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Substitutional Effect of Molecular Phosphorus with Nano Particle on the Performance of Black Gram (*Vigna mungo* L.)

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ABSTRACT

Background: Black gram (*Vigna mungo* L.), a vital pulse crop in India, accounts for about 10% of total pulse production. Phosphorus is essential for legume growth, but its use efficiency is low in acidic soils due to fixation. Nano-phosphorus offers a potential alternative by releasing phosphorus gradually, improving uptake efficiency.

Methods: A field experiment was conducted using randomized block design with 8 treatments and 3 replications to evaluate black gram response to nano-phosphorus substitutions. Treatments included combinations of recommended dose of phosphorus (RDP) through single super phosphate (SSP) and foliar sprays (FS) of nano DAP or nano phosphorus at 15 days after sowing (DAS) and flowering.

Result: Results showed that 75% RDP through SSP + FS of nano DAP @ 5 ml L^{-1} significantly improved pod number (48.67), pod length (5.31 cm), seeds pod^{-1} (7.33), seed index (5.43 g) and yielded 20.13% and 55.44% higher seed yield than 100% SSP and control, respectively. This treatment also recorded the highest phosphorus uptake (13.38 kg ha^{-1}) and net return (₹ 37,507.46 ha^{-1}) with a return per rupee investment of 1.09. The study suggests that substituting up to 75% of molecular phosphorus with nano DAP enhances growth, yield and profitability of black gram in the terai region when supplemented with 20 kg N and 40 kg K ha^{-1}. This approach offers a sustainable fertilization strategy for post-*kharif* black gram cultivation. The study was limited to a single location, which may restrict the generalization of results across varying soil and climatic conditions.

Key words: Black gram, Foliar spray, Nano particle, Phosphorus, Yield.

INTRODUCTION

Pulses, often dubbed as “poor man’s meat,” are vital to ensuring food and nutritional security, particularly in vegetarian-dominated countries like India. Among pulses, black gram (*Vigna mungo* L.) ranks as the third most important pulse crop in India, contributing around 10% to national pulse production (Directorate of Economics and Statistics, 2021). It plays a crucial role in rice-based cropping systems, especially during post-*kharif* seasons utilizing residual soil moisture. In West Bengal, despite surpluses in rice, vegetables and potatoes, pulse cultivation remains neglected, creating a demand-supply gap. Black gram offers an excellent opportunity to bridge this gap, particularly in rainfed and rice-fallow areas, due to its short duration (90-100 days), low water requirement and adaptability to diverse agro-climatic conditions (Kumar *et al.,* 2015). Black gram contributes to soil fertility enhancement by converting atmospheric nitrogen into a form usable by plants (Choudhary *et al.,* 2025).

Phosphorus (P) is the second most essential macronutrient after nitrogen and is particularly crucial for legumes, given its role in root development, nodule formation and biological nitrogen fixation (BNF) (Rotaru and Sinclair, 2009; Yadav *et al.,* 2017). The productivity of pulses mainly depends on proper management of nutrients particularly phosphorus and sulphur (Phogat *et al.,* 2021).

However, phosphorus use efficiency (PUE) in Indian agriculture is critically low (18-20%), primarily due to fixation in acidic soils, leaching and microbial immobilization (Subramanian *et al.,* 2015; Jamir *et al.,* 2025). Excessive use of chemical P fertilizers like single super phosphate (SSP) not only increases production costs but also leads to environmental degradation, such as eutrophication and nutrient imbalance.

In this context, nano-fertilizers have emerged as a promising innovation to enhance nutrient use efficiency. Nano-scale phosphorus formulations like nano DAP and phosphorus nanoparticles offer controlled nutrient release, greater solubility and better foliar absorption, improving plant uptake while minimizing environmental losses (Rai *et al.,* 2012; Chhipa, 2017). Their high surface area and small particle size allow better penetration into plant tissues and soil systems (Siddiqi and Husen, 2017). Foliar application of nano-phosphorus is especially relevant for

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short-duration crops like black gram, where timely nutrient availability is crucial for maximizing yield potential (Ganapathy *et al.,* 2008).

Despite the recognized advantages of nano fertilizers, there is limited empirical evidence on their comparative efficacy over conventional phosphorus sources in pulse crops, particularly black gram. Most previous studies have focused on cereal crops or examined nano fertilizers in isolation rather than in combination with reduced rates of conventional fertilizers. There is also a lack of data on phosphorus uptake, economic viability and yield performance of black gram in Eastern India's acidic soils. Keeping the above facts in minds present study was conducted during the post-*kharif* season of 2023 and 2024 at Uttar Banga Krishi Viswavidyalaya with the objectives i) to assess the extent of substitution of single super phosphate with phosphorus nano fertilizers in terms of growth attributes, yield attributes and yield of black gram, (ii) to study the comparative performance of various phosphorus nano fertilizers over single super phosphate in terms of yield attributes and yield of black gram, (iii) to evaluate the variation in phosphorus uptake among different phosphatic fertilizer sources and (iv) to analyse the economics of black gram cultivation as influenced by various phosphorus nano fertilizers and single super phosphate.

This study aims to contribute toward sustainable intensification of pulse production in India. By validating nano phosphorus as a substitute for molecular phosphorus, it seeks to reduce chemical input dependence, enhance phosphorus use efficiency and improve profitability for smallholders. Adoption of nano fertilizers could help India meet its growing pulse demand, reduce fertilizer imports and promote environmentally sound farming practices, paving the way for resilient and sustainable agriculture in resource-constrained ecosystems.

MATERIALS AND METHODS

Site of experimentation

The study was carried out at the instructional farm of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari, Cooch Behar. Geographically, UBKV is situated in the Cooch Behar district of West Bengal at 26°19′86″N latitude and 89°23′59″E longitude. It is 43 m above mean sea level. The area has sandy loam soil and is located in West Bengal's Terai agro climatic zone. The terai zone supports 9.7% of the state's population and occupies roughly 13.5% of the state's total land.

Experimental soil

Before sowing, soil samples were taken from the experimental plot at a depth of 15 cm in order to examine the physico-chemical characteristics of soil in a laboratory. Samples were air-dried, ground and then passed through a 2 mm sieve before being stored in polythene bags for examination. The soil had a sandy loam composition, friable with good drainage. The reports of initial soil fertility along with the techniques used are given in Table 1.

Experimental details

Initially the field was ploughed thoroughly using a tractor drawn cultivator that cleared crop residues, deep rooted weeds and pulverized the soil. This was followed by a rotavator that loosened the soil and aided in preparation of seed bed. Following the tillage process, the experimen-tation plot was set up according to the plan and design. The statistical design adopted is randomized block design with eight treatments, replicated three times. Treatments encompasses of T_1: 100% RDP through SSP; T_2: 75% RDP through SSP + FS of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering; T_3: 50% RDP through SSP + FS of nano DAP @ 7.5 ml L^{-1} at 15 DAS and flowering; T_4: 25% RDP through SSP + FS of nano DAP @ 10 ml L^{-1} at 15 DAS and flowering; T_5: 75% RDP through SSP + FS of nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering; T_6: 50% RDP through SSP + FS of nano phosphorus @ 3 ml L^{-1} at 15 DAS and flowering; T_7: 25% RDP through SSP + FS of nano phosphorus @ 4 ml L^{-1} at 15 DAS and flowering; T_8: control (No phosphorus).

Black gram variety WBU-109 (Sulata) was used in the experiment and sown at a spacing of 30 cm × 10 cm. Plot size of 5 m × 6 m was retained in the experiment. To get the best plant populations, a seed rate of 20 kg ha^{-1} was employed. Data were recorded on agronomic parameters like plant height, root length, root volume, number of nodules $plant^{-1}$, dry matter accumulation (g m^{-2}) at 15 days' interval starting from 30 DAS upto harvest. Data on yield characteristics specifically number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and seed index was documented at the time of maturity. Seed yield and stover yield was recorded in an area of one square meter and transformed to the kg ha^{-1}. Data on phosphorus content in seed and stover were analysed using Vanado-molybdate yellow colour method (Jackson, 1973) and multiplied by dry matter in order to find out uptake. Lastly the different treatments were evaluated for their gross return, net return and returns per rupee investment.

Table 1: Initial chemical properties of experimental soil.

Chemical properties	Value	Method employed
Soil pH	5.07	Potentiometric Method (Jackson, 1967)
Soil EC (dS m^{-1})	0.268	Soil EC meter
Organic carbon (%)	0.82	Wet digestion method (Walkey *et al.,*1939)
Available nitrogen (kg ha^{-1})	178.59	Alkaline Potassium Permanganate Digestion method (Subbiah and Asija, 1956)
Available phosphorus (kg ha^{-1})	18.35	Bray's method (Bray and Kurtz, 1945)
Available potassium (kg ha^{-1})	146.21	Flame photometer method (Jackson,1967)

Statistical analysis

Data collected from field and laboratory were subjected to statistical analysis using statistical software SPSS, version 26. All the data were analyzed by analysis of variance and the significance of difference between means was then estimated using Duncan's multiple range test (DMRT) at 5% level of significance.

RESULTS AND DISCUSSION

Effect on growth attributes

Application of 75% RDP through single super phosphate + foliar spray of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering (T_2) recorded significantly tallest plant (27.93 cm, 44.24 cm, 55.05 cm and 53.82 cm at 30 DAS, 45 DAS, 60 DAS and at harvest respectively), developed lengthy and voluminous root system and produced maximum dry matter (19.80, 127.60 and 407 g m^{-2} at 30, 45 DAS and at harvest respectively) which was statistically at par with the application of 75 % RDP through single super phosphate + FS of nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering (T_5). Application of 50 % RDP through SSP + FS of nano DAP @ 7.5 ml L^{-1} at 15 DAS and flowering (T_3), 25% RDP through SSP + FS of nano DAP @ 10 ml L^{-1} at 15 DAS and flowering (T_4) and 50% RDP through SSP + FS of nano phosphorus @ 3 ml L^{-1} at 15 DAS and flowering (T_6) and 25% RDP through SSP + FS of nano phosphorus @ 4 ml L^{-1} at 15 DAS and flowering (T_7) were found statistically at par with each other in terms of plant height, root length, root volume and dry matter accumulation. Treatment having without phosphorus recorded significantly lowest values of growth attributes (Table 2).

Yield attributes and yield

Application of 75% RDP through single super phosphate along with foliar spray (FS) of nano DAP @ @ 5 ml L^{-1} at 15 DAS and flowering (T_2) exerted a remarkable influence on yield attributes of black gram (Table 3). This treatment recorded the highest number of pods $plant^{-1}$ (48.67), longest pod length (5.31 cm), maximum seeds pod^{-1} (7.33), greater seed index (5.43 g) and superior harvest index (30.31%), which cumulatively resulted in the highest seed yield (965 kg ha^{-1}) and stover yield (2220 kg ha^{-1}). The next best performance was observed with the application of 75% RDP through SSP + FS of nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering (T_5).

Overall, all treatments involving nano phosphorus particles outperformed conventional phosphorus fertilization in enhancing yield attributes and seed yield. Notably, the treatment with 100% phosphorus through SSP (T_1) produced 3.26, 5.02, 7.65, 10.14, 13.01 and 20.13% lower seed yield compared to T_7, T_4, T_6, T_3, T_5 and T_2, respectively. Among the two nano phosphorus sources, nano DAP emerged as more effective than nano phosphorus, highlighting its superior role in boosting productivity.

Phosphorus content and uptake

Results on phosphorus content and uptake by black gram revealed that there was great variation in phosphorus

Table 2: Growth attributes of black gram as influenced by nano DAP and phosphorus nano particle at different growth stages (pooled data over the years).

Treatments	Plant height (cm)			Root length (cm)			Root volume (cm^3)			Dry matter accumulation (g m^{-2})		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	At harvest
T_1	24.47b	38.23ab	46.12b	9.55ab	13.57ab	16.21b	0.35b	1.01b	1.38b	15.53b	94.60ab	334.40b
T_2	27.93c	44.24c	55.05f	10.68b	16.80b	18.93c	0.46e	1.31e	1.87e	19.80d	127.60d	407.00d
T_3	26.77bc	41.14bc	51.56def	10.15ab	15.35b	17.51bc	0.40d	1.20cd	1.61cd	18.53cd	107.80bc	387.20cd
T_4	26.08bc	40.73bc	49.47bcd	9.63ab	14.37ab	16.92bc	0.36bc	1.16c	1.49bc	17.60bcd	103.40bc	361.90bc
T_5	27.15c	43.80c	53.63ef	10.18ab	15.79b	18.12bc	0.44e	1.26de	1.76de	19.00cd	112.20c	397.10d
T_6	26.26bc	40.79bc	50.73cde	9.82ab	15.10b	16.99bc	0.38cd	1.15c	1.54bc	17.13bc	105.60bc	379.50cd
T_7	24.77b	40.42bc	47.57bc	9.59ab	13.97ab	16.83bc	0.34b	1.19cd	1.43bc	16.60bc	101.20abc	345.40b
T_8	21.11a	35.23a	42.65a	8.08a	11.29a	13.03a	0.28a	0.73a	0.94a	11.78a	88.00a	295.07a
CV (%)	4.83	5.93	3.89	11.82	13.03	7.33	4.70	4.61	7.01	7.68	7.03	5.03

contents and uptake by black gram due to substitution of molecular phosphorus through nano DAP and phosphorus nano particle (Fig 1 and 2). Highest phosphorus content and uptake in seed (0.52% and 4.98 kg ha^{-1}) and stover (0.38% and 8.41 kg ha^{-1}) was noted under T_2 (application of 75% RDP through single super phosphate + FS of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering) followed by application 75 % RDP through single super phosphate + FS of nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering.

Economics of production system

Economics of the black gram production revealed that highest gross return of ₹ 72001 ha^{-1} was realized whenever 75% recommended dose of phosphorus is substituted through nano DAP @ 5 ml L^{-1} at 15 DAS and flowering (T_2) which was followed by substitution of 75% RDP through foliar application nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering (T_5) with the gross return to the tune of ₹ 67923 ha^{-1}.

Table 3: Yield attributes of black gram as influenced by nano DAP and phosphorus nano particle at different growth stages (pooled data over the years).

Treatments	No. of pods plant^{-1}	Pod length (cm)	No. of seedspod^{-1}	Seed index (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1	36.22bc	4.81ab	6.33ab	4.83a	803.46b	2058.87ab	28.08b
T_2	48.67e	5.31c	7.33b	5.43b	965.17g	2219.60c	30.31c
T_3	47.00de	4.98bc	6.67ab	5.22ab	884.96e	2134.86abc	29.33bc
T_4	33.67ab	4.90b	6.67ab	5.06ab	843.76c	2099.09abc	28.68b
T_5	44.78de	5.02bc	7.00b	5.27ab	907.98f	2182.25bc	29.40bc
T_6	40.67cd	4.94b	6.67ab	5.09ab	864.92d	2107.67abc	29.10bc
T_7	36.89bc	4.88b	6.33ab	5.04ab	829.67c	2071.30ab	28.60b
T_8	29.06a	4.51a	5.67a	4.71a	620.91a	2014.36a	23.57a
CV (%)	4.70	3.80	3.82	5.93	1.27	3.39	2.64

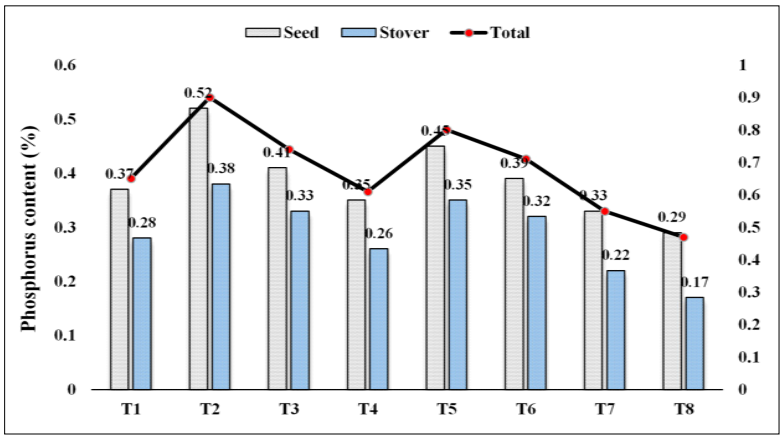


Fig 1: Phosphorus content in seed and stover of black gram as inflienced by nano DAP and phosphorus nano particle.

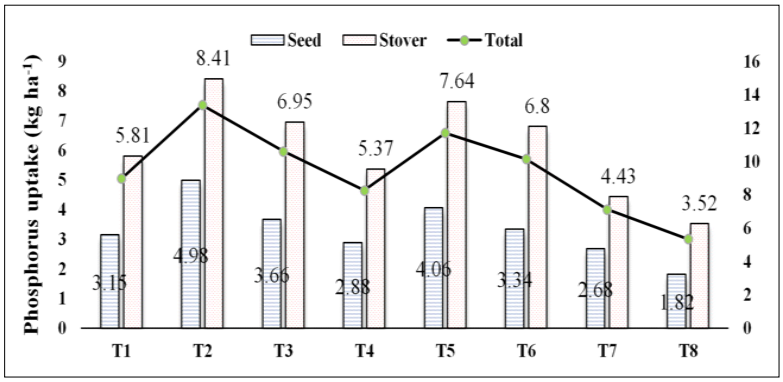


Fig 2: Phosphorus uptake in seed and stover of black gram as inflienced by nano DAP and phosphorus nano particle.

Highest net return to the tune of ₹ 37507 ha^{-1} was realized with 75% RDP through SSP and foliar application of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering (T_2) followed by application of 75% RDP through SSP and foliar application of nano phosphorus @ 2 ml L^{-1} at 15 DAS and flowering (₹ 5029 ha^{-1}). Lowest net return of ₹ 18211 ha^{-1} was found under T_8 where no phosphorus was given (Fig 3).

Highest returns per rupee investment of 1.09 was experienced with 75% RDP through SSP and foliar application of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering (T_2) while surprisingly lowest returns per rupee investment of 0.62 was found under T_8 (Fig 4).

Effect on growth attributes

Substitution of 25% molecular phosphorus with nano DAP or phosphorus nanoparticles markedly improved plant height and root growth over sole application of single super phosphate, owing to enhanced phosphorus availability that stimulates cell division, elongation and auxin-mediated root proliferation. Nano DAP outperformed phosphorus nanoparticles due to its dual supply of phosphorus and nano-scale nitrogen, promoting greater vegetative vigour and dry matter accumulation. Treatments without phosphorus showed the poorest growth, confirming phosphorus's crucial role in root and shoot development. Similar findings were reported by Prajapati *et al.* (2023) and Kanjilal *et al.* (2023), who observed stunted growth under phosphorus deficiency. Enhanced biomass with nano sources aligns with earlier studies (Priya *et al.,* 2015; Choudhary *et al.,* 2018; Yomso *et al.,* 2023) highlighting the role of efficient nutrient supply in boosting plant growth.

Effect on yield attributes and seed yield

The maximum number of pods $plant^{-1}$ and longer pods under nano DAP application resulted from improved phosphorus and nitrogen availability during flowering and fruiting, enhancing photosynthesis and nutrient utilization efficiency (Priya *et al.,* 2015; Choudhary *et al.,* 2018; Yomso *et al.,* 2023). The superior rooting system ensured a steady nutrient supply, contributing to better pod development, as also observed by Choudhary *et al.* (2018) and Kanjilal *et al.* (2023). Enhanced phosphorus absorption and translocation due to the high reactivity of nano DAP increased CO_2 fixation and photosynthate accumulation, leading to higher seed yield. In contrast, phosphorus omission caused poor root growth and lower

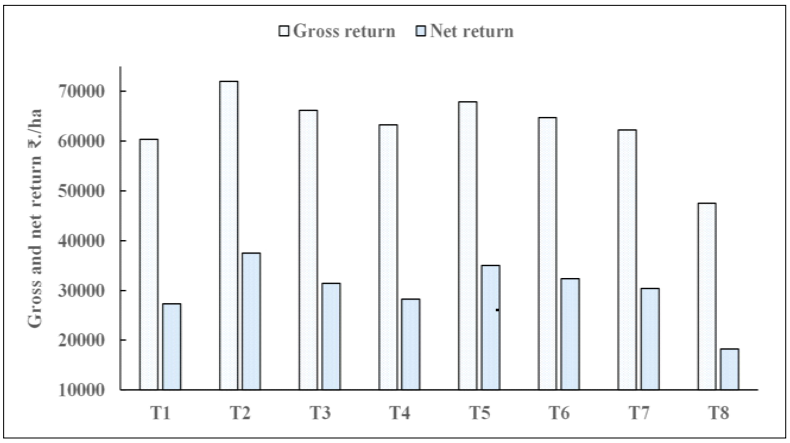


Fig 3: Gross and net return of black gram as influenced by nano DAP and phosphorus nanoparticle.

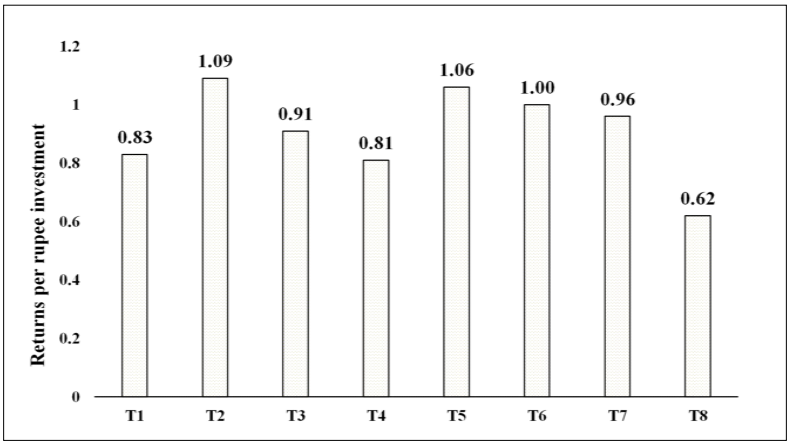


Fig 4: Returns per rupee investment of black gram as influenced by Nano DAP and phosphorus nano particle.

photosynthesis, reducing yield. Similar yield improvements with nano fertilizers were reported by Tarafdar *et al.* (2014); Shang *et al.* (2019); Astaneh *et al.* (2021); Meena *et al.* (2021) and Raj *et al.* (2021). The increased stover yield under nano phosphorus treatments was attributed to better nutrient uptake and translocation, corroborating findings by Kanjilal *et al.* (2023) and Poudel *et al.* (2023).

The observed improvements in yield attributes and productivity with nano DAP and nano phosphorus application highlight their potential as efficient nutrient management strategies for sustainable agriculture. By enhancing nutrient use efficiency and reducing reliance on conventional fertilizers, these nano-based interventions can minimize phosphorus losses through fixation and runoff, mitigating environmental impacts while maintaining high productivity. From a policy perspective, integrating nano fertilizers into national nutrient management programs can contribute to achieving sustainable development goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production).

Phosphorus content and uptake

Higher phosphorus content might be due to better availability of phosphorus for root acquisition with the integrated use of molecular phosphorus and nano DAP (Hagab *et al*., 2018; Nasrallah *et al*., 2022). More uptake of phosphorus was largely due to higher availability and concurrently maximum seed yield. Result of the present investigation is in conformity with Mala *et al*. (2016); Kah *et al*. (2018); Mcknight *et al*. (2020) and Sathyanarayana *et al*. (2021). Lowest uptake of phosphorus (1.82 kg ha^{-1}) was found in the absolute control plot (T_8).

Higher stover uptake may be due better phosphorus content as well as maximum biomass dry matter to the corresponding treatments.

Economics of black gram production

Adoption and rejection of any technology ultimately depends on its economic feasibility. Increased gross returns are primarily the result of higher yields obtained under specific treatments. Higher net return with the substitution of 25% phosphorus through foliar application nano DAP is due to proportionately higher gross return over total cost of cultivation. Kanjilal *et al.* (2023) reported highest net return and B:C ratio with the foliar application of nano-phosphorus at @ 2 ml L^{-1} at 15 DAS in green gram. Kumar *et al*. (2023) reported higher gross return, net return and B:C ratio with the application phosphorus nano particle @ 6 ml L^{-1} in soybean.

CONCLUSION

Substitution of 25% recommended dose of phosphorus through foliar application of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering was found best in terms of yield attributes and yield of black gram. On the economical view point, application of 75% RDP through SSP + foliar application of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering was found most profitable. Hence farmers of terai region can grow black gram profitably during post-*kharif* season (middle of September to first week of December) with the application of 75% RDP (30 kg P_2O_5) through SSP + foliar application of nano DAP @ 5 ml L^{-1} at 15 DAS and flowering along with 20 kg nitrogen and 40 kg potassium ha^{-1}.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Astaneh, N., Bazrafshan, F., Zare, M., Amiri, B. and Bahrani, A. (2021). Nano-fertilizer prevents environmental pollution and improves physiological traits of wheat grown under drought stress conditions. *Scientia Agropecuaria*. **12(1):** 41-47.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science.* **59(1):** 39-46.

Chhipa, H. (2017). Nanofertilizers and nanopesticides for agriculture. *Environmental Chemistry Letters*. **15:** 15-22.

Choudhary, D.K., Kumar, B. and Bharti, C. (2018). Role of nano phosphorus in maize and pigeonpea based intercropping system under medium-upland situation of Jharkhand. *International Journal of Advanced Research*. **6(12)**: 1137-1143.

Choudhary, C.S., Nongmaithem, D., Singh, A.P., Choudhary, S., Solo, V. and Karak, T. (2025). Effect of phosphorus levels and biofertilizers on the growth and yield of summer Black Gram (*Phaseolus mungo* L.). *Legume Research.* **48(1)**: 167-171. doi: 10.18805/LR-5354.

Directorate of Economics and Statistics (2021). Agricultural Statistics at a Glance. Ministry of Agriculture and Farmers Welfare, Government of India.

Ganapathy, M., Baradhan, G. and Ramesh, N. (2008). Effect of foliar nutrition on reproductive efficiency and grain yield of rice fallow pulses. *Legume Research*. **31(2):** 142-144.

Hagab, R.H., Kotp, Y.H. and Eissa, D. (2018). Using nanotechnology for enhancing phosphorus fertilizer use efficiency of peanut bean grown in sandy soils. *Journal of Advanced Pharmacy Education and Research*. **8(3):** 1-9.

Jackson, M.L. (1967). Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd; New Delhi, 498p.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice Hall of India, Pvt. Ltd. New Delhi, pp-498.

Jamir, T.I., Sharma, Y.K. and Uchoi, A. (2025). Nutrient composition, uptake, yield and phosphorus use efficiency of Black Gram as influenced by soil amendments and phosphorus in acidic soil of Nagaland. *Agricultural Science Digest*. **45(4):** 606-612. doi: 10.18805/ag.D-6214.

Kah, M., Kookana, R.S., Gogos, A. and Bucheli, T.D. (2018). A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues. *Nature Nanotechnology*. **13:** 677-684.

Kanjilal, B., Patra, P.S., Debnath, M.K., Paul, T., Saha, R., Ahmed, A.S. and Hoque, A. (2023). Impact of biologically synthesized phosphorus nano-particle on green gram (*Vigna radiata* L.) over molecular phosphatic fertilizer under acid soils of Eastern Sub-Himalayan region of India. *Journal of Plant Nutrition*. **46(16):** 4044-4053.

Kumar, A., Parihar, A.K. and Gupta, S. (2015). Urdbean for Sustainable Agriculture and Nutritional Security in India. *Popular Kheti.* **3(3):** 2-4.

Kumar, N., Samota, S.R., Venkatesh, K. and Tripathi, S. (2023). Global trends in use of nano-fertilizers for crop production: Advantages and constraints-A review. *Soil and Tillage Research*. **228:** 105645., https://doi.org/10.1016/j.still.2023.105645.

Mala, R., Selvaraj, R.C.A., Sundaram, V.B., Rajan, R.B.S.S. and Gurusamy, U.M. (2016). Evaluation of nano structured slow release fertilizer on the soil fertility, yield and nutritional profile of *Vigna radiata*. *Recent Patents on Nanotechnology*. **11(1):** 50-62.

Mcknight, M.M., QU, Z., Copeland, J.K., Guttman, D.S. and. Walker, V.K. (2020). A practical assessment of nanophosphate on soybean (*Glycine max*) growth and microbiome establishment. *Scientific Reports*. **10:** 9151.

Meena, R.H., Jat, G. and Jain, D. (2021). Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat. *Journal of Environmental Biology*. **42(2):** 302-308.

Nasrallah, A.K., Kheder, A.A., Kord, M.A., Fouad, A.S., El-Mogy, M.M. and Atia, M.A.M. (2022). Mitigation of salinity stress effects on broad bean productivity using calcium phosphate nanoparticles application. *Horticulturae*. **8(1):** 75. https://doi.org/10.3390/horticulturae8010075.

Nisha, R., S., Anooj, E.S., Rajendran, K. and Vallinayagam, S. (2021). A comprehensive review on regulatory invention of nano pesticides in Agricultural nano formulation and food system. *Journal of Molecular Structure*. **1239:** 130517. https://doi.org/10.1016/j.molstruc.2021.130517.

Phogat, M., Rai, A.P., Kumar, S. and Angmo, P. (2021). Effect of phosphorus and sulphur application on their dynamics and nodulation in soil under black gram [*Vigna mungo* (L.) Hepper] crop. *Legume Research*. **44(3):** 315-321. doi: 10.18805/LR-4085.

Poudel, A., Singh, S.K., Jiménez-Ballesta, R., Jatav, S.S., Patra, A. and Pandey, A. (2023). Effect of nano-phosphorus formulation on growth, yield and nutritional quality of wheat under semi-arid climate. *Agronomy*. **13(3):** 768. https://doi.org/10.3389/fpls.2023.1123462.

Prajapati , D., Gaur, A.S., Pathak , J., Mishra , S., Kumar , A., Yadav, K. and Kumar, S. (2023). A review: Pulses production, productivity, status and way forward for enhancing farmer's income of Bundelkhand Region, India. *International Journal of Environment and Climate Change*. **13(11):** 353-362.

Priya, B., Srinivasarao, M. and Mukherjee, S. (2015). Screening of phosphorus nano particle concentration based on their effects at germination and seedling level in mung, urd and cowpea. *Vegetos*. **28(4):** 169-178.

Rai, V., Acharya, S. and Dey, N. (2012). Implications of nanobiosensors in agriculture. *Journal of Biomaterials and Nano Biotechnology*. **3(2A)**: 315-324.

Rotaru, V. and Sinclair, T.R. (2009). Interactive influence of phosphorus and iron on nitrogen fixation by soybean. *Environmental and Experimental Botany*. **66:** 94-99. https://doi.org/10.1016/j.envexpbot.2008.12.001.

Sathyanarayana, E., Padmaja, G., Sharma, S.H.K., Vidya Sagar, G.E., Triveni, S., Bharghavi, J. and Rajashekhar, M. (2021). Effect of different sources and levels of nitrogen, phosphorus and zinc on soil fertility, nutrient content, uptake and yield of soybean. *The Pharma Innovation Journal*. **10(7):** 1152-1156.

Shang, Y., Hasan, M. K., Ahammed, G.J., Li, M., Yin, H. and Zhou, J. (2019). Applications of nanotechnology in plant growth and crop protection: A review. *Molecules*. **24(14):** 2558.

Siddiqi, K. S. and Husen, A. (2017). Plant response to engineered metal oxide nanoparticles. *Nanoscale Research Letters*. **12:** 92.

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for the estimation of available nitrogen in soil. *Current Science*. **25:** 258-260.

Subramanian, K.S., Manikandan, A., Thirunavukkarasu, M. and Rahale, C.S. (2015). Nano-fertilizers for Balanced Crop Nutrition. In: *Nanotechnologies in Food and Agriculture*. [M. Rai, C. Ribeiro, L. Mattoso and N. Duran (Eds.)], Springer. (pp. 69-80).

Tarafdar, J.C., Raliya, R., Mahawar, H. and Rathore, I. (2014). Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). *Agricultural Research*. **3:** 257-262. doi: 10.1007/s40003-014-0113-y.

Walkley, A., Black, I. A. and Armstrong, I. (1939). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*. **37(1):** 29-38.

Yadav, G.S., Babu, S., Meena, R.S., Debnath, C., Saha, P., Debbarma, C. and Datta, M. (2017). Effects of godawari phosgold and single super phosphate on groundnut (*Arachis hypogaea*) productivity, phosphorus uptake, phosphorus use efficiency and economics. *The Indian Journal of Agricultural Sciences*. **87(9):** 1165-1169.

Yomso, J., Menon, S., Na-Allah Sale, M. and Yumnam, J. (2023). Performance of mung bean as influenced by different levels of fertilizers and cropping systems in the semi-arid region of India. *Journal of Applied Biology and Biotechnology*. **11(5):**151-156.