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Phosphorus management in mungbean [*Vigna radiata* (L.) Wilczek] through PROM and microbial inoculants: A review

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Abstract
Mungbean [*Vigna radiata* (L.) Wilczek] is one of the crucial pulse crop grown in arid and semi-arid regions of India. It is a short duration pulse crop of *kharif* season which can be grown as compensational crop between *rabi* and *kharif* seasons. Mungbean is an admirable source of protein (25%) with high quality of lysine (460 mg/g) and tryptophan (60 mg/g) and it also contains about 1.3 percent fat, 3.5 percent minerals, 4.1 percent fiber and 56.7 percent carbohydrate. The sprouted seeds of greengram enclose an astonishing quantity of ascorbic acid (Vitamin C), riboflavin and Thiamine. It can also be grown for fodder as hay, straw or silage. Phosphorus is the next crucial nutrient element for plants after nitrogen. In conventional agriculture, to enrich its deficiency, expensive phosphatic fertilizers were applied in huge quantities. Disproportionate application of these chemical fertilizers over long periods has damaged natural properties of soils by killing soil micro flora and fauna leading to reduced agricultural production. Thus, chemical phosphatic fertilizers pose two fold complications in that on the one hand almost 85 percent of the applied P is lost forever which leads to environmental contamination and second soil ill health. Sustainable agriculture based on use of organics and biological fertilizers is an effective solution for overcoming these problems.

Keywords: Phosphorus, organics, mungbean, biological

Introduction

Effect of PROM

Growth parameters

Duraisami *et al.* (2001) [7] in an experiment on red loam soil at Paiyur (T.N.) observed that plant height of greengram increased significantly through different sources of phosphorus. The maximum height was recorded at 25 kg P_2O_5/ha through PROM (34/74) along with seed inoculation with PSB. Shaktawat *et al.* (2004) [16] conducted an experiment on greengram in Banswara on farmers field and reported that application of 100% recommended dose of phosphorus @ 40 kg P_2O_5/ha through PROM significantly increased number of branches/plant over control. Singh *et al.* (2015) [19] conducted a field experiment at Jobner to evaluate the response of different sources and levels of phosphorus on yield, nutrient uptake and net returns on mungbean under rainfed condition during *kharif*, 2008. They noticed that among the different sources, phosphorus rich organic manure (40 kg P_2O_5/ha) significantly increased the number of effective nodules per plant (32.27) by 13.02 and 10.89 percent, respectively in comparison to diammonium phosphate (28.55) and single super phosphate (29.10). Application of PROM also significantly increased the number of total nodules per plant (33.97) by 11.81 and 10.11 percent over DAP (30.38) and SSP (30.85), respectively. The SSP and DAP remained statistically at par with each other.

A field experiment was conducted by Yadav *et al.* (2017) [24] during *kharif*, 2012 on loamy sand soils of Jobner to study the effect of P-sources and P-solubilizers on plant growth and yield of mungbean. Results revealed that SSP + phosphocompost (PROM) recorded significantly higher plant height, dry matter accumulation/plant, number of branches/plant, number of total and effective nodules/plant, total chlorophyll content, and leaf area index in mungbean as compared to control, SSP and phosphocompost, alone.

Yield attributes and yield

Singh (2010) [18] conducted a field experiment at Jobner to study the response of mungbean to different sources and levels of phosphorus under rainfed conditions. Results revealed that application of phosphorus through PROM @ 40 and 60 kg P_2O_5/ha registered significantly higher number of pods/plant, seeds/pod, test weight and seed and straw yields of mungbean in comparison to SSP, DAP and control. While carrying out a field study at Jobner, Singh *et al.* (2015) [19] reported that application of PROM at 40 kg P_2O_5/ha in mungbean recorded significantly more number of pods/plant (31.97), number of seeds/pod (11.46), test weight (33.12 g), seed (8.36 q/ha) and straw (13.73 q/ha) yield as compared to control, DAP and SSP. They further explained that PROM was superior in increasing the seed yield by 17.74 and 12.21 percent, respectively, as compared to DAP and SSP.

Yadav *et al.* (2017) [24] studied the effect of phosphorus sources and phosphorus solubilizing microorganism on mungbean at Jobner and reported that combined application of SSP + PROM significantly improved the number of pods/plant (29.47), seeds/pod (10.92), test weight (31.02 g), seed (7.24 q/ha) and straw (12.45 q/ha) yield as compared to control, SSP and PROM alone. They further noticed that increase in yield and yield attributes was due to PROM, an organic source of nutrition and organic matter and various essential nutrients with phosphorus which provided food for beneficial microorganism in field and SSP a source of phosphorus with Ca and sulphur.

Nutrient concentration, uptake and quality

Shaktawat and Sharma (2001) [16] while working at Udaipur concluded that application of PR (34/74) providing 60 kg P_2O_5/ha alongwith FYM in soybean recorded significantly higher total N and P uptake over absolute control. However, it showed statistical equivalence with application of 60 kg P_2O_5/ha through SSP. Singh (2010) [18] while studying the response of mungbean to different sources and levels of phosphorus at SKRAU, Bikaner reported significant increase in N, P, K and protein content in seed and straw as well as their uptake with application of PROM @ 40 kg P_2O_5/ha in comparison to DAP and SSP. However, DAP and SSP was found statistically at par with each other. Singh *et al.* (2015) [19] at Jobner studied the influence of PROM application in mungbean and recorded significantly higher N (3.85 & 1.29%), P (0.46 & 0.211%) and K (0.39 &1.15%) contents in seed and straw and their uptake, protein content (24.06%) in seed and net returns as compared to control. Yadav *et al.* (2017) [24] at Jobner found that application of PROM along with SSP fertilizers in mungbean increased the availability of P through PROM. They further added that it help in complexing Fe and Al in soil, thereby reducing the P fixing capacity of soil.

Effect of Microbial inoculants

Growth parameters

Biswas and Patra (2007) [4] reported that inoculation of soil with VAM and seed inoculation with PSB registered greater canopy height, dry matter accumulation, LAI, CGR, NAR and nodulation in summer mungbean than lower doses of P and control. Vikram and Hamzehzarghani (2008) [23] studied the effect of PSB on nodulation and growth parameters of greengram. The study consisted of 18 treatments in which ability of 16 isolates of PSB to promote growth parameters in greengram crop was tested under greenhouse conditions and remaining 2 treatments were SSP and rock phosphate (RP) without inoculation. They reported that inoculation of greengram seed with strain PSBV-14 recorded the highest nodule number, nodule dry weight, shoot dry matter and total dry matter in greengram plants at 45 DAS stage. Majority of PSB isolates tested were able to improve the growth parameters of greengram significantly as compared to rock phosphate control and SSP control. Saharan and Nehra (2011) [14] reported that inoculation of plants with certain strains of plant growth promoting rhizobacteria (PGPR) like Pseudomonas fluorescens improved the biomass production through direct effects on root and shoots growth. They further stated that PGPR enhanced the seedling germination, stand health, plant height, chlorophyll content and nodulation in legumes as compared to control.

While investigating the effect of Rhizobium and vesicular arbuscular mycorrhizal fungi (VAM) on greengram under temperate condition., Bhat *et al.* (2011) [3] found that combined inoculation of VAM fungi and *Rhizobium* significantly increased dry weight (52.79 and 38.58 mg) of nodules/plant at flowering and at harvest stage, respectively. Whereas, sole *Rhizobium* inoculation recorded 45.96 and 33.58 mg dry weight of nodules/plant at flowering and at harvest stages, respectively. Inoculation with VAM alone yielded 42.40 and 30.26 mg dry weight of nodules/plant at these stages, respectively. Patel et al. (2013) [11] conducted a field experiment on *kharif* greengram at C.P. College of Agriculture, Sardarkrushinagar, Gujrat on loamy sand soil and observed that PSB inoculation significantly increased the number of branches/plant, plant spread, number of nodules/plant and dry matter accumulation over uninoculated control. Dhanya and Adeline (2014) [6] conducted an experiment to study the effect of *Pseudomonas fluorescens* and other PGPRs like *Rhizobium* and *Bacillus subtilis* on greengram. They found that after a period of 3 months, the plants grown with *Pseudomonas fluorescens* and PGPR biofertilizers were observed to have a longer shoot of 30.2 cm, a longer root of 5.5 cm, a high biomass of 6.8 g, and 42 as total number of nodules followed by plants inoculated with only PGPR biofertilizers 26.7 cm, 4.8 cm, 5.7 g and 36 nodules and the control plant with 19.2 cm, 3.8 cm, 4 g and nodules, respectively. Results of a field experiment conducted at Jobner by Yadav *et al.* (2017) [24] revealed that seed inoculation with P-solubilizers viz., *Aspergillus awamori* + *Psuedomonas striata* recorded significantly greater plant height, dry matter accumulation/plant, number of branches/plant, total chlorophyll content, LAI and number of total and effective nodules/plant in mungbean as compared to control, *Aspergillus awamori* and *Psuedomonas striata* alone.

A field experiment was conducted by Kumar and Yadav (2018) [9] at agriculture farm of S.K.N. Agriculture University, Jobner during *kharif*, 2014. The treatment consisted 20 combinations of phosphorus (0, 20, 40 and 60 kg/ha) and bio-organics (Control, PSB, VAM, vermicompost at 2 t/ha and vermicompost at 2 t/ha + VAM). Results indicated that application of vermicompost at 2 t/ha + VAM recorded the significantly highest value of growth attributes viz., plant height, number of branches/plant, dry matter accumulation, no. of total and effective nodules/plant, fresh and dry weight of nodules and CGR of mungbean over control, PSB, VAM and vermicompost @ 2 t/ha, respectively. Singh *et al.* (2018) [20] conducted a field experiment at

Faizabad (UP) and reported that integrated treatment of 80 kg P_2O_5/ha + PSB significantly increased the plant height, LAI, dry matter accumulation and number of branches/plant in mungbean crop in comparison to 60 kg P_2O_5/ha and absolute control. A pot experiment was conducted by Bhabai *et al.* (2019) [2] at UBKV, Coochbehar, West Bengal to investigate the effect of biofertilizer on production potential of greengram. The plants were grown in pots containing soils amended with consortium of Rhizobium + VAM + PSB. Four treatments comprising of P at 0, 20, 40, 60 kg/ha along with the above consortium culture in soil were applied in soil. They found that the important agronomic parameters like, plant height, shoot and root length, effective root nodule/plant, dry matter accumulation etc. were significantly increased by the addition of biofertilizer packages along with graded doses of phosphorus upto 60 kg/ha over uninoculated control and lower doses of phosphorus.

Yield attributes and yield

A field experiment was conducted by Singh and Pareek (2003) [17] at Jobner. They reported that maximum number of pods/plant, pod length, test weight and number of seeds/pod in mungbean were recorded when seed was incubated with PSB + Rhizobium which was found significantly superior than their individual inoculation. Balchandran *et al.* (2005) [1] conducted a field experiment at Nagpur, Maharashtra to study the effect of seed inoculation with *Rhizobium* and phosphate solubilizing bacteria (*Pseudomonas* and *Bacillus* sp.) on greengram. Results revealed that ½ RDF + 5 tonnes pressmud + *Rhizobium* + PSB improved the yield and yield contributing parameters viz., length of pod, number of pods/plant and harvest index as compared to control and their single inoculation. Choudhary *et al.* (2010) [5] evaluated the effect of fertility levels and bio-fertilizers on yield and quality of *kharif* mungbean on loamy sand soils of Anand Agricultural University, Gujarat. The experiment consisted of 12 treatments viz., three levels of fertility (0, 50 and 100% RDF) and four levels of bio-fertilizers (Control, *Rhizobium* inoculation, *Rhizobium* + PSB and *Rhizobium* + VAM). The results revealed that inoculation with *Rhizobium* + PSB (23.08) being at par with *Rhizobium* + VAM (22.85) and *Rhizobium* (22.30) recorded significantly higher number of pods/plant than that recorded under control. Significantly lower numbers of pods/plant (21.67) were recorded under control but it remained at par with *Rhizobium*. Inoculation with *Rhizobium* + PSB also recorded 11.93% higher pod length than control (7.08). The magnitude of increase in seed and stover yields under *Rhizobium* + VAM was to the tune of 21.00 and 14.23%, respectively over control.

Saharan and Nehra (2011) [14] reported that inoculation of legume seed with plant growth promoting rhizobacteria (PGPR) like *Pseudomonas fluorescens* improved the yield and nutrient uptake as compared to control. Bhat *et al.* (2011) [3] in their experiment on greengram found that combined inoculation of VAM + Rhizobium recorded maximum grain and straw yields (9.91 and 22.34 q/ha). The results were significant over uninoculated control or single inoculation. It might be due to positive influence of VAM fungi and *Rhizobium* inoculation on yield attributing characters, better nitrogen fixation, availability and solubilization of phosphorous. Rani *et al.* (2016) [12] reported from NDUAT, Kumarganj, Faizabad (U.P.) that inoculation of mungbean seed with PSB significantly increased the pods/plant and seeds/pod. An increase of 3.88% in seed and 3.99% in stover yield was also recorded with PSB inoculation than un-inoculation.

A field experiment consisting of five different modules was conducted by Sipai *et al.* (2017) [22] at RRS, SDAU, Bhachau, Kachchh to study the effect of different modules on yield and yield attributes of greengram. Different modules were as: T1 [Module1 - Soil application of 20 kg N/ha through FYM + *Trichoderma viride* @ 1.5 kg/ha + PROM @ 40 kg/ha + Seed treatment with *Rhizobium* @ 30 g/kg seed + Install 50 bird perches/ha + application of bio pesticides as per need]. T2 [Module 2 - Soil application of 20 kg N/ha through vermicompost + *Trichoderma viride* @ 1.5 kg/ha + PROM @ 40 kg/ha + Seed treatment with *Rhizobium* @ 30 g/kg seed + Install 50 bird perches/ha + application of bio pesticides as per need]. T3 [Module 3 - Soil application of 20 kg N/ha through FYM + *Trichoderma viride* @ 1.5 kg/ha + PROM + VAM @ 40 kg/ha + Seed treatment with *Rhizobium* @ 30 g/kg seed + Install 50 bird perches/ha + application of bio pesticides as per need]. T4 [Module 4 - Seed treatment with carbendazim + thiram @ 3 g/kg seed + apply 20 kg N and 40 kg P_2O_5/ha in the form of chemical fertilizer + apply prophenophos 50% EC @ 0.05% when *Helicoverpa* population exceeds 5 larvae/m row length + spray mancozeb 0.2% if incidence of *Aschochyta* leaf blight is observed]. T5 [Module 5 – Control]. The results indicated that there was significant difference among the treatments regarding the yield attributes viz., number of pods/plant, pod length and number of seeds/pod. Module T4 (35) and T2 (34) recorded the maximum number of pods/plant and these were at par with each other and were followed by modules T3 and T1 which were at par with each other and the least number of pods/plant were recorded with the module T5 (control). Module T4 and T2 recorded the maximum pod length and these were at par with each other. Module T4 (10.29), T3 (9.93) and T2 (9.90) recorded the maximum number of seeds per pod and these were at par with each other. Kumar and Yadav (2018) [9] based on their studies at Jobner reported that application of vermicompost @ 2 t/ha + VAM recorded the significantly highest number of pods/plant, number of grains/pod, test weight and grain, straw and biological yields over vermicompost at 2 t/ha, PSB, VAM and control, respectively. A field trial was carried out by Singh *et al.* (2018) [20] at Faizabad (UP) to know the effect of phosphorus and PSB on yield attributes, quality and economics of greengram. Results showed that the yield contributing characters viz., number of pods/plant, seeds/pod, test weight, biological yield and seed as well as stover yield was maximum at 80 kg P_2O_5/ha + PSB followed by 60 kg P_2O_5/ha + PSB.

Nutrient concentration, uptake and quality

Singh and Pareek (2003) [17] compared the levels of phosphorus with or without PSB on summer greengram and noticed that both phosphorus and PSB inoculation significantly influenced the content and uptake of N, P and K in greengram crop. Khan and Zaidi (2006) [8] studied the influence of composite inoculation of phosphate solubilizing organisms and an arbuscular mycorrhizal fungus on yield, grain protein and phosphorus and nitrogen uptake by greengram. Results showed that protein content in seeds increased upto 30% due to inoculation of *Bradyrhizobium* alone, *Bradyrhizobium* + VAM and triple inoculation of

Penicillium variable + *Bacillus subtilis* + VAM compared to control (N20:P40). In comparison, the protein contents increased even further by 40 and 30%, following the triple inoculation of *Bradyrhizobium* + *Bacillus subtilis* + VAM relative to the control. Total average P uptake in grain and straw was significantly increased with dual and triple inoculation treatments, maximum being with *Bradyrhizobium* + VAM + *Bacillus subtilis*. While testing the effect of different PSB strains on greengram, Vikram and Hamzehzarghani (2008) [23] reported that, PSBV-13 recorded the highest root, shoot and total P uptake in greengram plants at 45 DAS. All strains of PSB tested in this study resulted in significantly higher shoot P uptake and total P uptake compared to RP control and SSP control. In an experiment conducted at SKUAST, Shalimar (Kashmir), Singh *et al.* (2009) [21] evaluated the performance of greengram under temperate conditions with inoculation of *Rhizobium*, VAM and N levels. Results indicated a significant improvement in availability of N, P and K over control.

Kumawat *et al.* (2009) [10] reported that application of vermicompost at 2 t/ha, seed inoculation with PSB and 40 kg P2O5/ha significantly increased the N, P and K concentration in seed, straw, their total uptake and protein content in mungbean due to improved nutritional environment in the rhizosphere as well as its utilization in the plant system as compared to control. Choudhary *et al.* (2010) [5] at AAU, Gujarat observed that significantly higher protein content (23.42%) in *kharif* greengram was obtained under *Rhizobium* + VAM over control which was at par with *Rhizobium* (22.83%) and *Rhizobium* + PSB (21.63%). Significantly lower protein content (19.47%) was recorded under control. Dhanya and Adeline (2014) [6] found that mungbean plant treated with Pseudomonas fluorescens and other PGPRs showed higher protein content as compared to individual inoculation. Yadav *et al.* (2017) [24] at Jobner found that combined inoculation of *Aspergillus awamori* + *Psuedomonas striata* in mungbean increased the availability and uptake of P and other nutrients. These microorganisms form chelates with cations such as Ca and Fe which results in effective solubilization of phosphates. In addition, these microbes also mineralize organic phosphorus and render more P in soil solution for plants to absorb. Results of an experiment laid out by Kumar and Yadav (2018) [9] showed that application of vermicompost @ 2 t/ha + VAM in mungbean recorded the significantly highest nitrogen (4.04 and 1.97%), phosphorus (0.50 and 0.25%), and potassium (1.02 and 2.36%) content in grain and straw and total uptake of nitrogen (104.7 kg/ha), phosphorus (9.71 kg/ha), and potassium (75.39 kg/ha) and protein content (25.25%), respectively over vermicompost at 2 t/ha, PSB, VAM and control, respectively.

Rekha *et al.* (2018) [13] conducted a field experiment in Gujarat to study the effect of FYM, phosphorus and PSB on yield, nutrient content and uptake by greengram on loamy sand soils. They reported that application of phosphorus at 40 kg/ha + PSB + FYM @ 10 t/ha recorded the maximum removal of nutrients from the soil. The maximum N, P, K, S, Fe and Zn content and uptake by greengram was recorded due to application of phosphorus at 40 kg/ha + PSB over rest of the treatments. Singh *et al.* (2018) [20] from UP also reported that integrated treatment of 80 kg P_2O_5/ha + PSB significantly increased the NPK uptake by mungbean crop. Based on the pot experiment studies at West Bengal, Bhabai *et al.* (2019) [2] reported that use of biofertilizer alone with graded doses of phosphorus (0, 20, 40 and 60 kg/ha) significantly increased the total P uptake by mungbean. The uptake of P (g/plant) were 0.87 at 45 DAS and 0.77 at 65 DAS under uninoculated condition, while the same were 1.41 and 1.63 g/plant, respectively at the inoculated condition at P 40 kg/ha. They further showed that maximum available P was 33.27 kg/ha at 45 days when applied with P @ 40 kg/ha under inoculated condition.

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