 Impact of locally derived organic materials and method of addition on maize yields and nitrogen use efficiencies in major and minor seasons of tropical south Asia. Com Soil Sci Plant Ana **39**:2584–2596.
Sharpley A. N., 1996 Availability of residual phosphorus in manured soils. Soil Sci Soc Am J **60**:1459–1466.
Sholly D. M., Richert B. T., Sutton A. L., Joern B. C., 2010 Effects of nitrogen and phosphorus application from swine manure on winter wheat growth and nutrient utilization. Com Soil Sci Plant Ana **41**:1797–1815.
Siddiqi M. Y., Glass A. D. M., 1981 Utilization Index: A modified approach to estimation and comparison of nutrient utilization efficiency in plants. J Plant Nutr **4**:289–302.
Sistani K. R., Adeli A., Tewolde H., 2010 Apparent use efficiency of nitrogen and phosphorus from litter applied to bermudagrass. Com Soil Sci Plant Ana **41**:1873–1884.

Staunton S., Leprince F., 1996 Effect of pH and some organic anions on the solubility of soil phosphate: implications for P bioavailability. Eur J Soil Sci **47**:231–239.

Steel R. G. D., Torrie J. H., Dickey D., 1996 Principles and Procedures of Statistics. New York: McGraw Hill.

Tarafdar J. C., Claassen N., 2003 Organic phosphorus utilization by wheat plants under sterile conditions. Biol Fert Soils **39**:25–29.

Traore O., Sinaj S., Frossard E., Van de Kerkhove J. M. 1999 Effect of composting time on phosphate availability. Nutr Cycl Agroecosyst **55**:123–131.

Valluru A., Vadez V., Hash C. T., Karanam P., 2010 A minute P application contributes to a better establishment of pearl millet (*Pennisetum glaucum* (L.) R. Br.) seedling in P deficient soils. Soil Use Manag **26**:36–43.

Van den Bossche A., De Neve S., Hofman G., 2005 Soil phosphorus status of organic farming in Flanders: an overview and comparison with the conventional management. Soil Use Manag **21**:415–421.

Vessey K. J., 2003 Plant growth promoting rhizobacteria as bioferitilizers. Plant Soil **255**:571-586.

Violante A., Gianfreda L., 1993 Competition in adsorption between phosphate and oxalate on an aluminum hydroxide montmorillonite complex. Soil Sci Soc Am J **57**:1235–1241.

Wardlaw I. F., 1990 The control of carbon portioning in plants. New Phyto 116:341-381.

Woolmanse R. G., Duncan D. A., 1980 Nitrogen and phosphorus dynamics and budgets in annual grassland. Ecology **61**:893–904.

Yaseen M., Malhi S. S., 2010 Differential growth response of wheat genotypes to ammonium phosphate and rock phosphate phosphorus sources. J Plant Nutr **32**:410–432.

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