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Original Article

Agronomic efficiency and profitability of cotton on integrated use of phosphorus and plant microbes

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Abstract

Cotton crop, plays a significant role in Pakistan's economy by ruling a prominent place in edible oil and local textile industry. Phosphorus (P) inaccessibility and deficiency of soil organic matter are the key restraints for low crop productivity in cotton. Therefore, a two years field study was designed during 2014-15, to explore the influence of phosphate solubilizing bacteria (PSB), farmyard manure (FYM), poultry manure (PM) and inanimate sources of P on various physiological, growth, yield and quality parameters of cotton crop at CCRI Multan. Field responses of seeds inoculated with two distinctive phosphate solubilizing bacteria (PSB) strains *viz*. S_0 = control, S_1 =strain-1, S_2 = strain-2 and eight organic, inorganic P sources *viz*., P_0= control, P_1 = 80 kg ha^{-1} P from inorganic source, P_2 = 80 kg ha^{-1} P from FYM, P_3 = 80 kg ha^{-1} P from PM, P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source, P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source, P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source, P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM were evaluated. Results revealed that inoculation of seeds with PSB and collective use of inorganic and organic sources of P had considerably increased the yield contributing attributes in cotton. However, the treatment P_7 (80 kg P ha^{-1} from PM + 40 kg P ha^{-1} from inorganic source) in coincidence with seeds inoculated with PSB (S_1) produced taller plant, maximum boll weight, significantly higher LAI and CGR. Significantly higher seed cotton yield, lint yield, fiber length and maximum BCR of 1.95 and 1.81 was also obtained from the P_7 treatment during both crop-growing seasons. In conclusion, combined use of 80 kg P ha^{-1} from PM + 40 kg P ha^{-1} from inorganic source and cotton seeds inoculated with strain-1 improved phosphorus uptake ensuing in greater consumption of photo-assimilates for maximum growth and yield.

Keywords: seed cotton, poultry manure, farmyard manure, phosphate solubilizing bacteria, fiber quality.

Eficiência e rentabilidade agronômica do algodão no uso integrado de fósforo e micróbios vegetais

Resumo

A safra de algodão, desempenha um papel significativo na economia do Paquistão, ao ocupar um lugar de destaque no óleo comestível e na indústria têxtil local. A inacessibilidade e a deficiência de fósforo (P) da matéria orgânica do solo são as principais restrições para a baixa produtividade das culturas em algodão. Portanto, um estudo de campo de dois anos foi desenvolvido durante 2014-15, para explorar a influência de bactérias solubilizantes de fosfato (PSB), esterco de capoeira (FYM), esterco de aves (PM) e fontes inanimadas de P sobre vários fatores fisiológicos, crescimento, rendimento e parâmetros de qualidade da cultura do algodão no CCRI Multan. Respostas de campo de sementes inoculadas com duas cepas distintas de bactérias solubilizantes de fosfato (PSB) viz. S0 = controle, S1 = cepa-1, S2 = cepa-2 e oito fontes orgânicas de P inorgânicas viz., P0 = controle, P1 = 80 kg ha-1 P de fonte inorgânica, P2 = 80 kg ha-1 P de FYM, P3 = 80 kg ha-1 P de PM, P4 = 40 kg ha-1 P de FYM + 40 kg ha-1 P de fonte inorgânica, P5 = 40 kg ha-1 P de PM + 40 kg ha-1 P de fonte inorgânica, P6 = 80 kg ha-1 P de FYM + 40 kg ha-1 P de fonte inorgânica, P7 = 80 kg ha-1 P de PM + 40 kg ha-1 P de fonte inorgânica e P8 = 40 Foram avaliados kg ha-1 P da FYM + 40 kg ha-1 P da PM. Os resultados revelaram que a inoculação de sementes com PSB e o uso coletivo de fontes inorgânicas e orgânicas de P aumentaram consideravelmente os atributos que contribuem para a produtividade no algodão. No entanto, o tratamento P7 (80 kg P ha-1 da PM + 40 kg P ha-1 da fonte inorgânica) em coincidência com sementes inoculadas com PSB (S1) produziu planta mais alta, peso máximo de cápsula, IAF e CGR significativamente maiores. Produtividade significativamente maior do algodão, rendimento de fiapos, comprimento da fibra e BCR máximo de 1,95 e 1,81 também foi obtida a partir do tratamento P7 durante as duas épocas de cultivo. Em conclusão, o uso combinado de 80 kg P ha-1 de PM + 40 kg P ha-1 de fonte inorgânica e sementes de algodão inoculadas com a cepa-1 melhoraram a captação de fósforo, resultando em maior consumo de foto assimilados para obter crescimento e produtividade máximos.

Palavras-chave: algodão de semente, estrume de aves, estrume de quintal, bactérias solubilizantes de fosfato, qualidade da fibra.

1. Introduction

Cotton (*Gossypium hirsutum* L.), the fiber plant is a principal cash crop, sown for both agricultural and industrial purposes in the tropical and temperate zones of the biosphere (Singh, 2004). It is predominantly used for lint production and its strength and potential to be adorned make it vital for textile stuffs (Jones and Kersey, 2002). Furthermore, it is the second most imperative source of edible oil in the world and major in Pakistan (Zhang, 2001). Cotton is the key source of employment for millions involved in production; processing, ginning, fabric industry and trade associated activities and contributes 60% of the foreign exchange earnings (Noreen et al., 2013). It contributes 0.8% share in gross domestic product and about 4.5% in agriculture value added products (Pakistan, 2018). It was grown on an area of 2.373 million hectares and produced 9.861 million bales with average production of 707 kg per hectare during 2018-19 (Pakistan, 2018). Pakistan being world's fourth largest fiber producer and third largest exporter of raw yarn and second prominent exporter of fiber in the world, per acre produce of cotton ranks thirteen in the world (Shuli et al., 2018). There is a huge gap between potential and the actual productivity of cotton. This gap is primarily due to cotton leaf curl virus diseases, severe insect pest attack, weeds invasion, atmospheric stresses such as high temperature and moisture stress during critical stages, less availability of quality of the seed, inappropriate planting techniques and ineffective managerial practices and limited supply of essential nutrients (Shuli et al., 2018; Arif et al., 2019).

Phosphorus is an essential element in nucleic acid and constituents of phospholipids in bio-membrane. It is also crucial for cellular energy transfer by means of protein phosphorylation and dephosphorylation, Pi is a basic regulator of signal transduction (Wu et al., 2005). Phosphorus scarcity adversely influences the nucleic acid, cellular membrane, leaf expansion, biosynthesis of photosynthetic pigments, dry matter production and other metabolic enzymes that finally declined the crop production up to 10-15% (Vance et al., 2003). Phosphorus is also a limited and non-renewable resource; existing assessments propose that economic supply of P may be rigorously exhausted over the next 300 years (Cordell and White, 2011). Improvement of P acquirement efficacy by mobilizing the residual soil P, as well as increasing the roots absorbing surface and acquisition ability for soil applied P to the plants is imperative for its sustainable management (Shen et al., 2013).

Collective use of organic and inorganic P sources is being considered the best way for increasing its accessibility to the cotton plants (Wang et al., 2008). The synergetic influence of organic with inorganic fertilizers improved the water holding capacity of soil, cation exchange capacity, soil aeration, phosphorus use efficiency (PUE) of applied fertilizer, soil nutrients availability, seed germination and plant growth rate which ultimately boosted up the final yield (Amanullah and Stewart, 2015). Furthermore, use of beneficial microbes (biofertilizers) such as phosphate solubilizing bacteria (PSB) as a seed inoculant, is competent of involvement in rhizosphere with agricultural crops can stimulate P accessibility to plants (Nico et al., 2012). As the beneficial microorganisms produce the organic acids which reduce the soil pH and improve the release of bounded P forms in the soil (Walpola and Yoon, 2012). PSB is not only vital for the reduction of the quantity of inorganic fertilizers and eco-friendly but also improves the crop efficiency (Yasmin and Bano, 2011).

However, the earlier studies conducted use both organic and chemical sources of P or PSB. Whereas collective usage of organic and chemical sources of P with PSB are rarely reported. It is hypothesized that collective use of organic and inorganic sources of phosphorus and seed inoculation with PSB would improve the growth attributes, yield and net returns from the cotton crop. Therefore, the existing research was planned keeping in view the objective to evaluate the role of PSB in enhancing the P uptake and increasing the productivity of cotton by exploiting distinctive sources of phosphorus.

2. Material and Methods

A field investigation was designed to assess the influence of P managing tactics on the growth, yield and fiber quality parameters of transgenic cotton at Central Cotton Research Institute (CCRI), Multan during 2014 and 2015. The experimental soil was silt loam having pH 8.0 and 8.09, organic matter 0.83% and 0.81%, EC 2.61 dS m^{-1} and 2.70 dS m^{-1}, total nitrogen 0.055% and 0.045%, available P 13.00 ppm and 11.60 ppm and available K 120.0 ppm and 112.0 ppm. Randomized Complete Block Design with factorial arrangement was used as experimental design and was repeated thrice. Experimental treatments comprised of two strains of PSM *viz*. S_0 = control, S_1 =strain-1, S_2 = strain-2 and eight organic, inorganic P sources *viz*. P_0= control, P_1 = 80 kg ha^{-1} P from inorganic source, P_2 = 80 kg ha^{-1} P from FYM, P_3 = 80 kg ha^{-1} P from PM, P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source, P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source, P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source, P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM.

A well-pulverized seedbed was made by cultivating the experimental soil three times. Beds and furrows were made with specific bed shaper and seeds of cotton cultivar CIM 602 manually dibbled. For optimum plant population, gap filling and thinning was practiced on 18^{th} and 32^{nd} days after sowing, respectively. Nitrogen fertilizer at 145 kg ha^{-1} was dispersed at 3 stages i.e. first at sowing time, second at the start of blooming and last at peak flowering stage. Potassium fertilizer was applied at 62 kg ha^{-1} at sowing time. Pre-emergence herbicide was applied along with four inter cultivations at 25, 40, 55 and 70 DAS to control weeds. Insect pests were controlled with spray assessments based on pest scouting. All other agronomic practices except fertilizer treatments were kept common for all experimental units. The crop was harvested when the cotton bolls were about 60% opened and growth and yield contributing traits data was documented by adopting prevailing techniques.

2.1. Observations

At the start of blooming, 10 randomly selected plants were tagged to measure the final plant height, sympodial branches, bolls plant^{-1} and mean boll weight. Manual harvesting of cotton was done twice from the central two rows of all experimental units to observe the seed cotton and lint yield per unit area during both growing seasons. Leaf Area Index (LAI) was computed by following the method used by Watson (1952).

Equation 1. $LAI = \left(leaf\ \ area / land\ \ area \right)$ (1)

Crop Growth Rate (CGR) was determined by adopting the procedure followed by Hunt (1978).

Equation 2. $CGR\left(g\ m^{-2} day^{-1} \right) = \left(W_2 - W_1 \right) / \left(T_2 - T_1 \right)$ (2)

where W_1 and W_2 are the total dry weights harvested at times T_1 and T_2, respectively.

Net Assimilation Rate (NAR) was also assessed by using the procedure advised by Hunt (1978).

Equation 3. $NAR\left(g\ m^{-2} day^{-1} \right) = Total\ dry\ matter / leaf\ \ area\ duration$ (3)

Fiber quality parameters were determined according to procedure proposed by Sundaram et al. (2002).

Collected data regarding various parameters was statistically analyzed by employing computer based software M STAT- C. Differences among treatments means were compared at probability level of 5% by using DMR test (Steel et al., 1997).

3. Results

Data concerning leaf area index (LAI) noted at various growth stages varied significantly due to interactive impact of PSB strains and distinctive P sources during both years (Figure 1a). Cotton seeds inoculated with strain-1 of PSB produced significantly higher LAI with the integrated use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from chemical source in 2014 and 2015.

Significant differences were recorded about crop growth rate (CGR) data at various growth phases of crop during both growing seasons (Figure 1b). Almost similar data trends were observed for CGR as cotton seeds inoculated with strain-1 of PSB produced significantly higher CGR with the integrated use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source during both study years.

Net assimilation rate (NAR) data was documented at distinctive crop stages varied significantly (Figure 1c). Integrated use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source in cotton field inoculated with both strains of PSB produced higher effects regarding NAR during both years.

The use of PSB strains and distinctive sources of P was noticed to affect plant height data significantly during both growing seasons (Figure 2a). Cotton seeds inoculated with strain-1 produced significantly taller plants with the application of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic fertilizer.

Sympodial branches reflect the combined response of genetic makeup and environmental conditions. An increase in this attribute may result in more bolls per plant, which

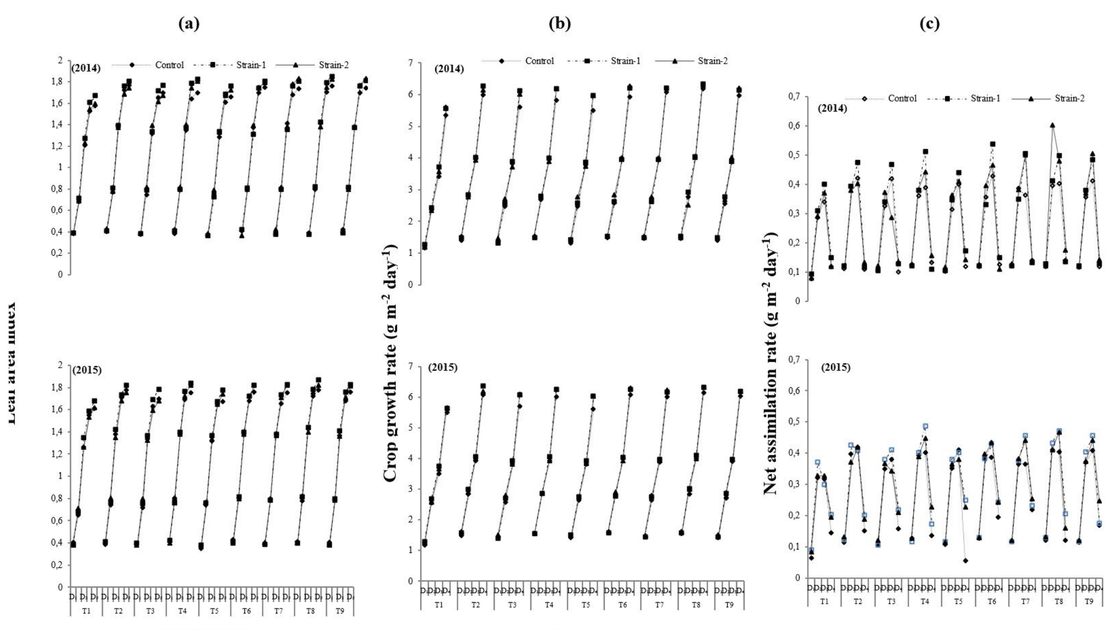

Figure 1. Influence of PSB strains and P sources on LAI (a) CGR (b) and NAR (c) of cotton.

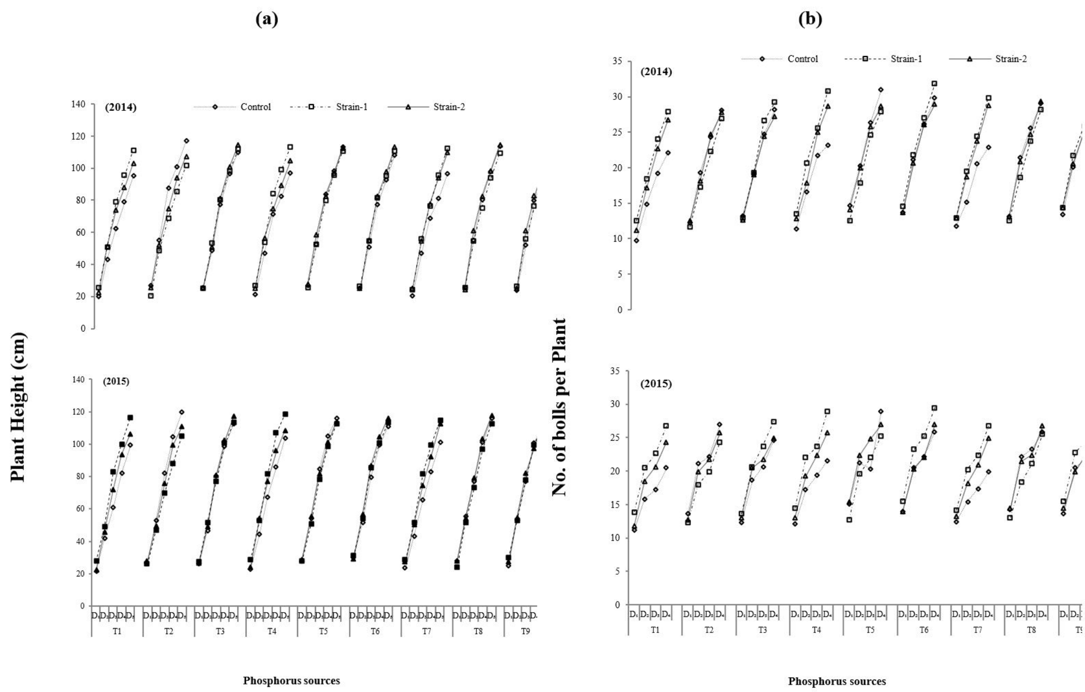

Figure 2. Influence of PSB strains and P sources plant height (a) number of bolls per plant (b) of cotton.

eventually enhance the productivity. The data concerning the number of sympodial branches denoted significant interactive effects between strains of PSB and various organic and inorganic sources of P during both years (Table 1). Superior sympodial branches were noted with the integrated use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source and where seed inoculation with strain-1of PSB was done during first growing season. While minimum sympodial branches were verified in control treatment. Whereas, higher number of sympodial branches was observed where 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source was followed in cotton field inoculated with strain-1 of PSB in 2015. Significantly lower sympodial branches were noted from control plots .

Number of bolls per plant was significantly influenced at various growth periods by PSB strains and distinctive sources of P during both years (Figure 2b). Integrated use of 80 kg ha^{-1} P from PM + 40 kg P ha^{-1} from inorganic source in cotton field inoculated with strain-1of PSB produced superior number of bolls at distinctive phases of plant sampling as compared to other treatments.

The data analysis showed significant effects of distinctive sources of P, PSB strains and their interaction on mean boll weight of cotton (Table 1). Integrated use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source in cotton field inoculated with strain-1 produced highest boll weight against the lowest boll weight noted in control treatment during Kharif 2014. While, collective use of 80 kg ha^{-1} from P FYM + 40 kg ha^{-1} P from inorganic source along with similar bacterial strain produced maximum boll weight compared with minimum boll weight in control treatment in 2015.

Seed cotton yield data exhibited significant effects of distinctive organic and inorganic phosphorus sources, PSB strains and their interaction (Table 1). Cotton seeds inoculated with strain-1 produced maximum seed cotton yield with combined use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source. Lowest seed cotton yield was documented from control plots.

Data exposed significant influence of PSB strains, sources of applied P and their interaction on cotton lint yield (Table 2). Cotton seed inoculated with strain-1 and supplied 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source produced maximum lint yield against the minimum lint yield recorded in control treated plots during both years.

Data indicated that among distinctive sources of P, maximum fiber fineness was recorded with the use of 80 kg ha^{-1} P from inorganic source and collective use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source against the minimum fiber fineness was documented in control plots during 2014 (Table 2). However, non-significant differences were observed for different applied P sources strains of PSB as well as their interaction regarding this attribute during 2015.

Data revealed that use of 80 kg P ha^{-1} from PM + 40 kg ha^{-1} P from inorganic source along with inoculation strain-1 produced maximum fiber uniformity in 2014 and 2015 (Table 2). While minimum fiber uniformity observed under control treatment.

Significantly higher fiber length was noted with the use of 80 kg ha^{-1} P from PM + 40 kg P ha^{-1} from inorganic source during 2014. Seed cotton inoculated with strain-1 and supplied 80 kg P ha^{-1} from inorganic source produced

Table 1. Influence of PSB strains and P sources yield and yield contributing attributes of Bt cotton.

Treatments	Sympodial branches		Mean Boll weight (g)		Seed cotton yield (kg ha^{-1})	
	2014	2015	2014	2015	2014	2015
Different sources of phosphorus						
P_0	21.92d	22.36b	2.87c	2.78b	2601.6c	2286.1d
P_1	26.26ac	27.71a	2.95ac	2.91ab	3487.8ab	3208.9ab
P_2	24.68cd	25.23ab	2.89bc	2.83ab	3252.7b	2828.8c
P_3	26.88ac	27.32a	2.97ab	2.91ab	3494.1ab	3167.2ab
P_4	25.41bc	26.30a	2.91ac	2.87ab	3225.2b	2883.9bc
P_5	26.61ac	27.61a	2.97ab	2.94a	3390.6ab	3114.1ac
P_6	27.83ab	28.06a	2.98ab	2.94a	3526.1ab	3039.2bc
P_7	28.72a	27.04a	3.00 a	2.96a	3695.6a	3376.0a
P_8	26.97ac	28.19a	2.96ac	2.92a	3404.7ab	3062.7ac
LSD	2.8121	3.8839	0.0946	0.1390	357.48	329.67
Different strains of phosphate solubilizing bacteria						
S_0	25.69	26.24	2.91b	2.84b	3165.2b	2849.1b
S_1	26.79	27.42	2.99a	2.95a	3475.2a	3142.2a
S_2	25.95	26.58	2.93b	2.90ab	3385.6a	2997.7ab
LSD	n.s	n.s	0.0546	0.0802	206.39	190.34
Interaction						
P_0S_0	21.11e	22.44bc	2.83d	2.70c	2510.5f	2186.8h
P_0S_1	22.53ce	23.20ac	2.90bd	2.84ac	2683.8df	2438.1fh
P_0S_2	22.12de	21.45c	2.87cd	2.81ac	2610.4ef	2233.3gh
P_1S_0	25.60ae	26.30ac	2.91bd	2.84ac	3246.3bd	3053.6ae
P_1S_1	26.89a	28.55ab	2.99ad	2.95ab	3694.3ac	3416.0ac
P_1S_2	26.31ad	27.64ac	2.96ad	2.94ab	3522.8ac	3157.1ae
P_2S_0	23.64be	24.31ac	2.87cd	2.79bc	3077.7cf	2722.6eh
P_2S_1	25.38ae	25.71ac	2.91bd	2.84ac	3343.0ac	2910.9bf
P_2S_2	25.01ae	25.68ac	2.90bd	2.87ac	3337.2ac	2852.8cf
P_3S_0	26.74ad	27.07ac	2.94ad	2.83ac	3290.0bd	3023.3ae
P_3S_1	27.88ab	27.55ac	3.02ac	2.99ab	3749.9ab	3458.6ab
P_3S_2	26.02ad	27.35ac	2.95ad	2.9abc	3442.5ac	3019.8ae
P_4S_0	24.79ae	26.13ac	2.88cd	2.83ac	3097.7cf	2760.6eg
P_4S_1	24.75ae	27.37ac	2.94ad	2.90ac	3273.2bd	2938.6bf
P_4S_2	26.70ad	25.41ac	2.92ad	2.89ac	3304.6bc	2952.6bf
P_5S_0	25.60ae	25.94ac	2.94ad	2.90ac	3252.5bd	2982.5bf
P_5S_1	27.88ab	29.21a	3.00ac	2.98ab	3436.8ac	3209.5ae
P_5S_2	26.35ad	27.69ac	2.96ad	2.94ac	3482.5ac	3150.3ae
P_6S_0	27.55ab	26.89ac	2.94ad	2.88ac	3334.7ac	2813.6df
P_6S_1	28.17ab	28.84ab	3.06ab	3.03a	3664.7ac	3137.3ae
P_6S_2	27.77ab	28.44ab	2.93ad	2.90ac	3579.0ac	3166.6ae
P_7S_0	28.89a	27.89ac	2.97ad	2.93ac	3480.9ac	3204.2ae
P_7S_1	29.10a	28.44ab	3.09a	3.02ab	3933.9a	3560.5a
P_7S_2	28.17ab	27.50ac	2.94ad	2.92ac	3672.0ac	3363.2ad
P_8S_0	27.26ac	28.60ab	2.93ad	2.90ac	3197.0be	2894.5bf
P_8S_1	26.62ad	27.95ac	3.02ac	2.97ab	3497.3ac	3210.1ae
P_8S_2	27.03ac	28.03ac	2.93ad	2.89ac	3519.8ac	3083.3ae
LSD	4.8707	6.7271	0.1639	0.2407	619.17	571.01

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. LSD: Least Significant Difference; n.s: Non Significant. Means followed by same letters (s) are not significantly different at $P < 0.05$.

Table 2. Influence of PSB strains and P sources fiber and fiber quality attributes of Bt cotton.

Treatments	Lint yield (kg ha^{-1})		fiber fineness (µ inch^{-1})		fiber uniformity	
	2014	2015	2014	2015	2014	2015
Different sources of phosphorus						
P_0	1015.3d	915.3c	3.91b	3.99	82.35b	82.30b
P_1	1388.4ac	1288.4ab	4.14a	4.18	82.64a	82.67a
P_2	1294.9c	1161.6ab	4.05ab	4.08	82.52ab	82.54a
P_3	1403.7ac	1281.5ab	4.10ab	4.16	82.62a	82.63a
P_4	1283.1c	1172.0b	4.04ab	4.07	82.52ab	82.49ab
P_5	1358.0bc	1235.8b	4.05ab	4.10	82.59a	82.64a
P_6	1439.4ab	1250.5ab	4.05ab	4.04	82.54ab	82.59a
P_7	1506.5a	1384.3a	4.14a	4.16	82.66a	82.69a
P_8	1377.2ac	1238.3b	4.09ab	4.10	82.60a	82.59a
LSD	138.96	137.58	0.1863		0.2129	0.2068
Different strains of phosphate solubilizing bacteria						
S_0	1256.5b	1152.1b	4.02	4.06	82.52b	82.52
S_1	1391.5a	1261.8a	4.07	4.12	82.65a	82.62
S_2	1374.2a	1228.6ab	4.07	4.11	82.51b	82.57
LSD	80.23	79.433	n.s	n.s	0.1229	n.s
Interaction						
P_0S_0	972.2f	865.5g	3.90	3.98	82.30d	82.24d
P_0S_1	1039.9ef	973.3eg	3.92	4.03	82.40bd	82.35bd
P_0S_2	1033.9ef	907.2fg	3.93	3.96	82.34cd	82.30cd
P_1S_0	1249.9ce	1216.6ad	4.09	4.19	82.53ad	82.58ad
P_1S_1	1479.9ac	1379.9ac	4.14	4.18	82.72ab	82.70ab
P_1S_2	1435.3ad	1268.6ad	4.18	4.16	82.66ad	82.72a
P_2S_0	1222.6de	1122.6df	3.99	4.04	82.45ad	82.49ad
P_2S_1	1329.9bd	1196.5ae	4.06	4.11	82.63ad	82.60ac
P_2S_2	1332.3bd	1165.7ce	4.11	4.10	82.47ad	82.53ad
P_3S_0	1296.3bd	1229.7ad	4.14	4.17	82.64ad	82.60ac
P_3S_1	1509.5ab	1376.2ac	4.07	4.19	82.67ad	82.71ab
P_3S_2	1405.3ad	1238.6ad	4.10	4.13	82.55ad	82.60ac
P_4S_0	1207.0df	1107.0df	3.94	3.99	82.39bd	82.36bd
P_4S_1	1309.0bd	1209.0ae	4.07	4.10	82.67ac	82.61ac
P_4S_2	1333.3bd	1200.0ae	4.10	4.13	82.48ad	82.51ad
P_5S_0	1291.9bd	1191.9ae	3.98	4.01	82.57ad	82.62ac
P_5S_1	1374.5ad	1241.2ad	4.05	4.08	82.69ac	82.66ab
P_5S_2	1407.6ad	1274.3ad	4.13	4.19	82.52ad	82.66ab
P_6S_0	1340.4bd	1173.8be	4.04	4.03	82.59ad	82.63ac
P_6S_1	1487.2ac	1253.9ad	4.00	4.04	82.53ad	82.58ad
P_6S_2	1490.6ab	1324.0ad	4.10	4.07	82.51ad	82.55ad
P_7S_0	1412.9ad	1312.9ad	4.09	4.11	82.62ad	82.66ab
P_7S_1	1594.9a	1428.2a	4.18	4.21	82.78a	82.73a
P_7S_2	1511.9ab	1411.9ab	4.16	4.14	82.59ad	82.68ab
P_8S_0	1315.6bd	1148.9ce	4.01	4.04	82.56ad	82.53ad
P_8S_1	1398.3ad	1298.3ad	4.11	4.16	82.71ab	82.65ac
P_8S_2	1417.6ad	1267.6ad	4.16	4.11	82.52ad	82.58ad
LSD	240.68	238.30	n.s	n.s	0.3688	0.3581

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. LSD: Least Significant Difference; n.s: Non Significant. Means followed by same letters (s) are not significantly different at $P < 0.05$.

highest fiber length during 2015 (Table 3). Lowest fiber length noted from control plots during both years.

Cotton seeds inoculated with strain-2 and fertilized with 80 kg ha^{-1} P from PM produced highest fiber elongation during both growing seasons (Table 3). Lowest fiber elongation was documented in control plots.

Fiber strength determines the yarn spin ability, as weak fibers are hard to handle during manufacturing process (Saleem et al., 2010). Analysis of the data exhibited significant impact of P sources and interaction between PSB strains and distinctive sources of P on fiber strength of cotton during 2014 (Table 3). Use of 80 kg ha^{-1} P from inorganic source produced significantly higher fiber strength during 2014 while cotton seeds inoculated with PSB strain-1 and applied 80 kg ha^{-1} from inorganic P source produced highest fiber strength during 2015. Lowest fiber strength documented in control plots during both years.

The realization of successful production techniques relies on two factors; first it should be easy to implement, second it should be inexpensive. The economics of the techniques is recorded on the basis of BCR that how much profit is accessible on the cost. Pursuing through the BCR considering treatments interaction, maximum BCR of 1.95 and 1.81 with net income of Rs. 1,43,560/- and 1,16,503/- were received with the use of 80 kg ha^{-1} P from PM + 40 kg P ha^{-1} from inorganic source in cotton raised with inoculated seeds of strain-1 during 2014 and 2015, respectively (Table 4). While minimum BCR was noted from control plots.

Table 3. Influence of PSB strains and P sources fiber quality attributes of Bt cotton.

Treatments	Fiber length (mm)		Fiber elongation (%)		Fiber strength (g tex^{-1})	
	2014	2015	2014	2015	2014	2015
Different sources of phosphorus						
P_0	26.34b	26.36b	6.34c	6.36b	30.42b	30.42b
P_1	26.72a	26.79a	6.71ab	6.71a	30.86a	30.88a
P_2	26.77a	26.74a	6.63ab	6.62a	30.70a	30.71a
P_3	26.74a	26.77a	6.82a	6.75a	30.78a	30.78a
P_4	26.69a	26.68a	6.60b	6.63a	30.69a	30.73a
P_5	26.74a	26.79a	6.73ab	6.72a	30.77a	30.79a
P_6	26.63a	26.69a	6.63ab	6.63a	30.70a	30.71a
P_7	26.80a	26.81a	6.72ab	6.73a	30.84a	30.82a
P_8	26.71a	26.79a	6.66ab	6.68a	30.74a	30.77a
LSD	0.2187	0.2205	0.2092	0.1878	0.2113	0.2015
Different strains of phosphate solubilizing bacteria						
S_0	26.71	26.72	6.59b	6.60b	30.74	30.73
S_1	26.63	26.73	6.60b	6.62ab	30.71	30.75
S_2	26.70	26.69	6.74a	6.72a	30.71	30.73
LSD	n.s	n.s	0.1208	0.1084	n.s	n.s
Interaction						
P_0S_0	26.26d	26.33d	6.28e	6.32e	30.34d	30.38d
P_0S_1	26.32cd	26.38bd	6.33de	6.39ce	30.43cd	30.49bd
P_0S_2	26.43bd	26.37cd	6.41ce	6.35de	30.49bd	30.39cd
P_1S_0	26.74ab	26.80a	6.70bc	6.67ac	30.92a	30.85a
P_1S_1	26.67ac	26.84a	6.66bd	6.71ac	30.90a	30.94a
P_1S_2	26.75ab	26.72ac	6.77ac	6.74ab	30.78ac	30.85a
P_2S_0	26.82a	26.75ab	6.53be	6.60ae	30.67ad	30.70ad
P_2S_1	26.73ab	26.77a	6.69bd	6.62ae	30.65ad	30.69ad
P_2S_2	26.75ab	26.69ad	6.67bd	6.64ae	30.78ac	30.74ab
P_3S_0	26.88a	26.83a	6.72ac	6.67ac	30.79ac	30.76ab
P_3S_1	26.69ac	26.79a	6.67bd	6.69ac	30.78ac	30.80ab
P_3S_2	26.66ac	26.70ad	7.07a	6.89a	30.76ac	30.79ab
P_4S_0	26.57ad	26.64ad	6.57be	6.60ae	30.67ad	30.72ad
P_4S_1	26.64ac	26.71ac	6.54be	6.51be	30.65ad	30.70ad

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. LSD: Least Significant Difference; n.s: Non Significant. Means followed by same letters (s) are not significantly different at P <0.05.

Table 3. Continued...

Treatments	Fiber length (mm)		Fiber elongation (%)		Fiber strength (g tex^{-1})	
	2014	2015	2014	2015	2014	2015
P_4S_2	26.85a	26.68ad	6.69bd	6.79ab	30.75ac	30.78ab
P_5S_0	26.73ab	26.78a	6.70bc	6.67ac	30.86ab	30.83ab
P_5S_1	26.72ab	26.78a	6.66bd	6.70ac	30.73ac	30.79ab
P_5S_2	26.77ab	26.80a	6.82ab	6.78ab	30.72ac	30.76ab
P_6S_0	26.64ad	26.67ad	6.59be	6.62ae	30.65ad	30.68ad
P_6S_1	26.60ad	26.70ad	6.54be	6.58ae	30.77ac	30.74ab
P_6S_2	26.65ac	26.71ac	6.75ac	6.69ac	30.69ad	30.71ad
P_7S_0	26.90a	26.84a	6.67bd	6.65ad	30.92a	30.86a
P_7S_1	26.70ab	26.77a	6.69bc	6.74ab	30.84ab	30.81ab
P_7S_2	26.78ab	26.82a	6.79ab	6.81ab	30.78ac	30.80ab
P_8S_0	26.86a	26.85a	6.58be	6.61ae	30.88a	30.81ab
P_8S_1	26.62ad	26.80a	6.63be	6.67ad	30.69ad	30.77ab
P_8S_2	26.66ac	26.72ac	6.77ab	6.76ab	30.66ad	30.73ac
LSD	0.3789	0.3819	0.3624	0.3253	0.3659	0.3489

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. LSD: Least Significant Difference; n.s: Non Significant. Means followed by same letters (s) are not significantly different at P <0.05.

Table 4. Economic analysis of cotton as affected by PSB strains and phosphorus sources during the year 2014 and 2015.

	2014					2015				
	Cost that vary	Total cost	Gross income	Net income	BCR	Cost that vary	Total cost	Gross income	Net income	BCR
Different sources of phosphorus										
P_0	15610	124250	195120	70870	1.57	13717	122357	171457	49101	1.40
P_1	32405	141045	261585	120540	1.85	30731	139371	240667	101296	1.73
P_2	27116	135756	243953	108196	1.80	24573	133213	212160	78947	1.59
P_3	29465	138105	262057	123953	1.90	27503	136143	237540	101397	1.74
P_4	28890	137530	241890	104360	1.76	26842	135482	216293	80810	1.60
P_5	30333	138973	254295	115322	1.83	28674	137314	233557	96244	1.70
P_6	34496	143136	264458	121322	1.85	31574	140214	227940	87726	1.63
P_7	36413	145053	277170	132117	1.91	34495	143135	253200	110065	1.77
P_8	28478	137118	255353	118234	1.86	26426	135066	229702	94636	1.70
Different strains of phosphate solubilizing bacteria										
S_0	18991	127631	237390	109759	1.86	17095	125734.6	213683	87948	1.70
S_1	25851	134491	260640	126149	1.94	23853	132493	235665	103172	1.78
S_2	25314	133954	253920	119966	1.90	22986	131626	224827	93201	1.71
Interaction										
$P_0 S_0$	15063	123703	188287	64585	1.52	13121	121761	164010	42249	1.35
$P_0 S_1$	21103	129743	201285	71542	1.55	19629	128269	182857	54589	1.43
$P_0 S_2$	20662	129302	195780	66478	1.51	18400	127040	167497	40458	1.32
$P_1 S_0$	30956	139596	243473	103877	1.74	29800	138440	229020	90580	1.65
$P_1 S_1$	38644	147284	277073	129789	1.88	36974	145614	256200	110586	1.76
$P_1 S_2$	37615	146255	264210	117955	1.81	35421	144061	236783	92722	1.64
$P_2 S_0$	26066	134706	230827	96121	1.71	23936	132576	204195	71619	1.54
$P_2 S_1$	32658	141298	250725	109427	1.77	30065	138705	218317	79612	1.57

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. BCR: Benefit Cost Ratio; LSD: Least Significant Difference. Means followed by same letters (s) are not significantly different at P <0.05.

Table 4. Continued...

	2014					2015				
	Cost that vary	Total cost	Gross income	Net income	BCR	Cost that vary	Total cost	Gross income	Net income	BCR
$P_2 S_2$	32623	141263	250290	109027	1.77	29717	138357	213960	75603	1.55
$P_3 S_0$	28240	136880	246750	109870	1.80	26640	135280	226747	91468	1.68
$P_3 S_1$	35999	144639	281242	136603	1.94	34252	142892	259395	116503	1.81
$P_3 S_2$	34155	142795	258187	115392	1.81	31619	140259	226485	86226	1.61
$P_4 S_0$	28125	136765	232327	95562	1.70	26103	134743	207045	72302	1.54
$P_4 S_1$	34178	142818	245490	102672	1.72	32171	140811	220395	79584	1.57
$P_4 S_2$	34367	143007	247845	104838	1.73	32255	140895	221445	80550	1.57
$P_5 S_0$	29504	138144	243937	105793	1.77	27884	136524	223687	87163	1.64
$P_5 S_1$	35610	144250	257760	113510	1.79	34246	142886	240713	97827	1.69
$P_5 S_2$	35884	144524	261187	116663	1.81	33891	142531	236273	93742	1.66
$P_6 S_0$	33347	141987	250103	108115	1.76	30221	138861	211020	72159	1.52
$P_6 S_1$	40327	148967	274853	125885	1.85	37163	145803	235298	89495	1.61
$P_6 S_2$	39813	148453	268425	119972	1.81	37339	145979	237495	91516	1.63
$P_7 S_0$	35124	143764	261067	117303	1.81	33464	142104	240315	98211	1.69
$P_7 S_1$	42842	151482	295043	143560	1.95	40602	149242	267037.5	117795	1.79
$P_7 S_2$	41271	149911	275400	125489	1.84	39418	148058	252240	104182	1.70
$P_8 S_0$	27232	135872	239775	103903	1.76	25417	134057	217087	83030	1.62
$P_8 S_1$	34034	142674	262297	119624	1.84	32311	140951	240757	99807	1.71
$P_8 S_2$	34169	142809	263985	121176	1.85	31550	140190	231247	91058	1.65

Whereas S_0 = control; S_1 =strain-1; S_2 = strain-2; P_1 = 80 kg ha^{-1} P from inorganic source; P_2 = 80 kg ha^{-1} P from FYM; P_3 = 80 kg ha^{-1} P from PM; P_4 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_5 = 40 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; P_6 = 80 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from inorganic source; P_7 = 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source; and P_8 = 40 kg ha^{-1} P from FYM + 40 kg ha^{-1} P from PM. BCR: Benefit Cost Ratio; LSD: Least Significant Difference. Means followed by same letters (s) are not significantly different at $P < 0.05$.

4. Discussion

Cotton plants demand optimum quantity of phosphorus from germination to maturity as it develops numerous mechanism of plant that encourages the root growth, strengthens the stem, improves the flower and boll development (Saleem et al., 2010). Therefore, multiple approaches were adopted to increase phosphorus availability in present study. Cotton seeds inoculated with strain-1 of PSB produced significantly higher growth attributes with the use of 80 kg ha^{-1} P from PM + 40 kg ha^{-1} P from inorganic source. It might be attributed that by enhancing phosphorus accessibility in cotton crop will ultimately enhance the plant growth with higher LAI (Arya and Singh, 2001). Similarly use of integrated sources of phosphorus helped for more expansion of leaves, increased light interception, enhanced plant height, higher CGR, NAR and enhanced the sympodial branches (Mandal and Sinha, 2004). The NAR monitored an increasing trend during the early phases of cotton growth and reduced subsequently. This might be due to higher respiration of leaves in comparison to photosynthesis and reciprocal shadowing of leaves and subsequently reduced mobilization of photo-assimilates from leaves towards bolls, which minimized the NAR. Araei and Mojaddam (2014) documented that organic manures improved the rate of cytokinin and chlorophyll contents in crops, which eventually enhanced the NAR.

Collective use of organic and inorganic P sources improved the cotton growth and productivity as compared with the sole applications (Ghosh et al., 2006). It might be due to the fact that integrative use of P sources enhanced the accessibility of water holding capacity, soil applied nutrients, stimulation of soil microbial biomass, blockage of P absorbing sites in the soil and boosted rates of mineralization whereas higher dose of chemical fertilizers alone could probably hurt the roots by salts accumulation around them (Dekissa et al., 2008). This eventually improves the synthesis of number of bolls due to the greater root length and assists in higher P uptake ensuing in more consumption of assimilates for bolls development. Soil dwelling bacteria have the potential of synthesizing plant hormones which might be liable for enhancement of plant-microbial interaction and for more nutrient uptake thus ultimately enhances the seed cotton and fiber quality parameters by promoting overall crop growth (Saleem et al., 2010). Besides P-solubilization different strains of PSB also produced phytohormones thus improved the crop productivity (Sundaram et al., 2016).

5. Conclusion

The organic fertilizers studied provide macro and micronutrients, they can improve cotton productivity without the use of chemical fertilizers. However, the combined application of poultry manure and inorganic sources of phosphorus in cotton created with inoculated seeds of strain-1 produced a significantly higher yield with the maximum cost-benefit ratio. It helps to reduce the use of inorganic fertilizers and promotes sustainable agriculture.

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