Soil Environ. 37(2): 129-135, 2018
DOI:10.25252/SE/18/61580
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Effect of rock phosphate based compost and biofertilizer on uptake of nutrients, nutrient use efficiency and yield of cotton

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Abstract

Phosphorus deficiency in alkaline and calcareous soils is a worldwide burning issue. The use of mineral phosphatic fertilizers is quite popular throughout the world to cope with this deficiency. However, efficient use of these phosphatic fertilizers is still questionable. A study was conducted to improve the efficiency of these mineral phosphatic fertilizers using phosphorus-solubilizing bacteria (PSB) and phosphorus enriched compost (PEC) in cotton. Results showed that integrated use of PSB and PEC in different combinations improved nutrient use efficiency, growth and seed-cotton yield compared to alone application of single super phosphate (SSP). Significant improvement in morphological characteristics of cotton were recorded due to combinations of PSB and PEC with SSP.

Keywords: Cotton, organic farming, phosphorus management

Introduction

Phosphorus is the second most essential macronutrients and is taken up in largest amount after nitrogen (Reddy *et al*., 2004; Shen *et al*., 2011). It is critical for root growth and fruit setting in most of the crops, thus its sufficient supply is essentially required for several physiological processes like early heading and uniform maturity, early root and seedling, seed formation and water-use efficiency etc. (Cordell *et al*., 2009). It is crucial for respiration, cell division, photosynthesis, storage and transfer of energy (Reddy *et al*., 2004). Briefly, its deficiency causes significant loss in crop productivity.

Cotton (*Gossypium hirsutum* L.) is one of the main cash crops of Pakistan. It has played a significant role in industrial development and employment generation (Olmstead and Rhode, 2018). It is known as backbone of Pakistan's economy. Its impact on the economic development of the country is well established. It occupies the 2nd position with respect to cultivated area in the country (Rehman *et al.*, 2017). But cotton belt in Pakistan is situated in the region where soils are alkaline, calcareous and deficient in organic matter (Ali and Abdulai *et al*., 2010). In these soils, phosphorus deficiency is very common issue because phosphorus in these soils is either converted into insoluble form due to P precipitation with Ca^{2+} and Mg^{2+} or fixation in the soils (Tiessen *et al.*, 1984). That is why; none of cotton cultivars in Pakistan succeeded to give its potential yield.

Phosphorus availability to plant roots in calcareous / alkaline soils is limited due to its less mobility in soils and more fixation (Shen *et al.*, 2011). Efforts were made to cope with this problem though selection of phosphorus responsive cotton cultivars and band placement of phosphatic fertilizers but still the efficiency of phosphatic fertilizers remained up to 25% (Delgado *et al*., 2002) that has greatly affected the potential of cotton cultivars in Pakistan.

Soil microbes particularly phosphorus solubilizing bacteria (PSB) play an effective role in soil P dynamics. These microorganisms either solubilize P in the soils through release of organic acids or prevent precipitation of Ca^{+2} and Mg^{+2} to cover P deficiency in calcareous / alkaline soils (Afzal and Bano, 2008). Thus, these microbes may contribute to develop models of sustainable agriculture (Sáez *et al*., 2012). The use of PSB is such an effective approach that would offer novel means to improve phosphorus use efficiency (Estrada-Bonilla *et al.*, 2017).

Compost is an excellent source of micro and macro nutrients depending on the composition and nature of wastes (Morales-Corts *et al*., 2018). Compost can be enriched with specific nutrient using amendments such as use of rock phosphate (RP) during composting. Thus, phosphorus enriched compost provides P nutrition to crops through their decomposition as well as may act as soil conditioner (Cameron *et al*., 2004). In present scenario, most of the

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countries are facing problem of soil P deficiency and trying to get rid of expensive P chemical fertilizers by supplementing with such P enriched compost or using PSB (Babana and Antoun, 2006). Phosphorus enriched compost is being considered on high priorities worldwide owing to its effectiveness for soil health and safe disposal (Delgado *et al*., 2002; Satyanarayana *et al*., 2002). Phosphorus enriched compost recovers soil health though physical and chemical changes in soil such as soil structure, aeration, CEC, water holding capacity and bulk density etc. (Alburquerque *et al*., 2007). Moreover, it is safeguard for PSB that solubilizes fixed or precipitated phosphorus in soils and thus has shown positive effects on restoring soil fertility, mobilization and recycling of soil nutrients, which are at alarmingly low levels in Pakistan (Shahbaz *et al*., 2013).

Rare information is available for use of phosphorus-enriched compost for efficient use of phosphatic fertilizers in cotton particularly synchronizing its application with efficiency of phosphorus solubilizing bacteria. So, the main emphasis of this study was to determine the integrated impact of rock phosphate enriched compost and PSB inoculants on phosphorus use efficiency, growth and yield of cotton.

Materials and Methods

The effects of phosphorus solubilizing bacteria inoculum (PSBI) and phosphorus enriched compost (PEC) was evaluated on phosphorus use efficiency, growth and yield of cotton under controlled conditions in glazed pots using silt loam soil (pH, 8.20; organic matter 0.46%; total nitrogen 0.039%; available phosphorus 8.60 mg kg^{-1}).

Treatment plan and application

The treatment plan included different percentage of recommended P from SSP and PEC with and without PSB inoculants (PSBI): T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC and T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan. Equal quantity of N (120 kg ha^{-1}) and K (60 kg ha^{-1}) as urea and SOP, respectively, were used in all treatments. The required quantity of compost was mixed thoroughly in 10 kg before filling in respective pot while SSP was placed 2.5 inches below 03 seeds of cotton cv. IUB 2013. After seed sowing, the pots were irrigated to field capacity moisture level. At stage of two leaves per plant, only one plant was maintained in each pot while others were incorporated in soil of respective pot.

Isolation and application of PSB inoculum

Phosphorus solubilizing bacteria (PSB) i.e. a pre-isolated strain (P-10) of PGPR containing ACC-deaminase and phosphatase activity was taken from the Soil Microbiology and Biochemistry Laboratory of the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad. It was prepared by growing in the 250 mL conical flasks containing general purpose medium (GPM). The GPM contained glucose (1.5 g L^{-1}), peptone (0.5 g L^{-1}), $MgSO_4.7H_2O$ (0.1 g L^{-1}), K_2SO_4 (0.5 g L^{-1}), citric acid (2 g L^{-1}), $FeSO_4$. $7H_2O$ (traces), $(NH_4)_2SO_4$ (0.5 g L^{-1}). The flasks were incubated at 28±1°C for 48 h under shaking (100 rpm) conditions. After incubation, optical density was measured. The suspension of PSB was used for seed coating. A slurry containing 5 mL of 15% sugar solution, 10 mL liquid culture and 35g of sterilized peat plus clay was used as carrier material during coating. Inoculated seeds were placed over night for drying.

Preparation of rock phosphate enriched compost

A locally fabricated composting unit consisting of a crusher, oven, grinder and composter was used for making the compost from organic wastes of fruits and vegetables. Organic waste material was collected from local markets of Faisalabad city. Collected organic waste material was air dried for 24 hours. Air dried organic waste material was sorted to remove all unwanted substances (stones, glasses, cork etc.) in the organic waste. Graded material was crushed to remove excess moisture and then it was oven dried at 65°C for 24 h before grinding. Oven dried material was crushed in a grinding unit of composter to convert raw form of waste into ground form. Crushed material was poured in composter (mixing unit) and rotated at suitable temperature and water to convert material into compost. Oven dried and finely ground compost was enriched with 50% of recommended rate of P as single super phosphate (SSP) and rock phosphate (RP), separately and enriched compost was incubated in a specially prepared “Composter” for six days.

Plant analysis

Sampled leaves and petioles of cotton were oven dried until constant weight, ground and analyzed for macro nutrients as described by Wolf (1982). Nitrogen was analyzed according to Jackson (1962) while phosphorus by using vanadate-molybdate spectrophotometric procedure. Potassium was determined by flame photometer (Chapman and Pratt 1961).

Nutrient use efficiency

To check percent of P recovered from applied SSP, apparent recovery efficiency (ARE) of phosphorus was calculated using formula given below [modified from Shahbaz *et al*. (2013)]:

$$ARE\,(\%) = \frac{Nutrient\ uptake\ in\ treated\ plant - Nutrient\ uptake\ in\ control}{Amount\ of\ nutrient\ applied} \times 100$$

Whereas nutrient uptake was product of dry mass and nutrient concentration. Similarly, to address the question how efficiently plant used P for biomass production, agronomic use efficiency was also calculated. The formula is:

$$Agronomic\ use\ efficiency = \frac{Biomass\ of\ treated\ plant - Biomass\ in\ control}{Amount\ of\ nutrient\ applied} \times 100$$

Similarly, to address the question what portion of absorbed nutrient was converted into yield or plant biomass, physiological use efficiency (PUE) was also calculated using formula given below:

$$PUE = \frac{Biomass\ of\ treated\ plant - Biomass\ in\ control}{Nutrient\ uptake\ (treated) - Nutrient\ uptake\ (control)}$$

Statistical analysis

All the data were analyzed using completely randomized design (Steel *et al*., 1997) while means were compared using Least Significant Difference test.

Results

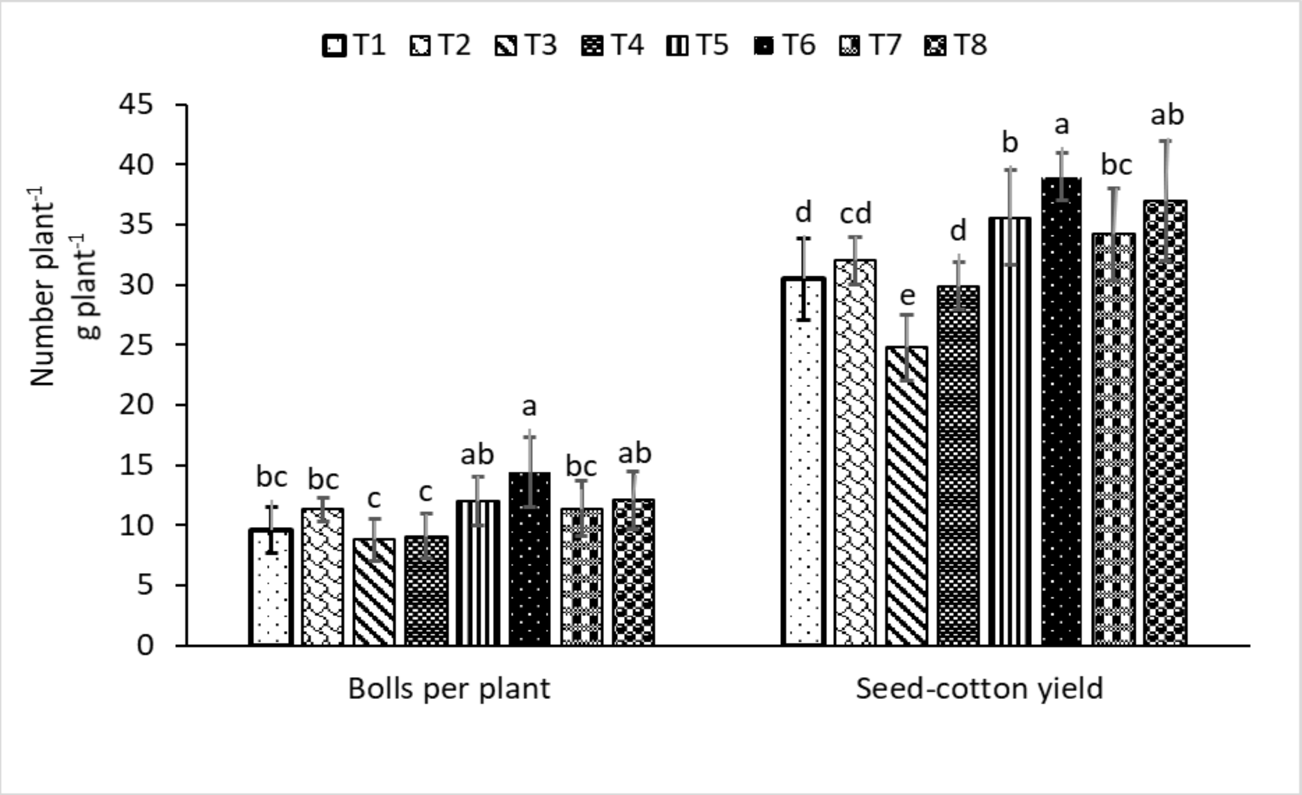
The application of PSBI and PEC affected the plant height, sympodial and monopodial branches and chlorophyll contents (Table 1). Cotton plants showed maximum height in treatment T_6, followed by T_5 where 50% of P was substituted with organic P source with and without PSB inoculants. However, no considerable difference in monopodial and sympodial branches was observed (Table 1). Contrary to monopodial and sympodial branches, significant differences in SPAD chlorophyll contents was observed. Among all tested combinations, treatments T_5 and T_6 (50% SSP + 50% PEC ± PSBI) was statistically more effective combination for improving chlorophyll contents, plant fresh and dry weight compared to treatment T_1 where 100% P was applied from SSP (Table 1). Plants with improved plant height led to more setting of square bolls per plant (Figure 1) and depicted proportional significant change in plant fresh and dry weight (Table 1). The plants were provided with P from inorganic source (SSP), organic source (RP-compost) and biofertilizer (PSBI) not only bore more number of square bolls per plant but also showed corresponding increase in seed-cotton yield (Figure 1). Integrated phosphorus management eventually offered fruitful base for setting up of square bolls and better seed-cotton yield compared to SSP alone application (Figure 1).

Previously, it is claimed that none of the P based amendments could substitute chemical P fertilizers without loss in yield. However, it was observed that right combinations of inorganic (SSP), organic (PEC) and biofertilizer (PSBI) brought a remarkable breakthrough in plant growth and seed-cotton yield compared to alone application of SSP (Table 1, Figure 1). Additionally, integrated P management improved leaf phosphorus contents due to more plant phosphorus uptake (Table 2) compared to control treatment (100% P from SSP only). Corresponding variations in plant N and K uptakes were also found as was observed for plant P uptake due to

Table 1: Comparative effects of PSBI and PEC with and without SSP on morphological parameters of cotton

P source combinations	Plant height (cm)	No. of branches per plant		Chlorophyll contents (SPAD)	PDW (g plant^{-1})	PFW (g plant^{-1})
SSP-RPC-PSB		Mono-podial	Sym-podial			
$T_1 = SSP_{100}$	46.1e	1.3 b	9.7 b	36.1 de	23.7 c-e	44.1 e
$T_2 = SSP_{100} + PSB$	49.1 d	3.1 a	10.0 b	37.9 cd	26.6 b	49.1 cd
$T_3 = RPC_{50}$	42.1 f	3.0 a	9.6 b	39.3 bc	21.1 e	39.1 f
$T_4 = RPC_{50} + PSB$	48.1 de	1.3 b	9.8 b	34.1 e	22.4 de	43.1 e
$T_5 = SSP_{50} + RPC_{50}$	57.1 b	3.6 a	11.5 a	41.9 ab	26.9 ab	52.1 ab
$T_6 = SSP_{50} + RPC_{50} + PSB$	63.6 a	1.8 b	11.8 a	42.3 a	29.6 a	54.1 a
$T_7 = SSP_{25} + RPC_{50}$	50.1 d	3.4 a	11.0 a	40.1 a-c	24.9 b-d	47.1 d
$T_8 = SSP_{25} + RPC_{50} + PSB$	53.6 c	1.6 b	11.3 a	40.3 a-c	25.6 bc	50.1 bc

Means in each column followed by the same letter(s) do not differ significantly at 0.05 probability according to LSD test. Whereas T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC, T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan.



Bars followed by the same letter(s) do not differ significantly at 0.05 probability according to LSD test.

T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC, T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan.

Figure 1. Comparative effects of PSBI and PEC with and without SSP on number of bolls and yield of cotton

Table 2: Comparative effects of PSBI and PEC with and without SSP on cotton shoot N, P and K contents and uptakes in cotton

P source combinations	**Shoot nutrient concentration (%)**			**Nutrient uptake (mg g^{-1})**		
SSP-RPC-PSB	**N**	**P**	**K**	**N**	**P**	**K**
$T_1 = SSP_{100}$	1.54 c	0.62 bc	1.25 cd	363 d	146 cd	297 c-e
$T_2 = SSP_{100}$ + PSB	1.57 bc	0.71 a-c	1.29 b-d	417 c	188 bc	346 b-d
$T_3 = RPC_{50}$	1.16 d	0.56 c	1.11 d	244 e	117 d	236 e
$T_4 = RPC_{50}$+ PSB	1.18 d	0.58 c	1.15 d	264 e	129d	258 de
$T_5 = SSP_{50} + RPC_{50}$	1.75 a	0.80 a	1.52 a	469 b	214 ab	411 ab
$T_6 = SSP_{50} + RPC_{50}$ + PSB	1.79 a	0.83 a	1.58 a	530 a	245 a	469 a
$T_7 = SSP_{25} + RPC_{50}$	1.69 ab	0.76 ab	1.41 a-c	419 c	188 bc	352 bc
$T_8 = SSP_{25} + RPC_{50}$ + PSB	1.74 a	0.69 a-c	1.47 ab	443 bc	177 bc	377 bc
LSD value	*0.1460*	*0.1787*	*0.2026*	*36.887*	*44.947*	*89.637*

Means in each column followed by the same letter(s) do not differ significantly at 0.05 probability according to LSD test. Whereas T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC, T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan.

integrated P management (Table 2). Consequently, significant improvements in leaf N and K contents occurred (Table 2). In short, different P source combinations increased P uptake by 10 to 15% that also increased uptakes of N and K (Table 2). It resulted in a clear-cut distinction between nutrient uptakes from treated and control plants

(Table 2) which subsequently gave rise to difference in seed-cotton yield in treated and control plants (Figure 1).

Integrated P management using SSP, PEC and PSBI significantly affected nutrient use efficiency compared to SSP alone application (Tables 3, 4). Contrary to control, plants supplied with P from SSP, compost and PSBI showed more physiological use efficiency. Similarly, a noteworthy difference arose between N and K physiological use efficiency of treated and control plants (Table 3). These upsurges in physiological use efficiency subsequently resulted in higher yields of treated plants. Similar improvements in P recovery efficiency and P agronomic use efficiency was also found in treatments comprising of different combinations of SSP, compost and PSBI (Table 3, 4). Consequently, corresponding increases in agronomic and recovery efficiency of N and K compared to control treatment.

Table 3: Comparative effects of PSBI and PEC with and without SSP on fertilizer use efficiency in cotton

P source combinations	Nutrient recovery efficiency (%)			Physiological nutrient use efficiency (mg mg^{-1})		
SSP-RPC-PSB	**N**	**P**	**K**	**N**	**P**	**K**
$T_1 = SSP_{100}$	30.2 a-c	16.5 cd	78.5 b	65.2 b	166 ab	80.8 a-c
$T_2 = SSP_{100} + PSB$	34.7 a-c	21.1 a-c	90.2 ab	63.7 bc	144 ab	78.0 b-d
$T_3 = RPC_{50}$	34.4 a-c	13.3 d	92.3 ab	86.7 a	185 a	91.2 a
$T_4 = RPC_{50} + PSB$	38.6 a	14.6 cd	103.4 a	85.0 a	178 a	88.2 ab
$T_5 = SSP_{50} + RPC_{50}$	24.9 c	24.1 ab	74.1 b	57.3 cd	127 b	66.2 de
$T_6 = SSP_{50} + RPC_{50} + PSB$	27.5 bc	27.5 a	81.4 b	55.9 d	122 b	63.8 e
$T_7 = SSP_{25} + RPC_{50}$	34.8 a-c	21.2 a-c	89.2 ab	59.3 bcd	134 b	71.4 c-e
$T_8 = SSP_{25} + RPC_{50} + PSB$	36.8 ab	19.9 b-d	94.2 ab	57.7 cd	147 ab	68.6 c-e
LSD value	*10.806*	*7.2287*	*21.549*	*7.1044*	*43.827*	*12.311*

Means in each column followed by the same letter(s) do not differ significantly at 0.05 probability according to LSD test. Whereas T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC, T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan.

Table 4: Comparative effects of PSBI and PEC with and without SSP on agronomic nutrient use efficiency in cotton

P source combinations	Agronomic nutrient use efficiency (mg mg^{-1})		
SSP-RPC-PSB	**N**	**P**	**K**
$T_1 = SSP_{100}$	19.7 c-e	26.3 c-e	39.5 c-e
$T_2 = SSP_{100} + PSB$	22.2 b	29.5 b	44.3 b
$T_3 = RPC_{50}$	17.5 e	23.4 e	35.2 e
$T_4 = RPC_{50} + PSB$	18.6 de	24.9 de	37.3 de
$T_5 = SSP_{50} + RPC_{50}$	22.4 ab	29.9 ab	44.9 ab
$T_6 = SSP_{50} + RPC_{50} + PSB$	24.7 a	32.9 a	49.4 a
$T_7 = SSP_{25} + RPC_{50}$	20.7 b-d	27.6 b-d	41.5 b-d
$T_8 = SSP_{25} + RPC_{50} + PSB$	21.3 bc	28.4 bc	42.6 bc
LSD value	*2.3584*	*3.1467*	*4.7174*

Means in each column followed by the same letter(s) do not differ significantly at 0.05 probability according to LSD test. Whereas T_1 = 100% from SSP, T_2 = 100% P from SSP + PSBI, T_3 = 50% P from PEC, T_4 = 50% P from PEC+ PSBI, T_5 = 50% P from SSP +50% P from PEC, T_6 = 50% P from SSP +50% P from PEC + PSBI, T_7 = 25% P from SSP +50% P from PEC, T_8 = 25% P from SSP +50% P from PEC + PSBI. A treatment without fertilizers and compost was also included in treatment plan.

Discussion

Calcareous soils in semi-arid to arid regions are deficient in phosphorus mainly because of rapid fixation or precipitation of applied phosphorus with Ca^{2+} and Mg^{2+} (Bargaz *et al.*, 2018) Resultantly, plant roots cannot use this unavailable form of phosphorus. Moreover, low organic matter contents in such soils badly lower P uptake in plants (Abd-Alla *et al.*, 2014). Deficient levels of phosphorus significantly affected in plant height, biomass and bolls per plant as were observed treatment T_1. A number of innovative and efficient technologies have been adopted either to reduce the fixation of applied P or solubilize the already fixed phosphorus (Vassilev *et al*., 2015). Phosphorus solubilizing microorganism produce organic acids to solubilize the fixed P (Krishnaraj and Dahale, 2014) which lowers the pH (Behera *et al.*, 2017). The acidification by microbial cells leads to the release of P anion by substitution of H^+ and Ca^{2+} (Trivedi and Sa, 2008; Behera et al., 2017). Contrary to treatment T_1 (application of SSP fertilizer alone), improved growth parameters such as plant height, number of bolls per plant, plant fresh and dry weight per plant in treatments having inoculation of PSB might be due to synergetic effect of mineral P and PSB inoculants. That is why; pots where PEC was applied had plants with better growth and yielding attributes than pots of SSP application alone.

The combined application of PSB inoculants and compost was found more efficient and effective approach in order to improve growth as well as nutrient uptakes. These improvements might be due to synergetic effect of PSB and compost because organic matter plays key role in sustainability of microbial population (Behera *et al*., 2017). Moreover, application of compost improves physical and chemical properties of soils and creates suitable environment for root growth and better nutrient uptake.

Phosphorus solubilizing bacteria solubilize the unavailable form of phosphorus, thus more phosphorus contents were found in plants of treatments T_5 and T_6, which subsequently gave rise to difference in seed-cotton yield in treated and control plants. Subsequently, the efficient use of SSP might occur owing to BPS. Estrada-Bonilla *et al.* (2017) also witnessed the same results and reported a rise in labile organic P level in treatment containing PSB inoculants. Similar findings were also reported by Billah and Bano (2015) who reported that inoculation of PSB was effective to release P from low-grade rock phosphate. In last decade, Afzal and Bano (2008) and Babana and Antoun (2006) also reported such improvement due to PSB inoculants. The key findings of this study suggest using rock phosphate as integral part of PSB and compost to correct the phosphorus deficiency in calcareous/alkaline soils.

Acknowledgments

The authors are thankful to Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad for providing rock phosphate-based P enriched compost and isolation of PSB used during the study.

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