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Response of black gram to soil amendments and phosphorus in acidic soil of Nagaland

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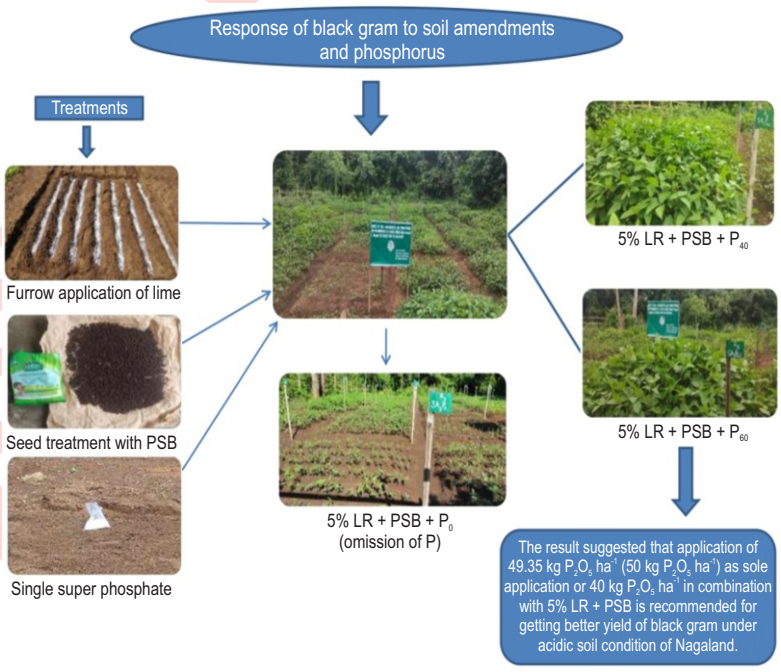
Abstract

Aim: To assess the influence of soil amendments and phosphorus on the performance of black gram, and to determine the optimum dose of phosphorus for better seed yield of black gram (*Vigna mungo* L. Hepper) in acid soil of Nagaland.

Methodology: Four soil amendment levels [SA_0(control), SA_1 (5% LR), SA_2 (PSB), SA_3 (5% LR + PSB)] and four phosphorus levels (0, 20, 40 and 60 kg P_2O_5 ha^{-1}) were laid out in a Factorial Randomized Block Design with three replications. Black gram variety SBC-40 was sown at a spacing of 30×10 cm. The data were statistically analysed by Fisher-Snedecor 'F' test at 0.05 level of probability, and the optimum dose of phosphorus was estimated by employing linear regression on the basis of seed yield of two years of field trails.

Results: Soil amendments and phosphorus significantly influenced the growth, yield attributes and yield of black gram. The pooled seed and stover yield increased by 29.9% and 35.7% over SA_0 in response to SA_3, and by 45.3% and 55.9% over control (P_0) in response to 60 kg P_2O_5 ha^{-1} (P_{60}), respectively. The optimum dose of phosphorus application was estimated to be 49.35 kg P_2O_5 ha^{-1}.

Interpretation: The study inferred that 50 kg P_2O_5 ha^{-1} as sole application or SA_3P_{40} (5% LR+ PSB + 40 kg P_2O_5 ha^{-1}) were found to be most promising for obtaining better yield of black gram under acidic soil of Nagaland.



Key words: Acidic soil, Black gram, Phosphorus level, Soil amendments

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Introduction

Pulses are the primary source of protein for country like India, where the vast majority of the population is vegetarian. It is an integral part of daily Indian meals, constituting roughly 14% of the total protein intake in the average Indian diet. Pulses possess the ability to fix atmospheric nitrogen which is safe and economical for plants; it also constitutes a symbiotic association with *Rhizobium* bacteria living in their root nodules. Thereby, pulses leave a substantial quantity (20-80 kg N ha^{-1}) of fixed atmospheric nitrogen. Black gram (*Vigna mungo* L. Hepper) is a major pulse crop grown throughout India. Black gram cultivation in India during the kharif season estimates around 30.73 lakh hectares in area with a production of 15.05 lakh metric tonnes (Ministry of Agriculture and Farmers Welfare, 2023-24). Madhya Pradesh, Uttar Pradesh, Rajasthan, Karnataka and Andhra Pradesh are the major producers of black gram in India. North-eastern regions of India account less than 5% in pulse production (Das *et al.,* 2016). In Nagaland, black gram occupies 310 hectares with a production of 255 metric tonnes (Directorate of Economics and Statistics, 2023). Soil acidity and phosphorus deficiencies limit crop production in North-east region (Majumdar *et al.,* 2022). Phosphorus deficiency in most soil acts as a major bottleneck to legume productivity (Lopez-Arredondo *et al.,* 2014).

Phosphorus is crucial for accelerating nitrogen transformation and regulating enzymes that enhance biological nitrogen fixation, making its availability a critical limiting factor (Vance *et al.,* 2003; Zhang *et al.,* 2014). It is an integral constituent of majority of enzymes which is of paramount importance in the transformation of energy, carbohydrate metabolism, and fat metabolism and also in respiration (catabolism of carbohydrates) in plants. Inadequate soil phosphorus severely constrains legume development by impairing biological nitrogen fixation, reducing nodule formation, and restricting photosynthesis (Yadav *et al.,* 2017). In Nagaland, soil fertility status was mapped at 1.0 km grid intervals throughout all parts of the state. It was observed that 100% of TGA of Nagaland comprised degraded acidic soils (with pH < 5.5), out of which, 9.25% of TGA belonged to strongly acidic (pH <4.5) and 90.75% of TGA under moderately acidic (pH 4.5-5.5) soils (Behera *et al.*, 2026). Crop productivity in acid soil is mainly affected by Al and Fe toxicity, P deficiency, low base saturation, impaired biological activity, acidity-induced fertility and other nutritional problems (Kumar *et al.,* 2012).

Soil acidity management on such soils is, therefore, imperative for improving crop productivity. Liming is the most favourable management practice to ameliorate acidic soils having soil pH of less than 5.5. Application of lime reduces the concentration of H^+, solubility of Fe, Al and Mn; and elevates soil pH. It also aids in reducing the toxicity effect of Al and facilitates the increase in availability of phosphorus and molybdenum. Soil with acidity-induced fertility problems, phosphorus deficit is one of the major issues which cripple the plant growth and crop productivity. Phosphate-solubilizing microorganisms secrete siderophores that chelate metal ions, thereby enabling insoluble soil phosphate available for plant assimilation (McRose and Newman, 2021). Ion exchange, chelation and production of organic acids including gluconic, keto-gluconic and lactic acid have been affiliated to phosphorus solubilizing bacteria (Chakdar *et al.,* 2018). It can solubilize phosphorus by secreting low-molecular-weight acids like lactic, formic, malonic, gluconic and citric, which can dissolve the mineral form of phosphorus. Use of biofertilizers like PSB is also a holistic approach to meet the phosphorus requirement of the plant without compromising the environmental health.

Soil acidity related fertility problem coupled with traditionally minimal use of mineral fertilizers are often held accountable for low levels of crop productivity in the state (Konyak *et al.,* 2020). It is, therefore, imperative to ascertain the yield benefits of individual as well as combined application of lime, chemical fertilizers and biofertilizer (PSB) in a particular edapho-climatic condition. Keeping the above facts into consideration, the present study was undertaken with the objective to assess the effect of soil amendments and phosphorus on the growth and yield of black gram. Novelty of this study is to develop an effective integrated soil acidity management approach particularly for enhancing the productivity of black gram in acidic soils of Nagaland. By mitigating soil acidity and phosphorus fixation, the study ultimately aims to establish the ideal phosphorus requirements for cultivating black gram.

Materials and Methods

A field trial was carried out at an experimental farm of the School of Agricultural Sciences (SAS), Nagaland University, Medziphema, Nagaland during the kharif season (July to October) of 2021 and 2022 with black gram (variety: SBC-40) as a test crop. The experimental site in located at 25º 45´30´´ N latitude and 93º53´04´´ E longitude, 310 m above mean sea level, with a humid sub-tropical climate receiving an average rainfall of 2000 to 2500 mm per annum from April to September, while remaining period from October to March remains dry. The experimental field was sandy loam in texture with soil pH 4.31, EC 0.15 dSm^{-1}, organic carbon 20.7 g kg^{-1}, and available N, P and K status 200.71, 9.18 and 168.34 kg ha^{-1}, respectively, lime requirement 20.99 t ha^{-1}, total potential acidity 20.4 cmol (p^+) kg^{-1}, pH dependent acidity 16.9 cmol (p^+) kg^{-1}, exchangeable acidity, Al^{3+}, H^+, Ca^{2+} and Mg^{2+} 3.5, 3.0, 0.5, 0.8 and 0.6 cmol (p^+) kg^{-1}. Soil samples were analyzed by using standard procedures (Singh *et al.,* 2019).

The individual plot size measured 2.1×2 m^2 with a planting spacing of 30×10 cm. The treatment consists of 4 levels of soil amendments (SA_0 -control, SA_1 -5% LR, SA_2 -PSB, SA_3 -5% LR + PSB) and 4 levels of phosphorus (0, 20, 40 and 60 kg P_2O_5 ha^{-1}), thereby making 16 treatments in combination (Sa_0P_0, Sa_0P_{20}, Sa_0P_{40}, Sa_0P_{60}, Sa_1P_0, Sa_1P_{20}, Sa_1P_{40}, Sa_1P_{60}, Sa_2P_0, Sa_2P_{20}, Sa_2P_{40}, SA_2P_{60}, SA_3P_0, SA_3P_{20}, SA_3P_{40} and SA_3P_{60}). The experiment was conducted in a Factorial Randomized Block Design with three replications. Lime (@ 5% LR) was applied in furrows 10 days prior to sowing and $CaCO_3$ was used as liming material. Seeds were treated with PSB (*Bacillus megaterium*) @ 20 g kg^{-1} one day

before sowing. Phosphorus was supplied through single superphosphate (SSP). Recommended doses of N and K @ 20 kg N and 40 kg K_2O ha^{-1} were applied as urea and muriate of potash. Calculated doses of fertilizers were applied on the day of sowing. Data on various growth parameters, yield attributes and yield were recorded. Obtained data from the experiment were processed, classified, tabulated and systematically analysed adopting Fisher-Snedecor 'F' test, using ANOVA at a significance level of 5% (Gomez and Gomez, 1984). The Statistical Product and Service Solutions (SPSS) software program, Origin Lab, and Statistix 8.1. was used for data analysis. The optimum dose of phosphorus fertilizer was determined on the basis of average seed yield of two years of experimentation by using linear regression.

Results and Discussion

The perusal of data showed that the growth attributes recorded at 25, 50 DAS and at harvest during in both years of experimentation were significantly influenced with the application of soil amendments and phosphorus (Table 1). Plant height and number of branches per plant were significantly higher in amended plots over control. At all growth stage, the maximum plant height and number of branches were recorded when lime was applied in conjunction with PSB (SA_3); during 2021 and 2022, the treatment SA_3 at harvest increased the plant height to an extent by 18.8 and 37.4% and the number of branches per plant by 23.3 and 39.8% over control, respectively.

A critical evaluation of data (Table 1) further revealed that in the year 2021 during the initial growth stage the influence of PSB on growth attributes was inconspicuous, however, with the progressive growth stages, the effect of PSB was more evident. With the advancement of days, a significant increase in the growth parameters and a conspicuous difference among the treatments were observed, likely because PSB requires time to colonize the rhizosphere and facilitate gradual release of nutrients. Irrespective of years and amendments, the plant height recorded at 25, 50 DAS and at harvest ranged from 9.17 to 15.19, 22.43 to 42.60 and 27.99 to 48.32 cm; and the number of branches per plant recorded at 25, 50 DAS and at harvest ranged from 0.50 to 1.10, 1.35 to 2.10 and 1.50 to 2.28, respectively. Liming enhances nutrient solubility due to moderation of soil reaction; greater the uptake of nutrients more production of protoplasm, thereby increasing rapid cell division and cell elongation which is favourable for plant growth and development.

This significant increase can also be attributed to role of phosphorus solubilising bacteria in phosphorus nutrition by increasing its availability to plants by liberating phosphorus from inorganic and organic soil phosphorus pools by solubilisation and mineralization, thereby enabling the plant to absorb more phosphorus resulting in improved growth attributes. These results are in conformity with the findings of Dabesa and Tana (2021) who reported enhanced growth attributes of soybean under acidic soil, and Sen *et al.* (2026) who demonstrated that combining lime with PSB significantly outperforms lime application alone, enhancing soil available phosphorus by 38% and acid phosphatase levels by 27%. A gradual increase in plant stature and number of branches per plant was observed at successive growth stages with the increasing phosphorus levels. In both the trials, the maximum value of plant height and number of branches per plant at harvest were recorded at 60 kg P_2O_5 with a value of 35.81 cm and 2.00 during 2021 and 46.94 cm and 2.37 during 2022, respectively. Increase in plant height might be owing to the fact that

Table 1: Effect of soil amendments and phosphorus on growth parameters of black gram

Treatments	Plant height (cm)						Number of branches per plant					
	2021			2022			2021			2022		
	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest
Soil amendments												
SA_0 (Control)	9.28	22.43	27.99	13.33	30.50	35.15	0.50	1.35	1.50	0.63	1.50	1.63
SA_1 (5% LR)	10.17	26.65	31.99	14.44	38.59	42.57	0.73	1.60	1.78	0.97	1.88	2.07
SA_2 (PSB)	9.17	24.35	29.32	13.55	34.19	38.43	0.58	1.50	1.63	0.73	1.65	1.80
SA_3 (5% LR + PSB)	9.83	28.28	33.27	15.19	42.60	48.32	0.92	1.70	1.85	1.10	2.10	2.28
SEm±	0.18	0.30	0.25	0.25	30.50	0.35	0.03	0.05	0.04	0.04	0.05	0.05
CD (P=0.05)	0.52	0.87	0.71	0.71	38.59	1.02	0.09	0.13	0.12	0.11	0.13	0.14
Phosphorus levels												
P_0	7.89	19.30	24.34	12.22	30.82	35.10	0.35	1.05	1.23	0.50	1.35	1.45
P_{20}	9.49	24.74	29.61	13.60	34.14	38.89	0.62	1.43	1.58	0.77	1.68	1.83
P_{40}	10.77	28.03	32.80	14.90	39.15	43.54	0.85	1.78	1.95	1.02	1.97	2.13
P_{60}	10.30	29.65	35.81	15.80	41.77	46.94	0.92	1.88	2.00	1.15	2.13	2.37
SEm±	0.18	0.30	0.25	0.25	0.35	0.35	0.03	0.05	0.04	0.04	0.05	0.05
CD (P=0.05)	0.52	0.87	0.71	0.71	1.02	1.02	0.09	0.13	0.12	0.11	0.13	0.14

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Table 2: Effect of soil amendments and phosphorus on yield attributes of black gram

Treatments	Pod length (cm)		Pods per plant		Seed per pod		Test weight (g)	
	2021	2022	2021	2022	2021	2022	2021	2022
Soil amendments								
SA_0 (Control)	4.12	4.15	9.71	11.43	5.95	6.36	41.66	41.67
SA_1 (5% LR)	4.30	4.33	11.20	12.82	6.49	6.68	41.81	41.88
SA_2 (PSB)	4.20	4.27	10.32	12.03	6.34	6.53	41.79	41.74
SA_3 (5% LR + PSB)	4.44	4.52	11.88	14.28	6.77	6.82	41.90	42.00
SEm±	0.06	0.06	0.17	0.20	0.04	0.02	0.26	0.17
CD (P=0.05)	0.16	0.18	0.49	0.58	0.10	0.06	NS	NS
Phosphorus levels								
P_0	3.95	4.04	8.80	10.17	5.75	6.15	41.62	41.64
P_{20}	4.24	4.28	10.41	11.90	6.33	6.46	41.74	41.76
P_{40}	4.38	4.44	11.82	14.03	6.69	6.87	41.86	41.89
P_{60}	4.49	4.52	12.08	14.47	6.78	6.91	41.94	41.99
SEm±	0.06	0.06	0.17	0.20	0.04	0.02	0.26	0.17
CD (P=0.05)	0.16	0.18	0.49	0.58	0.10	0.06	NS	NS

phosphorus enhanced photosynthetic activity of plants and facilitates root proliferation, hasten cell division and multiplication that eventually elevated the growth and development conducive for plant height. Also an adequate supply of phosphorus facilitate ancillary support to nitrogen supply through the role of phosphorus in biological nitrogen fixation and its availability assisted the plants to attain more vigour in terms of plant height; furthermore phosphorus improves photosynthesis and translocation of photosynthates to different plant parts stimulating meristematic development in potential apical buds and intercalary meristem, which eventually enhances root and shoot development in terms of growth. These results are in congruence with the findings of Choudhary *et al.* (2024) in summer black gram under acidic soil.

During 2021 and 2022, the application of soil amendments and phosphorus had markedly enhanced the pod length, pod per plant and seed per pod except for test weight of black gram seed. During both the years of experimentation, the yield attributes were recorded higher in amended plots over control. Across two years of trials and soil amendments, the yield attributes of black gram varied: pod length from 4.12 to 4.52 cm; pods per plant from 9.71 to 14.28; seeds per pod from 5.95 to 6.82, and test weight from 41.66 to 42.00 g (Table 2). However, in case of pod length, a significant increase was observed only in lime treated plots either applied alone or combined; while in sole PSB treated plots, the pod length of black gram was slightly higher than control but was statistically non-significant. The data further revealed that lime treated plots produced higher number of pods per plant and seed per pod in comparison to control and sole PSB treated plots. The maximum value on yield attributes was recorded under SA_3 (5% LR+PSB) treatment, which was significantly superior to other soil amendment treatments.

During 2021 and 2022, the combined application of 5% LR+PSB enhanced pod length by 7.7 and 8.9%, pods per plant by 22.3 and 24.9% and seed per pod by 13.7 and 7.2% over control, respectively. The apparent increase can be attributed to adequate supply of nutrients, particularly NPK due to liming and their subsequent increase in uptake, thereby resulting higher photosynthesis and better translocation of carbohydrates to fruiting sink due to liming. Similarly, longer pods likely resulted from this improved source-to-sink movement of photosynthates, combined with enhanced phosphorus availability via PSB inoculation—a critical factor for pod initiation and seed development. There were apparent differences in amended plots compared to control plots. These variations stem from lime application ensuring an adequate supply, and subsequent uptake of essential macronutrients (NPK).

Additionally, PSB further amplified available phosphorus, stimulating robust root architecture and nodulation. This enhanced root system boosted overall nutrient absorption, ultimately driving the superior yield attributes observed. These results are in line with that of Uchoi and Sharma (2023) who reported similar findings in black gram under acidic soil. Also, PSB facilitates higher absorption and utilization of phosphorus which resulted better development of flowers and pod formation. These results are in agreement with the findings of Choudhary *et al.* (2025) in summer black gram under acidic soil of Nagaland. During both 2021 and 2022, application of phosphorus @ 60 kg P_2O_5 ha^{-1} yielded the highest agronomic values, including a pod length of 4.49 cm and 4.52 cm, 12.08 and 14.47 pod per plant, 6.78 and 6.91 seed per pod, and a test weight of 41.94 and 41.99 g. However, this treatment was statistically comparable to 40 kg P_2O_5 ha^{-1} application. P_{40} enhanced the yield attributes by 10.8 and 9.9%, 34.3 and 37.9% and 16.3 and 11.7% in pod length, pod per plant and seed per pod over control. Improvement in yield attributes with the application of phosphorus can be attributed to the key role of phosphorus in flowering, fruiting and seed development. The results corroborate with the findings of Kumar

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Table 3: Effect of soil amendments and phosphorus on yield of black gram

Treatments	Seed yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Biological yield (kg ha^{-1})		Protein yield (kg ha^{-1})	
	2021	2022	2021	2022	2021	2022	2021	2022
Soil amendments								
SA_0 (Control)	372.45	593.88	643.25	1089.50	1015.70	1683.38	71.38	121.11
SA_1 (5% LR)	457.41	698.08	833.27	1332.23	1290.68	2030.31	96.53	148.52
SA_2 (PSB)	408.29	668.01	743.41	1242.47	1151.70	1910.48	82.00	139.92
SA_3 (5% LR + PSB)	499.83	755.54	939.30	1413.47	1439.13	2169.01	108.89	166.87
SEm±	7.87	7.16	13.77	18.96	21.39	25.14	1.66	1.74
CD (P=0.05)	22.74	20.67	39.78	54.76	61.78	72.60	4.79	5.03
Phosphorus levels								
P_0	349.52	533.58	584.89	977.21	934.42	1510.79	67.69	104.61
P_{20}	413.80	593.13	747.88	1100.67	1161.68	1693.80	82.58	121.58
P_{40}	487.14	792.86	906.26	1483.50	1393.40	2276.36	101.70	170.12
P_{60}	487.52	795.94	920.21	1516.30	1407.73	2312.24	106.82	180.10
SEm±	7.87	7.16	13.77	18.96	21.39	25.14	1.66	1.74
CD (P=0.05)	22.74	20.67	39.78	54.76	61.78	72.60	4.79	5.03

and Debbarma (2023) in green gram under nearly neutral soil. Significant interaction of soil amendments and phosphorus were found on pod per plant and seed per pod of black gram, except for pod per plant during 2021 (Table 4). It was observed that at all levels of soil amendments, the maximum pod per plant and seed per pod were recorded at P_{60} (60 kg P_2O_5 ha^{-1}) and were at par with P_{40} (40 kg P_2O_5 ha^{-1}). Thus, it could be inferred that in all soil amendment levels, phosphorus had a positive effect on pod per plant and seeds per pod. The maximum pod per plant and seed per pod were recorded with treatment combination SA_3P_{60} which were found to be at par with SA_3P_{40} while minimum was recorded at SA_0P_0.

A significant variation between treatment combination can be ascribed to the fact that in the event of soil with low phosphorus status and soil pH, the probable attainability of phosphorus for plant uptake gets higher with increasing level of phosphorus in conjunction with amendments (lime and PSB), which enhance phosphorus availability as well as other essential nutrients by improving soil reaction through liming and solubilising as well as mineralisation of fixed phosphorus by PSB that might have further increased the availability of phosphorus for plant uptake, thereby favouring a series of individual processes such as photosynthesis, N fixation and cell division promoting plant growth and development. This is in congruence with that of Uzege *et al.* (2023) who reported positive interaction of lime and phosphorus on pod per plant, and seed per pod of cow pea; Jamir *et al.* (2022) observed similar interaction of PSB and phosphorus on seeds per pod of black gram.

The data pertaining to seed, stover, biological and protein yield of black gram of two years of field trials are presented in Table 3. A significant disparity among the soil amendment treatments on yield of black gram was evident. Irrespective of years, the response of yield to soil amendments was in order the following: $SA_3>SA_1>SA_2>SA_0$. The combined application of 5% LR + PSB (SA_3) exhibited superior yield than sole application of lime (SA_1) and PSB (SA_2) with maximum value on seed yield (499.83 and 755.54 kg ha^{-1}), stover yield (939.30 and 1413.47 kg ha^{-1}), biological yield (1439.13 and 2169.01 kg ha^{-1}) and protein yield (108.89 and 166.87 kg ha^{-1}) recorded at SA_3. During 2021 and 2022, the combined application of 5% LR and PSB enhanced the seed yield by 34.2 and 27.2%, stover yield by 46.0 and 29.7%, biological yield by 41.6 and 28.8% and protein yield by 52.5 and 37.7% over control. Since, liming enhanced availability of major nutrients (NPK) to plant by improving soil reaction which favoured early root development and cell multiplication resulting higher absorption of other essential nutrients, thereby improved the growth parameters, grain and biological yield; also increase in available Ca^{2+}, given the nature of liming material ($CaCO_3$), favours excellent seed filling. Bossolani *et al*. (2022) reported similar trend with application of lime on yield of soybean in acid soil. PSB inoculation indirectly increase nitrogen fixation, thereby increasing the availability of nitrogen for plant uptake resulting in higher nitrogen content in seed consequently enhanced the protein content.

On contrary, the plot where no amendments were applied showed minimum yield, which may be attributed to low soil nutrient status coupled with low activity of soil micro-organism as influenced by soil acidity. The results are in conformity with that of Jamir *et al.* (2025) in summer black gram under acidic soil. Irrespective of years, phosphorus @ 60 kg P_2O_5 ha^{-1} recorded maximum seed yield (795.94 kg ha^{-1}), stover yield (1516.30 kg ha^{-1}), biological yield (2312.24 kg ha^{-1}) and protein yield (180.10 kg ha^{-1}), which was at par with 40 kg P_2O_5 ha^{-1}, expect for protein yield. During 2021 and 2022, application of 40 kg P_2O_5 ha^{-1} increased the seed yield by 39.3 and 48.5%, stover yield by 54.9 and 51.8%, biological yield by 49.1 and 50.6% and protein yield by 50.2 and 62.6%, respectively. Yield improvement in response to phosphorus application can be attributed to the positive influence

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Table 4: Interaction effect of soil amendments and phosphorus on yield attributes and yields of black gram

Soil amendments	Pod per plant								Seed per pod							
	Phosphorus levels															
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
	2021				2022				2021				2022			
SA_0	8.13	9.17	10.47	11.07	9.67	10.67	12.53	12.87	5.52	5.81	6.20	6.28	5.99	6.19	6.62	6.66
SA_1	9.07	11.07	12.27	12.40	10.47	12.60	13.93	14.27	5.71	6.52	6.81	6.90	6.19	6.47	7.00	7.04
SA_2	8.27	9.80	11.46	11.73	9.87	11.27	13.27	13.73	5.57	6.29	6.70	6.82	6.04	6.52	6.76	6.80
SA_3	9.73	11.60	13.07	13.13	10.67	13.07	16.40	17.00	6.19	6.71	7.05	7.11	6.37	6.67	7.10	7.14
SEm±	0.23				0.40				0.07				0.04			
CD (P=0.05)	NS				1.16				0.20				0.11			

	Seed yield (kg ha^{-1})								Stover yield (kg ha^{-1})							
	2021				2022				2021				2022			
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
SA_0	322.14	366.28	400.46	400.92	480.65	526.00	684.50	684.37	507.39	594.87	727.56	743.20	872.50	966.41	1250.09	1269.00
SA_1	373.18	427.12	514.31	515.04	564.00	622.82	802.56	802.94	646.77	794.88	938.49	952.95	1055.37	1178.31	1539.72	1555.54
SA_2	325.45	372.65	467.23	467.84	499.50	586.46	792.68	793.39	522.86	684.70	878.03	888.05	904.24	1077.00	1463.68	1524.98
SA_3	377.33	489.14	566.56	566.26	590.18	637.25	891.70	903.04	662.56	917.09	1080.95	1096.62	1076.71	1180.96	1680.52	1715.70
SEm±	15.75				14.32				27.54				37.92			
CD (P=0.05)	45.48				41.35				79.55				109.51			

	Biological yield (kg ha^{-1})								Protein yield (kg ha^{-1})							
	2021				2022				2021				2022			
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
SA_0	829.53	961.15	1128.02	1144.12	1353.15	1492.40	1934.58	1953.37	58.23	67.29	77.75	82.25	90.01	104.08	140.56	149.77
SA_1	1019.94	1222.00	1452.80	1467.99	1619.37	1801.13	2342.28	2358.48	73.79	88.13	110.71	113.48	111.16	130.05	172.54	180.33
SA_2	848.31	1057.35	1345.26	1355.89	1403.74	1663.45	2256.36	2318.37	61.68	73.05	93.34	99.92	97.12	117.99	166.97	177.61
SA_3	1039.89	1406.22	1647.51	1662.91	1666.89	1818.21	2572.22	2618.75	77.06	101.84	125.01	131.65	120.15	134.22	200.40	212.71
SEm±	42.78				50.27				3.32				3.49			
CD (P=0.05)	NS				145.20				9.58				10.07			

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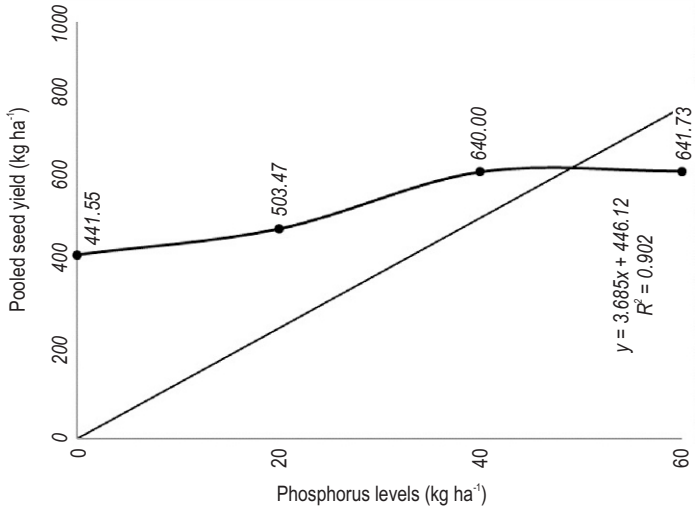


Fig. 1: Response of black gram seed yield to phosphorus application.

of elevated dose of phosphorus on root growth promoted rhizobia activity on plant roots and induced nodulation; bringing about better performance of the crop in terms of plant height, number of branches per plant, seed development and dry matter accumulation per plant. Increase in protein yield as compared to preceding lower level of phosphorus could be attributed to increased nitrogen content in seed and seed yield augmented by phosphorus application.

These results corroborate with the findings of Hangsing *et al.* (2020) in green gram under acidic soil. The interaction effect of soil amendments and phosphorus on yield (seed yield, stover yield, biological yield and protein yield; barring biological yield in 2021 were found significant (Table 4). An increasing trend with increase in the level of phosphorus irrespective of soil amendments were observed, aside from seed yield in 2021, which could be attributed to an increase in supply of phosphorus as the level of phosphatic fertilizer ascended coupled with soil amendments, which act as complementary counterpart in boosting the phosphorus status in the soil by improving soil reaction and mobilization of unavailable phosphorus which further favours improvement in yield and yield attributes. The maximum value of seed yield (during 2022), stover yield, biological yield and protein yield were recorded at SA_3P_{60}, aside from protein yield in 2022, were found to be at par with SA_3P_{40}. While, the maximum seed yield (during 2021) was recorded at SA_3P_{40}, which was at par with SA_3P_{60}.It was apparent that the yield at SA_3 was superior to rest of the amendment levels; while, the overall maximum values on yield (seed yield, stover yield, biological yield and protein yield) were recorded at treatment combination SA_3P_{60} which was statistically at par with SA_3P_{40}. Although the yield at SA_1 was higher than SA_2, the performance of these two amendment levels in conjunction with P_{60} and P_{40} were statistically at par. Henceforth, it could be inferred that SA_3 performed better among the soil amendment levels while P_{60} exhibited higher yield which was at par with P_{40} at all amendment levels. Therefore, SA_3P_{40} was considered as the best combinations for obtaining better yield of black gram. The results are also in line with that of Bekele *et al*. (2023) who reported positive interaction of lime and phosphorus on yield of groundnut; Sameer *et al*. (2025) reported similar positive interaction of phosphorus solubilizing bacteria and phosphorus on yield of mung bean.

A linear relationship between phosphorus application and seed yield was fitted on the basis of average seed yield of two years of experimentation. The relationship between phosphorus and seed yield could be articulated by high coefficient of determination (R^2 = 0.902, Fig 1). Based on the regression equation, the optimum dose of phosphorus fertilizer was estimated to be 49.35 kg P_2O_5 ha^{-1} for obtaining maximum seed yield of black gram in the present set of conditions. From the study, the conclusion can be drawn that application of soil amendments and phosphorus exhibited significant influence on the growth parameters and yield of black gram. Better performance of black gram was observed with application of SA_3 soil amendment, while P_{60} exhibited better performance but was statistically at par with P_{40}. Among the treatment combinations, SA_3P_{40} was statistically at par with SA_3P_{60}. Thereby, SA_3P_{40} demonstrated to be the best combinations for obtaining better yield of black gram in acidic soils of Nagaland.

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