Integrated use of phosphorus, farmyard manure and biofertilizer improves the yield and phosphorus uptake of black gram in silt loam soil

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Abstract

An experiment on the use of farmyard manure and biofertilizer along with application of chemical phosphorus was conducted to assess the impact of differential doses of phosphorus, farmyard manure and consortium biofertilizer application on the development, yield and phosphorus uptake during the year 2018 and 2019. The impact of different treatments was recorded on the plant height, dry matter partition, yield and yield attributes, phosphorus uptake and soil phosphorus availability using standard methods. The data revealed significant improvement in yield, yield attributes, phosphorus uptake and soil phosphorus availability. The integration of farmyard manure and biofertilizer with 60 kg ha$^{-1}$ SSP (single superphosphate) has improved the black gram yield by 7.4% and 3.28% respectively over the use of 60 SSP alone. The phosphorus uptake in black gram with application of Farm yard manure and biofertilizer along with 60 kg ha$^{-1}$ SSP has improved the uptake by 7.18% and 2.51% respectively over the use of 60 kg ha$^{-1}$ SSP alone. The results highlight the need of integrated application of farm yard manure, biofertilizer for sustainable production of black gram in the region.

1. Introduction

Black gram (Vigna mungo L.) is a leguminous short-season crop that is one of India’s most significant pulse crops. Black gramme seeds contain 17 to 34 percent protein, making them a cost-effective source of protein. [1]. The black gram was cultivated over 3.51 million ha area and production of about 2.08 million tons, with 593 kg ha$^{-1}$ average productivity in India in the year 2017–18 [2]. Phosphorus is a primary macronutrient, essential for plant growth and development. The earth crust contains about 0.1% phosphorus, where most of this is present either in insoluble or unavailable form to plants. The low availability of phosphorus in the soil
limits about 40% of crop production in cultivated areas around the globe [3]. The problem of P unavailability further aggravates as the added P fertilizers undergo fixation at exchange complexes within the soil making it unavailable to plants [4].

Phosphorus is an essential component of nucleic acid, phospholipids, protein, coenzyme, and the energy cycle, and plays a significant role in plant growth, root development, nodulation, nitrogen fixation, flowering, and fruiting [5–7]. The addition of phosphorus improves the grain yield of legumes such as Phaseolus vulgaris [8], Glycine max [9], Vicia faba [10], Cicer arietinum [11], Vigna unguiculata [12], etc. Excessive use of phosphatic fertilizers has been associated with soil and water pollution [6], i.e., eutrophication of lakes and water bodies.

The integrated use of organic manures and chemical fertilizers in crop production has proved to be helpful in maintaining higher crop productivity and sustainability in crop production [13]. The organic materials are known for their potential to act as an alternative source of multiple nutrients and their capability to improve the soil characteristics such as bulk density, water holding capacity, soil microbial activities, soil structure and infiltration rate, while reducing soil compaction and soil erosion [14, 15]. Therefore, application of phosphorus with organic manure and biofertilizers may help in compensating the supply shortage and rising price of chemical fertilizers. Many studies have concluded that crops utilize only 15–20% of the applied phosphorus [16, 17] and remaining get fixed in soil or converted to the form not readily available to the crops [18]. Biofertilizers (Azotobacter, Azospirillum, Rhizobium, phosphobacteria and VAM fungi) are proving to be cost-effective alternative to expensive fertilizers, supplement nitrogen and phosphorus fertilizers by fixing environmental nitrogen, converting insoluble phosphorus from the soil into soluble form, enhances soil nutrient availability to the plants [19] and improves crop yields.

Integrated approach of nutrient management may derive maximum benefits from organic and inorganic fertilizers in an integrated manner and helps in maintaining optimum soil fertility and crop productivity [20]. Hence, the experiments under consideration were undertaken to access the response of black gram to differential doses of phosphorus, FYM and consortium biofertilizer application.

2. Materials and procedures

2.1 The soil and the experimental site

The investigation was carried out during the summer season of the year 2018 and 2019 to access the impact of unified phosphorus management on the growth, yield and phosphorus uptake in black gram. The field experiment was initiated at the farm of Punjab Agricultural University Regional Research Station, Gurdaspur, India, situated at 32.05° N and 75.43° E at an elevation of 225 m above mean sea level. The soil of the experiment site is characterized as the silt loam in texture with bulk density 1.49 Mg m\(^{-3}\), pH 7.6 (1:2 soil: water ratio), electrical conductivity of 0.20 dSm\(^{-1}\), 0.23% organic carbon, 19.0 kg ha\(^{-1}\) available phosphorus, 118.2 kg ha\(^{-1}\) available potassium.

The experimental site is characterized as subtropical and semi-arid climate and receives about 700 mm rainfall annually. The weather during the study period is characterized as hot and dry summers (April-June), where temperature ranges from 16–42°C. The mean maximum temperature recorded is as high as about 42°C in the May-June months.

2.2 Treatments and experimental design

Current investigation comprised of eight treatments which laid out in randomized complete block design with three replicates during both the years. The treatments include T\(_0\)-control,
T₃-60 kg ha⁻¹ SSP, T₂- 2.5 t ha⁻¹ farmyard manure (FYM), T₄-2.5 t ha⁻¹ FYM + 60 kg ha⁻¹ SSP, T₅-2.5 t ha⁻¹ FYM + 30 kg ha⁻¹ SSP, T₆-consortium biofertilizer, T₇- Consortium+60 kg ha⁻¹ SSP and T₈- Consortium+30 kg ha⁻¹ SSP. The whole of the nitrogen was broadcasted at the time of sowing using urea (46% N) and phosphatic fertilizer was used as per treatments through single superphosphate (16% P₂O₅). Each replication plot was 2.6 m wide x 3.0 m long. The well rotten farmyard manure (FYM) was added to surface soil and mixed before sowing as per treatment. The FYM had 0.58% N, 0.25% P and 0.57% K. The consortium biofertilizer consist of Phosphorus Solubilizing Bacteria, Azotobacter and Plant Growth Promoting Rhizobacteria. The powdered consortium biofertilizer was moisten and uniformly allocated over black gram seeds. The consortium biofertilizer coated seeds were air dried under shade before sowing.

2.3 Crop management

The sowing of black gram cultivar Mash-1008 was done in the first fortnight of the march during the year 2018 and 2019. The sown of black gram was done with row spacing of 22.5 cm with seed rate of 50 kg ha⁻¹. Pendimethlin @ 2.5 liter per hectare was sprayed after sowing to check the weeds. All the fertilizers application, weed control, insect-pest control, irrigation and other cultural practices were done as per the PAU package of practices for rabi crops.

2.4 Soil and plant observations

In each plot, five plants were chosen at random and tagged to record observations on plant height, branches per plant, number of pods per plant, and number of seeds per pod. Dry matter partitioning was performed on a representative plant from each plot, with leaf, stem, and roots dried separately. The roots were excavated by inserting iron pipe (6 inches diameter) into the soil keeping the plant base at the centre of pipe. The soil thus excavated was washed over the wire mesh under running water and roots were separated. The leaf, stem and roots were dried in an oven at 60°C till the constant weight was achieved. The grain yield and straw yield were recorded on whole plot basis and converted into t/ha. The thousand grain weight at harvesting was also measured.

Using a colorimeter, the phosphorus content of plant tissue was measured using the vanado-molybdate method [21]. Phosphorus uptake was calculated by multiplication of P content (%) in grain with the grain yield (kg ha⁻¹).

2.5 Analytical statistics

The data from the plants were subjected to an analysis of variance (ANOVA) using the GLM procedure in SAS 9.1 statistical software (SAS, California). The significance of differences in means was tested with the Duncan Multiple Range Test.

3. Results

3.1. Effect of different phosphorus levels, FYM and biofertilizer on plant growth and dry matter partition

The perusal of the data (Table 1) shows that the plant height was significantly affected by the application of manures, biofertilizers and phosphorus application. The data revealed that maximum plant height was observed in treatment T₃ (18.8 cm), followed by treatment T₆ and T₄. At harvesting, maximum plant height was recorded in the treatment T₃ where 2.5 t/ha FYM was applied along with 60 kg SSP, that was statistically at par with the treatment T₆, T₄, T₇ and T₈. The highest plant height under such treatment may be due to improved availability of
Phosphorus and soil physical environment. The accessibility of phosphorus also improves the utilization of N and K in the plant system. As phosphorus is involved in the energy cycle of plant in addition to its involvement in protein and lipids in the plant system, that help in improving plant growth.

The data on the root dry matter accumulation in various treatments revealed that the early root growth of black gram at 35 DAS was significantly affected by the different combinations of source of phosphorus, FYM and biofertilizers (Table 2). The root dry mass at 35 DAS (days after sowing) was higher in the treatments where chemical fertilizer were integrated with the organic and biofertilizers such as T3 and T4 as compared to application biofertilizer, organic manure and chemical fertilizer alone. The root dry matter at the harvesting stage was significantly higher in the treatment T3 where FYM was applied in addition to the full dose of phosphorus followed by use of biofertilizer and chemical fertilizers. Choudhary et al., [22] also reported beneficial effects of biofertilizer and organic manure on root growth and development. The recent studies had showed that phosphorus application enhanced root system resulting in better soil-root contact and finally higher P uptake and absorption of mineral nutrients [23].

Table 1. Effect of phosphorus levels, farmyard manure and biofertilizer on plant height and dry matter accumulation.

| Treatments                                    | Plant height (cm) | Root dry matter | Leaves dry matter | Branches/stem dry matter |
|-----------------------------------------------|-------------------|-----------------|-------------------|--------------------------|
|                                               | 30 DAS At harvesting | 30 DAS At harvesting | 30 DAS At harvesting | 30 DAS At harvesting |
| T0-control,                                   | 15.8c             | 26.1d           | 0.39g             | 2.94c                    |
| T1-60 kg SSP,                                 | 17.3c             | 30.7abc         | 0.53d             | 3.91b                    |
| T2-farmyard Manure (FYM) 2.5 t/ha,            | 17.7b             | 29.5bc          | 0.43f             | 3.34c                    |
| T3-2.5 t ha⁻¹ FYM+60 kg SSP                   | 18.8a             | 32.0a           | 0.52e             | 4.85a                    |
| T4-2.5 t ha⁻¹ FYM + 30 kg SSP                 | 17.4b             | 30.7abc         | 0.65b             | 4.31b                    |
| T5-consortium biofertilizer                   | 16.4c             | 28.7c           | 0.57c             | 3.89b                    |
| T6-consortium biofertilizer +60 kg SSP        | 18.5a             | 31.3ab          | 0.37h             | 4.29b                    |
| T7-consortium biofertilizer +30 kg SSP        | 17.5b             | 30.1abc         | 0.80a             | 4.03b                    |
| CV                                            | 3.22              | 5.68            | 5.57              | 8.30                     |
| Pr>F (Treatment)                              | <0.01             | <0.01           | <0.01             | <0.01                    |
| Pr>F (Year × Treatment)                       | 0.92              | 0.24            | 0.97              | 0.15                     |
| Error (MS)                                    | 0.32              | 2.89            | 0.008             | 0.11                     |

Table 2. Yield and yield attributes under different phosphorus levels, farmyard manure, and biofertilizer treatments.

| Treatments                                    | No of pod | Grain yield (t/ha) | Biomass yield (t/ha) | Thousand grain weight (g) | Grain P content (%) |
|-----------------------------------------------|-----------|--------------------|----------------------|---------------------------|--------------------|
| T0-control,                                   | 18.6c     | 3.54d              | 16.51d               | 37.34b                    | 0.207a             |
| T1-60 kg SSP,                                 | 25.9b     | 4.57ab             | 19.73ab              | 39.02a                    | 0.215a             |
| T2-farmyard manure (FYM) 2.5 t/ha,            | 25.9b     | 4.24bc             | 18.01c               | 38.14ab                   | 0.211a             |
| T3-2.5 t ha⁻¹ FYM+60 kg SSP                   | 29.7a     | 4.91a              | 20.99a               | 39.0a                     | 0.215a             |
| T4-2.5 t ha⁻¹ FYM + 30 kg SSP                 | 26.5b     | 4.55ab             | 19.08bc              | 38.12ab                   | 0.211a             |
| T5-consortium biofertilizer                   | 21.5c     | 3.89cd             | 17.94c               | 37.92ab                   | 0.209a             |
| T6-consortium biofertilizer +60 kg SSP        | 28.9ab    | 4.72a              | 20.39ab              | 38.7ab                    | 0.213a             |
| T7-consortium biofertilizer +30 kg SSP        | 25.7b     | 4.12c              | 18.32c               | 37.78ab                   | 0.209a             |
| CV                                            | 9.57      | 6.67               | 5.53                 | 3.10                      | 2.78               |
| Pr>F (treatment)                              | <0.01     | <0.01              | <0.01                | <0.01                     | <0.01              |
| Pr>F (Year × Treatment)                       | 0.27      | 0.96               | 0.32                 | 0.73                      | 0.70               |
| Error (MS)                                    | 5.89      | 0.083              | 1.09                 | 0.70                      | 0.0003             |
3.1 Effect of different phosphorus levels, FYM and biofertilizer on yield and yield attributes

The data revealed that the number of pods were significantly high (29.7) in the treatment T₃ (FYM + 60 kg ha⁻¹ SSP) as compared to T₁ and statistically at par with the treatment T₆. The thousand-grain weight was also higher in the treatment T₁ and T₃ that were statistically at par with the treatments T₂, T₄, T₅, T₆ and T₇.

The black gram grain yield was significantly affected by the dose of phosphorus, FYM and biofertilizer application (Table 2). The black gram grain yield was significantly higher in the treatment T₃ as compared to control, T₂ and T₇. The grain yield in T₃ was 7.4 and 4.0% higher than the treatment T₁ and T₆. The application of FYM + 60 kg ha⁻¹ SSP and biofertilizer +60 kg ha⁻¹ SSP has improved the grain yield by 7.4% and 3.28% over the use of 60 SSP alone. The grain yield improvement may be resulted from the improved soil supply of phosphorus with the integrated use of FYM and biofertilizers. Apa´ez Barrios et al., [24] reported that the inadequate supply of phosphorus affects the photosynthetic processes as well as photosynthates supply to nodules and also adversely affect the root growth, activity and nodule formation.

The biomass yield of the black gram was increased with increasing rates of phosphorus application integrated with FYM and biofertilizers up to 60 kg ha⁻¹ SSP. The biomass yield in T₃ (20.99) significantly higher than the control and at par with the use of chemical fertilizer alone. The biomass yield with application of FYM + 60 kg SSP (T₃) was 6.4 and 2.9% higher than the treatment T₁ and T₆. Thus, the integrated use of FYM +60 kg ha⁻¹ SSP and biofertilizer + 60 kg ha⁻¹ SSP has improved the grain yield by 6.4% and 3.34% over the use of 60 SSP (T₁) alone. The improvement in biomass yield may be ascribed to the favourable effect of phosphorus application and other organics on plant height, dry matter production, and number of pods as reported by Niraj and Ved [25] and Parashar et al [26].
The grain P content was not significantly affected by the application of phosphorus, FYM and biofertilizers, however grain P content in T3 treatment was 3.86% higher than the control.

### 3.3 Phosphorus availability and uptake under different phosphorus levels, FYM and biofertilizer application

The data revealed highest available soil phosphorus in the treatment T3 followed by T4 and T2 (Fig 2B). The soil available phosphorus was highest where FYM was applied along with chemical phosphorus fertilizer. The higher soil available phosphorus in the treatments where FYM was applied may be due to addition of extra phosphorus through the FYM and decomposition of FYM produces organic acids which might had improved the availability of phosphorus in the soil. The biofertilizers has also improved the P availability due to phosphorus solubilizing action of bacteria’s and fungi applied to the seeds.

The soil availability has affected the phosphorus uptake of black grams (Fig 2A). A significantly higher P uptake was observed in the treatment T3 (26.4 kg/ha) as compared to control. The phosphorus uptake in treatment with application of FYM along with 60 kg ha⁻¹ SSP (T3) was statistically at par with treatment T6 and T1. The improved soil availability may be resulted from the application of fertilizer, whereas application of fertilizer along with FYM and biofertilizer was more efficient in raising the soil available phosphorus. The microbes from the biofertilizer and organic acids from the FYM decomposition converts unavailable phosphorus to available form.

### 4. Discussion

Phosphorus plays important role in metabolic processes associated with shooting organs, energy generation, synthesis of nucleic acid, photosynthesis, and respiration of legume crops [27–29]. The P have crucial role in nodule energetic transformations thus legumes require more phosphorus as compared to cereals [30]. Phosphorus is found in soil as primary P minerals (apatite) and secondary clay minerals, such as calcium, iron, and aluminium phosphates, which are important in maintaining phosphorus buildup and availability through desorption and dissolution processes [31]. With the application of farmyard manure and biofertilizer, the field experiment revealed an increase in plant height, number of pods, root and shoot biomass, and root and shoot biomass (Tables 1 and 2). The integrated application of organics and fertilizers has increased the thousand grain weight by enhancing flowering and seed formation [32, 33]. The farmyard manure releases phosphorus and other macro and micronutrients upon

![Fig 2. (a) Phosphorus uptake under different treatments (Bars represents standard error) (LSD = 1.92) 2 (b) Soil available phosphorus under different treatments before harvesting.](https://doi.org/10.1371/journal.pone.0266753.g002)
decomposition, in addition it dissolves the unavailable form of phosphorus through the release of organic acids on decomposition of farmyard manures [31]. The improved availability of phosphorus in soil has been observed (Fig 2B) in response to application of farmyard manure and biofertilizer. The magnitude of availability was higher in the plots with addition of farmyard manures as compared to initial phosphorus status in the soil. The use of biofertilizers has also improved the phosphorus availability to plants due to the mineralization, solubilization and translocation action of phosphorus solubilizing through production of organic acid and proton extrusion [34, 35]. Nahas [36] attributed increase in solubilization of insoluble phosphate due to organic acids produced by microbes to the drop in soil pH, soil cations chelating, and competition with phosphate for adsorption sites in the soil solution. The increased availability of phosphorus in soil has also resulted in the improvement in phosphorus uptake in black gram (Table 2). Ganesan [37] also reported improved root and shoot growth of plant along with increased P uptake in black gram compared to untreated plants. Kaur and Reddy [38] and Shahzad et al. [39] also observed improved soil P status and plant P nutrition with inoculation with phosphate solubilizing bacteria resulted from higher alkaline phosphatase activity. Khatkar et al [40] also observed yield improvement with microbial inculcation of urd-bean seeds. Thus, addition of farmyard manure not only add up to nutrient pools but also creates favourable root zone environment for better root activity and nutrient uptake. Likewise, inoculation of black gram seed with consortium biofertilizer improves soil phosphorus availability and plant uptake. Mahanta et al [41] reported inoculation of soyabean seed with phosphorus solublizing bacteria and VAM may substitute about 50% phosphatic fertilizer under soyabean-wheat crop rotation, similar results have been found with black gram in the present study.

5. Conclusions

The results revealed significant improvement in yield, soil phosphorus availability and phosphorus uptake in black gram. The integrated use of organic sources such as farm yard manure and consortium biofertilizers improved the phosphorus availability and uptake. The use of farm yard manure and biofertilizer in combination with 60 kg ha\(^{-1}\) SSP increased grain output by 7.4% and 3.28%, respectively, above the use of 60 kg ha\(^{-1}\) SSP alone. Thus, combined use of organic and inorganic chemical fertilizers may be recommended instead of chemical fertilizer alone to reduce the dependence on chemical fertilizers, to have improvement in soil health for sustainable production of black grams in the region.

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References

1. Gour YD, Microbiology, physiology and agronomy of nitrogen fixation: Legume-Rhizobium symbiosis. Proc. Indian Nat Sci Acad, 1993; 59:333–358.
2. Anonymous 2018, Agricultural statistics at a glance 2018. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Govt. of India; 2018 New Delhi.
3. Bargaz A, Faghire M, Abdi N, Farissi M, Sifi B, Drevon JJ, et al. Low soil phosphorus availability increases acid phosphatases activities and affects P partitioning in nodules, Seeds and Rhizosphere of Phaseolus vulgaris. Agriculture 2012; 2:139–153. https://doi.org/10.3390/agriculture2020139
4. Zhu F, Qu L, Hong X, Sun X, Isolation and characterization of a phosphate-solubilizing halophilic bacterium Kushneria sp. YCWA18 from Daqiao Saltern on the coast of yellow sea of China. Evid Based Complement Alternat Med, 2011, 6. https://doi.org/10.1155/2011/615032 PMID: 21716683
5. Sepetoglu H, Grain legumes. Department of Field Crops, Faculty of Agriculture, University of Ege, Yzmir, Turkey. 2002.
6. Marschner P, Marschner’s Mineral Nutrition of Higher Plants. 3rd Edition, Academic Press, San Diego. 2012; p: 651.
7. Yugandhar P, Savithramma N, Green synthesis of calcium carbonate Nanoparticles and their effects on seed germination and seedling growth of Vigna Mungo. Int J Advanced Res, 2013; 1(8): 89–103.
8. Tessema T, Alemayehu B, Effect of Phosphorus Application and Varieties on grain yield and yield components of Common Bean (Phaseolus vulgaris L.). Am J Plant Nutr Ferti Tech, 2015; 5:79–84.
9. Devi KN, Singh LNK, Devi TS, Devi HN, Singh TB, Singh KK, et al. Response of soybean [Glycine max (L.) Merrill] to sources and levels of phosphorus. J Agri Sci 2012; 4: 44–53.
10. Tekle E, Kubure, Raghavaiah CV, Ibrahim H, Production Potential of Faba Bean (Vicia faba L.) Genotypes in Relation to Plant Densities and Phosphorus Nutrition on Vertisols of Central Highlunds of West Showa Zone, Ethiopia, East Africa. Advances Crop Sci Tech 2016; 4:214.
11. Ullah S, Jan A, Ali M, Ahmad A, Ullah A, Ahmad G, et al. Effect of phosphorous under different application methods on yield attributes of chickpea (cicer arietinum L.). Int J Agri Environ Res 2017; 3: 79–85.
12. Karikari B, Arkorful E, Addy S, Growth, Nodulation and Yield Response of Cowpea to phosphorus fertilizer application in Ghana. J Agron 2015; 14: 234–240.
13. Nambiar KKM, Abrol IP, Long term fertilizer experiments in India-An over view. Fertilizer News. 1992; 34: 11–20.
14. Soumare M, Tack FMG, Verloo MG, Effects of a municipal solid waste compost and mineral fertilization on plant growth in two tropical agricultural soils of Mali. Bioresour. Tech. 2003; 86:15–20. https://doi.org/10.1016/s0960-8524(02)00133-5 PMID: 12421002
15. Möller K, Influence of different manuring systems with and without biogas digestion on soil organic matter and nitrogen inputs, flows and budgets in organic cropping systems. Nutr Cycl Agroecosyst 2009; 84:179–202.

16. Swarup A, Lessons from long term fertilizer experiments in improving fertilizer use efficiency and crop yields. Fert News 2002; 47(12):59–73.

17. Syers JK, Johnston AE, Curtin D (2008) Efficiency of soil and fertilizer phosphorus use—reconciling changing concepts of soil phosphorus behaviour with agronomic information, FAO Fertilizer and Plant Nutrition Bulletin 18. FAO, United Nations, Rome.

18. Roberts TL, Johnston AE, Phosphorus use efficiency and management in agriculture. Resour Conser Recycl 2015; 105:275–281.

19. Ahemad M, Kibret M. Mechanisms and applications of plant growth promoting rhizobacteria: current perspective. J King Saud Univ Sci 2014; 26(1):1–20.

20. Shree S, Singh VK, Ravi K. Effect of integrated nutrient management on yield and quality of cauliflower. The Bioscan 2014, 9(3):1053–1058.

21. Chapman H D, and Pratt P F, Methods of analysis for soil plant and waters. Berkley: University of California, Division of Agriculture. 1961, pp 150–179.

22. Choudhary R, Singh K, Manohar RS, Yadav AK, Sangwan A. Response of different sources and levels of phosphorus on yield, nutrient like uptake and net returns on mung bean under rain fed condition. Indian J Agric Res, 2015; 35: 263–268.

23. Zafar M, Abbasi M, Rahim N, Khaliq A, Shaheen A, Jamil M, et al. Influence of integrated phosphorus supply and plant growth promoting Rhizobacteria on growth, nodulation, yield and nutrient uptake in *Phaseolus vulgaris*. Afr J Biotecnol 2011; 10(74):16793–16807.

24. Apáez Barrios P, Escalante Estrada JA, González R, Chávez M. Analysis of Cowpea Growth and Production in Maize Trellis with Nitrogen and Phosphorus. Int J Agri Sci, 2014; 4: 102–108.

25. Niraj VPS, Ved P. Effect of phosphorus and sulphur on growth, Yield and quality of black gram (*Phaseolus mungo*), Asian J Soil Sci, 2014, 9(1):117–120.

26. Parashar A, Jain M, Tripathi L. Effect of Sulphur and Phosphorus on the Growth and Yield of Black Gram (*Vigna mungo* L.), Ind J Pure App Biosci, 2020; 8(5): 276–280.

27. Vance C. P, Uhde-Stone C, Allan D. L. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. New Phytol 2003; 157: 423–447. https://doi.org/10.1046/j.1469-8137.2003.00695.x PMID: 33873400

28. Chaudhary MI, Adu-Gyamfi JJ, Saneoka H, Nguyen NT, Suwa R, Kanai S, et al. Lightfoot DA, Fujita K, Effect of phosphorus deficiency on nutrient uptake nitrogen fixation and photosynthetic rate in mungbean, mungbean and soybean. Acta Physiol Plant 2008; 30: 537–544.

29. Zhang Z, Liao H, Lucas WJ, Molecular mechanisms underlying phosphate sensing, signaling, and adaptation in plants. J Integr Plant Biol 2014; 56: 192–220. https://doi.org/10.1111/jipb.12163 PMID: 24417933

30. Rotaru V, Sinclair TR, Interactive influence of phosphorus and iron on nitrogen fixation by soybean. Environ Exp Bot 2009; 66(1): 94–99.

31. Mitran T, Mani PK, Effect of organic amendments on rice yield trend, phosphorus use efficiency, uptake, and apparent balance in soil under long-term rice-wheat rotation. J Plant Nutr, 2017; 40(9):1312–1322.

32.ullah A, Ali A, Waseem M, Nadeem MA, Tahir M, Iqbal A, et al. Response of two mung bean cultivars with different phosphorus levels under Faisalabad condition. Int J Applies Agric Res, 2010; 5(5):621–628.

33. Verma G, Kumawat N, Morya J. Nutrient management in mung bean (*Vigna radiate* (L.) Wilczek) for higher production and productivity under semi-arid tract of central India. Int J Curr Microbial App Sci, 2014; 6(7):488–493.

34. Marra LM, de Oliveira SM, Soares CRFS, de Souza Moreira FM, Solubilisation of inorganic phosphates by inoculants strains from tropical legumes. Scientia Agricola, 2011, 68:603–609.

35. Gupta G, Panwar J, Jha P, Natural occurrence of *Pseudomonas aeruginosa*, a dominant cultivable Dizotrophic endophytic bacterium colonizing *Pennisetum glaucum* (L) Br. Appl Soil Ecol, 2013; 64:252–261.

36. Nahas E, Factors determining rock phosphate solubilization by microorganism isolated from soil. World J Microbiol Biotechnol, 1996; 12:18–23.

37. Ganesan V. Rhizoremediation of cadmium soil using a cadmium-resistant plant growth promoting rhizopseudomonad. Current Microbiol, 2008; 56:403–407. https://doi.org/10.1007/s00284-008-9099-7 PMID: 18239844
38. Kaur G, Reddy MS, Influence of P-solubilizing bacteria on crop yield and soil fertility at multi locational sites. European J Soil Biol, 2014; 61:35–40.

39. Shahzad SM, Khalid A, Arif MS, Riaz M, Ashraf M, Iqbal Z, Co-inoculation integrated with P-enriched compost improved nodulation and growth of chickpea (Cicer arietinum L.) under irrigated and rainfed farming systems. Biol Fertil Soils, 2014; 50:1–12.

40. Khatkar R, Abraham T, Joseph AS, Effect of Bio fertilizers and sulphur levels on growth and yield of black gram (Vigna mungo L.). Legume Res, 2007; 30(3):233–234.

41. Mahanta D, Rai R K, Mishra S D, Raja A, Purakayastha T J and Varghese E Influence of phosphorus and biofertilizers on soybean and wheat root growth and properties. Field Crop Res 2014. 166: 1–9.