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Kore Meghana
Department of Soil Science and Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

AV Rajani
Department of Soil Science and Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Navdeep Singh Bhati
Department of Soil Science and Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
Kore Meghana
Department of Soil Science and Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat, India

Effect of phosphorus and Phosphorus Solubilizing Bacteria (PSB) on nutrient content and uptake by soybean crop

Kore Meghana, AV Rajani and Navdeep Singh Bhati

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Abstract
A pot experiment was conducted during *kharif,* 2022 in the Net house of Department of Soil Science & Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh to study the effect of Phosphorus and Phosphorus Solubilizing Bacteria (PSB) on soil phosphorus availability, yield and nutrient uptake by soybean. The experiment was laid out in factorial completely randomized design with three replications having 16 treatments combinations *viz.* 4 levels of phosphorus (0, 40, 60, 80 kg ha^{-1}) and 4 levels of phosphorus solubilizing bacteria (PSB) (0, 1, 2, 3 l ha^{-1}). Results revealed that nutrients like N, K and S content in seed and stover of soybean unaffected under the application Phosphorus and PSB. Whereas, the phosphorus content, significantly increased by the application of phosphorus up to 80 kg ha^{-1} and PSB 3 l ha^{-1}. Nutrient uptake like N, P, K & S, is significantly increased by the application of application of phosphorus up to 80 kg ha^{-1} and PSB 3 l ha^{-1}.

Keywords: Soybean, Phosphorus, PSB, Nutrient content and Nutrient uptake

Introduction
In the world India is the largest producer of pulses. Soybean [*Glycine max* (L.) Merrill], a leguminous crop originated in China. It is basically a pulse crop and gained the importance as an oil seed crop because contains 20% cholesterol free oil. It is an introduced and commercially exploited crop in India. In India area, production and productivity of soybean during year 2021 is 12.04 million hectares, 14.97 million tonnes and 976.2 kg ha^{-1}, respectively. Maharashtra stood first rank in both area and production (FAO). Soybean is considered as a miracle crop because of its dual qualities, *viz*, high protein (40-42%) and oil content (20%) in seed. It also contains various vitamins and minerals. In India, soybean cultivation was started in 1977. It also contains various vitamins and minerals. Soybean protein is rich in valuable amino acid lysine (5%), (Dhadave *et al.,* 2018) [2]. Being a legume, it fixes a large amount of atmospheric nitrogen in soil and it improves the fertility of soil by leaving residual nitrogen (50-300 kg ha^{-1}) through fixation of atmospheric nitrogen. Therefore, soybean improves the soil fertility in which it is grown. It transfers nitrogen taken from air into the soil, making it rich and fertile. Soybean crop is known as "Golden Bean". "Miracle Crop", "Wonder Crop" and “gold of soil”. It is well known that common Indian diet is deficient in protein both in quality and quantity. In this respect, soybean could be regarded as the boneless meat, as it is rich in protein. Among grain legumes, Soybean is an economically important crop that can be grown in diverse environments throughout the world.
Phosphorus is a major and essential macronutrient required for the growth and development of plants. It is the tenth most abundant element in the earth’s crust. It is also called “key of life”. It plays a key role in different growth processes occurring in plants, such as root development, flowering, seed formation, photosynthesis, maturation and essential for energy transfer, other bio chemical and genetic activities of plant. Its functions cannot be performed by any other nutrient, and an adequate supply of P is required for optimum growth and reproduction. Phosphorus can limit normal plant growth if not provided by the soil or by appropriate quantities of fertilizers.

Phosphorus is one of the most immobile, inaccessible, and unavailable nutrient present in the soil, so it is considered as a most limited factor of many crop production system, due to the formation of complexes with Al or Fe in acidic soils or Ca in calcareous soils (Nisha *et al*., 2014) [14].

Microbial inoculants (biofertilizers) are cost-effective, eco-friendly, and renewable sources of plant nutrients. They act as a safe supplement to chemical fertilizers and help reduce ecological damage. Rhizobium and Phosphorus-Solubilizing Bacteria (PSB) are common inoculants that improve legume yields by fixing nitrogen in root nodules and making insoluble phosphorus available to plants (Raja and Takankhar, 2017) [17]. PSB release organic acids that dissolve fixed phosphorus, increasing its availability for crops. The biochemical properties of soil have often been proposed as early and sensitive indicators of soil ecosystem health. Activities of soil enzymes indicate the direction and strength of all kinds of biochemical processes in soil and act as key biological indicator of soil. Soil enzymes play an essential role in energy transfer environmental quality, organic matter decomposition, nutrient cycling and crop productivity (Mina *et al*., 2011) [12]. A number of microorganisms are considered important for agriculture to promote better enzyme activity and biological health of soil. Since the information on soybean to inoculation with PSB inoculants is meagre.

Materials and Methods

A pot experiment was conducted during *kharif,* 2022 in the Net house of Department of Soil Science & Agricultural Chemistry, College of Agriculture, Junagadh Agricultural University, Junagadh and Gujarat. The soil of the experiment site was clay in texture and slightly alkaline in reaction (7.98) and EC 0.48 dSm^{-1}. The soil was low in available nitrogen (225 kg ha^{-1}), medium in available phosphorus (37.49 kg ha^{-1}), high in available potash (321.93 kg ha^{-1}) and medium in available sulphur (17.9 ppm).

The experiment was laid out in factorial completely randomized design with three replications having 16 treatments combinations *viz.* 4 levels of phosphorus (0, 40, 60, 80 kg ha^{-1}) and 4 levels of phosphorus solubilizing bacteria (PSB) (0, 1, 2, 3 l ha^{-1}). The various treatments were control *i.e.* Without application of phosphorus and PSB(T_1), without P but PSB 1 l ha^{-1} (T_2), without phosphorus but PSB 2 l ha^{-1} (T_3), without P but PSB 3 l ha^{-1} (T_4), 40 kg P_2O_5 ha^{-1} and PSB 0 l ha^{-1} (T_5), 40 kg P_2O_5 ha^{-1} and PSB 1l ha^{-1}(T_6), 40 kg P_2O_5 ha^{-1} and PSB 2 l ha^{-1}(T_7), 40 kg P_2O_5 ha^{-1} and PSB 3 l ha^{-1} (T_8), 60 kg P_2O_5 ha^{-1} and PSB 0 l ha^{-1}(T_9), 60 kg P_2O_5 ha^{-1} and PSB 1 l ha^{-1}(T_{10}), 60 kg P_2O_5 ha^{-1} and PSB 2 l ha^{-1} (T_{11}), 60 kg P_2O_5 ha^{-1} and PSB 3 l ha^{-1} (T_{12}), 80 kg P_2O_5 ha^{-1} and PSB 0 l ha^{-1} (T_{13}), 80 kg P_2O_5 $ha^{-1}$and PSB 1 l ha^{-1} (T_{14}), 80 kg P_2O_5 $ha^{-1}$and PSB 2 l ha^{-1} (T_{15}) and 80 kg P_2O_5 $ha^{-1}$and PSB 3 l ha^{-1} (T_{16}). The pots were uniformly basal dressed with 30 kg N ha^{-1} in form of urea and DAP and phosphorus applied as per the treatments. PSB applied as per the treatments. The soybean variety GJS-3 sown in each pot with 5 seeds. The samples of seed and stover were collected at the time of harvesting from the produce of each pot and first oven dried at 60 °C to a constant weight. Each dried sample was ground to a fine powder. These samples were subjected to chemical analysis for the determination of nitrogen, phosphorus, potassium and Sulphur concentration and uptake. The N, P, K, S, contents were analysed by Micro-kjeldahl, Vanado-molybdo phosphoric acid yellow colour, Flame photometric, Turbidimetric methods respectively. Nutrient uptake by seed and stover is calculated by multiplying the nutrient content of soybean seed and stover with their respective yield

Results and Discussion

Nutrient content in seed and stover

Effect of phosphorus

The application of different P dose significantly influenced the seed P content at harvest. The highest seed P content (0.40%) at application of phosphorus P_3 (80 kg P_2O_5 ha^{-1}). While lowest seed P content (0.32%) was observed in the control *i.e.* no external application of phosphorus P_0 (0 kg P_2O_5 ha^{-1}) and an examination data (Table 1) indicated that application of different P dose significantly in influenced the stover P content. The highest stover P content (0.32%) was registered with the application of phosphorus P_3 (80 kg P_2O_5 ha^{-1}) at harvest. On the contrary, lowest P content in stover (0.23%) observed in the control treatment P_0 (0 kg P_2O_5 ha^{-1}). A significant increase in P content was observed due to application phosphorus. This may be due to phosphorus increases root growth of the crop which ultimately helped in increasing the P absorption by soybean and also may enhance the availability of the soil phosphorus for plant nutrition. Similar results were reported by Ranjit *et al.* (2007) [18] in ground nut, Yadav *et al.* (2017) [25], Mir *et al.* (2013) [13] in *Vigna mungo*, Sepat and Yadav (2008) [20] in moth bean.

But application of different phosphorus levels did not exert any significant effect on nitrogen, potassium, and sulphur content in seed and stover. However, the highest values of seed N (4.91%), seed K (1.46%), and stover K (1.03%) were recorded at P_3 (80 kg ha^{-1}). Sulphur content in both seed and stover also remained statistically non-significant across all phosphorus levels.

Effect of phosphorus solubilizing bacteria

Application of different levels of PSB significantly influenced the seed and stover P content. The highest seed P content (0.39%) and highest stover P content (0.31%) observed at application of PSB_3 (3L PSB ha^{-1}) comparison to control (table 1). Significant increase in P content was increased with increasing the level of PSB. This is due to the application of PSB increases the solubilization of phosphorus. Solubilization was attributed to production of non-volatile organic acids. These organic acids were effective chelating agents and form stable complexes with Ca, Mg, Fe, Al and thus render P available to the plants. These results are in close conformity with the findings of Gaind and Gaur (2002) [3] in soybean, Gull *et al.* (2004) [5] in chick pea, Yadav *et al.* (2017) [26].

But Different levels of phosphorus solubilising bacteria did not exert any significant effect on nitrogen, potassium, and sulphur content in seed and stover.

Interaction effect of phosphorus and PSB

The interaction effect of different levels of phosphorus and phosphorus solubilising bacteria on nitrogen, potassium, phosphorus and sulphur concentration in seed and stover was found to be non-significant.

Table 1: Effect of phosphorus and PSB on nitrogen, potassium, phosphorus and sulphur content (%) in seed and stover at harvest

Treatments	N (%)		K (%)		P (%)		S (%)	
	Seed	stover	Seed	Stover	Seed	Stover	Seed	Stover
Phosphorus (P)								
P_0 : 0 kg P_2O_5 ha^{-1}	4.73	1.53	1.38	0.94	0.32	0.23	0.29	0.48
P_1 : 40 kg P_2O_5 ha^{-1}	4.80	1.51	1.40	0.96	0.35	0.28	0.29	0.50
P_2 : 60 kg P_2O_5 ha^{-1}	4.86	1.56	1.42	0.97	0.38	0.29	0.30	0.51
P_3 : 80 kg P_2O_5 ha^{-1}	4.91	1.59	1.46	1.03	0.40	0.32	0.31	0.52
S.Em.±	0.07	0.03	0.02	0.02	0.01	0.01	0.01	0.01
C.D. at 5%	NS	NS	NS	NS	0.02	0.02	NS	NS
Phosphorus Solubilizing Bacteria (PSB)								
PSB_0 : 0 L PSB ha^{-1}	4.76	1.51	1.39	0.93	0.33	0.24	0.28	0.48
PSB_1 : 1 L PSB ha^{-1}	4.77	1.55	1.40	0.97	0.36	0.27	0.29	0.49
PSB_2 : 2 L PSB ha^{-1}	4.87	1.57	1.42	0.99	0.37	0.29	0.31	0.51
PSB_3 : 3 L PSB ha^{-1}	4.89	1.55	1.45	1.00	0.39	0.31	0.32	0.53
S.Em.±	0.07	0.03	0.02	0.02	0.01	0.01	0.01	0.01
C.D. at 5%	NS	NS	NS	NS	0.02	0.02	NS	NS
Interaction (PxPSB)								
S.Em.±	0.14	0.06	0.04	0.05	0.01	0.01	0.02	0.02
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	5.13	7.16	5.12	8.27	6.81	6.78	10.13	8.60

Nutrient Uptake

The nutrients uptake by seed and stover (i.e. N, P, K and S) were significantly influenced (Table 2).

Nitrogen (N) uptake by seed and stover

Effect of phosphorus

Under the given level of phosphorus, the application of P_3 (80 kg P_2O_5 ha^{-1}) significantly improved the N uptake by seed (331.43 mg $plant^{-1}$) and stover (247.68 mg $plant^{-1}$) compared to the control. While, the recorded significantly the lowest N uptake by seed (243.43 mg $plant^{-1}$) and (202.32 mg $plant^{-1}$) by stover observed under P_0 (control). The highest level of P resulted maximum uptake of N due to close interrelationship between N and P metabolism in plant cell. This might be due to quick supply of available plant nutrients to plants due to application of phosphorus. Similar results were reported earlier by Ijgude and Kdam (2008) [6] in soybean, Kumar *et al*. (2008) [9] in groundnut and Thenua and Kumar (2011) [24] in chickpea.

Effect of Phosphorus Solubilizing Bacteria

Uptake of N was significantly affected by various level of PSB. Under the given level of PSB, significantly higher uptake of N (312.44 mg $plant^{-1}$) by seed and (231.56 mg $plant^{-1}$) stover was recorded with the application of PSB_3 (PSB 3 L ha^{-1}). However, it was found statistically at par with application PSB_2 (2 L PSB ha^{-1}). While lowest N uptake (246.28 mg $plant^{-1}$) seed and stover (205.30 mg $plant^{-1}$) recorded in control. Similar results were reported by Gaind and Gaur (2002) [3], Zayed (2003) [27], Son *et al*. (2006) [23], Shubhangi *et al*. (2008) [21] in soybean.

Interaction Effect of Phosphorus and PSB

Various levels of phosphorus and PSB exerted non-significant effect on uptake of N by seed and stover.

Potassium uptake by seed and stover

Effect of phosphorus

The application of P_3 (80 kg P_2O_5 ha^{-1}) significantly increased uptake of K (98.51 mg $plant^{-1}$) by seed and stover (159.87 mg $plant^{-1}$). While significantly the lowest K uptake by seed (71.36mg $plant^{-1}$) and stover (124.01 mg $plant^{-1}$) was recorded in the treatment P_0 (0 kg P_2O_5 ha^{-1}). Application of phosphorus might have nutritional environment in rhizospheric as well as in plant leading to increased uptake and translocation of nutrients especially of N, P and K in reproductive structures which led to higher content and uptake. This might be due to quick supply of available potassium to plants due to application of various levels of P_2O_5. Similar results were reported by Shubhangi *et al*. (2008) [21], Kumar *et al*. (2008) [9] in groundnut, Singh *et al.* (2018) [22] and Yadav *et al*. (2017) [26].

Effect of Phosphorus Solubilizing Bacteria

Uptake of K by seed (91.79 mg $plant^{-1}$) and stover (149.52 mg $plant^{-1}$) significantly increased with the application of PSB_3 (3 L $PSBha^{-1}$). However, it was found statistically at par with application PSB_2 (2 L PSB ha^{-1}). While, significantly the lowest values recorded in the treatment PSB_0 with the values K uptake by seed (74.41 mg $plant^{-1}$) and by stover (125.84 mg $plant^{-1}$). Similar results were reported by Raja and Takankhar (2020) [16], Rahangdale *et al.* (2021) [15] and Ghadge and Murumkar (2020) [4] in soybean.

Interaction Effect of Phosphorus and PSB

Interaction effect of different levels of phosphorus and PSB level on uptake K by seed and stover were found non-significant.

Phosphorus uptake by seed and stover

Effect of phosphorus

The application of P_3 (80kgP_2O_5 ha^{-1}) recorded the highest uptake of P (27.36 mg $plant^{-1}$) by seed and stover (49.37 mg $plant^{-1)}$. While, the recorded significantly the lowest P uptake by seed (16.69 mg $plant^{-1}$) and stover (29.90 mg $plant^{-1}$). Application of phosphorus leading to increased uptake and translocation of nutrient P in reproductive structures which led to higher uptake. The studies showed significant and positive correlation with uptake of P. The higher doses of phosphorus obviously gave higher uptake of phosphorus by seed and stover. Similar results were earlier reported by Devi *et al*. (2012) [1] in soybean crop and Singh *et al.* (2018) [22] in green gram.

Effect of Phosphorus Solubilizing Bacteria

Uptake of P was significantly affected by various level of PSB. Under the given level of PSB, significantly higher uptake of P (25.26 mg $plant^{-1}$) by seed and (46.53 mg $plant^{-1}$) stover was recorded with the application of PSB_3 (PSB 3 L ha^{-1}). While, lowest P uptake by seed (17.25mg $plant^{-1}$) and stover (32.67mg plant^{-1}) was observed in the control treatment (PSB_0). This might be due to phosphate solubilizing bacteria (PSB) solubilize unavailable phosphorus by secretion of organic acids and phosphatase enzyme. These all might have contributed towards increased available phosphorus status of the soil (Kachot *et al*., 2001) [7]. Thus, increased yield of seed and stover ultimately, improvement in uptake of phosphorus by seed and stover. Similar results found by Mahanta and Rai (2008) [11], Shubhangi *et al.* (2008) [21] and Yadav *et al.* (2017) [26].

Interaction Effect of Phosphorus and PSB

Various treatments of phosphorus and PSB exerted significant effect on uptake P by seed. Among different treatments of phosphorus and PSB, application of P_3 (80 kg P_2O_5 ha^{-1}) and PSB_3 (3 L PSB ha^{-1}) recorded the highest uptake P (35.06mgplant^{-1}) by seed. The combined effect of phosphorus and PSB play a pivotal role due to their synergistic effect. The overall development of plant in terms of root and shoot might have resulted in higher absorption of nutrients as well as moisture. The higher photosynthesis and higher production of assimilates, resulted in higher uptake P by seed. These results are in conformity with those reported by Sawarkar and Thakur (2001) [19]. Kumawat *et al*. (2021) [15] in soybean, Khan *et al.* (2022) [8] in Mung bean.

Interaction effect of different levels of phosphorus and PSB level on phosphorus uptake by stover was found non-significant.

Sulphur uptake by seed and stover

Effect of phosphorus

The results summarised in Table 2 indicated that that the uptake of S was significantly affected by various level of phosphorus. Under the given level of phosphorus, the application of P_3 (80 kg P_2O_5 ha^{-1}) significantly higher uptake of S (21.21 mg plant^{-1}) by seed and stover (81.33 mg plant^{-1}). However, it was found statistically at par with application P_2 (60 kg P_2O_5 ha^{-1}) uptake by seed (19.32 mg plant^{-1}) and stover (74.28 mg plant^{-1}). While, the recorded significantly the lowest S uptake by seed (14.87 mg plant^{-1}) and stover (63.65 mg plant^{-1}). Similar results earlier reported by Kumar *et al*. (2008) [9] in ground nut crop and Thenua and Kumar (2011) [24] in chick pea.

Effect of Phosphorus Solubilizing Bacteria

Uptake of S was significantly affected by various level of PSB. Under the given level of PSB, the application of PSB_3 (3 L PSB ha^{-1}) significantly higher uptake of S (20.10 mg plant^{-1}) by seed and (79.21 mg plant^{-1}) stover. However, it was found statistically at par with application PSB_2 (2 L PSB ha^{-1}). While, the recorded significantly lowest S uptake by seed (15.09 mg plant^{-1}) and stover (64.49 mg plant^{-1}) in the treatment PSB_0. Phosphate solubilizing bacteria (PSB) solubilize unavailable phosphorus by secretion of organic acids and phosphatase enzyme. These all might have contributed towards increased available phosphorus status of the soil. Thus, increased yield of seed and stover ultimately, improvement in uptake of S. Raja and Takankhar (2020) [16] found that increased PSB application increases the sulphur uptake. Highest uptake of sulphur recorded with application of 10ml PSB in soybean.

Interaction Effect of Phosphorus and PSB

Interaction effect of different levels of phosphorus and PSB level on uptake S by seed and stover were found non-significant.

Table 2: Effect of phosphorus and PSB on nitrogen, potassium, phosphorus and sulphur uptake (mg plant^{-1}) by soybean seed and stover

Treatments	N uptake (mg plant^{-1})		K uptake (mg plant^{-1})		P uptake (mg plant^{-1})		S uptake (mg plant^{-1})	
	Seed	Stover	Seed	Stover	Seed	Stover	Seed	Stover
Phosphorus (P)								
P_0: 0 kg P_2O_5 ha^{-1}	243.43	202.32	71.36	124.01	16.69	29.90	14.87	63.65
P_1: 40 kg P_2O_5 ha^{-1}	264.75	216.11	78.07	133.41	19.04	38.35	16.24	69.09
P_2: 60 kg P_2O_5 ha^{-1}	309.86	220.27	90.23	141.75	24.23	42.80	19.32	74.28
P_3: 80 kg P_2O_5 ha^{-1}	331.43	247.68	98.51	159.87	27.36	49.37	21.21	81.33
S.Em.±	7.78	4.66	2.25	3.54	0.58	0.92	0.70	2.50
C.D. at 5%	22.42	13.41	6.49	10.21	1.82	2.66	2.02	7.20
Phosphorus Solubilizing Bacteria (PSB)								
PSB_0: 0 L PSB ha^{-1}	246.28	205.30	74.41	125.84	17.25	32.67	15.09	64.49
PSB_1: 1 L PSB ha^{-1}	281.68	219.89	82.50	138.83	21.12	39.12	17.13	70.43
PSB_2: 2 L PSB ha^{-1}	308.80	229.64	89.47	144.85	23.68	42.11	19.32	74.22
PSB_3: 3 L PSB ha^{-1}	312.44	231.56	91.79	149.52	25.26	46.53	20.10	79.21
S.Em.±	7.78	4.66	2.25	3.54	0.63	0.92	0.70	2.50
C.D. at 5%	22.42	13.41	6.49	10.2	1.82	2.66	2.02	7.20
Interaction (PxPSB)								
S.Em.±	15.57	9.31	4.51	7.09	1.26	1.85	1.41	5.0
C.D. at 5%	NS	NS	NS	NS	3.64	NS	NS	NS
C.V.%	9.38	7.28	9.23	8.78	10.03	7.98	13.59	12.02

Table 3: Interaction effect of phosphorus and PSB on phosphorus uptake by soybean seed

	P_0	P_1	P_2	P_3
PSB_0	15.26	15.35	18.27	20.13
PSB_1	15.51	18.90	24.60	25.46
PSB_2	16.88	20.35	28.71	28.81
PSB_3	19.09	21.55	25.32	35.06
S.Em.±	1.26			
C.D. at 5%	3.64			

Conclusion

Application of 80 kg P_2O_5 ha^{-1} significantly enhanced phosphorus content in seed and stover and improved uptake of N, K, S, and P, while 3 L PSB ha^{-1} also recorded the highest phosphorus content and markedly increased nutrient uptake, particularly of phosphorus, at harvest. Although phosphorus and PSB had no significant effect on N, K, and S concentrations, their combined use proved effective in improving phosphorus uptake and overall nutrient assimilation, highlighting their role in enhancing crop productivity and nutrient use efficiency.

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