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Effect of Different Levels of Phosphorus and Phosphorus Solubilizing Bacteria on the Growth and Yield of Soybean (*Glycine max* L.)

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ABSTRACT

Background: Soybean is an important legume crop that contributes largely to protein and edible oil. For sustainable crop production and soil fertility, biofertilizers play an important role. The current experimental trial was held to study the influence of various phosphorous levels and phosphorous solubilizing bacteria on the growth and yield attributes of soybean (*Glycine max*. var. Shivalik). The trail was conducted on sandy loamy soils of the central plain zone of Punjab.

Methods: The trial was accomplished during the *Kharif* season in the year 2022-2023 on the Shivalik (Himso-333) Variety of soybean. In this study, four levels of phosphorous (50%, 75%, 100%, 125%) in combination with Phosphorous solubilizing bacteria (PSB) were used to study their influence on soybean growth and yield. The experimental design followed was a randomized block design which consists of 7 treatment combinations and was replicated three times.

Result: The study revealed that the soybean has shown a significant response to phosphorous levels and Phosphorous solubilizing bacteria with regard to growth and yield attributes. It is observed that the growth and yield parameters of the soybean have shown an increasing trend up to 75% P_2O_5 and then decreased from 100% P_2O_5 in all the parameters. The maximum plant height was observed at 86.4 cm in T5 (75%P_2O_5 + PSB) and the minimum was recorded as 70.9 cm in T1 (Absolute control). The maximum Seed yield was recorded as 2.03 t/hac in T5 (75%P_2O_5 + PSB) followed by 1.76 t/hac in T4 (50%P_2O_5 + PSB) and the minimum was obtained as 1.05 t/hac in T1 (Absolute control). This study concluded that the Biofertilizer can be used as a sustainable Agri-input to improve soil health and ultimately yield. Biofertilizers play an important role in sustainable crop production.

Key words: Biofertilizer, Levels, Phosphorous solubilizing bacteria, Soybean, Sustainable crop production.

INTRODUCTION

The role of pulse crop is well known from ancient times. The population is estimated to increase by 10 billion, which makes food and nutritional security, a challenging task. Legume crops would provide protein more sustainably than any other sources (Sahruzaini *et al*., 2020). Many research findings have revealed that legume involvement in the cropping systems has numerous sustainable benefits in agriculture. The soil chemical properties such as CEC (Cation exchange capacity), Soil organic carbon, soil fertility by enhancing nitrogen fixation and P solubilization can be improved. Legumes intercropped with other crops have the potential to boost productivity and minimize the prevalence of pests and diseases. Legume inclusion in the intercropping system leads to crop diversification (Lal, 2017; Sahruzaini *et al*., 2020; Stagnari *et al*., 2017; Meena *et al*., 2020; Kumawat *et al*., 2022).

Soybean (*Glycine max* L.) is native to East Asia. According to the world scenario, the estimated soybean production of the world in 2021-2022 is 385.524 million Metric tonnes which have been increased by 21.458 million metric tonnes compared to the previous year. Brazil is the leading country in soybean production with 144 million metric tonnes. The US stands 2nd with a production of 119.884 million metric tonnes. Brazil tops the soybean productivity with 3564 kg\hac followed by the US with 3417 kg/ha (SPOA).

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The total estimated production and area of soybean in India in the year 2021 is 118.88 lakh tonnes and 119.982 Lakh Hectares respectively. In terms of production and productivity of soybean, India ranks 5th. Soybean is widely grown as an oil seed crop. Soybean contributes about 11225.85 metric tonnes out of 69284.21 Metric tonnes of oil seed production in India. Madhya Pradesh is the leading state in soybean production and area with 52.292 Lakh metric tonnes and 55.687 Lakh hectares respectively. Maharashtra occupies second place with 48.325 Lakh metric tonnes and 43.848 lakh hectares in production and area respectively. Together, Madhya Pradesh, Maharashtra and

Rajasthan account for 92-93% of soy output and area. Gujarat, Karnataka and Telangana additionally have noticed an increase in soybean production in recent years (SPOA). Soybean is a leguminous crop that is a rich source of protein as well as oil. Soybean is mostly grown as an oil seed crop than a pulse crop. It is well known as a wonder crop as it has multipurpose utilization (Fentahun, 2019). It is also called a yellow jewel, Cinderella crop, or Golden bean. Soybean is a highly climate-resilient crop, self-pollinated crop, C_3 Plant and short-day crop. It has a tap root system and epigeal germination. Sandy loamy to clay soil is favorable for the growth of soybean at a PH of 5.5-7.0. Soybean is abundant in protein of about 43.2%, oil content of up to 20%, Carbohydrates of 20.5%, fiber of 3.7%, water of 8.1%, minerals of about 4.5% (Kaur and Kaur 2022). Major unsaturated fatty acids present in soybean are linoleic acid (54%) and linolenic acid (7-8%) (El-Rahman *et al*., 2019). Soybean has a wide variety of utilization such as food, forage, fodder, industrial, construction, lubricants, engine oil purposes, *etc*. Soyabean in our diet reduces the risk of health problems. Soybean is also called poor man's meat as it is rich in high-quality protein. It contains a good amount of vitamins, thiamine and riboflavin. In today's world of growing population, there is an urgent need of increasing crop productivity concurrently with good nutritional supplements. As a result, soybean can be a healthy food choice.

Phosphorous is the second most important macronutrient for plants. It is involved in many physiological processes of plants like respiration, photosynthesis, water stress and cell division. It is an integral part of DNA and RNA. It is essential for ATP (Adenosine triphosphate) production. Phosphorous is a prerequisite for the growth of plants, nodules, yield and protein content. Phosphorous is also required for Nitrogen fixation by the Nitrogenase enzyme (Musa and Yusuf, 2021). Studies revealed that the application of phosphorous to the soil would improve the N cycling and C sequestration over a long period of time. The phosphorous application can also augment microbial activities and improve soil organic matter (Wang *et al*., 2022; Ortas *et al*., 2020). Phosphorous dynamics in the soil include adsorption, desorption, mineralization and immobilisation. Phosphorous is moderately mobile in soil and mobile in plants. Phosphorous uptake by plants is mostly in the form of HPO_4^{2-}, $H_2PO_4^-$. The primary source of phosphorous is weathering of minerals containing phosphorous, organic matter decomposition and fertilizers. Most of the phosphorous we apply becomes unavailable as it gets fixed with Aluminium, Iron and calcium (Mardamootoo *et al*., 2021). According to the soil conditions, some of the phosphorous may be made available by the process of desorption, this couldn't be sufficient for plant nutrition. Biofertilizers are low-cost sustainable Agri-input that improve soil fertility. Phosphorous solubilizing bacteria secrete organic acids like citric acid, fumaric acid, malic acid and also phosphatase enzyme activity which are responsible for phosphorous solubilization (Shrivastava *et al*., 2018). Application of SSP (single super phosphate) along with PSB will improve the nutrition supplementation ability of the SSP fertilizers. Thus, inoculation of Biofertilizers would improve the efficiency of fertilizer usage and also substitute a portion of costly fertilizers (Asoegwu *et al*., 2020; Khalid *et al*., 2021). Inoculation of biofertilizers enhances the growth of plants, biomass production, nodulation, flowering, seed setting, yield and yield quality of produce. The increase in the protein content is due to the increased accumulation of nitrogen in the Seed (Abdelhamid, 2018).

MATERIALS AND METHODS

At the research farm of the Department of Agronomy, Lovely Professional University, Phagwara, Kapurthala district, which is located in the sub-tropical region of the central plains of Punjab, a research trial was carried out in the *Kharif* season of 2022-2023. The farm, which is 252 meters above mean sea level and 20 km from Jalandhar city in Punjab, is precisely situated between geographical coordinates of 31.24 North latitude and 75.6909 East latitude. The area has sandy loamy to clay-textured soil with a pH range of 7.8 to 8.5. The current site falls under the classification of the Trans-Gangetic Agro-climatic zone. It receives 527.1 mm of rainfall on average each year. The present research was done on the soybean variety Shivalik (Himso-333) to ascertain how various phosphorus levels and Phosphorous solubilizing bacteria inoculation would influence the development and yield of the crop.

Experimental design

The experimental design followed was randomised block design (RBD) which consists of 7 Treatments in 3 Replications. The different treatments include T1: Absolute Control, T2: 100% P_2O_5, T3: PSB, T4: 50% P_2O_5 + PSB, T5: 75% P_2O_5 + PSB, T6: 100% P_2O_5 + PSB, T7: 125% P_2O_5 + PSB. Sowing was done on July 10th 2022 and the Crop was harvested on November 11th 2022. The dimensions of each plot were taken as 5 m $\times$ 4 m.

Seed treatment

Seed treatment is a technique of inoculating seeds with beneficial strains of bacteria that can improve the growth, yield and nutrient uptake ability of plants. Some of biofertilizers can also mitigate pathogen attacks during the early stages of plant growth. In our present research, seeds were treated with Phosphorous solubilizing bacteria @ 100 grams per 10 kg of seeds. Efficient strains of PSB were obtained from Punjab agriculture university. Seeds are treated with PSB 5 hrs before sowing and shade dried and then sown in the field. Sowing was done on raised beds following the row method of sowing. The use of biofertilizers has been employed to increase soil fertility and lower cultivation costs.

Fertilizers

The recommended fertilizer dosage in the current study was 25 kg N, 60 kg P and 40 kg K. One application of nitrogen is made at the time of seeding and the other is made while the plant is in the flowering stage. At the time of planting, diammonium phosphate is used as a potassium supplement.

At the time of sowing, phosphorus is sprayed in four different concentrations: 100% P_2O_5, 50% P_2O_5, 75% P_2O_5 and 125% P2O5, or 60, 30, 45 and 75 kg P_2O_5/ha.

Plant height, chlorophyll content, leaf area index, number of branches, fresh weight and dry weight were among the morphological parameters that were timely recorded. At the time of harvest, the pods/plant and seed yield parameters were measured.

Plant height

In each plot, the height of random 5 plants was selected at 30 DAS, 60 DAS and 90 DAS and at harvest, observations were collected. The mean of these 5 plants was taken and analyzed in the OPSTAT and SPSS software.

Chlorophyll content

Chlorophyll A and Chlorophyll B content estimation was done by following the 80% Acetone method with the help of a Spectrophotometer at 645 nm and 663 nm respectively. 80 ml of pure acetone and 20 ml of distilled water were used to make 80% acetone. A leaf sample of 0.5grms was taken and crushed in Mortar and pestle by adding 40 ml of acetone until complete chlorophyll is extracted from the tissue. This extracted sample was taken into clean centrifuge tubes and centrifuged at 3000 rpm for 8 mins. Then this supernatant was transferred into a test tube and reading was taken in a spectrophotometer at 645 nm and 663 nm to get chlorophyll A and Chlorophyll B respectively of the samples separately (Shome *et al*., 2022).

Leaf area index

The leaf area of each leaf of the whole plant was measured with the help of the Leaf area metre provided in the lab. This was inserted into the formula below to get the final value (Shome *et al*., 2022).

$$\text{Leaf area index} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

Statistical analysis

The analysis of the variance of the data was done statistically in OPSTAT. A comparison of the means of all treatments was done with the help of SPSS software.

RESULTS AND DISCUSSION

The role of Biofertilizers in the agricultural ecosystem is very important, resulting in increased soil fertility, mineral and water uptake, root development, vegetative growth and also preventing diseases in field crops. The study found a substantial relationship between different levels of phosphorus and phosphorus-solubilizing bacteria on the growth and yield of soybean. The significant variation in the plant height among the different treatments at 30 DAS, 60 DAS, 90 DAS and at harvest is presented in Table 1. At 30DAS, the highest plant height was recorded as 35.55cm in the treatment T5 (75% P_2O_5 + PSB) which is statistically at par with the treatments T4 and T6 and the lowest plant height was found to be 25.53 cm with the treatment T1 (Absolute control). Where, at 60 DAS, the highest plant height was observed as 62.62 cm under the treatment T5 (75% P_2O_5 + PSB) which is statistically at par with the treatments T4 and T6 and the lowest plant height was found to be 46.44cm in T1. At 90 DAS, the maximum plant height was recorded as 78.64 cm in T5 (75% P_2O_5 + PSB) followed by 78.54cm in T4 (50% P_2O_5 + PSB) and the minimum height was recorded as 62.10 cm in T1 (control) treatments. The treatment T5 was found statistically at par with the treatments T4 and T6. At harvest, the highest plant height was found as 86.37cm with the treatment T5 which is statistically at par with the treatment T4 and T6 whereas the lowest plant height was recorded as 70.88 cm. The notable increase in the plant height is because of the inoculation of PSB along with the fertilizers which will improve the P-solubilization in the soil and make it available to the plant. Phosphorus-solubilizing bacteria are indirectly responsible for the Nutrient use efficiency of nitrogen and phosphorous (Duarah *et al*., 2011). Phosphorus is an important component of the cell nucleus which helps in cell division and root development thus leading to enhancement in the plant height. The results of the experiment appeal closely to the findings of David *et al*. (2022).

At 30 DAS, leaf area Index was found highest in T5 (75% P_2O_5 + PSB) and was recorded as 1.49 and the lowest was observed in T1 (control) as 0.63. At 60 DAS, the highest LAI was found as 2.67 in the T5 (75% P_2O_5 + PSB) which was statistically at par with the treatments T4 and the lowest

Table 1: Effect of different levels of phosphorous and PSB on plant height (cm) at 30, 60, 90 DAS and at harvest.

Treatments	30 DAS	60 DAS	90 DAS	At harvest
T1 (Absolute control)	25.53^{d}±0.86504	46.44^{e}±2.01200	62.10^{c}±4.15212	70.88^{d}±7.23393
T2 (100% P_2O_5)	28.33^{cd}±1.19308	51.20^{de}±4.25211	65.69^{bc}±4.70006	73.45^{cd}±2.56053
T3 (PSB)	28.55^{cd}±1.38597	53.32^{cd} ±3.14043	67.22^{bc}±5.10557	73.92^{cd}±3.39226
T4 (50% P_2O_5+PSB)	33.95^{ab}±3.37534	60.54^{ab}±3.16893	78.54^{a}±1.42717	84.93^{ab}±5.71604
T5 (75% P_2O_5+PSB)	35.55^{a}±1.38597	62.62^{a}±5.27702	78.64^{a}±6.14593	86.37^{a}±3.42112
T6 (100% P_2O_5+PSB)	33.77^{ab}±1.38597	58.25^{abc}±3.69469	72.28^{ab}±1.78124	80.35^{abc}±4.90758
T7 (125% P_2O_5+PSB)	31.84^{bc}±1.38597	55.92^{bcd}±1.94580	70.06^{b}±3.80426	76.73^{bcd}±2.20214
CD (5%)	2.75	5.42	7.21	8.67
SE	0.89	1.76	2.34	2.82
CV	4.97	5.49	5.74	6.24

Table 2: Effect of different levels of Phosphorous and PSB on Leaf area index at 30, 60, 90 DAS.

Treatments	30 DAS	60 DAS	90 DAS
T1 (Absolute control)	0.63^{e}±0.04509	0.95^{e} ±0.2316	0.87^{e}±0.25716
T2 (100% P_2O_5)	0.70^{de}±0.05292	1.30^{d} ±0.18502	1.30^{d}±0.05181
T3 (PSB)	0.79^{d}±0.05000	1.71^{c}±0.10817	1.60^{d}±0.28786
T4 (50% P_2O_5 + PSB)	1.31^{b}±0.05033	2.47^{ab}±0.08505	2.64^{b}±0.19296
T5 (75% P_2O_5 + PSB)	1.49^{a}±0.06506	2.67^{a} ±0.16703	3.24^{a}±0.05000
T6 (100% P_2O_5 + PSB)	1.19^{c}±0.1000	2.16^{b}±0.24214	2.40^{bc}±0.11533
T7 (125% P_2O_5 + PSB)	1.10^{c} ±0.01528	1.75^{c}±0.16959	2.09^{c}±0.24546
CD (5%)	0.09	0.23	0.31
SE	0.03	0.07	0.10
CV	5.05	7.09	8.69

Table 3: Chlorophyll content (mg/gram of fresh weight) at 30, 60, 90 DAS.

Treatments	30 DAS	60 DAS	90 DAS
T1 (Absolute control)	2.98^{e}±0.31193	4.97^{f}±0.34501	7.07^{d}±0.34176
T2 (100% P_2O_5)	3.24^{e}±0.29670	5.83^{e}±0.23714	7.87^{c}±0.43155
T3 (PSB)	3.81^{d}±0.18175	5.95^{de}±0.22008	8.08^{c}±0.30436
T4 (50% P_2O_5 + PSB)	4.73^{ab}±0.16503	6.97^{ab}±0.25813	8.96^{ab}±0.29513
T5 (75% P_2O_5 + PSB)	4.98^{a}±0.18175	7.26^{a}±0.28537	9.19^{a}±0.43016
T6 (100% P_2O_5 + PSB)	4.40^{bc}±0.11676	6.65^{bc}±0.35086	8.79^{ab}±0.31896
T7 (125% P_2O_5 + PSB)	4.09^{cd}±0.13650	6.41^{cd}±0.34501	8.44^{bc}±0.27025
CD (5%)	0.35	0.53	0.63
SE	0.11	0.17	0.21
CV	4.89	4.72	4.28

Table 4: Effect of different levels of phosphorous and PSB on number of branches at 60 and 90 DAS.

Treatments	60 DAS	90 DAS
T1 (Absolute control)	3.13^{d} ±0.11547	4.04^{d}±0.38575
T2 (100% P_2O_5)	3.60^{cd}±0.91652	4.74^{cd}±0.50560
T3 (PSB)	4.23^{bc}±0.60277	5.37^{bc}±1.04409
T4 (50% P_2O_5 + PSB)	5.48^{a}±0.29670	6.39^{ab}±0.32192
T5 (75% P_2O_5 + PSB)	5.77^{a}±0.14526	6.89^{a}±0.27301
T6 (100% P_2O_5 + PSB)	5.01^{ab}±0.46808	5.95^{ab}±0.41581
T7 (125% P_2O_5 + PSB)	4.133^{bc}±0.41633	5.71^{bc}±0.47149
CD (5%)	0.60	0.92
SE	0.20	0.30
CV	7.56	9.27

as 0.95 in T1 (Absolute control). At 90DAS, the highest and lowest LAI was found as 3.24 and 0.87 in T5 (75%P + PSB) and T1 (Control) respectively and shown in Table 2. Similar findings were documented by Kumar *et al*. (2020). The increase in the leaf area index is due to the fact that phosphorous being an important component for the energy transfer and translocation of nutrients in plants is responsible for cell elongation and division.

At 30 DAS, maximum chlorophyll content was recorded as 4.98 mg/gm of fresh weight in T5 (75% P_2O_5 + PSB) followed by 4.73 mg/gm of fresh weight in T4 (50% P_2O_5 + PSB) and lowest was observed as 2.98 mg/gm of fresh weight in T1 (absolute control). At 60 DAS, the highest chlorophyll content was reported as 7.26 mg/gm of fresh weight in T5 (75%P P_2O_5+ PSB) and the lowest was recorded as 4.97 mg/gm of fresh weight in T1 (absolute control). At 90 DAS, the highest chlorophyll content was examined as 9.19 mg/gm of fresh weight in T5 (75% P_2O_5 + PSB) and the lowest was recorded as 7.07 mg/gm of fresh weight in T1 (absolute control) and shown in Table 3. The increase in the chlorophyll content is attributed to the availability of phosphorous with inoculation of PSB. Phosphorous is an important component of chlorophyll and improve the photosynthetic activity which ultimately leads to the production of ATP molecules. These results are in correspondence with the findings of Shome, S *et al*., (2022) and Jakhar *et al*. (2018) which demonstrate that the application of phosphorous along with PSB would improve the chlorophyll content and thus photosynthesis.

The highest and lowest number of branches per plant was reported in T5 (75% P_2O_5 + PSB) and T1 (Control) as 5.77 and 3.13 respectively at 60DAS. At 90DAS, the maximum of branches was recorded as 6.89 in T5 (75% P_2O_5 + PSB) followed by 6.39 in T4 (50% P_2O_5 + PSB) and the minimum number of branches was recorded as 4.04 in T1 (Control) and presented in Table 4. The increase in the number of branches is attributed to the availability of nutrients in the root zone which improved the uptake of nutrients in the available form that enhances the metabolic process in the plant results on the increased number of branches and other growth attributes. Close results were recorded by Pawar, *et al*. (2018) and Pawar, P.U *et al*. (2018).

Table 5: Effect of different levels of phosphorous and PSB on fresh weight (90 DAS), dry weight (90 DAS), number of pods/plant and seed yield.

Treatments	Fresh weight (grams)	Dry weight (grams)	Pods/plant	Seed yield (ton/ha)
T1 (Absolute control)	57.64^{d}±3.22267	20.90^{d}±1.44222	106.18^{d}±8.64703	1.05^{d}±0.06429
T2 (100% P_2O_5)	60.22^{d}±3.01597	23.80^{cd}±2.26053	125.58^{c}±3.95518	1.43^{c}±0.14422
T3 (PSB)	61.85^{cd}±5.89509	26.80^{bc}±3.91535	130.66^{bc}±3.99395	1.52^{bc}±0.07211
T4 (50% P_2O_5 + PSB)	71.03^{ab}±2.55619	30.64^{ab}±2.91591	140.12^{ab}±5.68767	1.76^{b}±0.13528
T5 (75% P_2O_5 + PSB)	75.08^{a}±1.80267	33.10^{a}±2.60576	142.93^{a}±5.59851	2.03^{a}±0.20108
T6 (100% P_2O_5 + PSB)	70.02^{ab}±4.19958	27.13^{bc}±1.20139	137.71^{ab}±2.97095	1.74^{b}±0.09074
T7 (125% P_2O_5 + PSB)	67.84^{bc}±3.88984	26.50^{bc}±3.55949	134.06^{ab}±5.16172	1.63^{bc}±0.05568
CD (5%)	7.04	5.19	10.09	0.23
SE	2.29	1.69	3.27	0.07
CV	5.98	10.89	4.33	7.92

At 90DAS, the highest fresh weight was obtained as 75.08gm/plant in the treatment where 75% P_2O_5 of recommended phosphorous and PSB (T5) was applied and the lowest in the control treatment T1 as 57.64 gm/plant and shown in Table 5. The increase in fresh weight is attributed to the release of plant growth-promoting substances due to inoculation PSB along with the fertilizers at 90DAS. the highest dry weight was examined in the treatment T5 as 33.10gm/plant where 75% P_2O_5 of recommended phosphorous and PSB was applied and the lowest was observed as 20.90 gm/plant in the T1 treatment where both fertilizers and biofertilizers were not applied and shown in Table 5 and depicted graphically. Increase in the dry weight of plant was observed with from growth stage to harvest stage. It is attributed to the better source to sink efficiency. PSB improves the photosynthetic efficiency which enhances the photosynthates that ultimately result in increased growth and dry matter accumulation. Goswami *et al*. (2019) and Hossain *et al*. (2020) also screened close results related to the present findings.

The number of pods per plant was found highest in Treatment T5 (75% P_2O_5 + PSB) and lowest in T1 (Control) with 142.93 pods/plant and 106.18 pods/plant respectively as shown in Table 5. The results obtained is comparable with the investigations of Lingaraju *et al*. (2016), The increased number pods with the application of PSB and phosphorous fertilizers is attributed to the increased flowering and fruiting because of the availability of phosphorus and other nutrients in the available forms. Desai *et al*. (2019) and Pawar *et al*. (2018) also reported close results to these findings.

Total seed yield was found highest at 2.03 t/hac in T5 (75% P_2O_5 + PSB) followed by 1.76 t/hac in T4 (50%P + PSB) and lowest at 1.05 t/hac in T5(75% P_2O_5 + PSB) and T1 (Control) and represented in Table 5. The increased yield may have resulted from the enhanced growth and yield attributes of plants by the inoculation of PSB and different levels of phosphorous. Similar results were screened by Shome *et al*. (2022) and Kumar and Sharma (2018). A significant increase in the seed yield with different treatment combinations is attributed to the conversion of insoluble phosphorous into soluble phosphorous with the help of organic acids produced by the PSB. Improved biological nitrogen fixation and enhanced uptake of nutrients which further get translocated to the plant's parts. Thus, increased growth and yield attributes as seen in the case number of pods, plant height, LAI, chlorophyll, dry weight, etc lead to a significant increase in seed yield.

CONCLUSION

The experiment's findings suggest that the application of PSB and different phosphorus concentrations had a significant impact on the growth and yield characteristics of soybean. The soybean's growth and yield exhibited an ascending trend up to 75% P_2O_5 before declining beyond that. The investigation revealed that the 75% P_2O_5 + PSB treatment was the most effective; this indicates that applying 45 kg P_2O_5/ha of phosphorous combined with the PSB (phosphorous solubilizing bacteria) was preferred to all other treatments. Regarding plant height, branch density and seed output, treatment T4 (50 per cent P_2O_5 plus PSB) was found to be comparable to treatment T5 (75 per cent P_2O_5 plus PSB). Regarding leaf area index, chlorophyll content, pods/plant and seed yield, treatment T6 (100% P_2O_5 + PSB) was determined to be comparable to treatment T4 (50% P_2O_5 + PSB). The absolute control treatment (T1), which did not use either fertilizers or biofertilizers, had the lowest documented effectiveness of any treatment. We can suggest to farmers the combined application of phosphorus and biofertilizers application will be helpful for sustainable crop production.

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