Plant Archives Vol. 25, No. 2, 2025 pp. 2182-2188 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.312

EFFECT OF PHOSPHORUS LEVELS AND PSB STRAINS ON GROWTH, YIELD AND NUTRIENT UPTAKE OF SOYBEAN (*GLYCINE MAX* L.)

Akhila G.[1*], Raghuveer M.[2], Sri Ranjitha P.[3] and Krishna Chaitanya A.[4]
[1]Department of Agronomy, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar – 500030, Telangana, India
[2]Krishi Vignan Kendra, Adilabad, Professor Jayashankar Telangana Agricultural University – 504001, Telangana, India
[3]Agricultural Polytechnic (APT), Professor Jayashankar Telangana Agricultural University, Jogipet – 502273, Telangana, India
[4]Regional Sugarcane and Rice research station, Professor Jayashankar Telangana Agricultural University, Rudrur – 503188, Telangana, India
Corresponding author E-mail: gopannagariakhilareddy@gmail.com
(Date of Receiving : 22-07-2025; Date of Acceptance : 09-10-2025)

ABSTRACT

A field experiment was carried out in *kharif*, 2024 at Agricultural Research Station, Adilabad, to study the effect of phosphorus levels and PSB strains on growth, yield and nutrient uptake of soybean. The soil of the experimental site was clay-textured, slightly alkaline in reaction, with medium organic carbon content. Low in available nitrogen, medium in available phosphorus and high in available potassium. The experiment was laid out in a factorial randomized block design with three replications. Factor A included, P_0: Control; P_1: 20 kg P_2O_5 ha^{-1}; P_2: 40 kg P_2O_5 ha^{-1}; and P_3: 60 kg P_2O_5 ha^{-1}. Factor B included B_1: uninoculated; B_2: *Bacillus subtilis* and B_3: *Pseudomonas flourescens*. Significantly higher growth parameters, yield, nutrient content and uptake, as well as soil microbial and enzymatic activities were recorded with the application of 60 kg P_2O_5 ha^{-1}. The inoculation of *Bacillus subtilis* PSB strain recorded higher growth parameters, yield, nutrient content and uptake, soil microbial and enzymatic activities. Significantly higher cost of cultivation and net returns were recorded with 60 kg P_2O_5 ha^{-1} and inoculation of *Bacillus subtilis*. The interaction of 60 kg P_2O_5 with *Bacillus subtilis* recorded higher root biomass.
Keywords : Soybean, Phosphorus, Phosphorus solubilizing bacteria, Yield

Introduction

Soybean (*Glycine max* L.) is often called a “golden bean,” “miracle crop,” and “yellow jewel”. It contains about 20–22% oil and 40–44% protein, making it one of the most affordable sources of good-quality protein (Virk *et al.*, 2023). The Ministry of Agriculture and Farmers Welfare of India estimates soybean production in India for 2025 at 151.32 lakh tonnes. This is higher than the previous year's production of 130.62 lakh tonnes. Maharashtra is the leading state in soybean production (Department of Agriculture & Farmers Welfare, 2024).

Soybean thrives in sandy loam to clay soils, particularly when the pH ranges between 5.5 and 7.0. Soybean grows quickly and needs more nutrients than other legumes. While fertilizers help meet these high nutrient demands, using them continuously and in an unbalanced way can harm soil health (Virk *et al.*, 2023). After nitrogen, phosphorus (P) is the second most important nutrient for plant development (Alayar *et al.*, 2020). Phosphorus is involved in essential biological processes such as photosynthesis, respiration, and protein activation through phosphorylation. It also acts as a structural component of energy-transfer molecules like ATP and NADPH, in the Calvin cycle during photosynthesis (Hashida and Yamada, 2019). Root improvement, stalk and stem vigor, flower and seed formation, crop production, crop maturity and resistance to plant pests and diseases are the attributes associated with phosphorus availability. Phosphorus is needed in relatively large amounts by legumes for growth and has been reported to promote leaf area, biomass, yield, nodule number and nodule mass in different legumes (Chaudhary *et al*., 2015).

Phosphate-solubilizing bacteria (PSB), as a promising P solubilizer, can potentially raise the productivity of agronomic crops in agroecological niches (Tian *et al*., 2021). Phosphorus-solubilizing bacteria secrete organic acids like citric acid, fumaric acid, malic acid, and phosphatase enzyme activity, which are responsible for phosphorus solubilization. These strains *of Pseudomonas, Bacillus, Aspergillus, Penicillium,* etc., are some known phosphate solubilizers (Shrivastava *et al.,* 2018). PSBs transform the soil-bound phosphorus into more accessible forms for plants and increase the bioavailability of nutrients. Microbes by phosphorus cycling facilitate the mineralization of organic phosphorus, solubilizing insoluble inorganic forms, and enhancing plant uptake (Pang *et al*., 2024).

Materials and Methods

A field experiment was conducted to determine the effect of phosphorus levels and PSB strains on growth, yield and nutrient uptake of soybean (*Glycine max* (L.)) during *kharif* 2024 at Agricultural Research Station, Adilabad. The field is in Telangana State's Northern Zone and is 264 meters above mean sea level (MSL), 19º 39´ N latitude and 78º 32´ E longitude. The soil of the experimental site was Clay textured, slightly alkaline (7.79), non-saline (0.19 dS m^{-1}), medium organic carbon content (0.65%), low nitrogen availability (164 kg ha^{-1}), medium phosphorus availability (48.6 kg ha^{-1}) and high potassium availability (265 kg ha^{-1}). Recommended dose is 50:60:40 kg ha^{-1} of N, P_2O_5, K_2O. At the time of sowing, seed treatment was done with *Bacillus subtilis* (10 ml kg^{-1} seed) and *Pseudomonas flourescens* (10 ml kg^{-1} seed) with 5% jaggery. The seeds were dried in the shade and sown immediately after drying. The soybean variety used is AISb-50.

The experiment was laid out in FRBD (Factorial randomized block design) consisting four levels of Phosphorus P_0, control; P_1, 20 kg P_2O_5 ha^{-1}; P_2, 40 kg P_2O_5 ha^{-1}; and P_3, 60 kg P_2O_5 ha^{-1} and three levels of PSB strains B_1, uninoculated; B_2, *Bacillus subtilis* and B_3, *Pseudomonas flourescens*, with a total number of twelve treatments with three replications.

Statistical analysis of the data was carried out using analysis of variance (ANOVA) appropriate for a factorial randomized block design (FRBD), following the methodology outlined by Gomez and Gomez (1984). Results were interpreted at a 5% level of significance (P = 0.05). For parameters showing significant differences in the F-test, the critical difference (CD) was calculated to enable comparison among treatment means.

Results and Discussion

Effect of phosphorus levels

As shown in table 1, the initial and final plant population was higher with the application of 60 kg P_2O_5 ha^{-1} over rest of phosphorus levels. The increase in phosphorus levels linearly increased plant height (25.2, 54.7, 63.1 and 60.9 cm) and dry matter accumulation (4.3, 15.5, 19.6 and 19.9 g) was significantly higher with 60 kg P_2O_5 ha^{-1} found to be at par with 40 kg P_2O_5 ha^{-1} at 30 DAS, 60 DAS, 90 DAS and at maturity, respectively. The significantly higher root biomass was observed with 60 kg P_2O_5 ha^{-1} (0.81, 2.51, 3.09 and 3.97 g) at 30, 60, 90 DAS and at the maturity stage of the crop over all other phosphorus levels, respectively. This might be due to an adequate phosphorus supply, which enhanced root development, elongation, branching, and overall root mass, allowing better growth parameters. Kaur *et al.* (2023), Haqmal *et al.* (2023) and Feng *et al.* (2021) also observed similar results.

Data pertaining (table 2) to the plots fertilized with 60 kg P_2O_5 ha^{-1} attained 50% emergence (5.0 DAS), 50% flowering (44.2 DAS) and maturity (102.3 DAS) earlier than 0, 20 and 40 kg P_2O_5 ha^{-1}. Likewise, seed yield and haulm yield were recorded significantly higher with 60 kg P_2O_5 ha^{-1} (2169 and 4456 kg ha^{-1}) found to be at par with 40 kg P_2O_5 ha^{-1} (2107 and 4376 kg ha^{-1}). Phosphorus application accelerated the production of photosynthates and their translocation from source to sink, which ultimately resulted in higher yield. These findings are in accordance with Pranav *et al*. (2024), Ghasil *et al.* (2023) and Manoj *et al*. (2023).

Further, the application of phosphorus levels exhibited significant effect on nutrient content and uptake by seed and haulm as well as soybean (table 3). The nitrogen and potassium content in seed and haulm was recorded significantly highest with the application of 60 kg P_2O_5 ha^{-1} but found to be at par with the application of 40 kg P_2O_5 ha^{-1}. Although, significantly highest phosphorus content in seed was observed with 60 kg P_2O_5 ha^{-1} and found to be at par with the application of 40 kg P_2O_5 ha^{-1}. The application of 60 kg P_2O_5 ha^{-1} recorded significantly highest phosphorus content in haulm over rest of the phosphorus levels. Nitrogen uptake by seed, haulm and total uptake by soybean was significantly highest with 60 kg P_2O_5 ha^{-1}

but found to be at par with the application of 40 kg P_2O_5 ha^{-1}. However, phosphorus and potassium uptake by haulm and total uptake by soybean was recorded significantly highest with the application of 60 kg P_2O_5 ha^{-1} compared to all other treatments. This effect is likely due to the improved availability of essential nutrients to plants due to phosphorus supplementation, improving overall P acquisition and translocation of nutrients within the plant. The results are in close conformity with Rao and Nagarjun (2024), Dhadave *et al*. (2018) and Sahu *et al.* (2024).

Data (table 4) on available nitrogen and phosphorus after soybean harvest were significantly highest with 60 kg P_2O_5 ha^{-1} (185.3 and 56.4 kg ha^{-1}) and found to be at par with the application of 40 kg P_2O_5 ha^{-1}. The application of 60 kg P_2O_5 ha^{-1} recorded significantly highest available potassium (259.5 kg ha^{-1}) in soil after soybean harvest over all other phosphorus levels. Regarding phosphorus budgeting (table 5), positive gain of 15.2 kg ha^{-1} was recorded in the control compared to other phosphorus levels. Soil microbial and enzymatic activities are significantly influenced by the application of phosphorus levels. The significantly highest SMBP and acid phosphatase activity observed with the application of 60 kg P_2O_5 ha^{-1} (20.3 µg g^{-1} soil and 9.5 µg pNP g^{-1} h^{-1}) but found to be at par with 40 kg P_2O_5 ha^{-1} (19.6 µg g^{-1} soil and 9.4 µg pNP g^{-1} h^{-1}). However, alkaline phosphatase activity recorded significantly highest with 60 kg P_2O_5 ha^{-1} over rest of the phosphorus levels. Increased phosphorus supply improved nitrogen mineralization, stimulated microbial activity releasing enzymes into rhizosphere promoting root uptake efficiency. Solangi *et al.* (2024), Chauke *et al.* (2022) and Goswami *et al.* (2019)

Higher cost of cultivation and net returns were recorded with the application of 60 kg P_2O_5 ha^{-1} (Rs. 33567 ha^{-1} and Rs. 72709 ha^{-1}) but found to be at par with 40 kg P_2O_5 ha^{-1} (Rs. 32569 ha^{-1} and Rs. 70690 ha^{-1}).

Effect of PSB strains

As shown in table 1, the initial and final plant population was higher with the inoculation of *Bacillus subtilis* compared to other treatments. The inoculation of PSB strains showed significant effect on growth parameters *i.e*., plant height (24.6, 53.1, 61.3 and 59.4 cm), dry matter accumulation (4.1, 14.7, 18.7 and 19.1 g $plant^{-1}$), root biomass (0.55, 2.09, 2.50 and 3.39 g $plant^{-1}$) and significantly highest values were recorded with *Bacillus subtilis* found to be at par with *Pseudomonas flourescens* at 30 DAS, 60 DAS, 90 DAS and at maturity, respectively. Application of phosphate-solubilizing bacteria (PSB) increased growth parameters in soybean, possibly due to increased phosphorus solubilization and release of growth-promoting hormones, which further stimulate stem elongation and increased biomass. The results are in close conformity with Kore (2023), Rao and Nagarjun (2024) and Javed *et al.* (2023).

Data pertaining (table 2) to the plots inoculated with *Bacillus subtilis* attained 50% emergence (5.1 DAS), 50% flowering (44.3 DAS) and maturity (102.5 DAS) earlier than uninoculated and *Pseudomonas flourescens*. Similarly, seed yield and haulm yield were recorded significantly higher with *Bacillus subtilis* (2047 and 4381 kg ha^{-1}) found to be at par with *Pseudomonas flourescens* (1995 and 4310 kg ha^{-1}). This increased phosphorus availability likely improved nutrient uptake and supported better plant growth and productivity. The results were in accordance with Kore (2023), Shendage *et al*. (2020) and Sharma *et al*. (2018).

Further, (table 3) the inoculation of PSB strains exhibited significant effect on nutrient content and uptake by seed and haulm as well as soybean. The inoculation of *Bacillus subtilis* resulted in highest nitrogen content in seed, phosphorus and potassium content in haulm which was at par with *Pseudomonas flourescens*. Significantly highest phosphorus content in seed was attributed to inoculation of *Bacillus subtilis* which was statistically superior over remaining PSB treatments. Total nutrient uptake by soybean *i.e*., nitrogen (251.7 kg ha^{-1}), phosphorus (21.5 kg ha^{-1}) and potassium (122.5 kg ha^{-1}) was significantly highest with *Bacillus subtilis* found to be statistically superior over remaining PSB treatments. This improvement is likely due to the ability of PSB to convert insoluble phosphorus into plant-available forms, thereby promoting better root development, nutrient absorption, and overall plant growth. Rahangdale *et al.* (2022), Sahu *et al.* (2024) and Shome *et al*. (2022).

Post harvest soil nutrient status was significantly influenced by PSB strains (table 4). Available nitrogen in soil after soybean harvest was significantly highest with *Bacillus subtilis* (181.3 kg ha^{-1}) as compared to both PSB treatments. Subsequently, available phosphorus and potassium in soil after soybean harvest recorded highest with *Bacillus subtilis* (54.3 and 248.7 kg ha^{-1}) and found to be at par with *Pseudomonas flourescens* (53.4 and 243.2 kg ha^{-1}). Soil microbial and enzymatic activities are significantly influenced by the inoculation of PSB strains. The significantly highest SMBP, alkaline and acid phosphatase activity observed with inoculation of *Bacillus subtilis* (18.9 µg

g^{-1} soil, 61.7 and 9.3 µg pNP g^{-1} h^{-1}) but found to be at par with *Pseudomonas flourescens* (18.7 µg g^{-1} soil, 61.7 and 9.3 µg pNP g^{-1} h^{-1}). It might be due to phosphate solubilization and the release of organic acids, hormone production and mineralization. The similar results were reported by Sahu *et al*. (2024), Pradhan *et al*. (2017) and Hassan *et al*. (2017).

Higher cost of cultivation and net returns were recorded with inoculation of *Bacillus subtilis* (Rs. 32171 ha^{-1}, Rs. 68108 ha^{-1}) but found to be at par with *Pseudomonas flourescens* (Rs. 32171 ha^{-1}, Rs. 65568 ha^{-1}).

Interaction effect of phosphorus levels and PSB strains:

Interaction effect on root biomass (g $plant^{-1}$) was found to be significant with the application of phosphorus levels and PSB strains at 60 DAS, 90 DAS and at maturity stage which has been presented in the table 1 (a). The significantly higher root biomass was recorded with 60 kg P_2O_5 ha^{-1} when inoculated with *Pseudomonas flourescens* (2.72 g) and lower root biomass was recorded with control when uninoculated (1.11 g) at 60 DAS. Further analysis of the data revealed that significantly higher root biomass was recorded with 60 kg P_2O_5 ha^{-1} when inoculated with *Bacillus subtilis* (3.19 and 4.24 g) and lower root biomass was recorded with control when uninoculated (1.28 g) at 90 DAS and with control when inoculated with *Bacillus subtilis* (2.30 g) at maturity, respectively. It might be due to the combined effect of phosphorus application and inoculation of PSB strains, which promoted the root initiation and development, leading to an increase in root biomass. The results are in close conformity with Pandey *et al*. (2022).

Conclusion

Based on the results of the present investigation the following conclusions are drawn, the growth parameters, yield, nutrient content and uptake, as well as soil microbial and enzymatic activities, cost of cultivation and net returns were significantly higher with the application of 60 kg P_2O_5 and inoculation of *Bacillus subtilis*. Higher root biomass was obtained with the application of 60 kg P_2O_5 with *Bacillus subtilis*.

Table 1: Growth parameters of soybean as influenced by phosphorus levels and PSB strains

Treatments	**Plant population (No. ha^{-1})**		**Plant height (cm)**				**Dry matter accumulation (g $plant^{-1}$)**				**Root biomass (g $plant^{-1}$)**			
	Initial	**Final**	**30 DAS**	**60 DAS**	**90 DAS**	**At Maturity**	**30 DAS**	**60 DAS**	**90 DAS**	**At Maturity**	**30 DAS**	**60 DAS**	**90 DAS**	**At Maturity**
Factor A: Phosphorus levels (P)														
P_0: Control	214800	211200	23.3	46.3	54.3	53.0	3.6	12.8	15.6	15.8	0.24	1.34	1.75	2.41
P_1: 20 kg P_2O_5 ha^{-1}	214800	213500	23.8	49.4	56.2	54.8	3.7	13.5	17.0	17.2	0.42	1.80	2.17	2.93
P_2: 40 kg P_2O_5 ha^{-1}	214800	214000	24.9	54.1	61.3	59.3	4.1	15.1	19.1	19.5	0.69	2.25	2.81	3.75
P_3: 60 kg P_2O_5 ha^{-1}	214800	214200	25.2	54.7	63.1	60.9	4.3	15.5	19.6	19.9	0.81	2.51	3.09	3.97
S. Em±	300	110	0.5	1.2	1.5	0.9	0.1	0.3	0.5	0.5	0.02	0.04	0.03	0.05
CD (P=0.05)	**NS**	**NS**	**NS**	3.6	4.5	2.6	0.3	0.8	1.6	1.4	0.04	0.11	0.10	0.14
Factor B: PSB strains (B)														
B_1: Uninoculated	214400	213000	24.0	48.2	55.4	53.5	3.7	13.6	16.6	16.8	0.52	1.79	2.38	3.10
B_2: *Bacillus subtilis*	215000	213400	24.6	53.1	61.3	59.4	4.1	14.7	18.7	19.1	0.55	2.09	2.50	3.39
B_3: *Pseudomonas flourescens*	215000	213300	24.3	52.0	59.5	58.2	4.0	14.5	18.1	18.4	0.54	2.04	2.48	3.31
S. Em±	200	900	0.4	1.1	1.3	0.8	0.1	0.2	0.5	0.4	0.01	0.03	0.03	0.04
CD (P=0.05)	**NS**	**NS**	**NS**	3.2	3.9	2.2	0.2	0.7	1.4	1.3	**NS**	0.09	0.08	0.12
Interaction (P*B)														
S. Em±	400	1800	0.9	2.1	2.7	1.5	0.2	0.5	0.9	0.9	0.03	0.06	0.06	0.08
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	0.19	0.16	0.24

1 (a): Interaction effect of root biomass (g plant^{-1}) as influenced by phosphorus levels and PSB strains at 60 DAS, 90 DAS and at maturity

Treatments	Root biomass at 60 DAS				Root biomass at 90 DAS				Root biomass at maturity			
	B_1: Uninoculated	B_2: *Bacillus subtilis*	B_3: *Pseudomonas flourescens*	**Mean**	B_1: Uninoculated	B_2: *Bacillus subtilis*	B_3: *Pseudomonas flourescens*	**Mean**	B_1: Uninoculated	B_2: *Bacillus subtilis*	B_3: *Pseudomonas flourescens*	**Mean**
P_0: Control	1.11	1.46	1.44	1.34	1.28	1.76	2.22	1.75	2.41	2.30	2.51	2.41
P_1: 20 kg P_2O_5 ha^{-1}	1.51	1.99	1.89	1.80	2.39	1.94	2.17	2.17	2.73	3.12	2.94	2.93
P_2: 40 kg P_2O_5 ha^{-1}	2.29	2.35	2.10	2.25	2.77	3.09	2.56	2.81	3.52	3.88	3.84	3.75
P_3: 60 kg P_2O_5 ha^{-1}	2.23	2.58	2.72	2.51	3.08	3.19	2.99	3.09	3.74	4.24	3.93	3.97
Mean	1.79	2.09	2.04		2.38	2.50	2.48		3.10	3.39	3.31	
Factors	**S. Em±**		**CD (P=0.05)**		**S. Em±**		**CD (P=0.05)**		**S. Em±**		**CD (P=0.05)**	
P*B	0.06		0.19		0.06		0.16		0.08		0.24	

Table 2: Phenology, yield and economics of soybean as influenced by phosphorus levels and PSB strains

Treatments	Days to emergence (50% seedlings)	Days to 50% flowering (DAS)	Days to maturity (DAS)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Net returns (Rs. ha^{-1})
Factor A: Phosphorus levels (P)							
P_0: Control	5.2	44.6	103.3	1736	4086	30575	54478
P_1: 20 kg P_2O_5 ha^{-1}	5.2	44.6	103.3	1887	4228	31572	60875
P_2: 40 kg P_2O_5 ha^{-1}	5.0	44.3	102.7	2107	4376	32569	70690
P_3: 60 kg P_2O_5 ha^{-1}	5.0	44.2	102.3	2169	4456	33567	72709
S. Em±	0.1	0.2	0.3	28	47	-	1348
CD (P=0.05)	**NS**	**NS**	**NS**	81	137	-	3954
Factor B: PSB strains (B)							
B_1: Uninoculated	5.2	44.7	103.5	1883	4169	31871	60388
B_2: *Bacillus subtilis*	5.1	44.3	102.5	2047	4381	32171	68108
B_3: *Pseudomonas flourescens*	5.1	44.3	102.5	1995	4310	32171	65568
S. Em±	0.1	0.2	0.3	24	40	-	1167
CD (P=0.05)	**NS**	**NS**	**NS**	70	119	-	3424
Interaction (P*B)							
S. Em±	0.2	0.4	0.5	48	81	-	2335
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	-	**NS**

Table 3: N, P and K content and uptake of seed (kg ha^{-1}) and haulm (kg ha^{-1}) of soybean as influenced by phosphorus levels and PSB strains

Treatments	Seed						Haulm						Soybean uptake		
	Content			Uptake			Content			Uptake					
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Factor A: Phosphorus levels (P)															
P_0: Control	4.0	0.59	1.44	69.7	10.3	25.1	2.9	0.13	1.69	118.8	5.2	69.1	188.5	15.5	94.1
P_1: 20 kg P_2O_5 ha^{-1}	4.6	0.67	1.47	86.3	12.6	27.7	3.0	0.15	1.83	126.7	6.2	77.5	212.9	18.8	105.2
P_2: 40 kg P_2O_5 ha^{-1}	5.7	0.71	1.66	119.6	15.0	35.1	3.2	0.17	1.99	142.1	7.5	87.0	261.7	22.5	122.2
P_3: 60 kg P_2O_5 ha^{-1}	5.8	0.72	1.75	125.4	15.7	38.1	3.3	0.18	2.14	148.3	8.0	95.7	273.7	23.7	133.8
S. Em±	0.1	0.01	0.04	2.5	0.2	0.9	0.1	0.003	0.06	3.4	0.1	2.5	4.5	0.3	2.5
CD (P=0.05)	0.3	0.02	0.11	7.3	0.7	2.6	0.3	0.01	0.17	10.1	0.4	7.2	13.1	0.9	7.3
Factor B: PSB strains (B)															
B_1: Uninoculated	4.7	0.65	1.47	90.2	12.3	27.8	3.0	0.15	1.80	124.7	6.2	75.1	214.9	18.5	102.9
B_2: *Bacillus subtilis*	5.2	0.70	1.65	108.2	14.4	34.1	3.3	0.16	2.01	143.5	7.2	88.3	251.7	21.5	122.5
B_3: *Pseudomonas flourescens*	5.1	0.67	1.62	102.3	13.5	32.5	3.1	0.16	1.93	133.7	6.9	83.5	236.0	20.4	116.0

S. Em±	0.1	0.01	0.03	2.2	0.2	0.7	0.1	0.002	0.05	3.0	0.1	2.1	3.9	0.3	2.2
CD (P=0.05)	0.3	0.02	0.09	6.4	0.6	2.2	**NS**	0.01	0.15	8.7	0.3	6.2	11.3	0.8	6.3
Interaction (P*B)															
S. Em±	0.2	0.01	0.06	4.3	0.4	1.5	0.2	0.01	0.10	5.9	0.2	4.3	7.7	0.5	4.3
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 4: Soil chemical, microbial and enzymatic properties after soybean harvest as influenced by phosphorus levels and PSB strains

Treatments	**pH**	**Organic carbon (%)**	**Available (kg ha^{-1})**			**SMBP (µg g^{-1} soil)**	**Alkaline phosphatase activity (µg pNP g^{-1} h^{-1})**	**Acid phosphatase activity (µg pNP g^{-1} h^{-1})**
			N	**P_2O_5**	**K_2O**			
Factor A: Phosphorus levels (P)								
P_0: Control	8.0	0.42	168.9	48.3	224.5	16.1	45.8	8.8
P_1: 20 kg P_2O_5 ha^{-1}	8.1	0.42	173.5	51.0	234.6	17.3	54.2	9.1
P_2: 40 kg P_2O_5 ha^{-1}	8.1	0.43	182.2	53.9	237.5	19.6	66.2	9.4
P_3: 60 kg P_2O_5 ha^{-1}	8.2	0.44	185.3	56.4	259.5	20.3	70.7	9.5
S. Em±	0.1	0.01	1.8	1.0	2.5	0.4	1.5	0.1
CD (P=0.05)	**NS**	**NS**	5.1	2.7	7.2	1.1	4.3	0.2
Factor B: PSB strains (B)								
B_1: Uninoculated	8.1	0.42	175.0	49.4	225.2	17.4	54.4	9.1
B_2: *Bacillus subtilis*	8.2	0.43	181.3	54.3	248.7	18.9	61.7	9.3
B_3: *Pseudomonas flourescens*	8.1	0.43	176.1	53.4	243.2	18.7	61.7	9.3
S. Em±	0.1	0.01	1.5	0.8	2.1	0.3	1.3	0.1
CD (P=0.05)	**NS**	**NS**	4.4	2.3	6.3	0.1	3.7	0.2
Interaction (P*B)								
S. Em±	0.1	0.01	3.0	1.6	4.3	0.6	2.6	0.1
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 5: Phosphorus budgeting (kg ha^{-1})

Treatment	**Initial phosphorus (kg ha^{-1})**	**Applied phosphorus (kg ha^{-1})**	**Total phosphorus (kg ha^{-1})**	**Phosphorus uptake by crop (Seed + haulm) (kg ha^{-1})**	**Phosphorus balance in soil (kg ha^{-1})**		**Phosphorus gain/loss (kg ha^{-1})**
					Actual	**Expected**	
P_0: Control	48.6	0.0	48.6	15.5	48.3	33.1	(+)15.2
P_1: 20 kg P_2O_5 ha^{-1}	48.6	20.0	68.6	18.8	51.0	49.8	(+)1.2
P_2: 40 kg P_2O_5 ha^{-1}	48.6	40.0	88.6	22.5	53.9	66.1	(-)12.2
P_3: 60 kg P_2O_5 ha^{-1}	48.6	60.0	108.6	23.7	56.4	84.8	(-)28.5

References

Alayar, B., Ramesh, K., Venkatesh, M.S., Singh, R.K. and Rai, R.K. (2020). Phosphorus management in agriculture, Challenges and opportunities for sustainable crop production. *Agronomy*. **10**(6), 858.

Chaudhary, M.I., Adu-Gyamfi, J.J., Saneoka, H., Nguyen, N.T., Suwa, R., Kanai, S., Sugimoto, Y., Ohkama-Ohtsu, N. and Fujita, K. (2015). The role of phosphorus in legume growth and physiology. *An overview. Legume Perspectives*. **7**, 16–19.

Chauke, P.B., Nciizah, A.D., Wakindiki, I.I., Mudau, F.N., Madikiza, S., Motsepe, M. and Kgakatsi, I. (2022). No-till improves selected soil properties, phosphorous availability and utilization efficiency, and soybean yield on some smallholder farms in South Africa. *Frontiers in Sustainable Food Systems*. **6**, 1009202

Department of Agriculture & Farmers Welfare (2024). *Annual report 2024–25*. Ministry of Agriculture and Farmers Welfare, Government of India.

Dhadave, K.S., R.V. Kulkarni, R.B. Pawar, D.S. Patil and Khot, G.G. (2018). Effect of integrated phosphorus management on yield, nutrient uptake of soybean grown on p deficient soil. *International Journal of Current Microbiolgy and Applied Sciences*, **7**(11), 1033-1040.

Feng, Y.Y., He, J., Turner, N.C., Siddique, K.H. and Li, F.M. (2021). Phosphorus supply increases internode length and leaf characteristics, and increases dry matter accumulation and seed yield in soybean under water deficit. *Agronomy*. **11**(5), 930.

Ghasil, B.P., Meena, H., Manoj, R.K.Y., Choudhary, M., Ram, G., Yadav, S.L., Meena, S.N. and Meena, R.K. (2023). Correlation-Regression Studies on Independent and

Dependent Variables and Quality of Soybean [*Glycine max* (L.) Merrill] as in influenced by Phosphorus, Sulphur fertilization, and Plant Growth Regulator. *Agriculture Association of Textile Chemical and Critical Reviews Journal*, **11**(03), 176-182.

Gomez, K.A and Gomez, A.A. (1984). Statistical procedures for agricultural research. *John Wiley and Sons*. **2**, 680.

Goswami, S.P., Sacchidanand, B., Dubey, A.N. and Upadhyay, A.K. (2019). Effect of phosphorus levels on electrochemical properties, growth, yield and quality of soybean (*Glycine Max* L). *Annals of Agricultural Research*, **40**(02),1-7.

Haqmal, M., Dass, A., Nasrat, N.A., Choudhary, A.K., San, A.A., Gautam, M.K., Rajanna, G.A. and Sarkar, S.K. (2023). Effect of land configurations and phosphorus on root-shoot growth, yield attributes, harvest index and net B, C of soybean in Kandahar Afghanistan. *Annals of Agricultural Research*. **44**(1), 59-65.

Hashida, S. and Yamada, K.M. (2019). Inter-organelle NAD metabolism underpinning light responsive NADP dynamics in plants. *Frontiers in Plant Science*, **10**, 960.

Hassan, W., Bashir, S., Hanif, S., Sher, A., Sattar, A., Wasaya, A., Atif, H. and Hussain, M. (2017). Phosphorus solubilizing bacteria and growth and productivity of mung bean (*Vigna radiata*). *Pakistan Journal of Botany*, **49**(3), 331-336.

Javed, S., Ismail, S., Waikar, S.L. and More, S.S. (2023). Effect of microbial consortia inoculation on N, P and K content, uptake and yield of soybean (*Glycine max* L. Merrill.) and chickpea (*Cicer arietinum* L.) on Vertisol. *International Journal of Plant & Soil Science*, **35**(22), 779-790.

Kaur, R., Kaur, M. And Saini, S. (2023). Impact of biofertilizer application and phosphorus levels on the growth and yield of soybean (*Glycine max* L.). *Journal of Soil and Water Conservation*. **22**(3), 312-317.

Kore, M. (2023). Effect of phosphorus and phosphorus solubilizing bacteria (PSB) on soil phosphorus availability, yield and nutrients uptake by soybean 3724 (Doctoral dissertation, JAU Junagadh).

Manoj, S, M.K., Meena, H., Yadav, R.K., Yadav, V.K., Ghasil, B.P. and Danga, S. (2023). Productivity, profitability and quality of soybean [*Glycine max* (L.) Merrill] influenced by phosphorus and sulphur fertilization. *Legume Research*. doi, 10.18805/LR-5021

Pang, F., Li, Q., Solanki, M.K., Wang, Z., Xing, Y.X. and Dong, D.F. (2024). Soil phosphorus transformation and plant uptake driven by phosphate-solubilizing microorganisms. *Frontiers in Microbiology*. **15**, 1383813.

Pandey, S.B., Sachan, R., Patel, V. and Bhawan, R. (2022). Effect of sulphur, potassium and PSB on growth parameters, root architecture and quality of mustard (*Brassica juncea* L.). *International Journal of Plant Soil Sciences*, **34**(24), 122-127.

Pradhan, M., Pradhan, C. and Mohanty, S. (2017). Effect of P-solubilizing bacteria on microbial biomass P and phosphatase activity in groundnut (*Arachis hypogaea* L) rhizosphere. *International Journal of Current Microbiology and Applied Sciences*, **6**(4),1240-1260.

Pranav, M., Sharma, O.P., Sharma, V., Dhaker, D.L. and Sharma, J.K. (2024). Growth, yield and economics of soybean [*Glycine max* (L.) Merril] as influenced by phosphorus and potassium fertilization. *International Journal of Research in Agronomy*, **7**(6), 323-326.

Rahangdale, N., Kumawat, N., Jadav, M.L., Bhagat, D.V., Singh, M. and Yadav, R.K. (2022). Symbiotic efficiency, productivity and profitability of soybean as influenced by liquid bio-inoculants and straw mulch. *International Journal of Bio-resource and Stress Management*, **13**(1), 9-16.

Rao, G.E. and Nagarjun, P. (2024). Effect of different source of organic phosphorus and PSB on growth and productivity of soybean (*Glycine max* (L.) Merril). *International Journal of Research in Agronomy*, **7**(12), 526-533.

Sahu, R.K., Naqvi, I.Z., Tagore, G.S., Thakur, R.K., Yadav, S. and Mitra, N.G. (2024). Effect of microbial consortia on soil health, nutrient uptake and yield of soybean grown in a vertisol of Central India. *International Journal of Economic Plants*. **11**(1), 12-17.

Sharma, P., Bhatt, A. and Jyoti, B. (2018). Effect of seed bio-priming with microbial inoculants on plant growth, yield and yield contributing characters in soybean [*Glycine max* (L.) Merril]. *International Journal of Economic Plants*. **5**(2), 53-58.

Shendage, G.B., Kumbhar, A.S., Gorad, S. and Burungle, S.V. (2020). Effect of different levels of phosphorus and bio-fertilizers on yield and yield attributes of *kharif* soybean (*Glycine max* L.). *International Journal of Crop Sciences*, **8**(2), 2245-2247.

Shome, S., Barman, A. and Solaiman, Z.M. (2022). Rhizobium and phosphate solubilizing bacteria influence the soil nutrient availability, growth, yield, and quality of soybean. *Agriculture*, **12**(8),1136.

Shrivastava, M., Srivastava, P.C. and Rajput, V.D. (2018). Phosphate solubilizing microorganisms and their role in sustainable agriculture–A review. *International Journal of Chemical Studies*. **6**(2), 328–333.

Solangi, F., Zhu, X., Solangi, K.A., Iqbal, R., Elshikh, M.S., Alarjani, K.M. and Elsalahy, H.H. (2024). Responses of soil enzymatic activities and microbial biomass phosphorus to improve nutrient accumulation abilities in leguminous species. *Scientific Reports*. **14**(1), 11139.

Tian, J., Ge, F., Zhang, D., Deng, S., Liu, X. (2021). Roles of Phosphate Solubilizing Microorganisms from Managing Soil Phosphorus Deficiency to Mediating Biogeochemical P Cycle. Biology (Basel). 10(2),158.

Virk, H.K., Singh, K. And Sharma, P. (2023). Influence of phosphorus and biofertilizers on symbiotic parameters, productivity and profitability of soybean (*Glycine max*). *Indian Journal of Agronomy*. **68**(2), 227-231.