EFFECT OF SOIL AMENDMENTS AND PHOSPHORUS ON PERFORMANCE OF BLACK GRAM (*Vigna mungo* L. Hepper) IN ACIDIC SOIL OF NAGALAND

Thesis

submitted to

NAGALAND UNIVERSITY

in partial fulfillment of requirements for the Degree

of

Doctor of Philosophy

in

SOIL SCIENCE

by

TEMSUSANGLA I. JAMIR

Admn. No. Ph-283/19 Regn. No. Ph.D/ACSS/00326

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Nagaland

2024

Ph.D **TEMSUSANGLA I. JAMIR** **2024** **SOIL**

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DECLARATION

I, Ms. Temsusangla I. Jamir, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other university/institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Soil Science.

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CERTIFICATE - I

This is to certify that the thesis entitled **"Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Soil Science is the record of research work carried out by Ms. Temsusangla I. Jamir, Registration No. Ph.D/ACSS/00326 under my personal supervision and guidance.

The results of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN SOIL SCIENCE

This is to certify that the thesis entitled "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" submitted by Temsusangla I. Jamir, Admission No. 283/19 Registration No. Ph.D/ACSS/00326 to the NAGALAND UNIVERSITY in partial fulfillment of the requirement for the award of degree of Doctor of Philosophy in Soil Science has been examined by the Advisory Board and External examiner on …………………..

The performance of the student has been **Satisfactory/Unsatisfactory.**

Member	Signature
1. Prof. Y. K. Sharma (Supervisor & Chairman)	………………………….
2. Prof. Sanjay Swami (External examiner)	………………………….
3. Pro Vice Chancellor Nominee	………………………….
4. Prof. A. K. Singh	………………………….
5. Prof. P. K. Singh	………………………….
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Date:

Place: Medziphema (TEMSUSANGLA I. JAMIR)

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ABSTRACT

A field experiment was conducted to study the "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" during *kharif* season of 2021 and 2022, in the experimental farm of the Department of Soil Science, School of Agricultural Sciences (SAS), Nagaland University, Medziphema. The experiment was laid out in factorial randomized block design, the treatments 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 each replicated thrice. The study revealed that application of soil amendments and phosphorus significantly increased the growth, yield attributes, yield, nutrient concentration and uptake of black gram; SA_3 [i.e., application of lime @ 5% LR in conjunction with seed inoculated PSB (*Bacillus megaterium*)] performs better than other soil amendment treatments, also application of phosphorus @ 60 kg P_2O_5 ha^{-1} showed better results, but was at par with @ 40 kg P_2O_5 ha^{-1} on all accounts of yield and yield attributes. The seed and stover yield was increased by 29.9% and 35.7% over control in response to SA_3, and by 45.3% and 55.9% over control due to application of 60 kg P_2O_5 ha^{-1}. The highest values on yield and growth attributes were recorded at treatment combination SA_3P_{60}, which was at par with SA_3P_{40}. The optimum level of phosphorus calculated on the basis of pooled seed yield was found to be 49.35 kg P_2O_5 ha^{-1}. Application of soil amendments increased soil pH, EC, available N, P, K, exchangeable calcium and soil microbial biomass carbon, and reduced forms of soil acidity components significantly. Phosphorus application significantly enhanced the soil available nitrogen, phosphorus and soil microbial biomass carbon of post harvest soil. Interaction effect of soil amendments and phosphorus was significant for plant height, pods $plant^{-1}$, seed pod^{-1}, grain and stover yield;

nutrient uptake (N, P, K, Ca and Mg) and soil available P. Therefore, the results suggested that application of 49.35 kg P_2O_5 ha^{-1} (50 kg P_2O_5 ha^{-1}) along with soil amendments (5% LR + PSB) is recommended for getting better yield of black gram under acidic soil condition of Nagaland.

Key words: Black gram, lime, PSB, phosphorus, yield, nutrient uptake, soil properties.

CHAPTER I

INTRODUCTION

INTRODUCTION

Pulses are the primary source of protein for country like India, where the vast majority of the population is vegetarian. Food legumes, therefore, are important component of their diet; as such should accord paramount importance. 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 subtantial quantity (20-80 kg N/ha) of fixed atmospheric N depending upon the pulse crop species and environmental conditions of their growth.

Black gram (*Vigna mungo* L. Hepper) is one of the major pulse crops grown widely in India. It is native to India and also known as *urd* bean. It is cultivated as sole crop, mixed crop or sequential crop under rainfed or semi irrigated condition in *kharif* and spring/summer season. *Urd* bean is a rich source of food protein containing about 24% protein, which is almost three times that of cereals and other minerals and vitamins. It is rich in vitamin A, B_1, B_3 and C. The dry seeds are good source of phosphorus and have high calorie content (347 cal /100 g) therefore it is regarded as the cheapest available source of protein for the poor and vegetarians. It is consumed as dal, whole or splitted, husked or un-husked, and is highly nutritive containing high proportion of digestible protein with many essential amino acids. High values of lysine make black gram an excellent complement to rice in terms of balanced human nutrition. *Urd* bean is used as nutritive fodder especially for milch animals. Being a legume, black gram can fix atmospheric nitrogen in the soil and produces 22.10 kg of N ha^{-1} which has been estimated to be supplement of 59 thousand tons of urea annually (Senaratne and Ratnasinghe, 1993).

India is the largest producer, consumer and importer of pulses in the world. Area under pulses cultivation in India is 281.70 lakh hectares, which accounts for 35% global acreage and contributes 25% of global production. In India, area under *urd* is estimated to be 30.73 lakh hectares with a production of 15.05 lakh metric tonnes during *kharif* season (Anonymous, 2023-24). The states of Madhya Pradesh, Uttar Pradesh, Rajasthan, Karnataka and Andhra Pradesh are the major producers of black gram in India during *kharif* season. North Eastern regions of India account less than 5% in pulse production. In Nagaland, black gram (during 2022-23) occupies with 310 hectare with a production of 255 metric tonnes, (Anonymous, 2023).

The soils of North Eastern Regions (NER) of India are known for their strongly acidic reaction with special reference to Nagaland (Sharma *et al*., 2006). It is recorded that 11.2 million hectare (Mha) areas of NER of India are occupied by chemically degraded acid soils (pH < 5.5), being most intensified in Nagaland (97% of area) (Sharma *et al*., 2006). In Nagaland, soil fertility status was mapped at 1.0 km grid intervals throughout all parts of the state. It was observed that 83.6% of TGA of the state comprised degraded acidic soils (with pH < 5.5), out of which, 16.9% belonged to extremely acidic, 39.4% of TGA under very strongly acidic and 27.3% of TGA was under strongly acidic soils (Bandypadhyay *et al*., 2016). Crop production in acid soil is mainly affected by aluminium and iron toxicity, P deficiency, lower base saturation, reduced biological activity, acidity-induced fertility and other nutritional problems (Kumar *et al*., 2012). Acid soils have negative effect on plant growth which is principally related to aluminium, manganese and iron toxicity, deficiency of calcium and magnesium, nutrient imbalances and microbial imbalances. High concentration of aluminium ion at the root surface may obstruct the root from taking up phosphate and the aluminium inside the living cell may intervene with sugar phosphorylation. Soil acidity management and crop productivity improvement on such soils is therefore imperative for improving food security globally and regionally.

Phosphorus is an important plant nutrient next to nitrogen; Indian soils are low to medium in available P. Only about 30% of the applied phosphorus is available for crops and surplus P is converted into insoluble phosphorus. It is a structural component of nucleic acid, ADP and ATP; as well as essential for *Rhizobium* bacteria to convert atmospheric N into an ammonium form useable by plants and aids in better nodulation and effective functioning of the nodule bacteria for fixation of N to be used by plant during grain-development stage, which results to increase in grain yield. It is also essential for protein synthesis, flowering, fruiting and seed formation. Formation of energy rich phosphate bonds, phospholipids and development of root system in legumes is positively influence by application of phosphorus. Phosphorus meliorate the crop quality and resistance to diseases coupled with boosting the soil nitrogen content for the succeeding non-legume crops requiring lower doses of nitrogen application. Furthermore, phosphorus 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. It is closely associated to cell division and development. Phosphorus stimulates seed setting, hastens maturity and amplifies protein content. It plays a pivotal role in the nutrition of legumes and also improves biological nitrogen fixation and quality of grains (Kumar *et al*., 2009).

In soil, phosphorus does not exist as elemental form and is a reactive element. In soil solution it exists as insoluble inorganic phosphorus and insoluble organic phosphorus (Walpola and Yoon, 2012). The prime input of inorganic P in agricultural soil is applying phosphorus fertilizers. About, 70 to 90% of phosphorus fertilizer applied to soils is fixed by cations and converted inorganic P. Phosphorus gets immobilized by cations such as Ca^{2+}in calcareous or normal soils to form a complex calcium phosphate ($Ca_3(PO_4)_2$) and with Al^{3+} and Fe^{3+} in acidic soils to form aluminium phosphate ($AlPO_4$) and ferrous phosphate ($FePO_4$) (Satyaprakash *et al.*, 2017; Kumar *et al.*, 2018). These are insoluble forms and consequently unavailable. According to Walpola and Yoon, 2012, these accumulated phosphates are sufficient to maintain maximum crop yield for about 100 years if it could be mobilized, converted into soluble P forms using of Phosphate Solubilising Microorganism (PSM) (Kalayu, 2019).

Phosphate Solubilizing Bacteria (PSB) plays an indispensable role in supplementing phosphorus requirement of crop. In soil with acidity-induced fertility problems, phosphorus deficit is one of the major issues which cripple the plant growth and crop productivity. Plant obtains phosphorus from soil solution as $H_2PO_4^-$ and HPO_4^{2-}, which are least mobile element in plant and soil contrary to other macronutrients. Phosphorus precipitates in soil as orthophosphate or is adsorbed by Fe and AI oxides through legend exchange. Inoculation of phosphorus solubilising or mobilizing microorganisms with legumes crops has been found to substitute around 20% P requirement by P solublization (Singh *et al.*, 1998). Ion exchange, chelation and the creation of organic acids including gluconic, keto-gluconic and lactic acid have been associated to PSB for quite some time (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. Phosphorus Solubilizing Bacteria (PSB) embody a sustainable and environment friendly approach in dissolving phosphatic fertilizers and bound phosphorus thereby enhancing plant growth, phosphorus uptake and yield.

Soil acidity and phosphorus deficiencies limit crop production in North east region. Acidity of soil limits the availability of nutrients and instigates low productivity. In acid soil, phosphorus is deficient because soluble inorganic P is fixed by Al and Fe (Adnan *et al*., 2003) resulting in less availability of P for crop. Phosphorus is generally available to crops at soil pH of 6 and 7. Liming is the most desirable practice of amelioration of acidic soils having pH of less than 5.5. Lime requirement of soils of North Eastern Regions of the country is generally calculated using the data on pH, organic carbon, clay content and CEC of soils. Cost effective liming materials are available in north eastern states of the country as paper mill by-products like lime sludge, basic slag, paper mill sludge, etc. with cheap prices. Lime application declines the concentration of H^+, solubility of Fe, Al and Mn and increase in soil pH. It also helps reduce to the toxicity effect of Al. It also facilitates the increase in availability of phosphorus and molybdenum. 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. Lime application in combination with integrated nutrient management is often recommended to enhanced the phytoavailability of essential nutrients and ameliorate the other acidity-induced fertility constraints on such soils (Kumar *et al*., 2012). 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-climaticcondition. Keeping the above facts into consideration, present study entitled "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" was undertaken with the following objectives:

1. To assess the effect of soil amendments and phosphorus on growth and yield of black gram
2. To study the effect of soil amendments and phosphorus on nutrient composition and uptake
3. To study the effect of treatments on soil properties

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The information pertaining to the present investigation entitled "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" and related studies have been reviewed and presented in this chapter under the following headings.

2.1. Effect of Lime

2.1.1. Effect on crop growth, yield and nutrient composition

Sarker *et al*. (2014) investigated the root growth, yield potential and seed protein content of summer mung bean under different levels of lime and reported that lime application @ 2 t ha^{-1} was found beneficial for root growth and higher seed yield in summer mung bean.

Kumar *et al.* (2014) revealed that increasing levels of lime (furrow application) from 0 - 0.6 t ha^{-1} significantly increased growth, yield attributes and yield of rice bean. Protein quality was also significantly influenced by application of lime.

Meena and Varma (2016) demonstrated significant improvement in seed (524 kg ha^{-1}), straw (1426 kg ha^{-1}), biological yield (1949 kg ha^{-1}) and total NPK uptake (96.68 kg ha^{-1}) were recorded in 100% RDF. Similar results were observed with application of 200 kg lime ha^{-1} in mung bean. Interaction effect was also recorded at P=0.05 level of significance between fertility and lime levels on mung bean seed (622 kg ha^{-1}) and biological (2145 kg ha^{-1}) yield with 100% RDF + 200 kg lime ha^{-1} which were observed highest than all other treatments.

Rathod *et al*. (2017) conducted a field experiment on lateritic soil of Dapoli Konkan, Maharashtra to study the effect of lime, zinc and boron on yield and nutrient uptake by soybean. Results showed that combined application of 100% LR + Zn + B through soil and foliar spray along with RDF significantly increased the grain (25.52 q ha^{-1}) and straw yield (37.29 q ha^{-1}) and uptake of N, P, K, Ca, Mg and S was also found significantly influenced by the treatments on soybean.

Lynrah *et al*. (2017) reported that application of lime @ 1.5 t ha^{-1} gave significantly highest growth and yield of soybean.

Varma *et al*. (2017) observed that the growth and yield parameters in mung bean were found significant with an application of 200 kg ha^{-1} lime. Protein (%) and nutrient (%) and NPK uptake by the crop was found significant with application of RDF + 200 kg lime ha^{-1} as compare to other treatments which was at par with 100% RDF + 300 kg lime ha^{-1} and 125% RDF + 125 kg lime ha^{-1}.

Lynrah and Nongmaithem (2017) studied the effect of lime application on soybean under rainfed condition of Nagaland and found that lime application @ 1.5 t ha^{-1} registered highest values on growth and yield attributes *viz*. branches $plant^{-1}$, dry weight, crop growth rate, fresh weight of nodules, pods $plant^{-1}$ and pod length. Highest seed yield (2.71 t ha^{-1}) and stover yield (2.97 t ha^{-1}) and NPK uptake was also observed with lime application @ 1.5 t ha^{-1}.

Nakhro *et al*. (2018) found that application of lime enhanced the growth characters which increased the grain yield and stover yield of soybean by 79.42 % and 38.37 %, respectively over control.

Pati *et al*. (2020) conducted a field experiment at the *terai* situation of West Bengal (India) under different combination of phosphorus, boron and farm yard manure (FYM). The soil was acidic (pH 5.35) in reaction with sandy-loam in texture and hence, liming material was applied to find out the efficiency of the phosphorus (P) in determining the yield potential of the crop (lentil). The maximum grain yield of lentil was 13.85 q ha^{-1} at the lime- treated soil compared to the untreated control (6.63 q ha^{-1}). The effect of P was relatively lower in a soil not treated with lime. Hence, application of lime in soil can improve the use efficiency of P for lentil in an acidic soil of a region.

Odyuo and Sharma (2020) narrated that the highest plant height, number of branches $plant^{-1}$, number of pods $plant^{-1}$, number of grains pod^{-1}, seed, stover and protein yield, nutrients content and their uptake were recorded with 20 kg N + 50 kg P_2O_5 + 40 kg K_2O + 2 kg B + 656 kg lime ha^{-1} . However, the effect of this fertility level (F9) was at par with 20 kg N + 50 kg P_2O_5 + 40 kg K_2O + 656 kg lime ha^{-1} (F8 fertility level) with regard to seed and stover yield of green gram. The F8 fertility level increased seed, stover and protein yield to the extent of 76.7, 90.6 and 91.6% over control, respectively. Average seed yield under unlimed fertility levels was recorded 506.11 kg ha^{-1}, but average seed yield was recorded 727.62 kg ha^{-1} with application of lime fortified fertility levels. Lime fortified fertility levels enhanced seed yield by 43.8% over unlimed fertility levels. Maximum N, P, K, Ca and B content in seed and stover was recorded with F9 fertility level except P content in seed. However, difference between F8 and F9 fertility levels was at par except for N content in seed and B content. Highest uptake of N, P, K, Ca and B was recorded with F9 fertility level.

Ameyu and Asfaw (2020) conducted a study to determine the effect of lime and phosphorus fertilizers on soybean yields and to explore the best treatments that can maximize the productivity of soybean and revealed that lime x phosphorus interactions were significant. Application of phosphorus (30 kg ha^{-1}) significantly increased the plant height (67.03 cm), number of pods $plant^{-1}$ (49), number of seeds $plant^{-1}$ (77.67) above ground biomass (6160 kg ha^{-1}) and the grain yield (1828.44 kg ha^{-1}). A combined application of phosphorus at 30 kg ha^{-1} and lime at 5.64 t ha^{-1} had good response in reclaiming the soil and fostering the crop productivity, which is statically at pars with 4.23 lime t $ha^{-1}$and 30 kg P ha^{-1}. Study concluded that application of lime with phosphorus proved to be superior with respect to grain yield as well as other yield and growth parameters of soybean.

Dabesa and Tana (2021) revealed that the application of lime (3.12 t ha^{-1}) significantly increased plant height (77.2 cm), number of primary branches per plant (6.6), 100-seed weight (17.5 g), grain yield (3431 kg ha^{-1}), and harvest index (41%) of soybean.

Bordoloi (2022) revealed that the application of lime @ 400 kg ha^{-1} + vermicompost @ 2.0 t ha^{-1} + 50% RDF (10:20:10 kg ha^{-1}) + 20 kg ha^{-1} sulphur had recorded significantly higher yield of black gram i.e., 9.86 q ha^{-1}.

Singh and Singh (2022) carried out a field experiment consisting of sixteen treatments with different liming materials and phosphorus levels to evaluate the influence of different liming materials and levels of phosphorus on nutrient uptake, qualitative properties and yield of soybean [*Glycine max* (L.) Merr.]. Interaction effect of liming material and P was significant for plant height, number of root nodules $plant^{-1}$, number of pods $plant^{-1}$, stover and grain yield. Maximum uptake of N, P, K, S and Ca were found with calcium silicate @ 0.4 LR. Their interaction was significantly influenced in nutrient uptake by soybean.

Uchoi and Sharma (2023) concluded that lime application @ 200 kg ha^{-1} and P application up to 40 kg ha^{-1} significantly enhanced the growth, yield, quality and nutrient uptake of black gram.

2.1.2. Effect on soil properties

Dixit and Sharma (1993) narrated that liming significantly decreased the different forms of Al and Fe and acidities. Exchangeable, pH dependent and total acidity of the soil decreased.

Borah *et al*. (2000) reported that lime application increased soil pH and reduced all forms of soil acidity, while phosphorus application decreased all but pH-dependent acidity. The decrease in soil acidity was supported by reduction in forms of Al^{3+} with application of lime and phosphorus. However, lime and phosphorus interaction was not found significant except for exchangeable acidity. They suggested that grain yield of black gram increase by addition of lime and phosphorus application.

Fageria *et al.* (2010) reported that grain yield of common bean was significantly increased with the application of lime. There were significant changes in soil profile (0-10 and 10-20 cm depths) in pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), hydrogen + aluminium (H^{+}+Al^{3+}), base saturation, acidity saturation, cation exchange capacity (CEC), Ca^{2+} saturation, Mg^{2+} saturation, potassium (K^{+}) saturation and ratio of Ca/Mg, Ca/K and Mg/K. These soil chemical properties had significantly proved positive association with common bean yield.

Chimdi *et al*. (2012) observed that the interactions between lime rates and soil from different land use systems significantly affected soil pH and exchangeable acidity but was not found significant between lime rates, lime particles and different land use systems on soil properties. Increasing lime rates for both particles sizes relatively increased soil pH and exchangeable bases thereby reducing the magnitude of soil acidity, exchangeable acidity and Al saturation. However, applied lime rates with 100 mesh size proved to be more effective in reducing acidity related soil properties and increased soil pH.

Verde *et al.* (2013) suggested that manure and lime significantly reduced exchangeable acidity and increased soil pH. Application of manure alone or combined with lime or P fertilizer also increased Mg and K. Treatments that had sole lime, lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca. Soybean responded well and significantly to application of manure either alone or combined with lime, P or both. These results showed the potential role of lime, manure and P fertilizer in improving soil fertility and soybean yield.

Barman *et al.* (2014) observed that application of lime enhanced the available nitrogen, phosphorus, calcium, magnesium, sulfur and zinc content in soil.

Muindi *et al.* (2015) conducted a pot experiment at Waruhiu Farmers Training Centre, Githunguri to evaluate the lime-Al-P interactions in acid soils of the Kenya highlands. Extremely acidic (pH 4.48) and strongly acidic (pH 4.59) soils were used for the study. Four lime (CaO) rates and phosphorus (Ca $(H_2PO_4)_2$ rates were used. The liming rates were: 0, 2.2, 5.2 and 7.4 tonnes ha^{-1} for extremely acidic soil and 0, 1.4, 3.2, and 4.5 tonnes ha^{-1} for the strongly acidic soil. Phosphorus applications rates were: 0, 0.15, 0.30 and 0.59 g P kg^{-1} soil for the extremely acidic soil and 0, 0.13, 0.26, and 0.51 g P kg^{-1} for the strongly acidic soils. Lime-Al-P interaction significantly ($P \leq 0.05$) increased soil pH, extractable P, reduced exchangeable Al, Al saturation, P adsorption and standard phosphorus requirements (SPR). Use of 7.4 tonnes ha^{-1} lime in extremely acidic soils and 4.5 tonnes ha^{-1} lime in strongly acidic soils significantly reduced exchangeable Al and SPR by >70%.

Guddisa *et al.* (2016) narrated that application of both lime and phosphorus to the experimental plot increased exchangeable Ca, available phosphorus and total nitrogen while decreased exchangeable aluminium.

Therefore, application of lime and phosphorous on acid soil improves the pH of the soil, there by the availability of phosphorous and cations.

Lynrah *et al*. (2017) narrated that application of lime @ 1.5 t ha^{-1} recorded significantly highest soil pH after the harvest of the crop (5.01).

Bekele *et al*. (2018) reported that highest increment of pH from 4.83 at the control to 6.05 and reduction of exchangeable Al from 1.70 to 0.09 $cmol_c$ kg^{-1} were obtained from combined application of lime at 4 tons $CaCO_3$ ha^{-1} and VC at 7.5 tons ha^{-1}. The most significant decrease in exchangeable acidity (0.17 $cmol_c$ kg^{-1}) was observed in soil that was treated with 6 tons $CaCO_3$ ha^{-1} lime applied alone (93%) and combined application of lime at 4 tons $CaCO_3$ ha^{-1} with VC at 7.5 tons ha^{-1} by 81%. The highest contents of OM (4.1%) and total nitrogen (0.29%) were obtained from combined application of lime at 4 tons $CaCO_3$ ha^{-1} and VC at 7.5 tons ha^{-1}. Integrated application of chemical P (60 kg P ha^{-1}) with lime (2 tons ha^{-1}) plus VC (7.5 tons ha^{-1}) resulted in Bray-II P increased by 45% relative to control. The various combinations of the treatments also improved exchangeable Ca^{2+} and Mg^{2+} .The results indicate that integrated use of lime, vermicompost, and chemical P fertilizer can improve soil acidity and availability of nutrients.

Rajneesh *et al*. (2018) narrated that continuous application of fertilizers either alone or in combination of FYM or lime affected different forms of soil acidity (total acidity, total potential acidity, pH dependent acidity, extractable acidity, exchangeable acidity and non exchangeable acidity) significantly on surface and sub-surface layers. They suggested that continuous cropping with application of optimal doses of fertilizers along with lime significantly decreased different forms of soil acidity.

Ananthakumar *et al*. (2019) carried out an experiment to ameliorate both surface and subsurface soil acidity using different calcium sources *viz*., lime, dolomite and gypsum and to study their effect on availability of nutrients. The treatment combination includes application of lime and dolomite @ 50% lime requirement with and without elemental sulphur @ 100 kg ha^{-1} and was compared with gypsum levels and control. The results revealed that the application of lime and dolomite increased the soil pH, organic carbon content, available nitrogen content and dehydrogenase activity in both surface and subsurface soil. Exchangeable calcium and available sulphur contents were increased in gypsum treated plots compared to control. Low Exch. acidity and Exch. Al and high Exch. Mg content were observed with dolomite and elemental sulphur application.

Sultana *et al.* (2019) elucidate that soil pH increased by 0.5-1.11 units, higher values were observed with higher rates of lime application. Soil phosphorus availability increased, zinc and boron availability decreased, but the potassium and sulphur availability remained almost unchanged after liming. The study suggested that dololime @ 1 t ha^{-1} coupled with poultry manure @ 3 t ha^{-1} or FYM @5 t ha^{-1} would be an efficient practice for better soil acidic condition, soil fertility and productivity of crops.

Adisu *et al.* (2019) revealed that soil pH increased from 5.31 – 5.86 pH while exchangeable acidity decreased from 5.46 - 2.85 cmol (+) kg^{-1} with levels of lime and vermicompost (3.26 with 3 and 4.90 with 4.5 t ha^{-1}) respectively, which resulted in improved soil physico-chemical properties.

Meena and Prakasha (2020) concluded that soil pH, organic carbon and available N, P and K were significantly influenced by application of biochar and lime along with farmyard manure and chemical fertilizer.

Odyuo and Sharma (2020) reported that pH, available N, P, K, B and exchangeable Ca contents of the soil increased significantly and exchangeable

Al^{3+} and H^+ and total potential acidity of the soil decreased remarkably with application of lime containing fertility levels.

Abeje *et al*. (2021) narrated that pH, total nitrogen, available phosphorus, organic carbon, and cation exchange capacity were highly ($P < 0.01$) affected by the interaction of bio-, organic, and inorganic fertilizers and lime at both locations and years.

Dabesa and Tana (2021) noted that the application of lime (3.12 t ha^{-1}) significantly increased soil pH (5.6).

Lee *et al*. (2022) narrated that increasing rate of lime treated fertilizer increased the soil pH, EC, OM and exchangeable cations after crop harvest.

Singh and Singh (2023) narrated that application of liming materials of calcium silicate @ 0.4 LR increased pH-5.41 from the initial pH 5.31. The highest OC% was found in the plots receiving calcium silicate @ 0.4 LR (1.17%) and 80 kg P_2O_5 ha^{-1} (1.24%). The available N, P & exchangeable Ca^{2+} and Mg^{2+} in soil increased by application of liming materials and phosphorus and their interaction.

Uchoi and Sharma (2023) reported that lime application significantly enhanced the soil pH, available N, P, exchangeable Ca^{2+} and CEC while it also reduced total potential acidity and exchangeable Al^{3+} and H^+ after crop harvest. Significant improvement in available N and P status of soil was observed with P application. Hence, application of 200 kg lime ha^{-1} along with 40 kg P_2O_5 ha^{-1} proved to be beneficial for cultivation of black gram under acidic soil condition of Nagaland.

Tasung *et al*. (2023) reported that soil pH recorded maximum and exchangeable aluminium, exchangeable acidity and total acidity recorded minimum in 75% RDF+lime.

2.2 Effect of PSB

2.2.1. Effect on crop growth, yield and composition

Balachandran and Nagarajan (2002) conducted an experiment to study the effect of dual inoculation of *Rhizobium* and phosphobacteria with phosphorus on black gram in red lateritic sandy loam soil with pH 5.2 at Pudukottai (Tamil Nadu). They observed that the dual inoculation of*Rhizobium* and phosphobacteria recorded maximum plant height (48.3 cm), number of nodules (31.0 plant^{-1}), nodules dry weight (53.6 mg plant^{-1}) and a grain yield of 670 kg ha^{-1} which was 126.2% higher over control.

Tanwar *et al*. (2003) conducted a field study to investigate the effect of P (0, 20, 40 and 60 kg ha^{-1}) and biofertilizer (*Rhizobium* sp. and *Bacillus megaterium* var. phosphaticum) on the nutrient content and uptake of black gram. The biofertilizers were applied singly or in combination. The crop yield, N and P contents, and N and P uptake increased with increasing P rate up to 80 kg ha^{-1}. Inoculation with the combination of the biofertilizers resulted in higher yield, N and P content, N and P uptake of the grain and straw compared to no inoculation and individual inoculation.

Singh *et al*. (2003) evaluated the levels of phosphorus (0, 30, 60 and 90 kg ha^{-1}) with or without PSB on summer green gram. Inoculation of seeds with PSB increased the grain yield, protein content; influenced the nutrient content and uptake of N, P and K when compared to without inoculation. Also significant improvement in soil available nutrients such as, available nitrogen and phosphorus after harvest of green gram was observed with inoculation.

Dundari and Kumar (2004) concluded that growth attributes of black gram *viz*., plant height and leaf area index were positively influenced by the foliar spray of 2% DAP + seed and soil inoculation with phosphobacteria.

Nagar and Meena (2004) recorded that seed inoculation with PSB significantly increased total uptake of N, P and S by cluster bean over no inoculation.

Jain and Trivedi (2005) concluded that significant increase in protein content on application of 19.66 kg P_2O_5 ha^{-1} with PSB inoculation to soybean seeds.

Singh and Yadav (2008) conducted a study to evaluate the effect of phosphorus levels (0, 15, 30, 45 and 60 kg P_2O_5 ha^{-1}) and biofertilizers (untreated control, *Rhizobium*, PSB, *Rhizobium* + PSB) on growth, yield and nutrient uptake of long duration pigeon pea. The results showed that the application of 60 kg P_2O_5 ha^{-1} being at par with 45 kg P_2O_5 ha^{-1} recorded the maximum plant height (203.0 cm), number of primary branches (20.8), dry matter $plant^{-1}$ (159.6 g), grain yield (2260 kg ha^{-1}), stalk yield (8020 kg ha^{-1}) and uptake of N (112.3 kg ha^{-1}) and P (18.9 kg ha^{-1}). Among the biofertilizers, *Rhizobium* + PSB produced significantly taller plants (198.7 cm), maximum number of branches $plant^{-1}$ (18.9), dry matter $plant^{-1}$ (156.4 g), grain yield (2060 kg ha^{-1}), stalk yield (7560 kg ha^{-1}) and uptake of N (104.9 kg ha^{-1}) and P (16.9 kg ha^{-1}) than other biofertilizer treatments. Combined effect of 60 kg P_2O_5 ha^{-1} + *Rhizobium* + PSB produced significantly higher dry matter (165.8 g $plant^{-1}$), grain yield (2510 kg ha^{-1}) and phosphorus uptake (21.4 kg ha^{-1}) than other combination except 45 kg P_2O_5 ha^{-1} + *Rhizobium* + PSB.

Vikram and Hamzehzarghani (2008) observed that inoculation of green gram seeds with PSB (PSB-14) recorded the highest nodule number, nodule dry weight, shoot dry matter and total plant dry matter at 45 DAS. Also highest P content and its uptake in root and shoot of green gram plants were observed with inoculation.

Wagadre *et al*. (2010) observed that plant height, number of branches plant^{-1}, number of pods plant^{-1}, pod length, number of seed pod^{-1} as well as seed and straw yield (kg ha^{-1}) of summer green gram increased significantly by inoculation of seeds with PSB over no inoculation.

Rathore *et al*. (2010) suggested that application of FYM @ 5 t ha^{-1}, 40 kg P_2O_5 ha^{-1} and dual seed inoculation with PSB + VAM significantly increased the seeds and stover yield and uptake of N, P and K by *urd* bean. Combined effect of 5 t FYM ha^{-1}+ 40 kg P_2O_5 ha^{-1}, 5 t FYM ha^{-1}+ dual inoculation with PSB + VAM, and 40 kg P_2O_5 ha^{-1} + dual inoculation with PSB + VAM produced significantly higher yield and uptake of N, P and K by *urd* bean.

Devi *et al*. (2012) reported that application of SSP+PSB produced significantly higher number of nodules per plant, dry weight of nodules per plant, number of pods per plant and 100-seed weight than the other treatments. Maximum grain yield and total phosphorus uptake were also recorded when using SSP+PSB. Yield attributing characters, grain and stover yield were increased with increasing levels of phosphorus. Regarding evaluation of various efficiency fractions of soybean, agronomic efficiency, physiological efficiency and phosphorus use efficiency had more pronounced effects on combined application of SSP+PSB. Among the different levels the efficiency fractions increase up to 60 kg P_2O_5 ha^{-1} and declined at 80 kg P_2O_5 ha^{-1}.

Devi *et al*. (2013) narrated that application of 75% RDF coupled with vermicompost at the rate of 1 t ha^{-1} and PSB significantly increased oil and protein content of soybean seed.

Amruta *et al*. (2015) conducted a field experiment to assess the response of nutrient levels and spacing on growth and yield attributes of black gram cv. LBG-625 (Rashmi). Experimental results revealed that fertilizer application of

50:100:100 NPK kg ha^{-1}+ black gram *Rhizobia* (250 g ha^{-1}) + PSB- *Bacillus megaterium* (250 g ha^{-1}) with the spacing of 60 x 10 cm recorded significantly higher number of branches $plant^{-1}$ (5.60), number of leaves $plant^{-1}$ (29.87), plant spread $plant^{-1}$ (756.00), number of cluster $plant^{-1}$ (14.07), number of pods $cluster^{-1}$ (22.60), number of pods $plant^{-1}$ (54.40), pod weight $plant^{-1}$ (g) (22.60), seed recovery per cent (98.45) and processed seed yield (q ha^{-1}) (15.83) as compared to rest of the treatments. Hence, it can be concluded that the application of 50:100:100 NPK kg ha^{-1}+ black gram *Rhizobia* (250 g ha^{-1}) + PSB- *Bacillus megaterium* (250 g ha^{-1}) with the spacing of 60 x 10 cm would be useful to enhance the productivity of black gram. The conjunctive use of inorganic fertilizers and biofertilizer may be suggested for higher productivity along with overall betterment.

Kumar *et al*. (2015) investigated the effect of different phosphorus levels on nutrient content, uptake and economics of *urd* bean under custard apple based agri-horti system and reported that increasing phosphorus level up to 75 kg ha^{-1} significantly resulted highest total nutrient uptake of N, P and K by *urd* bean.

Kumar (2016) opined that to overcome the P nutrition requirement farmers use chemical fertilizers which are again ineffective due to the precipitation of a larger proportion of soluble P and also it raises the question of environmental consideration. In such situation, phosphate solubilizing bacteria (PSB) can bring out locked P into plant assimilable form in an eco-friendly fashion. PSB solubilize inorganic P primarily with the secretion of organic acids while organic P is mineralized by secreted phosphatases and phytase enzymes. Several PSB have been isolated, characterized and identified. Among these, the most powerful strains were denominated from the genus *Bacillus, Enterobacter, Pantoea, Pseudomonas, Acinetobacter, Rhizobium* and *Serratia*. However, the performance of such isolates is dependent on the soil physicochemical properties and climatic factors. Therefore, it is desirable to isolate, identify and characterize the efficient PSB in relation to soil physicochemical and environmental conditions for the development of soil specific bio-inoculants. Now a day's recombinant biotechnology is seen as a solution for any problem, only the major goal is the identification and isolation of a concerned gene. Thus, the best P solubilizing genes/consortium of genes may be screened and stably incorporated into the genome of indigenous plant growth promoting bacteria which were adapted to a specific soil and climatic characteristic.

Hassan *et al*. (2017) reported that inoculation with PSB, increased plant height (11.88-30.69%), branches plant^{-1} (18.35-39.20%), leaves plant^{-1} (12.10-41.30%), pods plant^{-1} (26.84-57.54%), seeds plant^{-1} (6.901-23.43%), pod length (13.00-38.02%) and 1000 seed weight (10.07-35.83%), number of effective nodules (7.0-18.0%), nodule density (12.0-21.0%), chlorophyll a and b (5.4-11.4% and 6.6-12.8%), carotenoids (11.4-43.5%), protein (0.05-0.15%), proline (0.09-0.321%), respectively as compared to un-inoculated control. And also increased uptake of macronutrients i.e., N (0.35-1.21% and 0.51-1.56%), P (0.18- 0.65% and 0.26-0.77%), K (1.01-2.89% and 1.21-3.11%), Ca (0.19-0.74% and 0.23-0.88%) and Mg (0.15-0.61 and 0.19- 0.78%) in root and shoot of mung bean compared to control.

Lynrah *et al*. (2017) found that application of 50% RDF+ *Rhizobium* @ 20 g kg^{-1} seed + Phosphate solubilising bacteria (PSB) @ 20 g kg^{-1} seed performed the best among the different nutrient sources and gave the highest soybean yield of 2.14 t ha^{-1}.

Nadeem *et al*. (2018) carried out a field experiment consisting of 12 treatments i.e. three levels of phosphorus [control 0 kg (P_0), 20 kg (P_1) and 40 kg (P_2) ha^{-1}] and four levels of bio-fertilizer [control (B_0), *Rhizobium*10 ml kg^{-1} seed (B_1), PSB 10 ml kg^{-1} seed (B_2) and *Rhizobium* + PSB both 10 ml kg^{-1} seed

(B_3)] with three replications. The uniform dose of nitrogen (N) and potassium (K) @ 20 kg ha^{-1} along with 10 t ha^{-1} FYM were applied to all the treatments. Result indicated that seed inoculation with B_3 (*Rhizobium* + PSB) significantly enhanced the growth, yield and nutrient content in cow pea over single inoculation of *Rhizobium* and PSB. Combined inoculation of seed with *Rhizobium* + PSB (B_3) along with 40 kg P ha^{-1} (P_2) significantly increased the stem girth (1.84 cm), total dry matter (13.91 g $plant^{-1}$), green pod and yield (196.37 g $plant^{-1}$ and 120.90 q ha^{-1}) over rest of treatment combination.

Shekhawat *et al*. (2018) reported that application of 40 kg P_2O_5 ha^{-1} + 2.5 t vermicompost + *Rhizobium* + PSB showed significantly higher yield, quality and symbiotic efficiency of black gram.

Zohmingliana *et al*. (2018) reported that dual inoculation with *Rhizobium* + PSB significantly increased plant height, number of branches and leaves $plant^{-1}$, number of pods $plant^{-1}$ and pods size of french bean over control, while *Rhizobium* alone was at par with control on these parameters. *Rhizobium* significantly increased the grain and stover yields over control while *Rhizobium* + PSB had significant effect over control as well as *Rhizobium* alone. Interaction effects revealed that highest grain and stover yields were obtained with 33 mg P_2O_5 kg^{-1} without inoculation and inoculation with *Rhizobium,* but yield was at par with 22 mg P_2O_5 kg^{-1} when crop inoculated with dual inoculants (*Rhizobium* + PSB).

Bhabai *et al*. (2019) conducted a pot experiment during at Uttar Banga Krishi Viswavidyalaya, Coochbehar, West Bengal to investigate the effect of biofertilizer on production potential of green gram. The plants were grown in pots containing soils amended with consortium of *Rhizobium* + VasicularArbascularMicorrhizae + Phosphate Solubilizing Bacteria. Four treatments comprising of P at 0, 20, 40, 60 kg ha^{-1} along with the above consortium culture in soil were applied in soil. The important agronomic parameters (shoot length, root length, effective root nodule plant^{-1}, and plant height, pods plant^{-1} and pod length) were significantly influenced by the addition of biofertilizer packages along with graded doses of phosphorus. The maximum pods plant^{-1} was recorded at P_3 suggesting that even at the lower dose of phosphorus @ 40 kg ha^{-1} (P_2) could bring about less variability on yield obtained @ 60 kg ha^{-1} (P_3).

Dkhar *et al.* (2019) revealed that combination of vermicompost @ 5 t ha^{-1} + coinoculation with *Rhizobium* + PSB (T_7) proved to be the best treatment in terms of maximum number of nodules (41.33, 44, 18.67 at 30, 45, 60 DAS respectively), the highest grain yield (13.92 q ha^{-1}), total biomass yield (89.77q ha^{-1}) and nutrient (N, P, K) uptake by green gram.

Chaurasiya *et al*. (2020) concluded that application of 40 kg P_2O_5 ha^{-1} + 30 kg S ha^{-1} with PSB inoculation (T_{13}) gave best results (grain yield of mung bean increased by 13.2%, 15.2%, 4.7% and 100.2% over T_2, T_4, T_{12} and T_1, respectively).

Shamsurahman *et al*. (2020) observed that seed treated by Phosphate Solubilising Bacteria (PSB) led to a significant increase in yield attributing characters and yield and gave 22.57% more yield of mung bean.

Singh *et al*. (2021) carried out a field experiment to study the different levels of phosphorus and PSB seed inoculation on growth and yield of mung bean. The seed inoculation with PSB and phosphorus @ 60 kg ha^{-1} recorded significantly higher plant height, leaf area index, and dry matter accumulation plant^{-1}, number of branches plant^{-1}, number of pods plant^{-1}, number seeds pod^{-1}, and number of nodules plant^{-1}, seed yield and biological yield than other treatments. Dry matter accumulation plant^{-1}, number of branches plant^{-1}, number of nodule plant^{-1}, number of pods plant^{-1}, were recorded significantly higher in seed inoculation with PSB and phosphorus @ 60 kg ha^{-1} but it was statistically at par with the application of phosphorus @ 40 kg ha^{-1}.

Parmar *et al*. (2021) reported that application of 60 kg P_2O_5 ha^{-1}, 20 kg S ha^{-1} and seed inoculation of PSB recorded significantly higher number of branches $plant^{-1}$, number of pods $plant^{-1}$, seeds pod^{-1}, seed yield (kg ha^{-1}) and stover yield (kg ha^{-1}) of moth bean while protein content was remain unaffected.

Sharma and Borah (2021) observed that seed treated with combined inoculation of *Rhizobium* @ 4g + *Bacillus megaterium* @ 5 ml /1000 ml of water + *Trichoderma viride* @ 5 ml /1000 ml of water recorded significantly higher field emergence (91.25%), speed of emergence (42.14), seedling dry weight (1.67 mg), shoot length (25.48 cm), seed yield (992 kg ha^{-1}), stover yield (1870 kg ha^{-1}), number of pods $plant^{-1}$ (37), number of seeds pod^{-1} (13.25), 100 seed weight (3.63 g), root length (9.22 cm) and nodulation (15) of black gram.

Sharma *et al*. (2021) reported significantly higher yield attributes and productivity of black gram as obtained by application of phosphorus solubilising bacteria (PSB) + Phosphorus (40 kg ha^{-1}) + FYM (10 t ha^{-1}) as compared to other treatments.

Jamir *et al*. (2022) concluded that 60 kg P_2O_5 ha^{-1} with dual inoculation of seeds along with *Rhizobium* + PSB significantly increased the growth and yield attributes such as plant height, plant population, Leaf Area Index (LAI), number of leaves $plant^{-1}$, number of branches $plant^{-1}$, Crop Growth Rate (CGR), number of pods $plant^{-1}$ (30.72), pod length (4.68 cm), number of seeds pod^{-1} (7.20), seed yield (1120.35 kg ha^{-1}), stover yield (2401.54 kg ha^{-1}) and harvest index (31.80%) of black gram over rest of the treatments.

Rabari *et al*. (2022) observed that as levels of phosphorus increase (0 to 40 kg P_2O_5 ha^{-1}), the value of seed yield and straw yield of black gram increases significantly over controls. In case of different bio fertilizers application significantly higher value were recorded under the combined application of PSB + VAM compared to the control. The result of interaction found superior combination of 40 P_2O_5 kg ha^{-1} along with VAM and PSB bio fertilizers application and remained at par with the with 40 P_2O_5 kg ha^{-1} along with PSB bio fertilizers.

2.2.2. Effect on soil properties

Nyekha *et al*. (2015) concluded that available P status of the post crop harvest soil also improved with the use of P and PSB.

Satyaprakash *et al*. (2017) narrated that soil bacteria having the phosphate solubilizing capacity are called as Phosphate Solubilising Bacteria (PSB). They convert the insoluble phosphate into soluble form through the production of organic acids and make it available for plant uptake and nutrition. They are also useful as biofertilizers as they belong to the plant growth promoting Rhizobacteria. This review is focused on the role of 'P' and 'PSB' in plant nutrition and sustainable agriculture.

Hassan *et al*. (2017) reported that PSB enhanced the availability of P and N up to 13.56% and 8.56% respectively in soil. Further PSB enhanced the soil microbial biomass i.e. MBC (35.4-48.6%), MBN (19.6-35.3%) and MBP (8.41-18.2%), and decreased the non-effective nodules ranging from 5.5-3.0%. The PSB had a convincingly positive impact on the growth, development and productivity of the mung bean and fruit quality, and P and N availability in the soil, and macronutrients uptake in plant without polluting the environment.

Nadeem *et al*. (2018) concluded that seed inoculation with B_3 (*Rhizobium* + PSB) significantly enhanced soil nutrient status over single inoculation of *Rhizobium* and PSB. Combined inoculation of seed with *Rhizobium* + PSB (B_3) along with 40 kg P ha^{-1} (P_2) significantly increased soil nutrient status *viz*., pH (6.20), available N (370.89 kg ha^{-1}), available P (38.57 kg ha^{-1}), available K (168.77 kg ha^{-1}), and organic carbon (2.80%) content over rest of treatment combination.

Dkhar *et al.* (2019) suggested that available nitrogen and organic carbon content was significantly influenced in treatment T_7 and T_4 with vermicompost and FYM along with co-inoculation of *Rhizobium* and PSB. Population of *Rhizobium* and PSB (58.33×104 and 56 ×104 cfu g^{-1} soil respectively), soil microbial biomass carbon (1603.91 μg g^{-1} soil), dehydrogenase and acid phosphatase activity was also significantly higher in T_7.

2.3. Effect of phosphorus

2.3.1. Effect on crop growth, yield, and composition

Mandal *et al*. (2005) carried out an experiment at Farm Bidhan Chandra Krishi Viswavidyalaya, West Bengal on green gram with phosphorus and observed that the application of phosphorus @ 60 kg P_2O_5 ha^{-1} recorded highest N, P and K uptake.

Singh and Singh (2013) conducted a field experiment to study the effect of phosphorus fertilization on nutrient composition of black gram. Results revealed that NPKS and protein concentration in seed was improved with 60 kg P_2O_5 ha^{-1} application compared to 0 and 30 kg P_2O_5 ha^{-1} treatments.

Mir *et al.* (2013) conducted a field experiment to study the effect of level of phosphorus, sulphur and phosphorus solubilising bacteria on black gram at Allahabad and observed that the crop growth parameters resulted maximum plant height (49.9 cm), number of leaves $plant^{-1}$ (50.8), number of nodules (27.8), haulm yield (28.9 q ha^{-1}), grain yield (8 q ha^{-1}) was found significantly with application of 60 kg P_2O_5 ha^{-1}. Inoculation of black gram seeds with phosphorus solubilizing bacteria recorded slightly higher grain yield (7.49 q ha^{-1}) as compared to no inoculation (7.39 q ha^{-1}).

Eutropia and Ndakidemi (2014) conducted field and glasshouse experiments to study the effect of *Bradyrhizobium japonicum* inoculation and phosphorus supplementation on macronutrient uptake by soybean. The results revealed that phosphorus supplementation significantly enhanced the uptake of N, P, K, Ca and Mg in roots, shoots, pods and the whole plant.

Niraj and Prakash (2014) observed that nutrients content and uptake of nitrogen, phosphorus, potassium, sulphur and protein content in black gram were registered highest with phosphorus application at 60 kg ha^{-1} as compared to other preceding levels of phosphorus.

Kumar *et al*. (2015) investigated the effect of different phosphorus levels on nutrient content, uptake and economics of *urd* bean under custard apple based agri-horti system and reported that increasing phosphorus level up to 75 kg ha^{-1} significantly resulted highest total nutrient uptake of N, P and K by *urd* bean.

Tiwari *et al*. (2015) carried out a field experiment to investigate the effect of levels of phosphorus on growth, yield and quality of summer green gram and found out that maximum seed and stover yield were obtained with phosphorus 60 kg ha^{-1} application. The seed yield were attributed due to increased in plant height, pods $plant^{-1}$ and seeds pod^{-1}. Application of 60 kg P_2O_5 ha^{-1} showed higher growth and seed yield in comparison to other P levels.

Nyekha *et al*. (2015) concluded that application of 75 kg P_2O_5 ha^{-1} produced higher plant height, number of pod^{-1}, seed, stover and protein yield of green gram, but 50 kg P_2O_5 ha^{-1} was at par regarding this parameter.

Chaudari *et al*. (2016) reported that the seed and straw yield as well as yield attributing characters and quality of black gram was significantly influenced by application of 40 kg P_2O_5 ha^{-1}, which showed superiority over control. Highest seed yield (852.42 kg ha^{-1}) and straw yield (1670.5 kg ha^{-1}) was recorded with application of 40 kg P_2O_5 ha^{-1}.

Dejene *et al*. (2016) reported that significantly the highest plant height (72.34 cm), leaf area index (3.257), effective nodules per plant (93.55), primary branches per plant (2.467), number of pods per plant (18.52), 100 seed weight (24.31 g), and seed yield (3176 kg ha^{-1}) of common bean were obtained from the highest rate of P (30 kg ha^{-1}).

Dereje *et al*. (2017) revealed that main effects of compost, lime, and phosphorus were significant for number of pods $plant^{-1}$ and number of seeds pod^{-1} of common bean. Grain yield responded to two-factor interactions effect of lime × phosphorus in both seasons and compost × phosphorus, compost × lime only in Belg and lime × phosphorus in Meher season. Hence, in Belg the maximum (2834.9 kg ha^{-1}) grain yield was obtained as a result of combined application of lime and phosphorus at rates of 1.28 tonne and 46 kg P_2O_5 ha^{-1}, respectively. Similarly, in Meher the highest grain yield (2418.1 kg ha^{-1}) was obtained due to application of compost and lime at rates of 10 and 1.28 tonnes ha^{-1}, respectively. However, application of phosphorus alone at rate of 23 kg P_2O_5 $ha^{-1}$was found economically viable.

Venkatarao *et al*. (2017) observed that highest plant height, total and effective number of nodules $plant^{-1}$, leaf area index, total chlorophyll content grain yield (1221 kg ha^{-1}) and straw yield (2988 kg ha^{-1}) of mung bean was found with the application of 40 kg P_2O_5 ha^{-1} which was at par with 60 kg P_2O_5 ha^{-1}.

Singh *et al*. (2017) observed that the highest value of growth attributes *viz*. plant height at 30, 60 DAS and at harvest, dry matter production, number of pods plant^{-1}, number of grains pod^{-1}, pod length, grain yield and nutrient uptake was recorded with the application of 60 kg P_2O_5 ha^{-1} and was superior over 40 kg P_2O_5 ha^{-1}. Significantly higher growth attributes, grain yield and nutrient uptake and economics of mung bean was produced with 60 kg P_2O_5 ha^{-1} application superior to other preceding levels.

Yadav *et al*. (2017) reported that a significant increased in protein content of grain, nitrogen, phosphorus and potassium concentration in grain and straw and total uptake of NPK of *urd* bean was observed with application of phosphorus up to 40 kg ha^{-1} and remained at par with 60 kg P_2O_5 ha^{-1}.

Nadeem *et al*. (2018) suggested that the application of P2 (40 kg P ha^{-1}) significantly increased the plant height, leaf area index, stem girth, number of nodules per plant, number of branches per plant, total dry matter, pod yield and NPK content in cowpea after harvesting.

Zohmingliana *et al*. (2018) observed that application of 33 mg P_2O_5 kg^{-1} resulted in the highest content of nitrogen and phosphorus in grain and stover of french bean whereas 22 mg P_2O_5 kg^{-1} gave highest content of potassium

Karnavat *et al*. (2018) found that application of 10 t FYM ha^{-1} gave maximum values of all the growth and yield attributes of green gram. This application registered 7.2 and 7.3% higher seed and stover yield as compared to control respectively. Significantly higher value of growth parameters, yield attributes, yield and quality parameters were recorded with 10 t FYM ha^{-1} application as compare to no FYM application. Phosphorus application 40 kg P_2O_5 ha^{-1} + PSB were significantly increased on growth and yield attributes (plant height, branches plant^{-1}, root nodules plant^{-1}, fresh and dry weight of root nodules, pod length, pods plant^{-1}, 1000 grain weight), seed and stover yield compared to PSB only. Application of 40 kg P_2O_5 ha^{-1}+PSB resulted significant increase in all these attributes over PSB only. Absolute control (only PSB) produced significantly poor performance of these attributes than rest treatments.

Kumar and Yadav (2018) observed that every increase in level of phosphorus up to 40 kg P_2O_5 ha^{-1} significantly increased the growth and yield attributing characters *viz.* plant height, branches $plant^{-1}$, dry matter accumulation, number and weight of root nodules $plant^{-1}$, pods $plant^{-1}$, grains pod^{-1}, test weight, grain, straw and biological yield of mung bean. However, it was found at par with 60 kg P_2O_5 ha^{-1}.

Kachave *et al*. (2018) reported that combined application of 100% N + 60 kg P_2O_5 ha^{-1} + PSB significantly improved the quality of black gram seeds in terms of test weight, protein content and protein yield.

Bhavya *et al*. (2018) showed that inoculation of vermicompost at 5 t ha^{-1}, seed inoculation with PSB and 100% recommended dose of phosphorus application significantly increased the N, P, K and S concentration in grain, haulm and their uptake by green gram.

Patel *et al*. (2019) conducted a field experiment to study the response of green gram to different level of phosphorus on yield, quality, nutrient content and uptake and observed that higher seed yield (1168 kg ha^{-1}), haulm yield (2475 kg ha^{-1}), protein content (19.34%), protein yield (226.20 kg ha^{-1}), nitrogen (3.09 and 0.59%) and phosphorus (0.71 and 0.58%) concentration in seed and haulm were recorded with 40 kg P_2O_5 ha^{-1} application. Remarkable improvement of NPK uptake by seed and haulm were also recorded under same treatment.

Hangsing *et al*. (2020) reported that application of phosphorus at 40 kg ha^{-1} recorded significantly the higher plant height (49.37 cm), number of leaves

(5.73), shoot dry weight (3.34 g plant^{-1}), LAI (3.34), CGR (6.37 g m^{-2} day^{-1}) and yield attributes such as number of pods plant^{-1} (17.56), length of pods (6.91 cm), seed yield (737.42 kg ha^{-1}) and stover yield (1973.01 kg ha^{-1}) respectively of green gram.

Singh *et al*. (2020) worked on three levels of phosphorous (30, 40 and 50 kg P_2O_5 ha^{-1}) and reported that maximum plant height (32.77 cm), number of nodules per plant (18.56), dry weight (11.92 g plant^{-1}), number of pods per plant (24.51) , number of grains per pod (6.40), test weight (47.60 g), grain yield (2.76 t ha^{-1}) and protein content (24.28%) of black gram under the application of phosphorous @ 40 kg P_2O_5 ha^{-1}.

Parashar *et al.* (2020) conducted a field experiment at the Research Farm, School of Agriculture, ITM University, Gwalior and observed that significantly higher plant height, number of branches as well as leaves per plant, number of root nodules per plant, grain and stover yield per hectare of black gram at maximum crop growth stage was reported under the application of phosphorus @ 60 kg P_2O_5 ha^{-1}.

Singh and Singh (2022) reported that maximum uptake of N, P, K, S and Ca of soybean was found with application of 80 kg P_2O_5 ha^{-1}.

2.3.2 Effect on soil properties

Deo and Khaldelwal (2009) reported that the available P content in soil increased significantly with increasing P_2O_5 levels. Highest value of available P in soil was found with the application of 60 kg P_2O_5 ha^{-1} and lowest in without P treated plots.

Yakubu *et al*. (2010) reported that P fertilization significantly increased the amount of N fixation and secretion of nitrogen by legumes crop thereby enhanced in improvement of available N status of the soil.

Amba *et al*. (2011) experimental result showed that soil pH, organic carbon, total nitrogen, and available phosphorus increased at post harvest soil profile as compared to soils sample before planting across depths. They concluded that phosphorus fertilization not only increased the nutrient status of the soil but also enhanced the nitrogen fixing ability of the legumes for a sustainable legume production and soil fertility management at Bauchi.

Souza *et al*. (2013) concluded that biological variables were sensitive and responded to increasing rates of P fertilizer; higher levels of P induced increases in microbial biomass carbon and reductions in qCO_2.

Kusro *et al*. (2014) revealed that balanced NPK fertilization through inorganic sources significantly increased the organic carbon, mineralizable nitrogen and NH^+ status of soil.

Kumawat *et al*. (2017) observed that highest soil organic carbon (0.166%), available nitrogen (139.87 kg ha^{-1}) and available P (19.59 kg ha^{-1}) content in soil were recorded with the application 40 kg P_2O_5 ha^{-1} of which was significantly superior to 20 kg P_2O_5 ha^{-1} and control.

Nadeem *et al*. (2018) reported that application of P_2 (40 kg P ha^{-1}) significantly increased available soil nutrient status *viz.*, pH, N, P, K and organic carbon.

Mohammad *et al* (2017) reported that application of phosphorus up to 40 kg P_2O_5 ha^{-1} recorded significantly higher microbial biomass carbon, nitrogen and phosphorus in soil as compared to absolute control and 20 kg P_2O_5 ha^{-1} but was at par with 60 kg P_2O_5 ha^{-1}.

Zohmingliana *et al*. (2018) reported that phosphorus and bio-inoculant application improved only phosphorus content significantly of post harvest soil.

Bhabai *et al.* (2019) concluded that the available phosphorus in soils was increased significantly irrespective of the inoculation. The maximum available 'P' was 33.27 kg ha^{-1} at 45 days when applied with P @ 40 kg ha^{-1} under inoculated condition. The interaction of phosphorus and biofertilizer on available phosphorus was significant.

Uchoi and Sharma (2023) observed that there was significant improvement of soil available N and P status with P application after the harvest of black gram.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" was conducted in the experimental farm of the Department of Soil Science, School of Agricultural Sciences, Nagaland University, Medziphema during the *kharif* seasons, 2021 and 2022. A brief detail of materials used and analytical techniques engaged for analysis of soils and plant materials are concisely mentioned in this chapter.

3.1. Experimental site

The experimental site lies at 25º 45´30´´ N latitude and 93º53´04´´ E longitude at an elevation of 310 m above mean sea level.

3.2. Climatic condition

The experiment farm lies in the humid sub-tropical zone with an average rainfall ranging from 2000 to 2500 mm per annum spread over 6 months i.e., April to September, while remaining period from October to March remains dry. the mean temperature ranges from 21ºC to 32ºC during summer and rarely goes below 8ºC in the winter season due to high atmospheric humidity. Monthly meteorological data during the experimentation period (July-October of 2021 and 2022) is given in Table 3.1 and depicted in Fig 3.1(a) & (b). According to Nagaland Post, 9 Feburary, 2022, the Nagaland State Disaster Management Authority (NSDMA) declared '**drought of a moderate nature**' in the entire state of Nagaland; the declaration came into effect from September 15, 2021 which continued to be in effect for 6 months and it was based on the scanty deficit and less than normal rainfall that has been observed from March to November 2021 [Anonymous (2022), February 9)]. The first field trial (i.e. July to October 2021) of present study coincided with the drought period.

Table 3.1: Meteorological observations during experimental period

Month	Week No.	Temperature (°C)			Relative humidity (%)			Rainfall (mm)
		Max.	Min.	Mean	Max.	Min.	Mean	
2021								
July	26	33.0	25.0	29.0	93	69	81.0	5.1
	27	33.2	24.7	29.0	89	73	81.0	19.2
	28	32.4	24.7	28.6	93	70	81.5	105.7
	29	33.7	24.7	29.2	95	70	82.5	53.3
	30	34.5	24.9	29.7	90	70	80.0	74.9
August	31	32.3	25.1	28.7	92	78	85.0	34.0
	32	33.2	24.5	28.9	93	68	80.4	25.2
	33	32.5	24.9	28.7	96	77	86.3	41.8
	34	32.4	24.3	28.3	92	68	79.8	7.0
September	35	32.3	24.3	28.3	93	73	82.9	52.9
	36	33.2	24.0	28.6	95	68	81.5	49.1
	37	33.8	23.9	28.9	94	68	80.6	42.2
	38	32.1	23.3	27.7	94	68	80.9	13.1
October	39	33.7	23.8	28.7	93	66	79.6	8.1
	40	32.3	23.1	27.7	94	71	82.7	5.0
	41	33.9	23.6	28.7	92	63	77.4	53.8
	42	33.3	23.6	28.5	95	70	82.8	69.1
	43	30.0	19.0	24.5	97	72	84.4	2.1
2022								
July	26	33.3	24.9	29.1	93	68	80.5	9.9
	27	34.2	24.7	29.5	91	66	78.5	77.1
	28	34.1	24.5	29.3	90	69	79.5	22.9
	29	33.9	24.5	29.2	92	75	83.5	135.3
	30	31.8	23.2	27.5	96	70	83.0	135.3
August	31	33.6	23.9	28.8	93	68	80.5	48.8
	32	33.3	23.9	28.6	96	71	83.7	114.7
	33	33.6	24.2	28.9	91	72	81.6	27.5
	34	34.1	24.5	29.3	94	68	81.1	64.2
September	35	32.7	24.3	28.5	93	68	80.7	9.0
	36	33.4	24.4	28.9	89	67	77.9	21.7
	37	31.9	23.5	27.7	91	72	81.6	42.8
	38	33.5	24.0	28.8	91	65	78.2	15.3
October	39	32.8	23.2	28.0	91	70	80.6	81.2
	40	31.9	23.5	27.7	95	74	84.5	31.0
	41	31.8	22.7	27.3	91	71	80.9	2.9
	42	30.9	20.6	25.7	94	65	79.1	19.7
	43	28.1	19.9	24.0	95	71	83.3	41.0

(Source: ICAR, Research Complex, NEH Region, Nagaland Centre, Jharnapani, Medziphema)

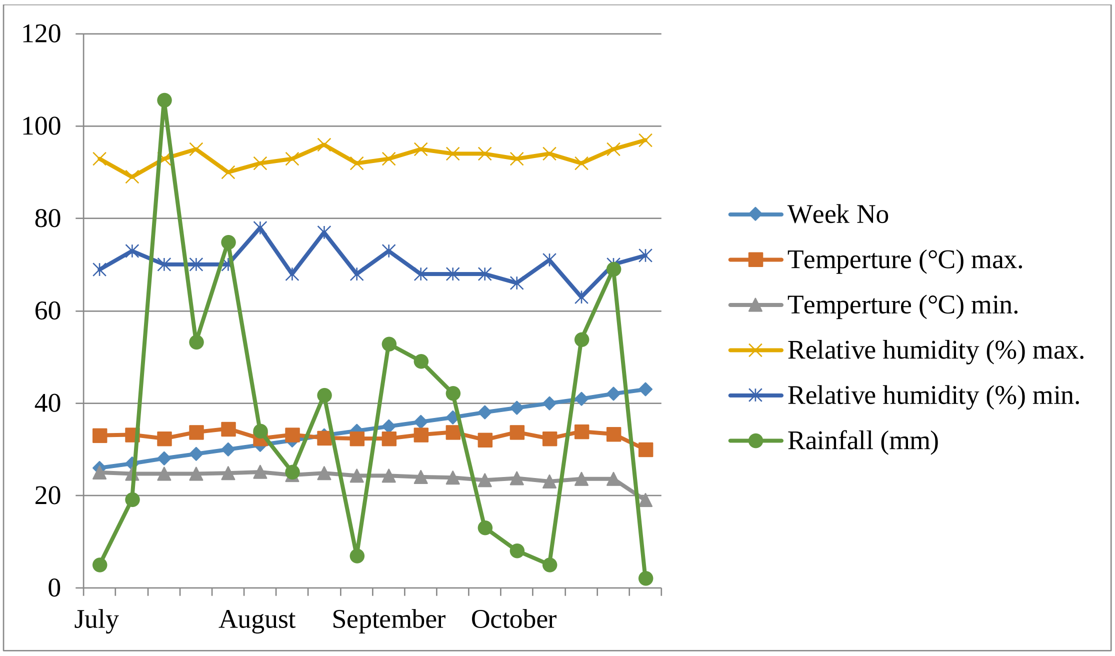


Fig 3.1(a): Meteorological observations during experimental period (July – October 2021)

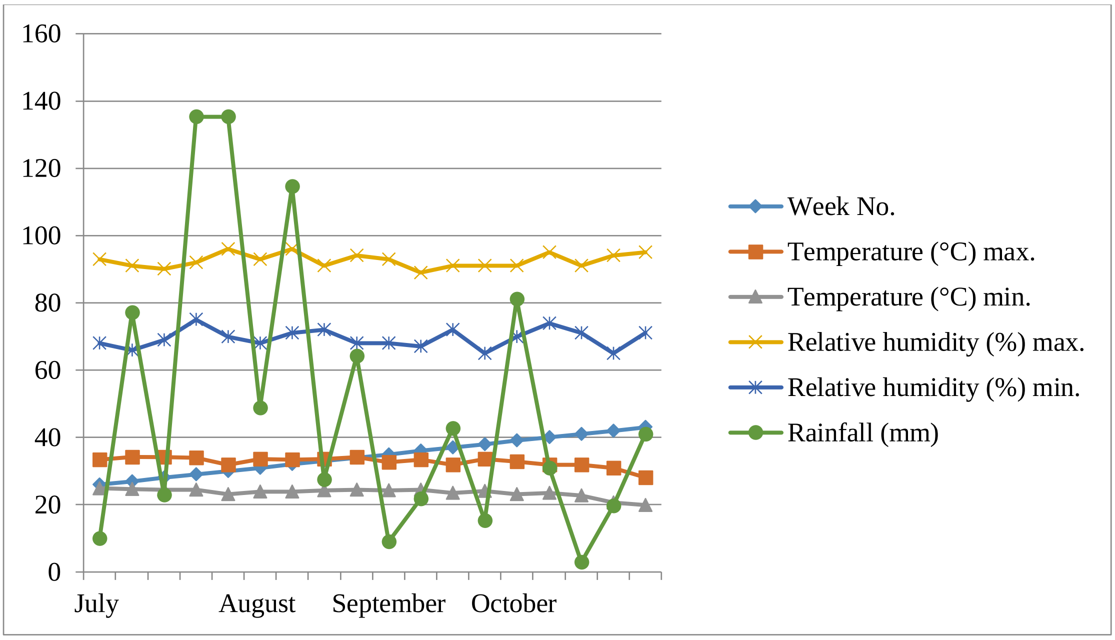


Fig 3.1(b): Meteorological observations during experimental period (July – October 2022)

3.3. Characteristic of the experimental soil

The soil was sandy loam in texture. The composite soil sample was collected from the experimental field (0-15 cm depth) before initiating the experiment. Pre-experimentation soil sample was analyzed for some important physicochemical properties. The results of analysis are presented in Table 3.2.

3.4. Experimental details:

i. Treatment details

A. Factor 1 (Soil amendments)

  i. Control
  ii. 5% lime of LR
  iii. PSB
  iv. 5% lime of LR + PSB

B. Factor 2 (Phosphorus levels)

  i. Control
  ii. 20 kg P_2O_5 ha^{-1}
  iii. 40 kg P_2O_5 ha^{-1}
  iv. 60 kg P_2O_5 ha^{-1}

ii.	Soil amendments	:4
iii.	Phosphorus levels	:4
iv.	Crop	:Black gram
v.	Crop variety	:SBC-40
vi.	Experimental design	:Factorial RBD
vii.	No. of replications	:3
viii.	No. of treatment combinations	:16
ix.	Total plots	:48
x.	Plots size	:2.1×2 m^2
xi.	Spacing	:30×10 cm

Table 3.2: Physicochemical properties of the experimental soil

Soil parameters	Values		Method
	2021	2022	
Lime requirement (t ha^{-1})	20.99	20.92	Shoemaker *et al* (1961) method
Soil pH	4.31	4.54	Glass electrode method (Jackson, 1973)
Electrical conductivity (dSm^{-1})	0.15	0.16	Richards (1954)
Organic carbon (g kg^{-1})	20.7	21.3	Rapid titration method by Walkley and Black (Jackson, 1973)
Available N (kg ha^{-1})	200.71	218.31	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	9.18	10.08	Bray and Kurtz method (1945)
Available K (kg ha^{-1})	168.34	172.48	Ammonium acetate method (Jackson, 1973)
Exchangeable Ca [cmol(p^+)kg^{-1}]	0.8	1.0	Versenate method (Black, 1965)
Exchangeable Mg [cmol(p^+)kg^{-1}]	0.6	0.6	Versenate method (Black, 1965)
Exchangeable Al^{3+} [cmol(p^+)kg^{-1}]	3.0	2.5	NaF solution (4%) in 1 *N*KCl extract titrated against 0.1 *N* HCl (Baruah and Barthakur, 1997)
Exchangeable H^+ [cmol(p^+)kg^{-1}]	0.5	0.5	Exchangeable H^+ = Exchangeable acidity –Exchangeable Al^{3+}
Exchangeable acidity [cmol(p^+)kg^{-1}]	3.5	3.0	1 *N*KCl solution titrated against 0.1 *N* NaOH solution (Baruah and Barthakur, 1997)
Total potential acidity [cmol(p^+)kg^{-1}]	20.4	19.6	$BaCl_2$-triethanolamine extract buffered at pH 8.0 to 8.2 (Baruah and Barthakur, 1997)
pH dependent acidity [cmol(p^+)kg^{-1}]	16.9	16.6	pH dependent acidity = Total potential acidity – Exchangeable acidity
Microbial biomass carbon (µg g^{-1})	424.74	484.97	Fumigation extraction method (Vance *et al.*, 1987)
Mechanical analysis			International pipette method (Piper, 1966)
Sand (%)	54.5	54.2	
Silt (%)	32.2	32.0	
Clay (%)	13.3	13.8	
Textural class	Sandy loam	Sandy loam	Triangle method (Piper, 1966)

3.5. Experimental procedure:

A rectangular plot having uniform fertility and even topography was selected for conducting trials. The field was first ploughed by tractor drawn plough and all stubbles were removed manually; then, large sized clods were again broken using a tractor drown rotavator to make a final seed bed. The field was then laid out accordingly as per the layout plan. Lime ($CaCO_3$), as per lime requirement (@ 5% LR), was applied in furrows 10 days prior to sowing. Four levels of phosphorus 0, 20, 40 and 60 kg P_2O_5 ha^{-1} were applied through single super phosphate; recommended dose of nitrogen and potassium (20 kg N and 40 kg K_2O ha^{-1}) were applied through urea and muriate of potash. Seed inoculation with phosphate solubilizing bacteria (*Bacillus megaterium* @ 200g per 10 kg seeds) was done the day before sowing as per the treatment protocol. The seed were sown on last week of July during 2021 and 2022 by line sowing method at 1.5 cm depth. Thinning was done 15 DAS maintaining row to row spacing at 30 cm and plant to plant 10 cm apart. Intercultural operation such as hand weeding was done at time to time when required. Harvesting of pods was done in four to five pickings. After final picking of pods, crop was harvested by cutting from the ground level with sickle to record the stover yield. The harvested pods were then sundried, threshed and cleaned manually.

3.6. Biometrical observation

3.6.1 Plant height (cm)

Plant height of five tagged plants was measured from the ground level to the tip of the main shoot of the plant at 25, 50 DAS and at harvest. The average height of the plant for each plot was calculated.

3.6.2 Number of branches plant^{-1}

From the main stem the total number of branches was counted from the selected five plants at 25, 50 DAS and at harvest and average was calculated for each plot.

3.6.3 Number of pods plant^{-1}

From each plot total number of pods from five tagged plants was counted manually. Average was worked out and expressed as number of pods plant^{-1}.

3.6.4 Pod length (cm)

The length of all the pods were measured from the tagged plant of each plot and the average was recorded in cm.

3.6.5 Seed pod^{-1}

The number of seeds from the five pods taken from the five selected plants was counted and the average values were taken to obtain the number of seed per pod.

3.6.6 Test weight (g)

From the threshed seeds of individual plots, 1000 seed samples were taken randomly and weighed to get the test weight of seed.

3.6.7 Seed yield (kg ha^{-1})

Plot wise pods were picked, sundried, threshed and cleaned manually after final picking. After picking weight of seed was taken and seed yield was calculated and expressed in terms of kg ha^{-1}.

3.6.8 Stover yield (kg ha^{-1})

After final picking the harvested plants from each plot was sundried properly and plot wise stover yield (including pod husk) was recorded and expressed in kg ha^{-1}.

3.7. Chemical analysis of the plant material

The black gram seeds and stover samples were oven dried at a temperature of 70ºC to attain a constant weight. The dried seeds and stover samples were then powdered and stored in a polythene bags with proper labeling for chemical analysis. The powdered seed and stover samples were analyzed for N, P, K, Ca and Mg content.

3.7.1 Nitrogen content

Half a gram powdered sample was digested with concentrated H_2SO_4 in presence of digestion mixture ($CuSO_4$+K_2SO_4) till the digest gave clear bluish green colour. The digested sample was further diluted carefully with distill water to known volume. Then entire aliquot was transferred to distillation unit (Micro kjeldahl- apparatus) and liberated ammonia was trapped in boric acid containing mixed indicator. Later it was titrated against standard H_2SO_4 and the amount of ammonia liberated was estimated in the form of nitrogen as per the procedure given by Black (1965).

3.7.2 Protein content (%)

The protein content in seed for each treatment was estimated by using following formula:

Protein content in seed (%) = 6.25 x N% in seed

3.7.3 Phosphorus content

The samples were wet digested with nitric acid (HNO_3) and perchloric acid ($HClO_4$). Ammonium molybdate vanadate method was employed for the determination of phosphorus in the plant extract by using spectrophotometer at 470 nm (Chapman and Pratt, 1962).

3.7.4 Potassium content

The aliquot after wet digestion for phosphorus estimation was diluted to the desirable level and were analyzed for potassium by using flame photometer as described by Hanway and Heidal (1952).

3.7.5 Calcium content

Calcium content was determined in the di-acid digest (HNO_3-$HClO_4$) of plant samples and then titrated against Versenate (EDTA) method (Prasad, 1998).

3.7.6 Magnesium content

It was determined by Di-acid (HNO_3-$HClO_4$) digestion of plant samples and titration of the aliquot against Versenate (EDTA) method (Prasad, 1998).

3.7.7 Nutrient uptake

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Yield ((kg ha}^{-1}\text{)}}{100}$$

3.8. Soil analysis

The soil samples were collected from a depth of 0-15 cm from each experimental plot after the crop harvest. The soil samples were dried in shade, ground using mortar and sieved through 2 mm sieve and stored in polythene bags with proper labeling for the analysis of various parameters using standard protocol as mentioned below.

3.8.1 Mechanical analysis

The sand, silt and clay fractions of soil samples were determined by the International Pipette method using 1*N* sodium hydroxide (NaOH) as a dispersing agent by Piper (1966).

3.8.2 Soil pH

Soil pH was determined in soil: water (1:2.5) ratio by glass electrode pH meter Jackson (1973).

3.8.3 Electrical conductivity

Electrical conductivity of all the sample was determined in soil:water (1:2) extract using conductivity meter and expressed as dSm^{-1} (Richards, 1954).

3.8.4 Soil organic carbon

Organic carbon was determined by rapid titration method of estimation outlined by Walkley and Black as described by Jackson (1973).

3.8.5 Available nitrogen

The available nitrogen was determined by alkaline potassium permanganate method suggested by Subbiah and Asija (1956) and the results were expressed in terms of kg ha^{-1}.

3.8.6 Available phosphorus

Available phosphorus was extracted with 0.03 *N* NH_4F in 0.025 *N* HCl solutions. The procedure is primarily meant for soils which are moderate to strongly acidic with pH around 5.5 or less and determined by Brays and Kurtz method (1945).

3.8.7 Available potassium

Available potassium content in soil was extracted with neutral normal ammonium acetate (pH 7.0). The potassium content in the extract was determined by flame photometer (Jackson, 1973).

3.8.8 Exchangeable calcium

The exchangeable calcium was extracted with neutral normal ammonium acetate and determined by versenate method, where known volume of soil extract was titrated with standard 0.01 *N* versenate (EDTA) solution using murexide (ammonium purpurate) indicator in the presence of NaOH solution (Black, 1965).

3.8.9 Exchangeable magnesium

The exchangeable magnesium was determined by using erichrome black T indicator with 0.01 *N* EDTA methods in the presence of ammonium chloride and ammonium hydroxide buffer (Black, 1965).

3.8.10 Total potential acidity

The total potential acidity of soil includes all the acidity components like extractable acidity, non exchangeable acidity, weak acidic carboxylic and phenolic hydroxyl groups of soil organic matter and partially neutralized hydroxyl Al polymers that could be present even in soils. The total potential acidity was determined by using $BaCl_2$-triethanolamine extract buffered at pH 8.0-8.2 as described by Baruah and Barthakur (1997).

3.8.11 Exchangeable acidity

Exchangeable acidity was determined by using 1 *N* KCl solution and titrating against 0.1 *N* NaOH until a pink colouration is obtained as mentioned by Baruah and Barthakur (1997).

3.8.12 Exchangeable Al^{3+}

Exchangeable Al^{3+} in soil was determined by adding 5ml of NaF solution (4%) in 1*N* KCl. This solution was then titrated against 0.1 *N* HCl until the pink colour disappeared as described by Baruah and Barthakur (1997).

3.8.13 Exchangeable H^+

The exchangeable H^+ was estimated by the difference between exchangeable acidity and exchangeable Al^{3+}.

Exchangeable H^+ = Exchangeable acidity - Exchangeable Al^{3+}

3.8.14 pH dependent acidity

The pH dependent acidity was estimated by the difference between total potential acidity and exchangeable acidity

pH dependent acidity = Total potential acidity - Exchangeable acidity

3.8.15 Microbial biomass carbon

The microbial biomass carbon of soil was determined by using the fumigation-extraction method by (Vance *et al.*, 1987). The fresh soil sample were placed in 50 mL beakers and kept in vacuum desiccators for fumigation with chloroform for 24 hours. The fumigated soil samples were treated with K_2SO_4 and placed in the shaker for few minutes. The extracts were filtered and digested using H_2SO_4 and then titrated against ferrous ammonium sulphate. The microbial biomass carbon was calculated as the difference between the values obtained from fumigated and non-fumigated soil samples.

3.9. Analysis of data

The data related to each character were tabulated and systematically analysed by the technique of analysis of variance as put forth by Fisher and Yates (1963) and Cochran and Cox (1962).

Plate No.1: General view of the prepared field

Plate No.2: Furrow application of lime 10 days prior to sowing

Plate No.3: Seed treatment with PSB

2021 GALLERY

Plate No.4: Field view at 5 days after sowing

Plate No.5: Field view at 10 days after sowing

Plate No.6: Field view at 25 days after sowing

Plate No.7: Field view at 50 days after sowing

Plate No.8: Flowering and Pod development

Plate No.9: Stover at the time of harvest

2022 GALLARY

Plate No.10: Field view at 5 days after sowing

Plate No.11: Field view at 10 days after sowing

Plate No.12: Field view at 25 days after sowing

Plate No.13: Field view at 50 days after sowing

Plate No.14: Flowering stage

Plate No.15: Pod development

Plate No.16: Stover at the time of harvest

Plate No.17: Seeds after threshing

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results pertaining to "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" carried out during 2021 and 2022 are presented in this chapter. The Nagaland State Disaster Management Authority (NSDMA) declared '**drought of a moderate nature**' in the entire state of Nagaland (refer: Chapter 3); thus the rainfall deficit affected the performance of the crop which was evident on growth, yield attributes and yield of black gram during 2021. Keeping in consideration of the given conditions the performance of the crop under various treatments is illustrated by the use of tables and graphs incorporated at appropriate places. The data recorded were analyzed and significant variations have been discussed.

4.1. Effect of soil amendments and phosphorus on growth and yield of black gram

4.1.1. Plant height

4.1.1.1. Effect of soil amendments

Data pertaining to plant height given in Table 4.1(a) and illustrated in Fig 4.1 revealed that there was a considerable increase in plant height with the advancement of days and also a conspicuous difference among the treatments. The pooled data of plant height in response to the application of soil amendments at 25, 50 DAS and at harvest varied from 11.30 to 12.51 cm, 26.46 to 35.44 cm and 31.57 to 40.79 cm, respectively. In the year 2021, at 25 DAS, among the soil amendments maximum plant height was observed at SA_1 (10.17 cm) which was found to be at par with SA_3 (9.83 cm) while minimum plant height was recorded at SA_2 (9.17 cm) that was at par with control (9.28 cm), whereas in 2022 (at 25 DAS) maximum plant height was recorded at SA_3

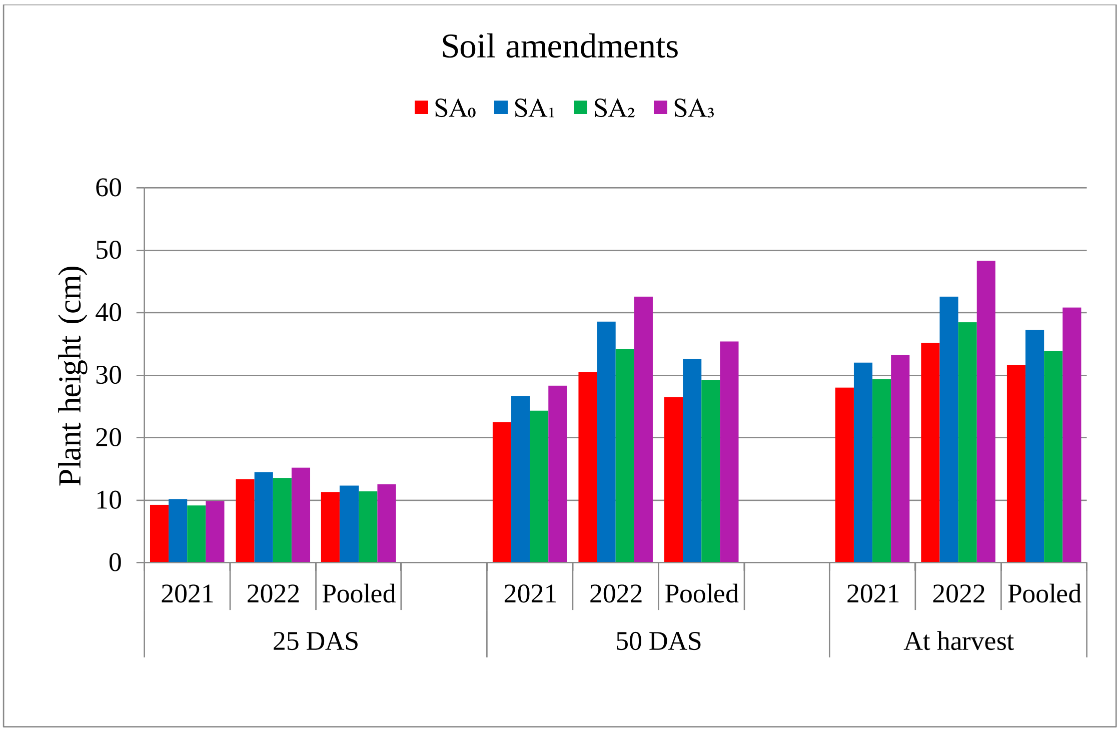
(15.19) and minimum plant height was recorded at control (13.33 cm) which was at par with SA_2 (13.55 cm). Now from the pooled data at 25 DAS, maximum plant height was observed at SA_3 (12.51 cm) which was found to be at par with SA_1 (12.31 cm) and minimum was noted at control (11.30 cm) which was at par with SA_2 (11.36 cm). Plant height at 50 DAS and at harvest showed similar trend in both the years of experimentation, maximum plant height was recorded at SA_3 with a pooled value of 35.44 cm and 40.79 cm respectively, while minimum plant height was recorded at control (26.46 and 31.57 cm, respectively). The plant height was significantly higher in amended plots over control; liming enhances nutrient solubility uptake due to moderation of soil reaction and greater the uptake of nutrients more production of protoplasm and thereby increasing rapid cell division and cell elongation favourable for plant height. These results are in conformity with the findings of Kumar *et al.* (2014) and Dabesa and Tana (2021). A critical evaluation of the data presented on Table 4.1(a) and depicted in Fig 4.1 further revealed that during the initial growth stage the influence of PSB on plant height was inconspicuous but with the progressive growth stages the effect of PSB was more evident. The increase in plant height can be attributed to role of phosphorus solubilising bacteria in phosphorus nutrition by increasing its availability to plants by liberating P from inorganic and organic soil P pools by solubilisation and mineralization. Hence, enabling the plant to absorb more P resulting in improved growth attributes. These finding are found relevant to Balachandran and Nagarajan (2002), Wagadre *et al.* (2010) and Singh *et al.* (2021). Application of lime (SA_1) and PSB (SA_2) enhanced plant height at harvest by 18.0% and 7.2% over control. Maximum plant height was recorded when lime and PSB applied in conjunction (SA_3). This treatment improved plant height to the extent of 29.2% as compared to control. Hence, combined application of lime and PSB was found more beneficial in comparison to sole application of lime or PSB.

Table 4.1(a): Effect of soil amendments and phosphorus on plant height of black gram

Treatments	Plant height (cm)								
	25 DAS			50 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	9.28	13.33	11.30	22.43	30.50	26.46	27.99	35.15	31.57
SA_1 (5% LR)	10.17	14.44	12.31	26.65	38.59	32.62	31.99	42.57	37.28
SA_2 (PSB)	9.17	13.55	11.36	24.35	34.19	29.27	29.32	38.43	33.87
SA_3 (5% LR + PSB)	9.83	15.19	12.51	28.28	42.60	35.44	33.27	48.32	40.79
SEm±	0.18	0.25	0.15	0.30	0.35	0.23	0.25	0.35	0.22
CD (P=0.05)	0.52	0.71	0.43	0.87	1.02	0.66	0.71	1.02	0.61
Phosphorus levels									
P_0	7.89	12.22	10.05	19.30	30.82	25.06	24.34	35.10	29.72
P_{20}	9.49	13.60	11.54	24.74	34.14	29.44	29.61	38.89	34.25
P_{40}	10.77	14.90	12.83	28.03	39.15	33.59	32.80	43.54	38.17
P_{60}	10.30	15.80	13.05	29.65	41.77	35.71	35.81	46.94	41.38
SEm±	0.18	0.25	0.15	0.30	0.35	0.23	0.25	0.35	0.22
CD (P=0.05)	0.52	0.71	0.43	0.87	1.02	0.66	0.71	1.02	0.61

Table 4.1(b): Interaction effect of soil amendments and phosphorus on plant height

Soil amendments	Plant height (cm)			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	50 DAS (pooled)			
SA_0	20.65	25.45	28.60	31.15
SA_1	27.08	30.66	35.58	37.18
SA_2	23.56	27.79	31.66	34.06
SA_3	28.94	33.86	38.51	40.44
SEm±	0.46			
CD (P=0.05)	1.31			
	At harvest (pooled)			
SA_0	25.05	30.17	34.01	37.06
SA_1	31.55	35.59	39.97	42.02
SA_2	27.64	32.99	35.56	39.30
SA_3	34.65	38.24	43.16	47.13
SEm±	0.43			
CD (P=0.05)	1.22			



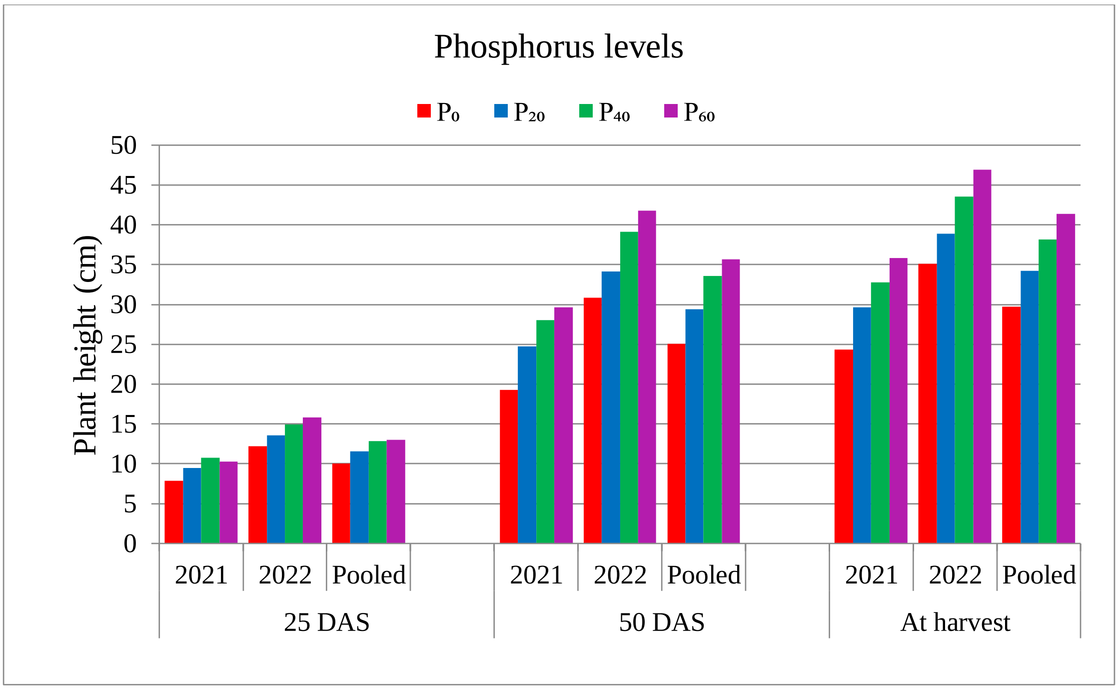


Fig 4.1: Effect of soil amendments and phosphorus on plant height of black gram

4.1.1.2. Effect of phosphorus levels

It is evident from the data presented in Table 4.1(a) and Fig 4.1 that there was significant increase in plant height with application of different levels of phosphorus. During 2021 and 2022, the pooled values of plant height at 25, 50 DAS and at harvest varied from 10.05 to 13.05 cm, 25.06 to 35.71 cm and 29.72 to 41.38 cm, respectively. During the first year of experimentation, at 25 DAS, maximum plant height (10.77 cm) was recorded at 40 kg P_2O_5 ha^{-1} which was statistically at par with 60 kg P_2O_5 ha^{-1} (10.30 cm) while in the second year and at pooled maximum plant height was recorded at 60 kg P_2O_5 ha^{-1} (15.80 and 13.05 cm, respectively). However from the pooled data at 25 DAS, plant height recorded with 60 kg P_2O_5 ha^{-1} was at par with 40 kg P_2O_5 ha^{-1} (12.83 cm). While plant height at 50 DAS and at harvest exhibited similar pattern with maximum value recorded at P_{60}. In both the trials and at all growth stages minimum plant height was recorded at control. The plant height gradually increased in successive growth stages with the increased in phosphorus levels. A critical examination of data indicated that at harvest each increasing level of phosphorus enhanced plant height significantly in comparison to preceding lower level of phosphorus. Maximum plant height was reported at P_{60} level, which enhanced the plant height by 39.2% over control. Increment in plant height might be owing to the fact that 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 phosphorus supply that indirectly aid in providing nitrogen supply and its availability assisted the plants to attain more vigour in terms of plant height. Similar finding was also reported by Venkatarao *et al*. (2017), Singh *et al*. (2017) and Parashar *et al*. (2020).

Interaction effect of soil amendments and phosphorus on plant height

It can be observed from the Table 4.1(b) that the interaction effect between soil amendments and phosphorus was significant on pooled plant height on 50th day and at harvest. The significant difference 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. Maximum pooled plant height at 50 DAS and at harvest was recorded with the application of treatment combination SA_3P_{60} (40.44 and 47.13 cm, respectively) while minimum was recorded at SA_0P_0 (20.65 and 25.05 cm, respectively).These finding are found relevant to Ameyu and Asfaw (2020) who reported positive interaction effect of lime and phosphorus on plant height. Similar results on interaction of PSB and phosphorus on plant height was also reported by Bhabai *et al*. (2019) and Jamir *et al*. (2022).

4.1.2. Number of branches plant^{-1}

4.1.2.1. Effect of soil amendments

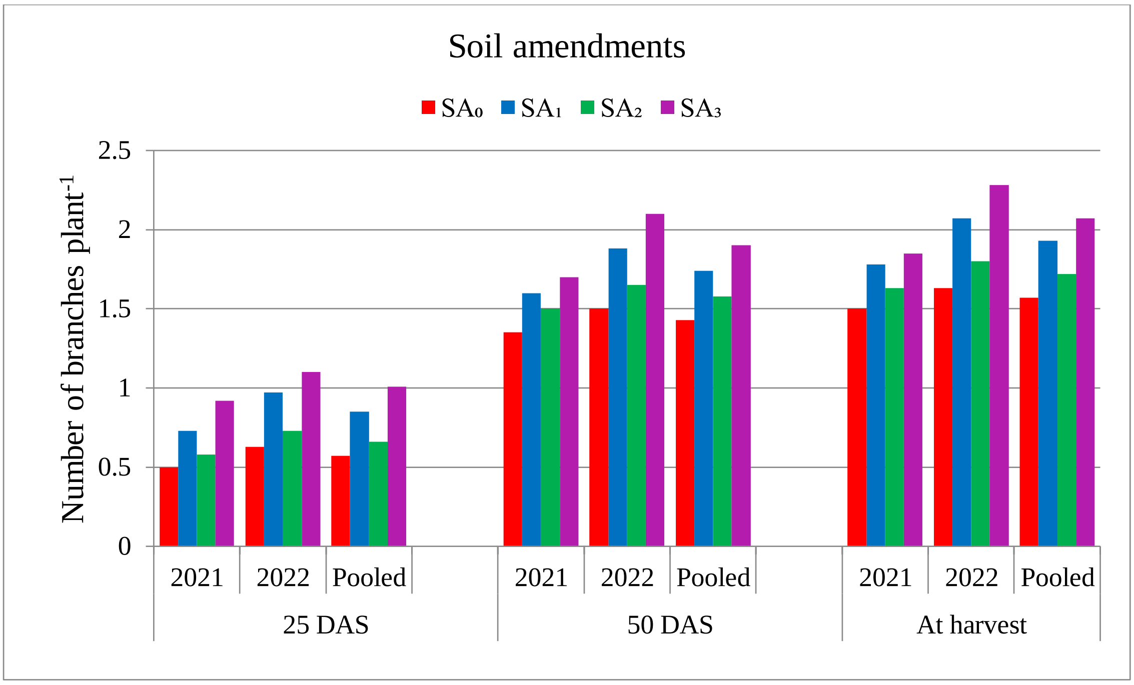
A perusal data on number of branches per plant registered at 25, 50 DAS and at harvest are presented in Table 4.2 and depicted in Fig 4.2. It is apparent from the Table 4.2 that soil amendments had significant effects on number of branches plant^{-1} at all growth stages of black gram. During 2021 and 2022, maximum number of branches plant^{-1} at 25, 50 DAS and at harvest was observed at SA_3 with a pooled value of 1.01, 1.90 and 2.07, respectively; while minimum number of branches plant^{-1} was recorded at control (0.57, 1.43 and 1.57, respectively). However in both the years of experimentation, during the initial growth stage (i.e., at 25 DAS), the number of branches noted under SA_2 (0.58 and 0.73, respectively) was statistically at par with SA_0 (0.50 and 0.63, respectively). Furthermore, during 2021, on 50th day after sowing and at harvest, the number of branches noted under SA_3 (1.70 and 1.85, respectively) was at par with SA_1 (1.60 and 1.78, respectively). Combine application of lime and PSB (SA_3) significantly increased number of branches per plant at harvest over sole application of lime (SA_1). The SA_3 treatment enhanced the number of branches per plant at harvest by 31.8% over control (SA_0). The increase in number of branches with the application of soil amendments might be due to liming which improves crop growth as an outcome of better availability of nutrients due to moderation of soil pH. These results are corroborated by the findings of Lynrah and Nongmaithem (2017) and Odyuo and Sharma (2020). Moreover, the influence of PSB on number of branches can be attributed to enhanced phosphorus accessibility of for plants through by PSB thereby favouring higher absorption and P use efficiency as well as other nutrients resulting positive influence on plant growth (Walpola and Yoon 2012). Nonetheless, further evaluation of data reflected that the effect of PSB on branches per plant during initial days of growth was not distinct and only at later stages the influence was apparent. Positive effects of inoculation on black gram were reported by Zohmingliana *et al*. (2018) and Singh *et al*. (2021).

4.1.2.2. Effect of phosphorus levels

The data given in Table 4.2 and delineated in Fig 4.2 further revealed that the number of branches plant^{-1} increased significantly with increasing P levels. From the pooled data, at all growth stages, maximum branches were observed at P_{60} with a pooled value of 1.03 (25 DAS), 2.01 (50 DAS) and 2.18

Table 4.2: Effect of soil amendments and phosphorus on number of branches plant^{-1} of black gram

Treatments	Number of branches plant^{-1}								
	25 DAS			50 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	0.50	0.63	0.57	1.35	1.50	1.43	1.50	1.63	1.57
SA_1 (5% LR)	0.73	0.97	0.85	1.60	1.88	1.74	1.78	2.07	1.93
SA_2 (PSB)	0.58	0.73	0.66	1.50	1.65	1.58	1.63	1.80	1.72
SA_3 (5% LR + PSB)	0.92	1.10	1.01	1.70	2.10	1.90	1.85	2.28	2.07
SEm±	0.03	0.04	0.02	0.05	0.05	0.03	0.04	0.05	0.03
CD (P=0.05)	0.09	0.11	0.07	0.13	0.13	0.09	0.12	0.14	0.09
Phosphorus levels									
P_0	0.35	0.50	0.43	1.05	1.35	1.20	1.23	1.45	1.34
P_{20}	0.62	0.77	0.69	1.43	1.68	1.56	1.58	1.83	1.71
P_{40}	0.85	1.02	0.93	1.78	1.97	1.88	1.95	2.13	2.04
P_{60}	0.92	1.15	1.03	1.88	2.13	2.01	2.00	2.37	2.18
SEm±	0.03	0.04	0.02	0.05	0.05	0.03	0.04	0.05	0.03
CD (P=0.05)	0.09	0.11	0.07	0.13	0.13	0.09	0.12	0.14	0.09



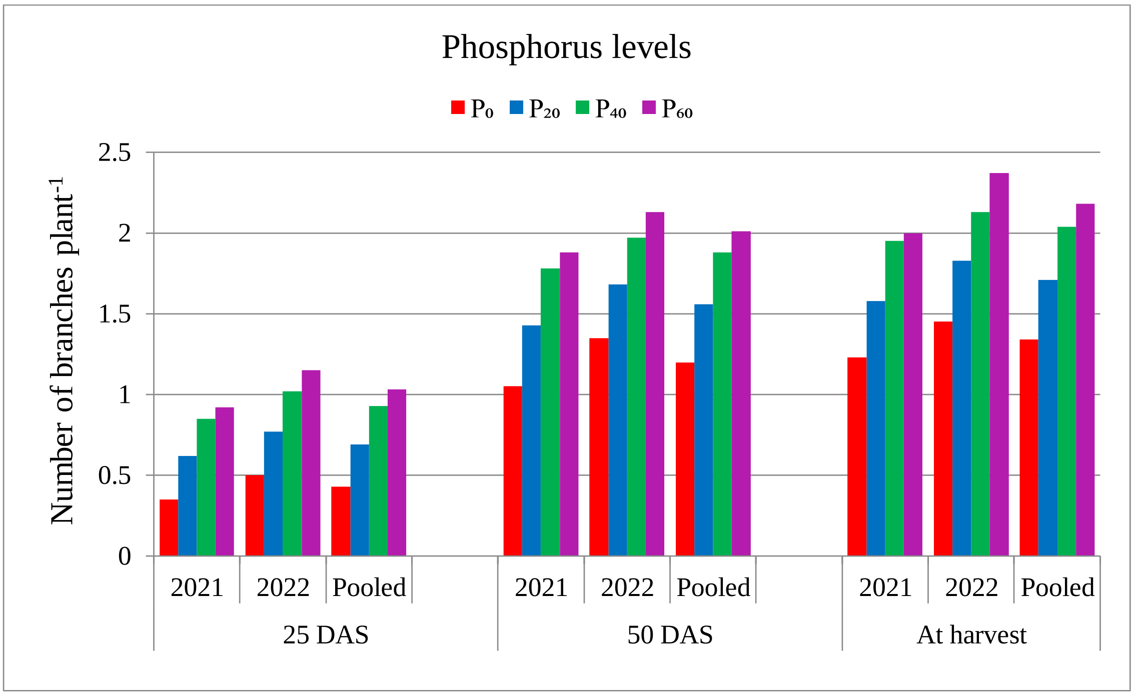


Fig 4.2: Effect of soil amendments and phosphorus on number of branches plant^{-1} of black gram

(at harvest) while minimum was recorded at control (0.43, 1.2 and 1.34, respectively). However, during 2021 at all growth stages number of branches plant^{-1} recorded at 60 kg P_2O_5 ha^{-1} was found to be at par with 40 kg P_2O_5 ha^{-1}. It was observed that, at harvest, number of branches per plant was enhanced by 62.6% by application of 60 kg P_2O_5 ha^{-1} over control. The increased in branches may be ascribed to P fertilization in soil deficient in phosphorus, thus improving the availability of P followed by more P uptake by plants and consequently enhance the process of photosynthesis and translocation of photosynthates to different parts for promoting meristematic development in potential apical buds and intercalary meristem which eventually enhanced root and shoot development in terms of growth. These findings are consistent with those reported by Prajapati *et al*. (2017), Kumar and Yadav (2018) and Parashar *et al*. (2020).

4.1.3. Number of pods plant^{-1} and pod length

4.1.3.1. Effect of soil amendments on pods plant^{-1}

An appraisal of data given in Table 4.3(a) and depicted in Fig 4.3 indicated that pod plant^{-1} was influenced markedly by soil amendments. Irrespective of treatments and year the number of pods per plant ranged from 8.80 to 14.47. A critical examination of data revealed that limed plots produced higher number of pods plant^{-1} in comparison to control and PSB treated plots. But, maximum pods per plant was recorded under SA_3 (lime + PSB) treatment, which was significantly superior to other soil amendment treatments. The SA_3 treatment improved pods per plant to the extent of 23.7% as compared to control. The significant variation in number of pods plant^{-1} can be attributed to higher photosynthesis and better translocation of carbohydrates to the fruiting sink due to liming. These findings are found relevant to Kumar *et al.* (2014) and Lynrah and Nongmaithem (2017). Also, PSB facilitates higher absorption and utilization of P which resulted better development of flowers and pod formation. Kumar *et al.* (2016) also suggested that increased nutrient and water uptake by plants might result in to better growth and yield attributes. The beneficial effect of PSB on yield attributes were also reported by Wagadre *et al*. (2010), Amruta *et al*. (2015) and Shekhawat *et al*. (2018).

4.1.3.2. Effect of phosphorus levels pods plant^{-1}

The data presented in Table 4.3(a) and illustrated Fig 4.3 further revealed that phosphorus levels also significantly influenced the number of pods plant^{-1}. During 2021 and 2022, maximum pods plant^{-1} was observed with the application of 60 kg P_2O_5 ha^{-1} with a pooled value of 13.28 which was at par with 40 kg P_2O_5 ha^{-1} (12.92) while minimum was recorded at control (9.48). From the study a significant increase in pods plant^{-1} with the increasing levels of phosphorus was observed, this can be due to the role of phosphorus in flowering and fruiting including seed development. Similar results were reported by Kumar and Yadav (2018) and Karnavat *et al*. (2018).

4.1.3.3. Effect of soil amendments on pod length

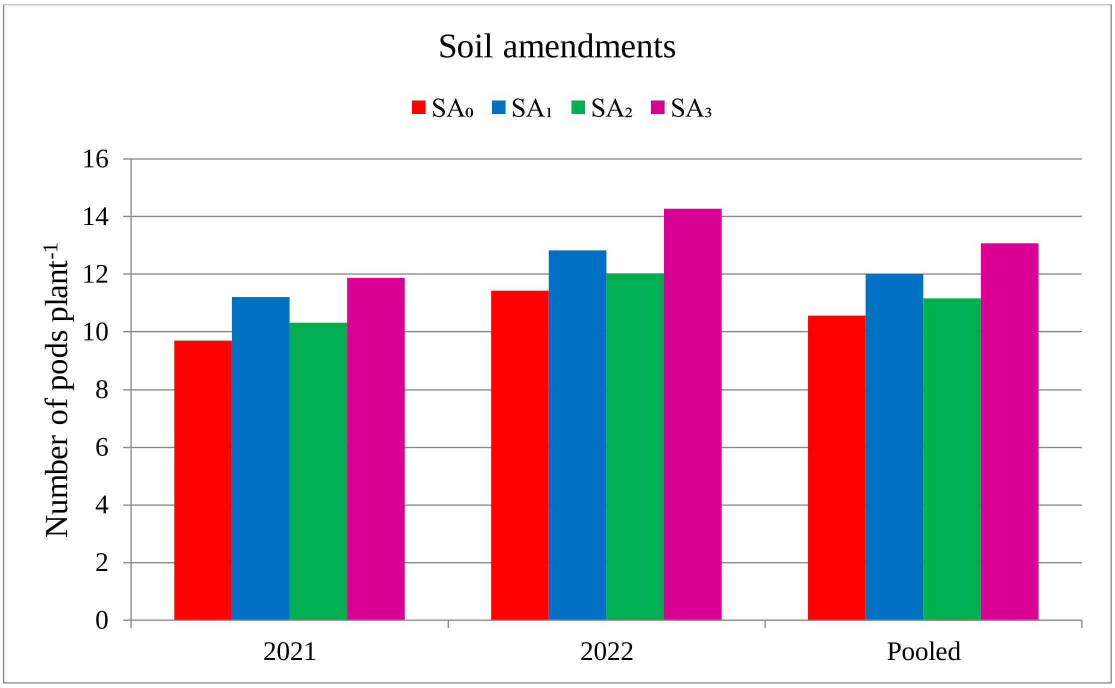
Data related to pod length of black gram are given in Table 4.3(a) and represented in Fig 4.4. It is evident that pod length was observed to be significantly longer in amended plots compared with control. From the pooled data, maximum pod length was recorded at SA_3 with a pooled value of 4.48 cm while minimum was recorded at control with a pooled value of 4.14 cm which was at par with SA_2 (4.23 cm). The significant increased in pod length was observed only in lime treated plots either applied as sole or combined while in sole PSB treated plots the pod length of black gram was enhanced slightly and was statistically not different to control. Combined application of lime and PSB significantly augmented the pod length by 8.2% over control. The enhancement in pod length can be attributed to better translocation of photosynthates to fruiting sink due to liming; coupled availability of phosphorus through PSB which is essential for pod formation and seed development. The results

Table 4.3(a): Effect of soil amendments and phosphorus on pod plant^{-1} and pod length of black gram

Treatments	Pod plant^{-1}			Pod length (cm)		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	9.71	11.43	10.57	4.12	4.15	4.14
SA_1 (5% LR)	11.20	12.82	12.01	4.30	4.33	4.32
SA_2 (PSB)	10.32	12.03	11.17	4.20	4.27	4.23
SA_3 (5% LR + PSB)	11.88	14.28	13.08	4.44	4.52	4.48
SEm±	0.17	0.20	0.13	0.06	0.06	0.04
CD (P=0.05)	0.49	0.58	0.37	0.16	0.18	0.12
Phosphorus levels						
P_0	8.80	10.17	9.48	3.95	4.04	3.99
P_{20}	10.41	11.90	11.15	4.24	4.28	4.26
P_{40}	11.82	14.03	12.92	4.38	4.44	4.41
P_{60}	12.08	14.47	13.28	4.49	4.52	4.50
SEm±	0.17	0.20	0.13	0.06	0.06	0.04
CD (P=0.05)	0.49	0.58	0.37	0.16	0.18	0.12

Table 4.3(b): Interaction effect of soil amendments and phosphorus on number of pod plant^{-1}

Soil amendments	Number of pod plant^{-1}			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2022			
SA_0	9.67	10.67	12.53	12.87
SA_1	10.47	12.60	13.93	14.27
SA_2	9.87	11.27	13.27	13.73
SA_3	10.67	13.07	16.40	17.00
SEm±	0.40			
CD (P=0.05)	1.16			
	Pooled			
SA_0	8.90	9.92	11.50	11.97
SA_1	9.77	11.83	13.10	13.33
SA_2	9.07	10.53	12.36	12.73
SA_3	10.20	12.33	14.73	15.07
SEm±	0.26			
CD (P=0.05)	0.75			



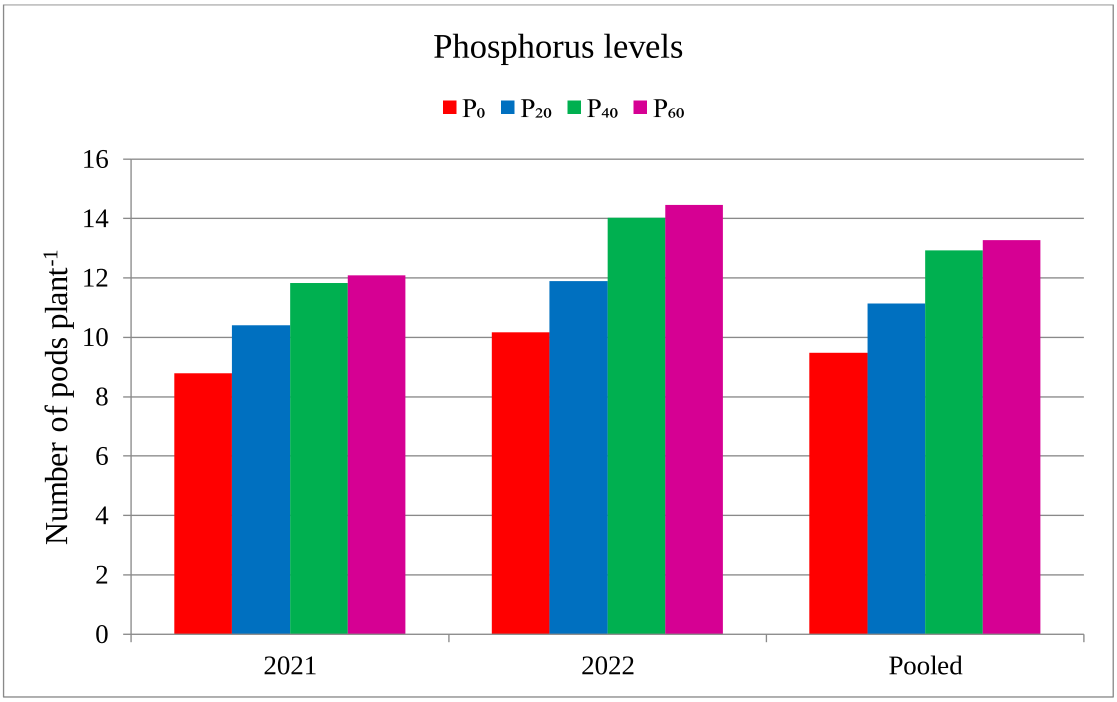
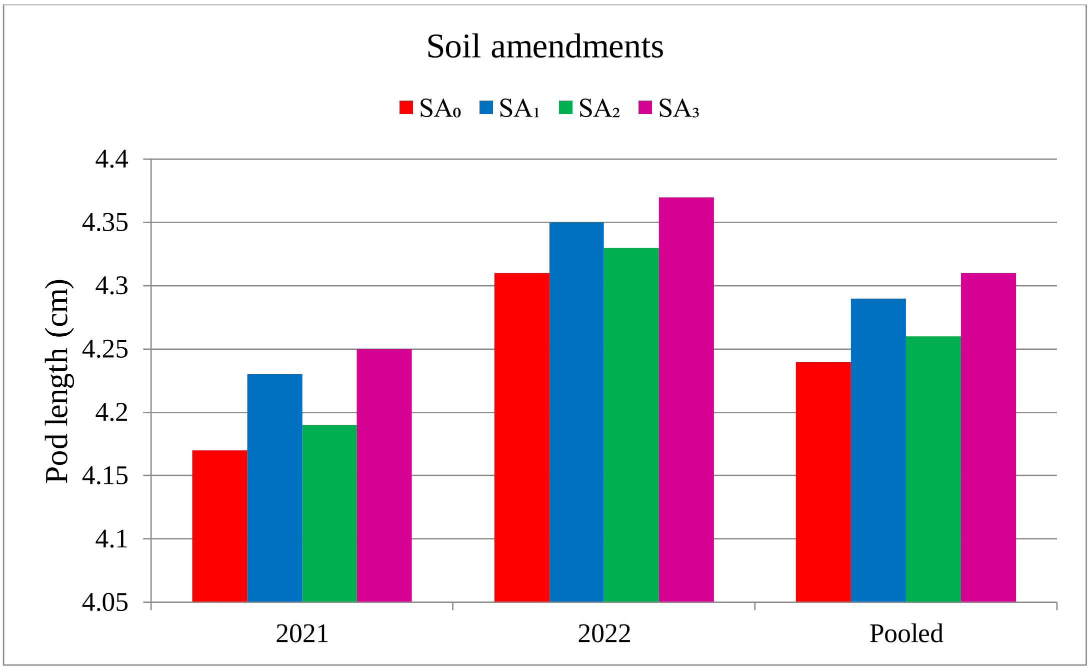


Fig 4.3: Effect of soil amendments and phosphorus on number of pods plant^{-1} of black gram



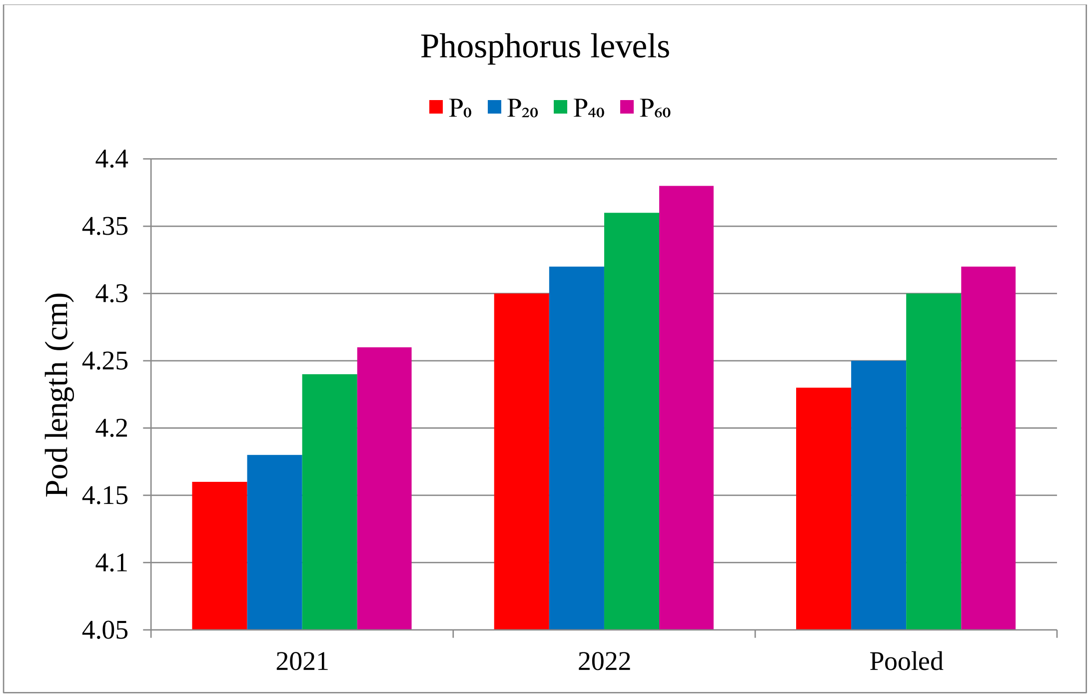


Fig 4.4: Effect of soil amendments and phosphorus on pod length of black gram

corroborate with the findings of Sarker *et al.* (2014) and Lynrah and Nongmaithem (2017).

4.1.3.4. Effect of phosphorus levels on pod length

Furthermore, the data given in Table 4.3(a) imparted that there was significant influence on pod length with the application levels of phosphorus. Irrespective of years of experimentation, it was observed that the pod length increased with increasing levels of phosphorus; this might be due to the pivotal role of phosphorus in flowering, fruiting and seed development. From pooled data, maximum pod length was registered with the application of 60 kg P_2O_5 ha^{-1} (4.50 cm) and was at par with 40 kg P_2O_5 while minimum at control (3.99).These results are in alignment with that of Singh *et al.* (2017) and Jamir *et al.* (2022).

Interaction effect of soil amendments and phosphorus on number of pods plant^{-1}

It can be observed from the Table 4.3(b) that during the second year of experimentation and at pooled data the interaction effect of soil amendments and phosphorus on number of pods plant^{-1} was significant which showed an increasing trend with increased in level of phosphorus irrespective of soil amendments; it could be due to increase in supply of P 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 P which further favours improvement in yield and yield attributes. The treatment combination SA_3P_{60} recorded the maximum number of pods plant^{-1} with a pooled value of 15.07, while minimum was recorded at SA_0P_0 with a pooled value of 8.90. However, SA_3P_{60} was at par with SA_3P_{40} treatment combination during second year and at pooled. The findings are parallel to that of Ameyu and Asfaw (2020) who reported significant interaction of lime and phosphorus on number of pods plant^{-1}. Similar results on interaction of PSB and phosphorus on number of pods per plant was also documented by Bhabai *et al.* (2019) and Jamir *et al*. (2022).

4.1.4. Seeds pod^{-1} and test weight

4.1.4.1. Effect of soil amendments on seeds pod^{-1}

Data presented in Table 4.4 exhibited that there was significant variation in seeds pod^{-1} with the application of soil amendments treatment during both the years of experimentation. From the pooled data, maximum number of seeds pod^{-1} was observed at SA_3 with a pooled value of 6.79 while minimum was recorded at control (6.16). It was also observed that application of PSB significantly increased seed per pod over control. Application of lime (SA_1) and PSB (SA_2) enhanced seeds per pod by 6.8 and 4.5% respectively over control. However, maximum seed per pod was obtained with combine application of lime and PSB (SA_3), which enhanced seed per pod by 10.2% over control. There was apparent difference in amended plots compared to control plots; this can be attributed to adequate supply of nutrients particularly NPK due to liming and their subsequent increase in uptake. These finding are found relevant to Odyuo and Sharma (2020) and Uchoi and Sharma (2023). Furthermore, PSB aided in boosting the availability of P leading to greater root development and nodulation which in turn resulted in more uptake of nutrients and ultimately mirrored in better yield attributes (Kumawat *et al*., 2009). These results support the findings of Singh *et al*. (2021) and Sharma and Borah (2021).

4.1.4.2. Effect of phosphorus levels on seeds pod^{-1}

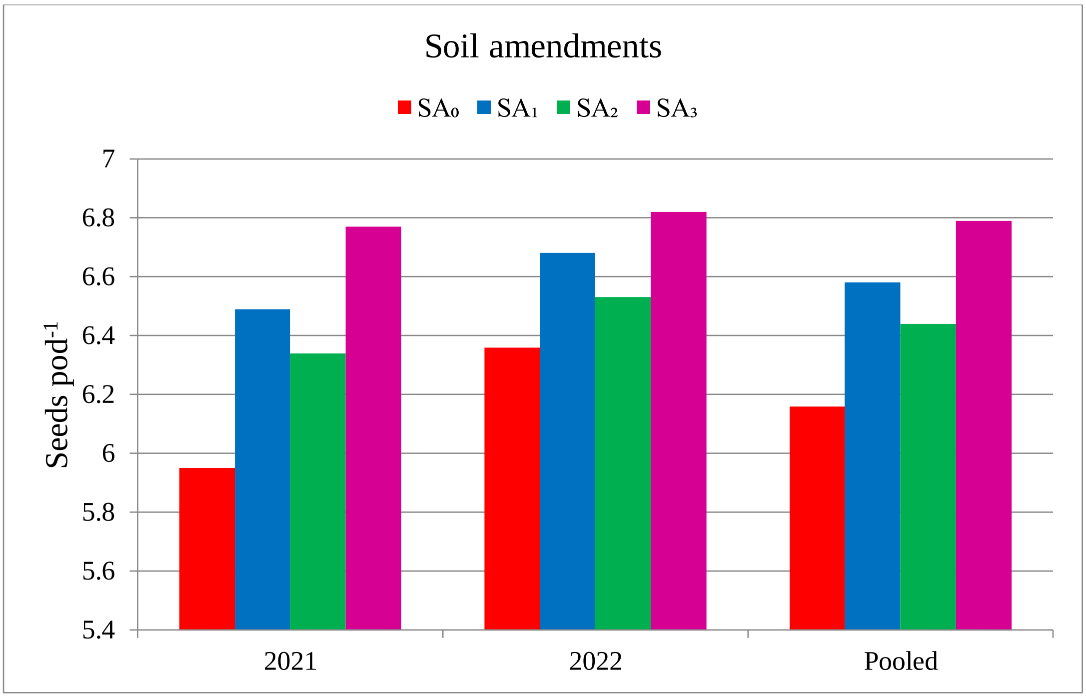
It is apparent from the data give in Table 4.4(a) that there was significant increase in number of seeds pod^{-1} with increasing phosphorus levels. Maximum number of seeds pod^{-1} was recorded with the application of

Table 4.4(a): Effect of soil amendments and phosphorus on seed pod^{-1} and test weight of black gram

Treatments	Seed pod^{-1}			Test weight (g)		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	5.95	6.36	6.16	41.66	41.67	41.66
SA_1 (5% LR)	6.49	6.68	6.58	41.81	41.88	41.84
SA_2 (PSB)	6.34	6.53	6.44	41.79	41.74	41.77
SA_3 (5% LR + PSB)	6.77	6.82	6.79	41.90	42.00	41.95
SEm±	0.04	0.02	0.02	0.26	0.17	0.15
CD (P=0.05)	0.10	0.06	0.06	NS	NS	NS
Phosphorus levels						
P_0	5.75	6.15	5.95	41.62	41.64	41.63
P_{20}	6.33	6.46	6.40	41.74	41.76	41.75
P_{40}	6.69	6.87	6.78	41.86	41.89	41.88
P_{60}	6.78	6.91	6.84	41.94	41.99	41.97
SEm±	0.04	0.02	0.02	0.26	0.17	0.15
CD (P=0.05)	0.10	0.06	0.06	NS	NS	NS

Table 4.4(b): Interaction effect of soil amendments and phosphorus on seed pod^{-1}

Soil amendments	Seed pod^{-1}			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	5.52	5.81	6.20	6.28
SA_1	5.71	6.52	6.81	6.90
SA_2	5.57	6.29	6.70	6.82
SA_3	6.19	6.71	7.05	7.11
SEm±	0.07			
CD (P=0.05)	0.20			
	2022			
SA_0	5.99	6.19	6.62	6.66
SA_1	6.19	6.47	7.00	7.04
SA_2	6.04	6.52	6.76	6.80
SA_3	6.37	6.67	7.10	7.14
SEm±	0.04			
CD (P=0.05)	0.11			
	Pooled			
SA_0	5.76	6.00	6.41	6.47
SA_1	5.95	6.50	6.90	6.97
SA_2	5.81	6.40	6.73	6.81
SA_3	6.28	6.69	7.07	7.13
SEm±	0.04			
CD (P=0.05)	0.11			



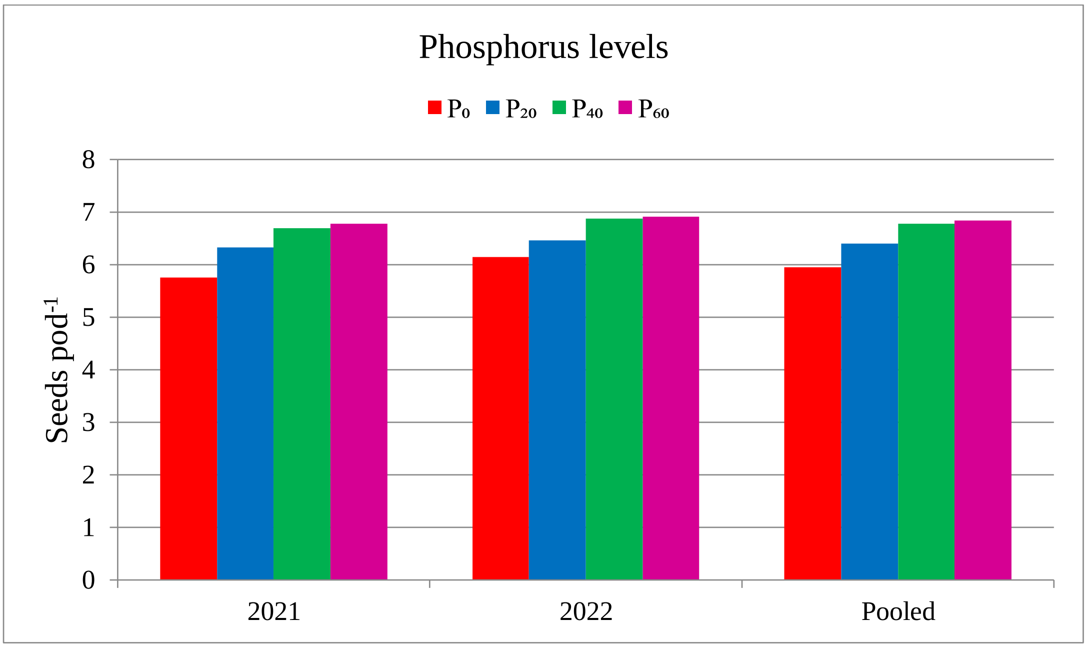


Fig 4.5: Effect of soil amendments and phosphorus on seeds pod^{-1} of black gram

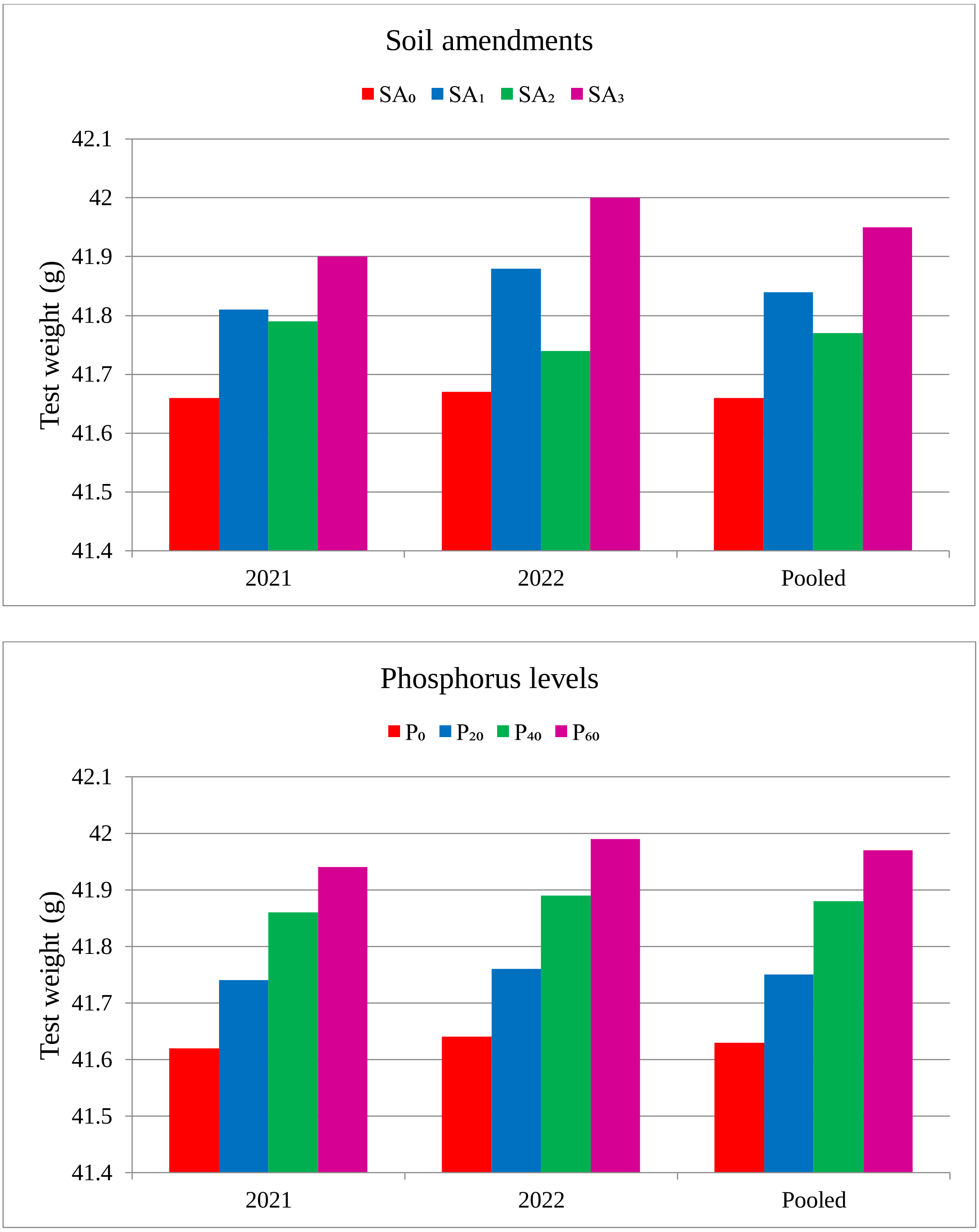


Fig 4.6: Effect of soil amendments and phosphorus on test weight of black gram

60 kg P_2O_5 ha^{-1} (6.84) which was at par with 40 kg P_2O_5 ha^{-1} (6.78) while minimum at control (5.95). The phosphorus level P_{40} and P_{60} improved seeds per pod by 13.9 and 14.9% in comparison to control. The improvement observed in seeds pod^{-1} could be attributed to the fact that phosphorus application encouraged better root growth which induced more absorption of nutrients by plants from soil for effective dry matter production and translocation of photosynthates from leaves to reproductive parts for better development for seeds (Gadi *et al.*, 2018 and Zohmingliana *et al.*, 2018). These findings are consistent with those reported by Kumar and Yadav (2018), Karnavat *et al*. (2018) and Singh *et al*. (2020).

4.1.4.3. Effect of soil amendments on test weight

Further evaluation of data given in Table 4.4(a) exhibited that the effect of soil amendments on test weight of black gram was statistically non-significant. Irrespective of amendments treatment test weight of black gram varied from 41.66 to 41.95 g.

4.1.4.4. Effect of phosphorus levels on test weight

The effect of phosphorus levels on test weight of black gram was statistically non-significant. However, numerically higher value of test weight was recorded with 60 kg P_2O_5 ha^{-1} (41.97 g) while minimum at control (41.63 g).

Interaction effect of soil amendments and phosphorus on seeds pod^{-1}

From Table 4.4(b) it is apparent that during 2021 and 2022, the interaction of soil amendments and phosphorus on seeds pod^{-1} was found significant. It was also observed that at all levels of soil amendments, maximum seed pod^{-1} was recorded at P_{60} (60 kg P_2O_5 ha^{-1}) that was 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 seeds pod^{-1}. However from the pooled data, maximum seeds pod^{-1} (7.13) was recorded with treatment combination SA_3P_{60} which was found to be at par with SA_3P_{40} while minimum 5.76 was recorded at SA_0P_0. Hence, SA_3P_{40} treatment combination was found optimum in case of seeds per pod. A critical examination of pooled data showed that each soil amendment level increased the seed per pod significantly under each level of phosphorus except P_{20}.This is in congruence with that of Ameyu and Asfaw (2020) and Uzege *et al*. (2023) who reported positive interaction of lime and phosphorus on seed per pod; and also confirms with that of Jamir *et al*. (2022) who found similar interaction of PSB and phosphorus on seeds pod^{-1} of black gram.

4.1.5. Seed yield

4.1.5.1. Effect of soil amendments

The data given in Table 4.5(a) and depicted in Fig 4.7 demonstrated that soil amendment exerted significant effect on seed yield of black gram. During 2021 and 2022, maximum seed yield was registered at SA_3 with a pooled value of 627.69 kg ha^{-1} while minimum seed yield was recorded at control with a pooled value of 483.16 kg ha^{-1}. The seed yield was higher in amended plots compared to control furthermore solo application of lime or in combination exhibited better yield than PSB alone. Sole application of lime and PSB increased pooled seed yield by 19.6 and 11.4% respectively over control. While application of lime in conjunction with PSB (SA_3) improved the seed yield to the extent of 29.9% over control. These results signified that liming had a positive effect on grain filling thereby eventually increased yield. Anetor and Akinrinde (2006) demonstrated that lime application significantly enhanced yield indices of legumes grown under acidic soils. The improvement in yield may also ascribed to the neutralization of exchangeable Al^{3+} ions and increase in available Ca^{2+} which favoured excellent seed filling; attributing to improvement in soil pH and other physico-chemical properties of soil that boosts plant accessibility to soil nutrients. On contrary no application of amendments resulted in minimum seed yield owing to low soil nutrient status in addition to poor activity of soil micro-organism as influenced by soil acidity. These findings are substantiated with those reported by Sarker *et al*. (2014) and Dabesa and Tana (2021). A critical examination of data inferred that there was significant influence of PSB on grain yield over control; this might be owing to the fact that phosphate solubilizing bacteria enhances the availability of phosphorus to the plants and its greater uptake. These results are in conformity with Hassan *et al*. (2017) and Singh *et al*. (2021).

4.1.5.2. Effect of phosphorus levels

It is evident from the data presented in Table 4.5(a) and depicted in Fig 4.7 that phosphatic fertilizer levels exerted significant effect on seed yield of black gram. In both the years of experimentation maximum seed yield was recorded at 60 kg P_2O_5 ha^{-1} with a pooled value of 641.73 kg ha^{-1} which was statistically at par with 40 kg P_2O_5 ha^{-1} (640.00 kg ha^{-1}) while minimum seed yield was recorded at control (441.55 kg ha^{-1}). Furthermore a critical evaluation of Fig 4.7, it is apparent that the seed yield of black gram increased with increasing levels of phosphorus while the yield plateau at 40 kg P_2O_5 ha^{-1}. Seed yield of black gram with application of 40 kg P_2O_5 (P_{40}) was increased by 44.9% over control. The augmented seed yield can be due to the increase in supply of phosphorus which attributed to profuse nodulation and cell multiplication resulting to more absorption of other essential nutrients from deeper layers of soil eventually favouring increased in yield indices. The present results are in collaboration with the findings of Kumar and Yadav (2018), Parashar *et al*. (2020) and Singh *et al*. (2020).

Interaction effect of soil amendments and phosphorus on seed yield

From the data presented in Table 4.5(b) it is evident that effect of soil amendments and phosphorus on seed yield was found significant in both the years. It can be observed that the seed yield at SA_3 was superior to rest of amendment levels; maximum seed yield was recorded at treatment combination SA_3P_{60} which was at par with SA_3P_{40}. Although seed yield at soil amendment 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} demonstrated to be the best combinations for obtaining better yield of black gram. These results confirm with the findings of Ameyu and Asfaw (2020) who reported significant interaction of lime and phosphorus; Nadeem *et al*. (2018) reported similar positive interaction of PSB and phosphorus.

4.1.5.1. Response of seed yield of black gram to phosphorus

The response of seed yield of black gram to phosphorus was calculated on the basis of average seed yield of two years of experimentation and data are presented in Table 4.5(d) and illustrated in Fig 4.9. The regression equation for phosphorus was Y=3.685x + 446.12 per kg phosphorus application in the range of 0 to 20 kg P_2O_5 ha^{-1} application of 1 kg P_2O_5 increased 3.09 kg, in the range of 20 to 40 kg P_2O_5 ha^{-1}, one kg phosphorus increased 4.96 kg while in the range of 40 to 60 kg P_2O_5 ha^{-1} one kg phosphorus increased 3.33 kg seed yield of black gram. The optimum dose of phosphorus (P_2O_5) was found 49.35 kg ha^{-1} and at this level one kg of P_2O_5 increase 3.77 kg seed yield of black gram. Therefore 49.35 kg P_2O_5 ha^{-1} was proved optimum dose for getting maximum seed yield of black gram in the present set of conditions.

Table 4.5(a): Effect of soil amendments and phosphorus on seed and stover yield of black gram

Treatments	Seed yield (kg ha^{-1})			Stover yield (kg ha^{-1})		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	372.45	593.88	483.16	643.25	1089.50	866.38
SA_1 (5% LR)	457.41	698.08	577.75	833.27	1332.23	1082.75
SA_2 (PSB)	408.29	668.01	538.15	743.41	1242.47	992.94
SA_3 (5% LR + PSB)	499.83	755.54	627.69	939.30	1413.47	1176.39
SEm±	7.87	7.16	5.32	13.77	18.96	11.72
CD (P=0.05)	22.74	20.67	15.05	39.78	54.76	33.14
Phosphorus levels						
P_0	349.52	533.58	441.55	584.89	977.21	781.05
P_{20}	413.80	593.13	503.47	747.88	1100.67	924.27
P_{40}	487.14	792.86	640.00	906.26	1483.50	1194.88
P_{60}	487.52	795.94	641.73	920.21	1516.30	1218.25
SEm±	7.87	7.16	5.32	13.77	18.96	11.72
CD (P=0.05)	22.74	20.67	15.05	39.78	54.76	33.14

Table 4.5(b): Interaction effect of soil amendments and phosphorus on seed yield of black gram

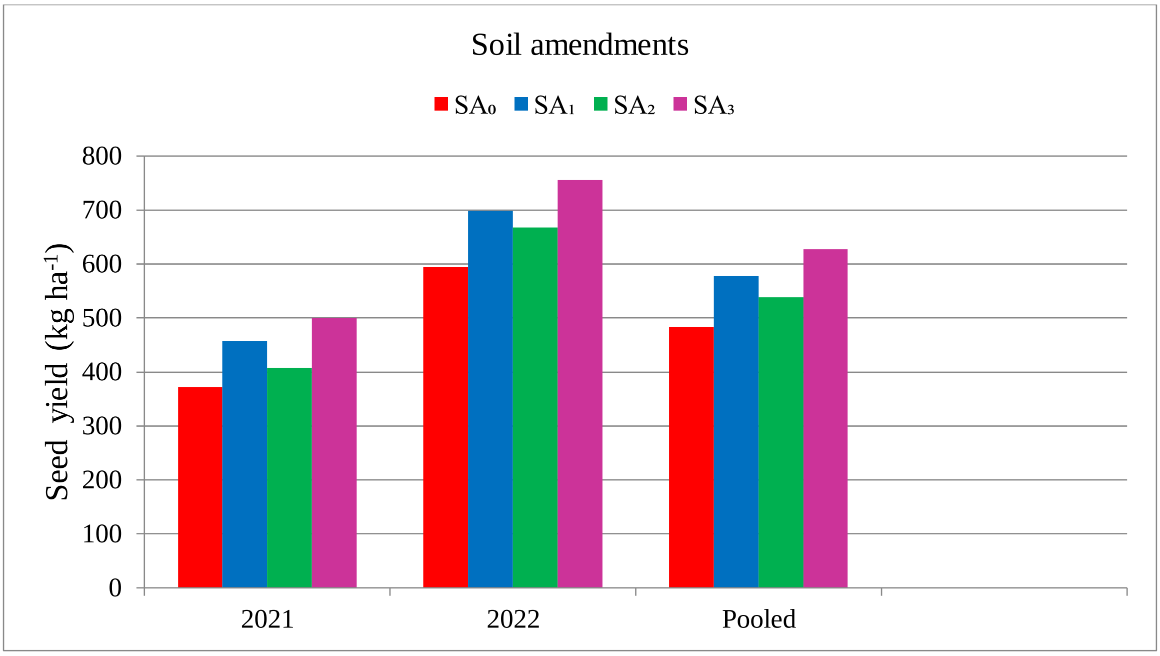
Soil amendments	Seed yield (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	322.14	366.28	400.46	400.92
SA_1	373.18	427.12	514.31	515.04
SA_2	325.45	372.65	467.23	467.84
SA_3	377.33	489.14	566.56	566.29
SEm±	15.75			
CD (P=0.05)	45.48			
	2022			
SA_0	480.65	526.00	684.50	684.37
SA_1	564.00	622.82	802.56	802.94
SA_2	499.50	586.46	792.68	793.39
SA_3	590.18	637.25	891.70	903.04
SEm±	14.32			
CD (P=0.05)	41.35			
	Pooled			
SA_0	401.39	446.14	542.48	542.64
SA_1	468.59	524.97	658.43	658.99
SA_2	412.47	479.55	629.96	630.61
SA_3	483.75	563.20	729.13	734.67
SEm±	10.64			
CD (P=0.05)	30.10			

Table 4.5(c): Interaction effect of soil amendments and phosphorus on stover yield

Soil amendments	Stover yield (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	507.39	594.87	727.56	743.20
SA_1	646.77	794.88	938.49	952.95
SA_2	522.86	684.70	878.03	888.05
SA_3	662.56	917.09	1080.95	1096.62
SEm±	27.54			
CD (P=0.05)	79.55			
	2022			
SA_0	872.50	966.41	1250.09	1269.00
SA_1	1055.37	1178.31	1539.72	1555.54
SA_2	904.24	1077.00	1463.68	1524.98
SA_3	1076.71	1180.96	1680.52	1715.70
SEm±	37.92			
CD (P=0.05)	109.51			
	Pooled			
SA_0	689.95	780.64	988.82	1006.10
SA_1	851.07	986.59	1239.10	1254.24
SA_2	713.55	880.85	1170.85	1206.51
SA_3	869.64	1049.02	1380.73	1406.16
SEm±	23.43			
CD (P=0.05)	66.29			

Table 4.5(d): Response of black gram to phosphorus application regarding seed yield of black gram

Pooled	Value of X (P_2O_5 kg ha^{-1})	Y = Seed yield (kg ha^{-1})	Response of Y (kg per kg of x)	Regression equation
	0	441.55	-	
	20	503.47	3.09	Y=3.685x+446.12
	40	640.00	4.96	R^2=0.902
	60	641.73	3.33	
Optimum level	49.35	627.97	3.77	



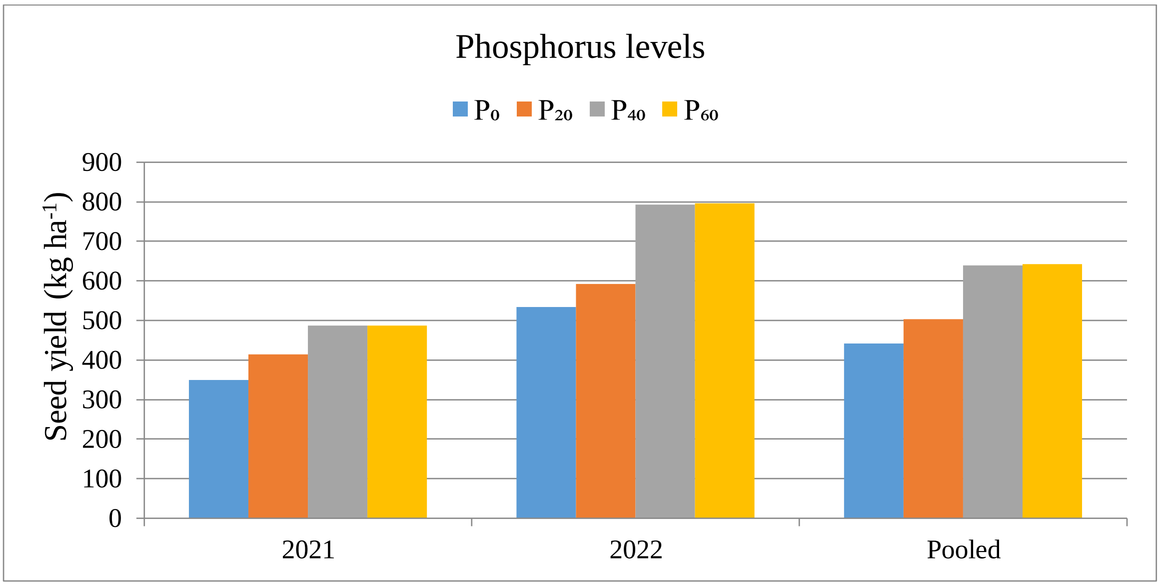
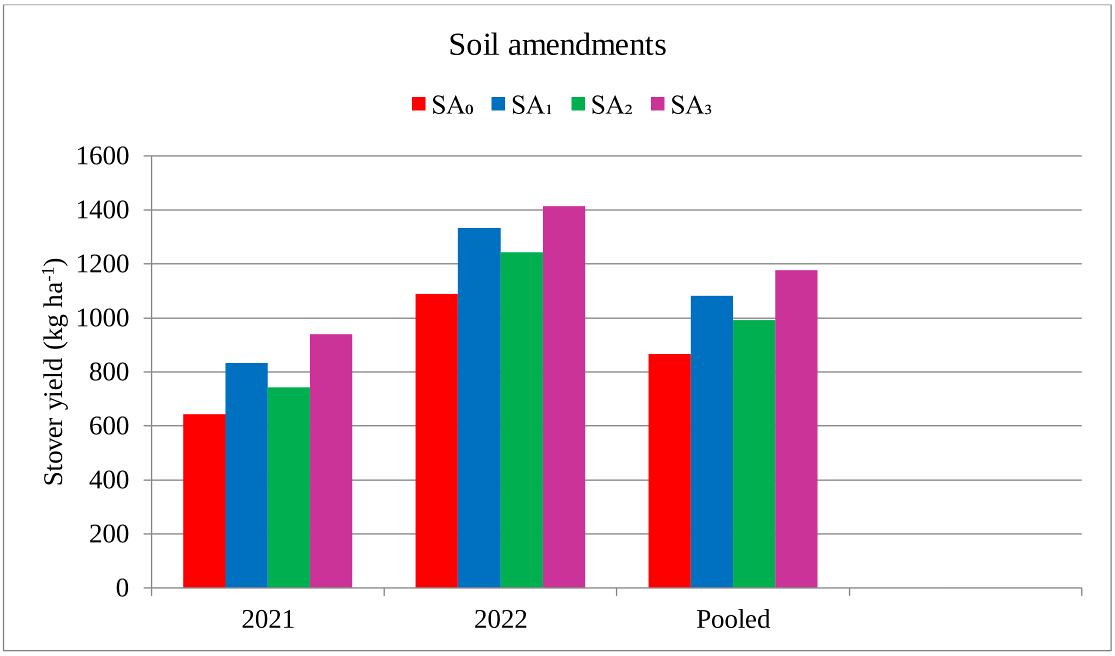


Fig 4.7: Effect of soil amendments and phosphorus on seed yield of black gram



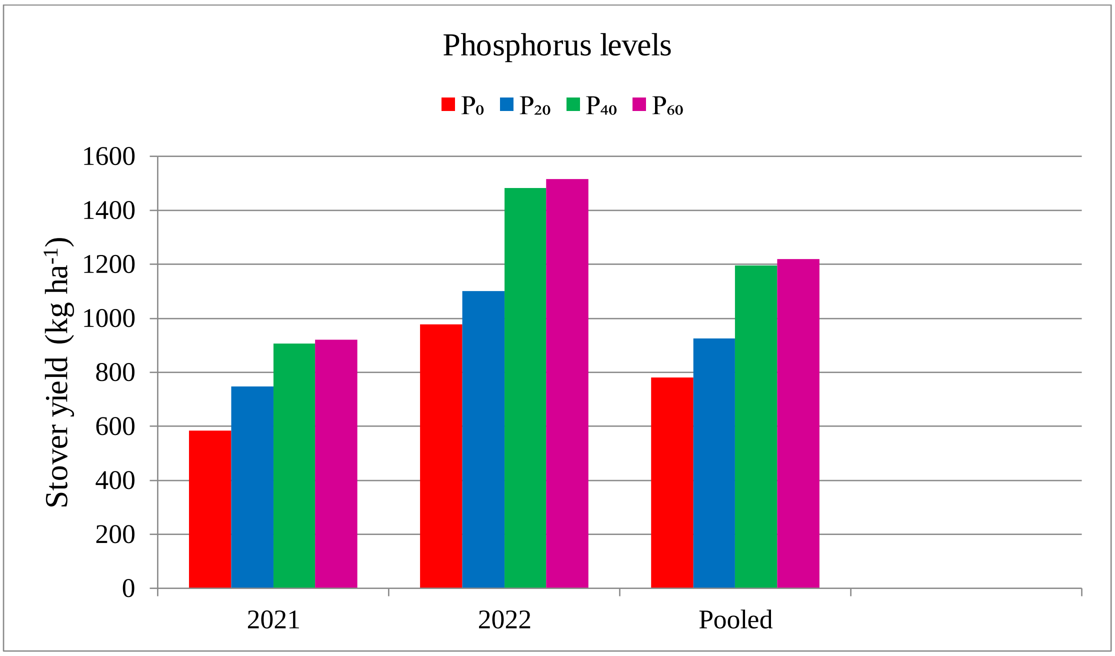


Fig 4.8: Effect of soil amendments and phosphorus on stover yield of black gram

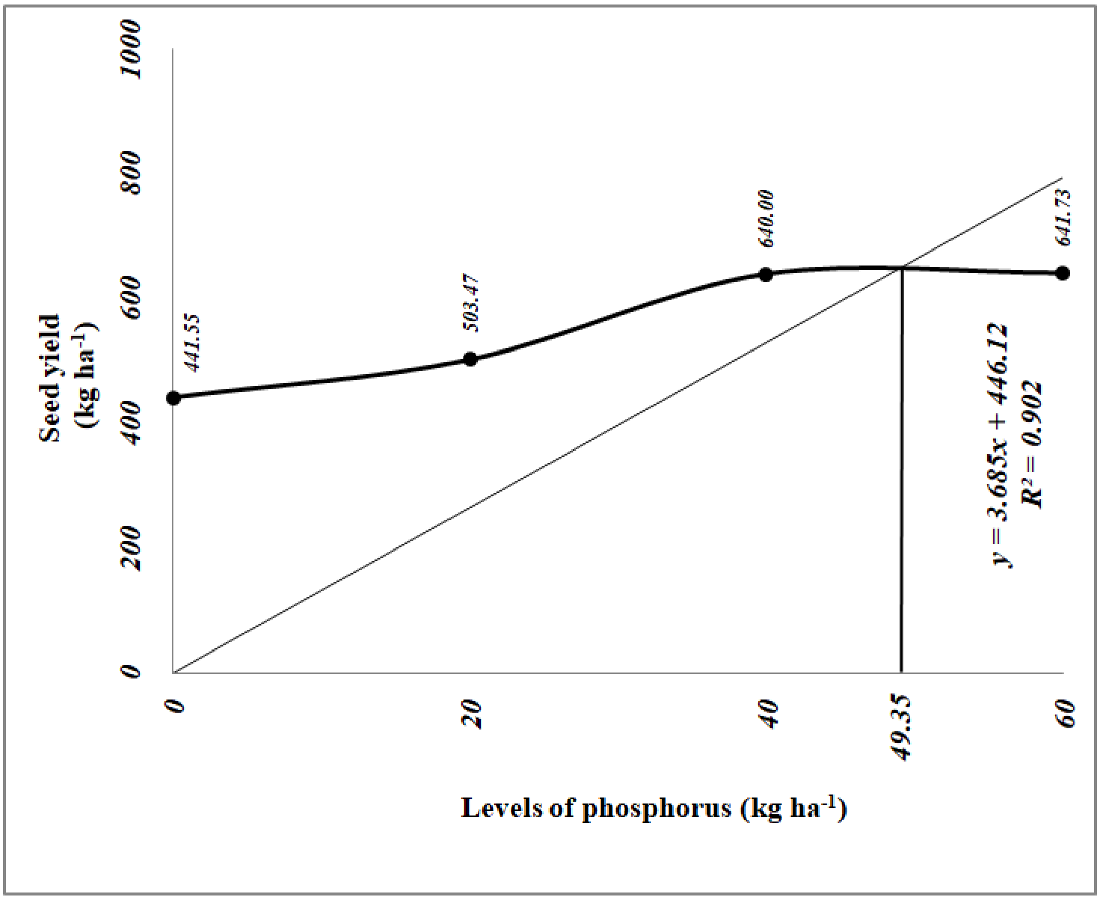


Fig 4.9: Response of black gram to phosphorus application regarding seed yield of black gram

4.1.6 Stover yield

4.1.6.1. Effect of soil amendments

It is apparent from the Table 4.5(a) and represented in Fig 4.8 that significant disparity occurred with the application of amendments on stover yield over control plots. During the study maximum stover yield was noted at SA_3 with a pooled value of 1176.39 kg ha^{-1} while minimum was registered at control with a pooled value of 866.38 kg ha^{-1}. Similar trend was observed with the amended plots in stover yield to those of seed yield over control. In the amended plots stover yield with sole application of lime or in conjunction with PSB was better than PSB alone and control. Since, liming enhanced availability of major nutrients to plant by improving soil reaction which favoured early root development and cell multiplication resulting higher absorption of other essential nutrients thereby improved growth parameters, grain and biological yield. These findings are substantiated with those reported by Kumar *et al.* (2014) and Sharma *et al*. (2021). The results presented in Table 4.5(a) further revealed that there was increased in stover yield with inoculation of PSB; this can be ascribed to the fact that PSB secretes a number of organic acid that might form chelates following effective solubilising of phosphate, facilitates nitrogen fixation, dry matter accumulation, rapid plant growth, higher absorption and utilization of phosphorus and other plant nutrients and ultimately exert positive effect on growth and yield attributes (Rathour *et al.*, 2015). Combined application of lime and PSB (SA_3) enhanced the stover yield by 35.8% over control. Similar results were reported by Parmar *et al*. (2021) and Rabari *et al*. (2022).

4.1.6.2. Effect of phosphorus levels

A perusal data presented in Table 4.5(a) revealed a progressive increased in stover yield with increasing phosphorus levels. Maximum stover yield was recorded with the application of 60 kg P_2O_5 ha^{-1} with a pooled value of 1218.25 kg ha^{-1} and minimum was recorded at control (781.05 kg ha^{-1}). The P_{60} level of phosphorus improved stover yield by 55.9% over control. The significant increase in stover yield with the application of phosphorus could be due to the positive influence of higher level of P on root growth promoted activity of rhizobia on plant roots and induced nodulation; bringing about better growth of plants in terms of plant height, number of branches per plant and dry matter accumulation $plant^{-1}$. The present results are in collaboration with the findings of Kumar and Yadav (2018) and Parashar *et al*. (2020).

Interaction effect of soil amendments and phosphorus on stover yield of black gram

The data given in Table 4.5(c) revealed that effect of soil amendments and phosphorus on stover yield was significant. Irrespective of treatment combination the pooled stover yield varied from 689.95 to 1406.16 kg ha^{-1}. Maximum yield was recorded at SA_3P_{60} (1406.16 kg ha^{-1}) which was at par with SA_3P_{40} (1380.73 kg ha^{-1}) and minimum at control (639.95 kg ha^{-1}). Similar interaction of lime and phosphorus on stover yield was reported by Ameyu and Asfaw (2020); the results are also in line with that of Jamir *et al*. (2022) who found similar interaction of PSB and phosphorus on stover yield of black gram.

4.2. Effect of soil amendments and phosphorus on nutrient composition

4.2.1. Nitrogen content in seed and stover

4.2.1.1. Effect of soil amendments

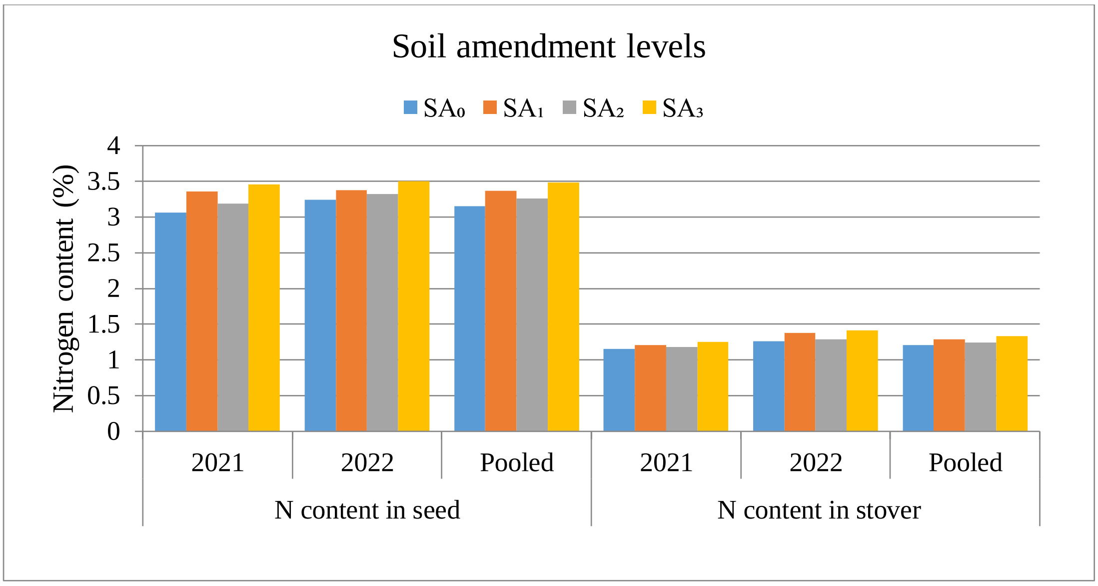
The data presented in Table 4.6 and Fig 4.10 revealed that the nitrogen content in seed and stover of black gram were positively influenced by the application of soil amendments. During 2021 and 2022, maximum N contentwas recorded at SA_3 with a pooled value of 3.48% in seed and 1.33% in stover while minimum was registered at control with a pooled value of 3.15 and 1.21%, in seed and stover, respectively. The data also inferred that N content in seed and stover were higher in amended plots compared to control, while even among the amended plots N content was more in lime treated plots compared to unlimed plots; it could be attributed to favourable soil condition contrived through liming which boosted nutrient availability and nutrient uptake also better growth and activity of roots. The results are in close agreement with the findings of Varma *et al*. (2017) and Odyuo and Sharma (2020). Although, N content was slightly lower in PSB amended plots than limed plots but there was significant increase over control; enhancement in N content in seed and stover could be due to the fact that phosphorus solubilising bacteria improve the supply of available P to plants which might have utilized in better root development and nodulation followed by higher nitrogen fixation in the soil and thereby introducing more N into the root system and consequently enhances the nitrogen content.Similar results were recorded by Singh *et al*. (2003), Tanwar *et al.* (2003) and Kumar *et al*. (2015).

4.2.1.2. Effect of phosphorus levels

An appraisal of data in Table 4.6 showed that N content in seed and stover were significantly affected with the application of levels of phosphorus. In both years of experimentation, an apparent increase in N content in seed and stover was observed with increasing levels of P; this could be due to the fact that plant absorbed proportionately high amount of N as the pool of available phosphorus increased in the soil by adding higher doses of phosphorus (Patel *et al.*, 2019). From the pooled data, maximum N content in seed and stover was recorded at P_{60} (3.55 and 1.32%, respectively) while minimum value was recorded at control (3.11 and 1.19%, respectively). These findings are substantiated with those reported by Patel *et al*. (2019) and Uchoi and Sharma (2023).

Table 4.6: Effect of soil amendments and phosphorus on nitrogen content in seed and stover and protein content in seed of black gram

Treatments	Nitrogen content (%)						Protein content (%)		
	Seed			Stover					
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	3.06	3.24	3.15	1.15	1.26	1.21	19.10	20.23	19.67
SA_1 (5% LR)	3.36	3.38	3.37	1.21	1.38	1.29	20.99	21.14	21.06
SA_2 (PSB)	3.19	3.32	3.26	1.18	1.29	1.24	19.97	20.75	20.36
SA_3 (5% LR + PSB)	3.46	3.50	3.48	1.25	1.41	1.33	21.64	21.86	21.75
SEm±	0.02	0.02	0.01	0.02	0.01	0.01	0.10	0.10	0.07
CD (P=0.05)	0.05	0.04	0.03	0.05	0.04	0.03	0.30	0.28	0.20
Phosphorus levels									
P_0	3.09	3.13	3.11	1.10	1.28	1.19	19.30	19.56	19.43
P_{20}	3.18	3.27	3.23	1.18	1.32	1.25	19.86	20.46	20.16
P_{40}	3.32	3.42	3.37	1.23	1.37	1.30	20.75	21.39	21.07
P_{60}	3.49	3.61	3.55	1.27	1.38	1.32	21.79	22.57	22.18
SEm±	0.02	0.02	0.01	0.02	0.01	0.01	0.10	0.10	0.07
CD (P=0.05)	0.05	0.04	0.03	0.05	0.04	0.03	0.30	0.28	0.20



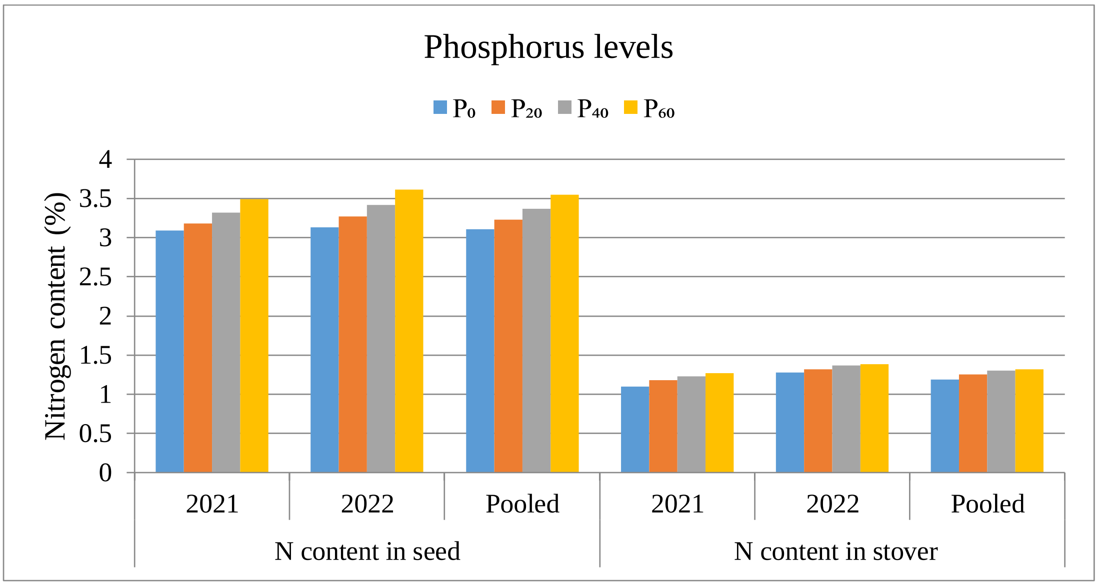
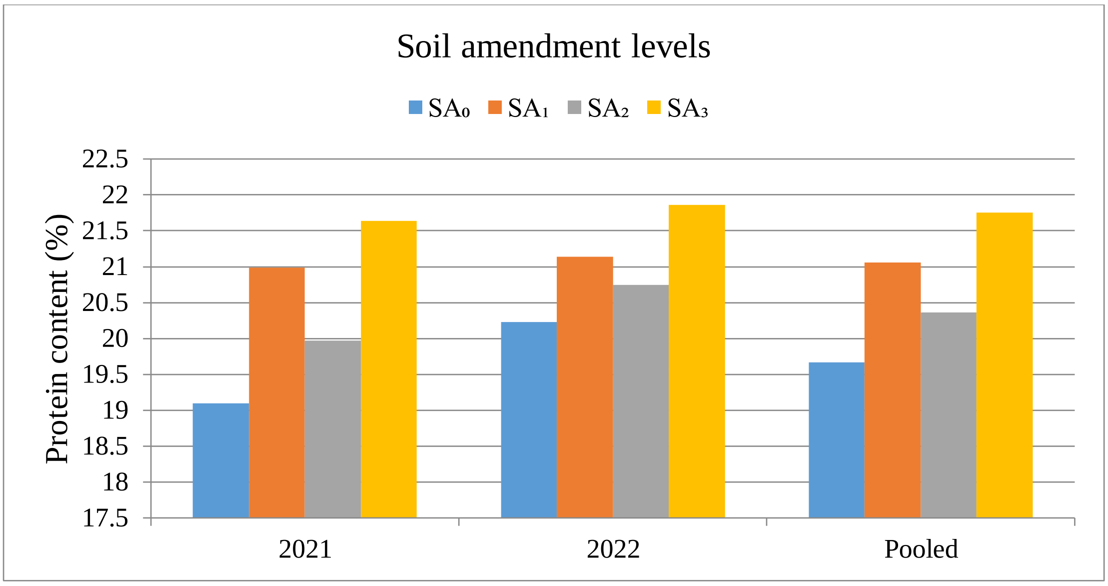


Fig 4.10: Effect of soil amendments and phosphorus on nitrogen content in seed and stover of black gram



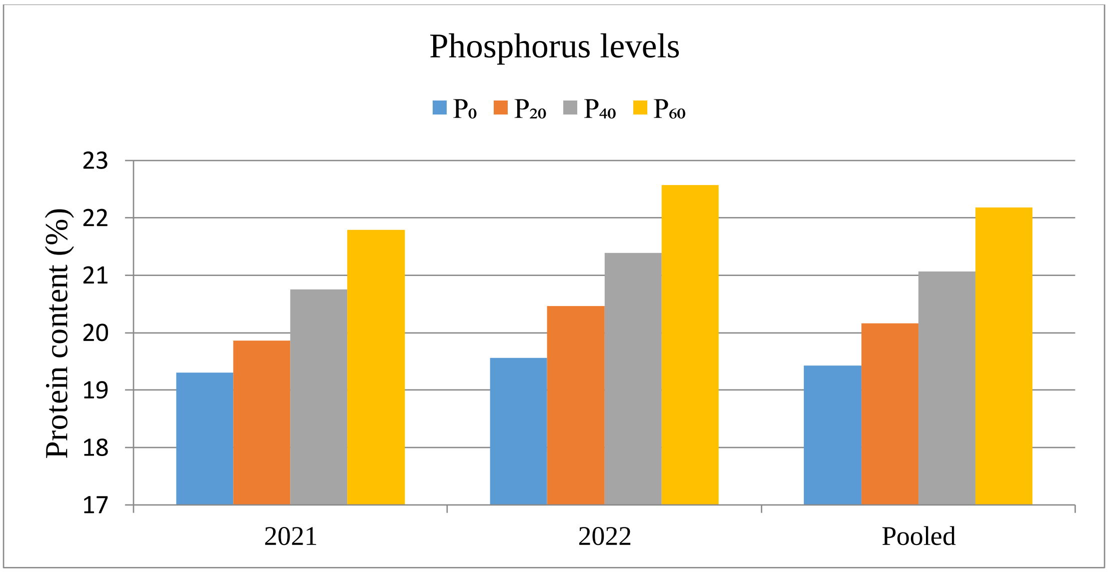


Fig 4.11: Effect of soil amendments and phosphorus on protein content in seed of black gram

4.2.2. Protein content (%)

4.2.2.1. Effect of soil amendments

It is apparent from the data presented in Table 4.6 and illustrated in Fig 4.11 suggested that soil amendments exerted significant effect on protein content of seed. In both the years of experimentation, the protein content in response to amendment levels was in order, $SA_3>SA_1>SA_2>SA_0$, i.e., 21.75, 21.06, 20.36 and 19.67%, respectively. A critical examination of data revealed that protein content recorded at soil amendment levels consisting of lime either applied alone or combined performed better than rest of the amendment levels. Incorporation of lime improves the soil pH but ease the availability of NPK that is added to the soil maximizing the nutrient supply for plant growth (Zhao *et al.*, 2007). The present results are in collaboration with the findings of Nyekha *et al*. (2015) and Odyuo and Sharma (2020). However, protein content recorded at PSB amended plots was significantly higher as compared to control. PSB inoculation indirectly increase nitrogen fixation thereby increasing the availability of nitrogen for plant uptake resulting in higher nitrogen content in seed and consequently enhanced the protein content. These results are in conformity with Jain and Trivedi (2005), Kachave *et al*. (2018) and Parmar *et al*. (2021).

4.2.2.2. Effect of phosphorus levels

The data given in Table 4.6 and depicted in Fig 4.11 indicated that with every increasing phosphorus level, there was a significant increase in protein content as compared to preceding lower level of phosphorus which could be attributed to increasing nitrogen content in seed augmented by phosphorus application. During 2021 and 2022, maximum protein content was recorded at 60 kg P_2O_5 ha^{-1} with a pooled value of 22.18% while minimum was recorded at control with a pooled value of 19.43%. Similar results were reported by Kachave *et al*. (2018), Patel *et al*. (2019) and Singh *et al*. (2020).

4.2.3. Phosphorus content in seed and stover

4.2.3.1. Effect of soil amendments

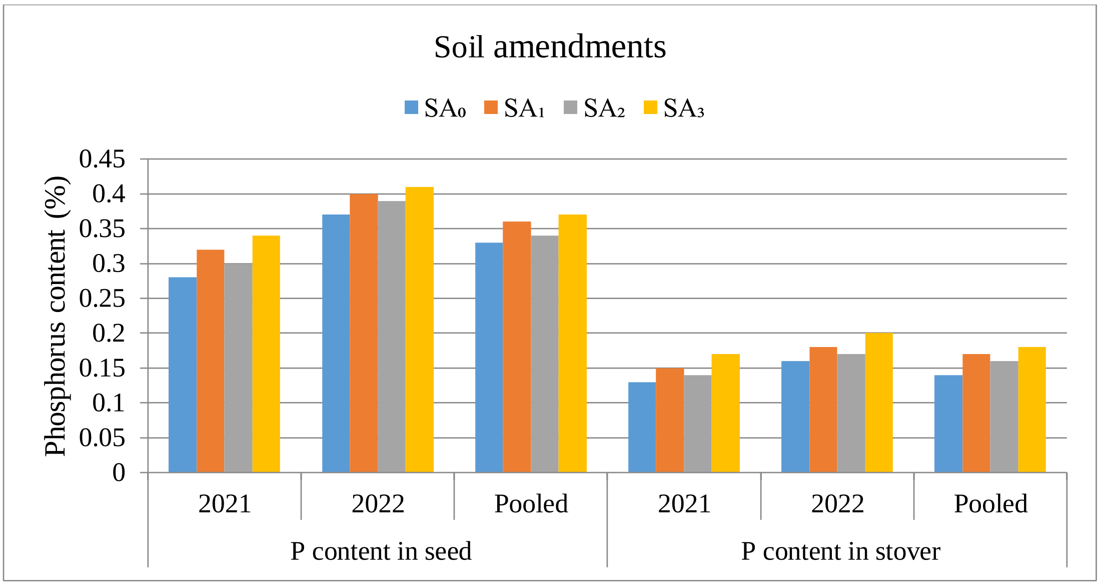
The data pertaining to phosphorus content in seed and stover of black gram are presented in Table 4.7 and Fig 4.12. A significant disparity occurred with the application of soil amendments on phosphorus content in both seed and stover. In both the years of experimentation, maximum numerical value of phosphorus content in seed and stover was recorded at SA_3 with a pooled value of 0.37 and 0.18%, respectively. While minimum phosphorus content in seed and stover was recorded at control with a pooled value of 0.33 and 0.14%, respectively. Further evaluation of data given in Table 4.7 revealed a trend of phosphorus content in seed and stover in response to soil amendments in order as followed: $SA_3 > SA_1 > SA_2 > SA_0$, i.e., 0.37, 0.36, 0.34 & 0.33%, and 0.18, 0.17, 0.16 & 0.14%, respectively. Thus it infer that lime amended either sole or in conjoint exhibited superior P content in seed and stover over PSB sole and control. Uchoi and Sharma (2023) stated that P concentration in seed and stover increased with lime application owing to soil moderation after addition of lime thereby increased native nutrients and better mobility in plant system. These results are in alignment with the findings reported by Varma *et al*. (2017) and Rathod *et al*. (2017). Furthermore, PSB increase the availability of phosphorus to the plants by mineralization of insoluble phosphorus and enhanced its subsequent assimilation of phosphorus hence its increase in P content. Similar findings were reported by Tanwar *et al.* (2003), Singh *et al*. (2003) and Vikram and Hamzehzarghani (2008).

4.2.3.2. Effect of phosphorus levels

It is apparent from the Table 4.7 and Fig 4.12 that phosphorus application brought about a significant improvement on phosphorus content in seed and stover. During 2021 and 2022, maximum P content in seed and stover were registered at 60 kg P_2O_5 ha^{-1} with a pooled value of 0.38 and 0.18%,

Table 4.7: Effect of soil amendments and phosphorus on phosphorus content in seed and stover of black gram

Treatments	Phosphorus content (%)					
	Seed			Stover		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	0.28	0.37	0.33	0.13	0.16	0.14
SA_1 (5% LR)	0.32	0.40	0.36	0.15	0.18	0.17
SA_2 (PSB)	0.30	0.39	0.34	0.14	0.17	0.16
SA_3 (5% LR + PSB)	0.34	0.41	0.37	0.17	0.20	0.18
SEm±	0.004	0.003	0.003	0.003	0.002	0.002
CD (P=0.05)	0.01	0.01	0.01	0.01	0.01	0.01
Phosphorus levels						
P_0	0.27	0.36	0.32	0.13	0.15	0.14
P_{20}	0.30	0.38	0.34	0.14	0.17	0.15
P_{40}	0.32	0.41	0.36	0.16	0.18	0.17
P_{60}	0.34	0.42	0.38	0.17	0.19	0.18
SEm±	0.004	0.003	0.003	0.003	0.002	0.002
CD (P=0.05)	0.01	0.01	0.01	0.01	0.01	0.01



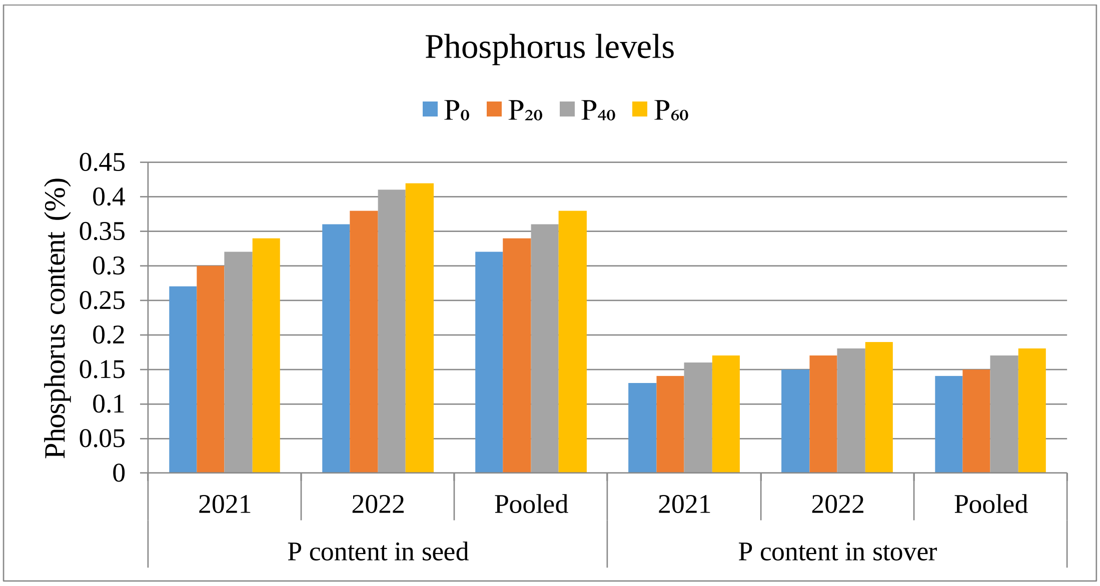


Fig 4.12: Effect of soil amendments and phosphorus on phosphorus content in seed and stover of black gram

respectively, while minimum at control with a pooled value of 0.32 and 0.14%, respectively. The increase in P content in both seed and stover can be ascribed to phosphorus application which augmented its concentration in soil solution thereby induced higher nutrient assimilation by plant. Higher concentrations of phosphorus within plant system catalyzed the metabolic activities ultimately plant absorbed more nutrients (Yadav, 2011 and Girma *et al*. 2014). These results corroborate with the findings reported by Singh and Singh (2013) and Niraj and Prakash (2014).

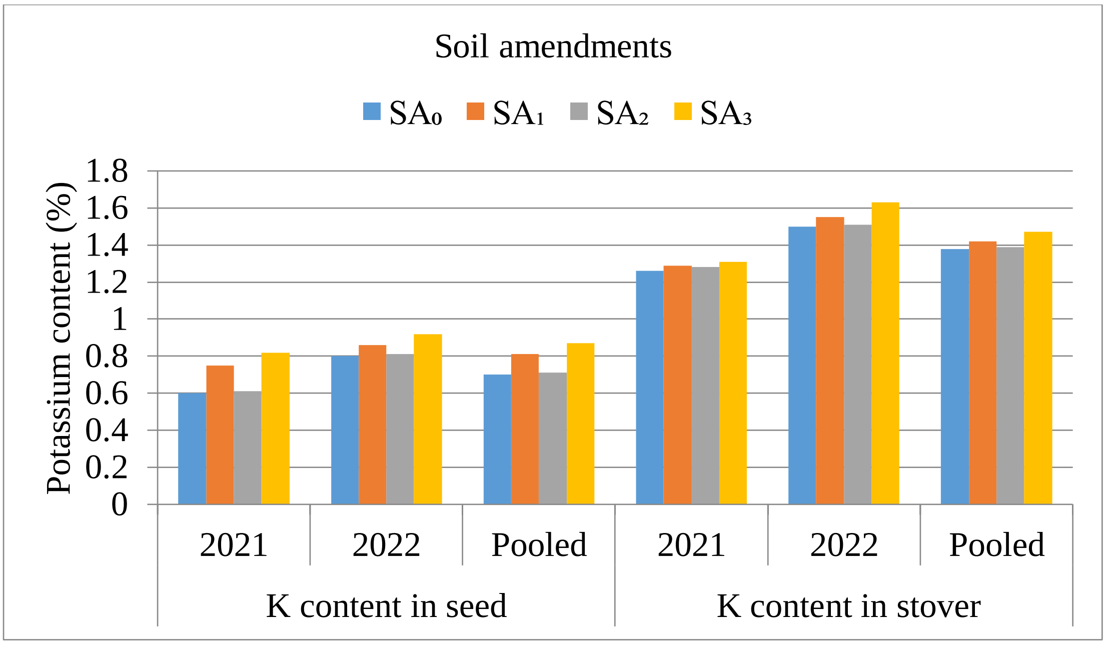
4.2.4. Potassium content in seed and stover

4.2.4.1. Effect of soil amendments

An appraisal of data given in Table 4.8 and illustrated in Fig 4.13 clearly indicates that potassium content in seed and stover were influenced markedly by soil amendments. During 2021 and 2022, maximum potassium content was registered at SA_3 with a pooled value of 0.87% in seed and 1.47% in stover while minimum was registered at control (0.70 and 1.38%, respectively) which was found to be at par with SA_2 in both seed and stover. The data in Table 4.8 lucidly indicated that there was an increase in potassium content in seed and stover in lime amended plots either applied alone or in combination; the enhancement could be due to the fact that liming contrived a favourable soil condition which favoured increase in availability of macro and micro nutrients, thereby might have contributed in increase in potassium content in seed and stover of black gram.The results are in close agreement with the findings of Varma *et al*. (2017) and Singh and Singh (2022). A critical evaluation of the data further revealed that potassium content at PSB sole amended plots (SA_2) was not statistically different to that of control.

Table 4.8: Effect of soil amendments and phosphorus on potassium content in seed and stover of black gram

Treatments	Potassium content (%)					
	Seed			Stover		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	0.60	0.80	0.70	1.26	1.50	1.38
SA_1 (5% LR)	0.75	0.86	0.81	1.29	1.55	1.42
SA_2 (PSB)	0.61	0.81	0.71	1.28	1.51	1.39
SA_3 (5% LR + PSB)	0.82	0.92	0.87	1.31	1.63	1.47
SEm±	0.01	0.02	0.01	0.005	0.008	0.005
CD (P=0.05)	0.04	0.05	0.03	0.013	0.024	0.013
Phosphorus levels						
P_0	0.65	0.81	0.73	1.27	1.53	1.40
P_{20}	0.68	0.83	0.76	1.28	1.54	1.41
P_{40}	0.71	0.87	0.79	1.29	1.56	1.42
P_{60}	0.74	0.89	0.81	1.30	1.57	1.43
SEm±	0.01	0.02	0.01	0.005	0.008	0.005
CD (P=0.05)	0.04	0.05	0.03	0.013	0.024	0.013



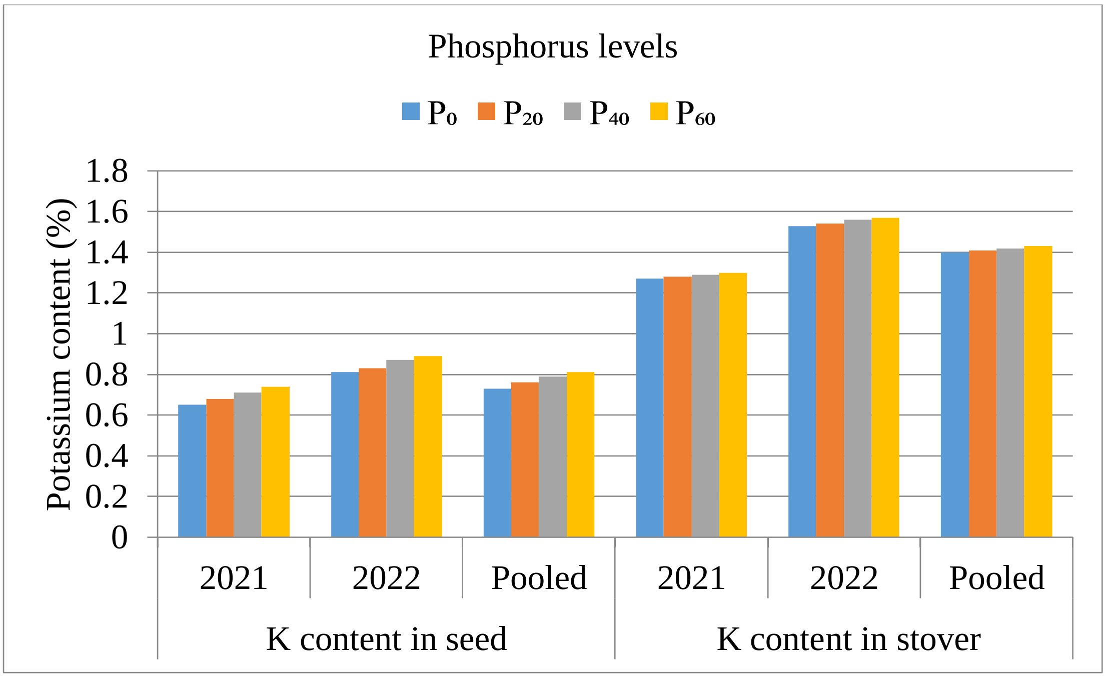


Fig 4.13: Effect of soil amendments and phosphorus on potassium content in seed and stover of black gram

4.2.4.2. Effect of phosphorus levels

From the data given in Table 4.8 and illustrated in Fig 4.13 further reveals that effect of phosphorus application on potassium content in seed and stover of black gram was statistically significant. Irrespective of years of experimentation, the potassium content in seed and stover in response to phosphorus application ranged from 0.65 to 0.89% and 1.27 to 1.57%, respectively. The potassium content in seed and stover obtained at phosphorus level P_{60} was superior to the preceding lower level of P but was found to be statistically at par with P_{40}. An increase in potassium content was observed both in seed and stover with increasing levels of P dose; this could be due to improvement in root growth and development by phosphorus which enable the plant to draw nutrients and water from wider area of soil system. The results are in congruent with Singh and Singh (2013) and Niraj and Prakash (2014).

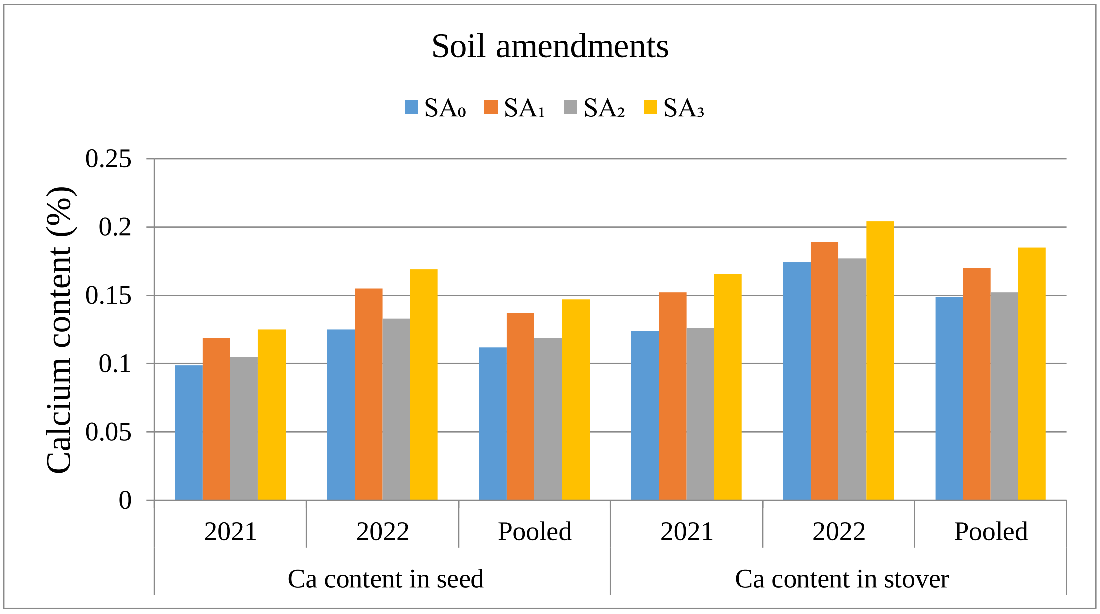
4.2.5. Calcium content in seed and stover

4.2.5.1. Effect of soil amendments

Data given in Table 4.9 and depicted in Fig 4.14 indicated that the calcium content in seed and stover increased significantly with the application of soil amendments. In both the years of experimentation, calcium content varied from 0.112 to 0.147% in seed and 0.149 to 0.185% in stover; wherein the maximum pooled calcium content in seed (0.147%) and stover (0.185%) was recorded at SA_3. However calcium content in seed (during 2021) and stover (during 2021 and 2022) at SA_1 was at par with SA_3 but not at pooled data. A critical evaluation of data of the present study revealed that the increased was observed only at lime treated plots either applied alone or combined while the calcium content in seed and stover in PSB amended plots (SA_2) was not statistically different to that of control. The enhanced calcium content in seed and stover of black gram with lime application could be attributed to the presences of calcium in lime and owing to the fact that $CaCO_3$

Table 4.9: Effect of soil amendments and phosphorus on calcium content in seed and stover of black gram

Treatments	Calcium content (%)					
	Seed			Stover		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	0.099	0.125	0.112	0.124	0.174	0.149
SA_1 (5% LR)	0.119	0.155	0.137	0.152	0.189	0.170
SA_2 (PSB)	0.105	0.133	0.119	0.126	0.177	0.152
SA_3 (5% LR + PSB)	0.125	0.169	0.147	0.166	0.204	0.185
SEm±	0.003	0.004	0.002	0.005	0.007	0.004
CD (P=0.05)	0.010	0.010	0.007	0.014	0.020	0.012
Phosphorus levels						
P_0	0.105	0.140	0.122	0.134	0.175	0.154
P_{20}	0.112	0.147	0.130	0.141	0.182	0.161
P_{40}	0.114	0.147	0.130	0.147	0.194	0.170
P_{60}	0.117	0.148	0.132	0.146	0.194	0.170
SEm±	0.003	0.004	0.002	0.005	0.007	0.004
CD (P=0.05)	NS	NS	NS	NS	NS	NS



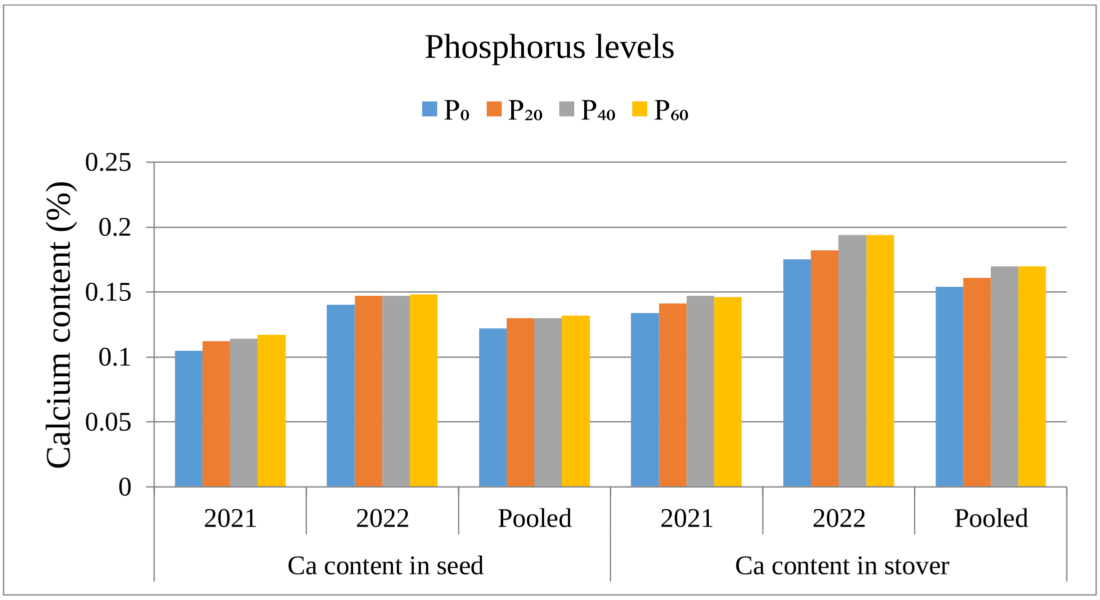


Fig 4.14: Effect of soil amendments and phosphorus on calcium content in seed and stover of black gram

was used as liming material coupled with improvement in soil pH which facilitates the availability of nutrients like P, Ca, Mg etc in soil system and ultimately the concentration of calcium and magnesium in plants increased. These results were in alignment with the findings reported by Odyuo and Sharma (2020) and Singh and Singh (2023).

4.2.5.2. Effect of soil phosphorus levels

From the data presented in Table 4.9 it is evident that phosphorus application could not exert any significant effect on calcium content neither in seed nor in stover. However, irrespective of phosphorus levels the calcium content of seed and stover ranged 0.122 to 0.147% and 0.149 to 0.185%, respectively.

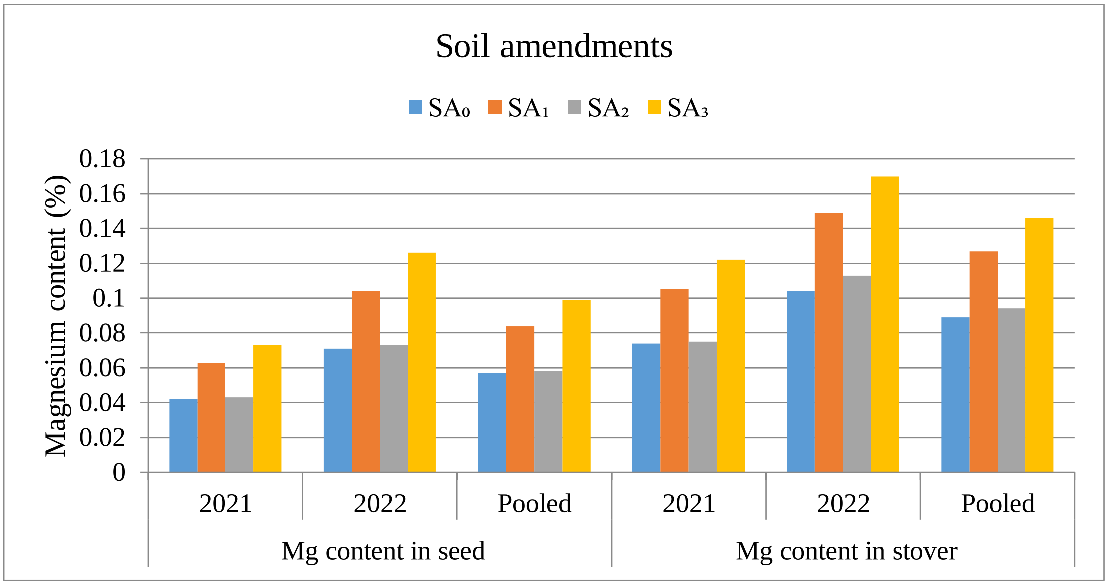
4.2.6. Magnesium content in seed and stover

4.2.6.1. Effect of soil amendments

The data related to magnesium content in seed and stover is presented in Table 4.10 and Fig 4.15. Soil amendments markedly increased the magnesium content in seed and stover of black gram. The responses of magnesium content in seed as well as stover to soil amendments showed similar trend as that of calcium content. From the pooled data, maximum magnesium content in seed (0.099%) and stover (0.146%) was recorded at SA_3 which was at par with SA_1 during 2021 while minimum magnesium content in seed (0.057%) and stover (0.089%) was recorded at control which was at par with SA_2. Sole application of PSB (SA_2) could not exert any influence on Mg content in seed and stover of black gram. The enhancement was only observed at lime amended plots either applied alone or in conjoint; this could be attributed to liming as it improves nutrient availability. The results are in close agreement with the findings of Uchoi and Sharma (2023) and Singh and Singh (2023).

Table 4.10: Effect of soil amendments and phosphorus on magnesium content in seed and stover of black gram

Treatments	Magnesium content (%)					
	Seed			Stover		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	0.042	0.071	0.057	0.074	0.104	0.089
SA_1 (5% LR)	0.063	0.104	0.084	0.105	0.149	0.127
SA_2 (PSB)	0.043	0.073	0.058	0.075	0.113	0.094
SA_3 (5% LR + PSB)	0.073	0.126	0.099	0.122	0.170	0.146
SEm±	0.004	0.004	0.003	0.005	0.004	0.003
CD (P=0.05)	0.012	0.010	0.008	0.014	0.013	0.009
Phosphorus levels						
P_0	0.056	0.094	0.075	0.091	0.135	0.113
P_{20}	0.054	0.092	0.073	0.093	0.134	0.113
P_{40}	0.054	0.093	0.073	0.095	0.132	0.113
P_{60}	0.057	0.095	0.076	0.096	0.135	0.116
SEm±	0.004	0.004	0.003	0.005	0.004	0.003
CD (P=0.05)	NS	NS	NS	NS	NS	NS



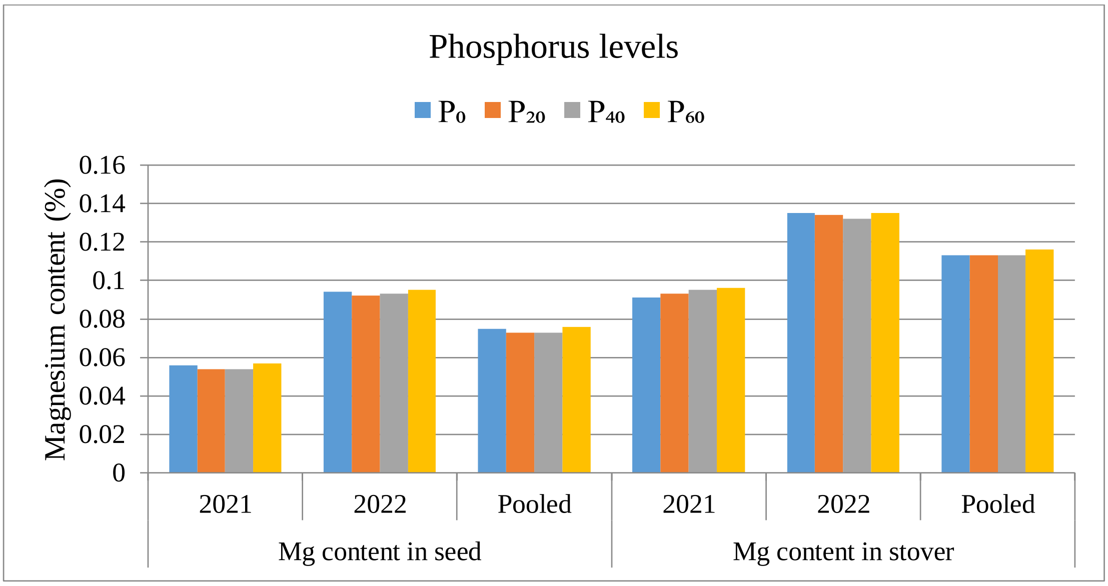


Fig 4.15: Effect of soil amendments and phosphorus on magnesium content in seed and stover of black gram

4.2.6.2. Effect of phosphorus levels

It is apparent from the Table 4.10 and depicted in Fig 4.15 that different levels of phosphorus did have any significant influence on magnesium content neither in seed nor in stover of black gram. However, irrespective of application of different P levels the pooled values of magnesium content varied from 0.073 to 0.076 % in seed and 0.113 to 0.116 % in stover of black gram.

4.3. Effect of soil amendments and phosphorus on nutrient uptake

4.3.1. Nitrogen uptake in seed and stover

4.3.1.1. Effect of soil amendments

From the data given in Table 4.11(a) and represented in Fig 4.16 it can be observed that soil amendment increased the nitrogen uptake in seed, stover and total N uptake. From the pooled data, maximum value was recorded at SA_3 which increased the nitrogen uptake to an extent by 43.2% in seed, 50.3% in stover and 46.1% in total N uptake over control. However, irrespective of amendments levels the pooled N uptake varied from 15.40 to 22.06 kg ha^{-1} in seed, 10.62 to 15.97 kg ha^{-1} in stover and 26.02 to 38.03 kg ha^{-1} in total N uptake. The significant increase in nitrogen uptake in seed, stover and total N uptake can be ascribed to the improvement in yield and nitrogen content due to liming and PSB application. The results are in close agreement with the findings of Varma *et al*. (2017) and Lynrah and Nongmaithem (2017). Inoculation of PSB improved the nitrogen status in the soil which was reflected in nitrogen uptake. Similar results were reported by Tanwar *et al*. (2003), Singh and Yadav (2008) and Kumar *et al* (2015). Further evaluation of data Table 4.11(a) revealed the effect of soil amendments on nitrogen uptake in seed, stover and total of black gram was in order as such: $SA_3 > SA_1 > SA_2 > SA_0$. Application of 5% LR in conjunction with PSB exhibited better uptake, taking in account the combined benefits of lime and PSB as

Table 4.11(a): Effect of soil amendments and phosphorus on nitrogen uptake in seed and stover of black gram

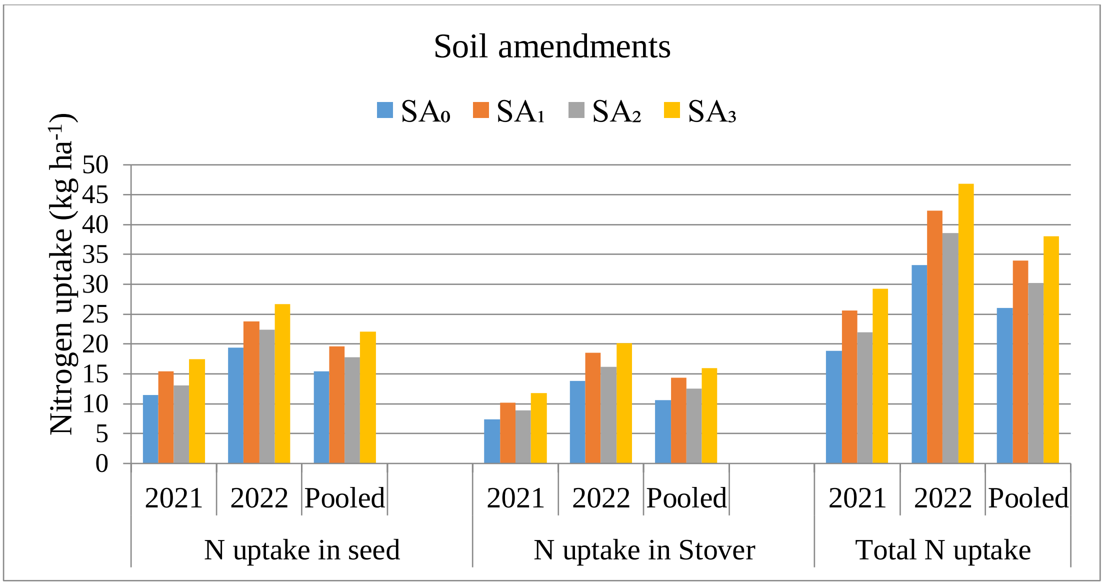
Treatments	Nitrogen uptake (kg ha^{-1})								
	Seed			Stover			Total		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	11.42	19.38	15.40	7.44	13.81	10.62	18.86	33.19	26.02
SA_1 (5% LR)	15.44	23.76	19.60	10.15	18.54	14.34	25.59	42.30	33.95
SA_2 (PSB)	13.12	22.39	17.75	8.84	16.16	12.50	21.96	38.55	30.25
SA_3 (5% LR + PSB)	17.42	26.70	22.06	11.82	20.12	15.97	29.24	46.82	38.03
SEm±	0.27	0.28	0.19	0.24	0.38	0.23	0.48	0.61	0.39
CD (P=0.05)	0.77	0.81	0.54	0.70	1.10	0.64	1.39	1.77	1.10
Phosphorus levels									
P_0	10.83	16.74	13.78	6.46	12.60	9.53	17.29	29.33	23.31
P_{20}	13.21	19.45	16.33	8.84	14.62	11.73	22.05	34.07	28.06
P_{40}	16.27	27.22	21.75	11.24	20.35	15.80	27.51	47.57	37.54
P_{60}	17.09	28.82	22.95	11.71	21.06	16.39	28.81	49.87	39.34
SEm±	0.27	0.28	0.19	0.24	0.38	0.23	0.48	0.61	0.39
CD (P=0.05)	0.77	0.81	0.54	0.70	1.10	0.64	1.39	1.77	1.10

Table 4.11(b): Interaction effect of soil amendments and phosphorus on nitrogen uptake in seed and stover of black gram

Soil amendments	Nitrogen uptake (kg ha^{-1})							
	Phosphorus levels							
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
	Seed (2021)				Seed (2022)			
SA_0	9.32	10.77	12.44	13.16	14.40	16.65	22.49	23.96
SA_1	11.81	14.10	17.71	18.16	17.79	20.81	27.61	28.85
SA_2	9.87	11.69	14.93	15.99	15.54	18.88	26.72	28.42
SA_3	12.33	16.29	20.00	21.06	19.22	21.47	32.06	34.03
SEm±	0.53				0.56			
CD (P=0.05)	1.53				1.61			
	Seed (pooled)				Stover (pooled)			
SA_0	11.86	13.71	17.46	18.56	8.08	9.39	12.32	12.71
SA_1	14.80	17.45	22.66	23.50	10.45	12.92	16.79	17.21
SA_2	12.70	15.28	20.82	22.20	8.47	10.90	14.97	15.67
SA_3	15.78	18.88	26.03	27.55	11.11	13.70	19.12	19.95
SEm±	0.38				0.45			
CD (P=0.05)	1.09				1.27			

Table 4.11(c): Interaction effect of soil amendments and phosphorus on total nitrogen uptake of black gram

Soil amendments	Total nitrogen uptake (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	14.82	17.45	21.07	22.12
SA_1	18.82	23.76	29.46	30.34
SA_2	15.57	19.71	25.60	26.95
SA_3	19.97	27.28	33.92	35.82
SEm±	0.96			
CD (P=0.05)	2.77			
	2022			
SA_0	25.06	28.75	38.50	40.43
SA_1	31.68	37.00	49.43	51.10
SA_2	26.78	32.65	45.98	48.78
SA_3	33.81	37.89	56.38	59.19
SEm±	1.22			
CD (P=0.05)	3.54			
	Pooled			
SA_0	19.94	23.10	29.78	31.27
SA_1	25.25	30.38	39.45	40.72
SA_2	21.18	26.18	35.79	37.87
SA_3	26.89	32.59	45.15	47.50
SEm±	0.78			
CD (P=0.05)	2.20			



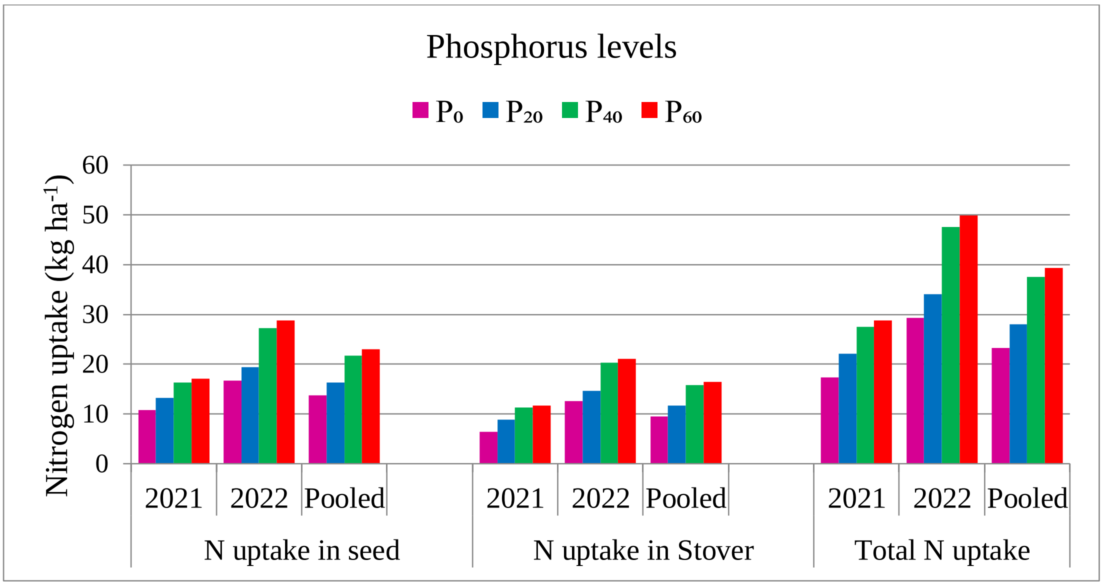


Fig 4.16: Effect of soil amendments and phosphorus on nitrogen uptake in black gram

projected in nutrient content and yield whilst in control plot due to low supply of nutrients suppressed the growth and development of crop thereby low N content as well as low yield.

4.3.1.2. Effect of phosphorus levels

Data given in Table 4.11(a) and Fig 4.16 exhibited the positive influence of phosphorus on nitrogen uptake in seed, stover and total uptake. During 2021 and 2022, maximum nitrogen uptake in seed, stover and total uptake was registered at 60 kg P_2O_5 ha^{-1} with a pooled value of 22.95, 16.39 and 39.34 kg ha^{-1}, respectively; while, minimum nitrogen uptake (13.78 kg ha^{-1} in seed, 9.53 kg ha^{-1} in stover and 23.31 kg ha^{-1} in total uptake) was registered at control. Application of 60 kg P_2O_5 ha^{-1} increased the nitrogen uptake to an extent of 66.5% in seed, 71.9% in stover and 68.7% in total uptake over control. However, N uptake in stover (during 2021 & 2022) and total N uptake (during 2021) at 60 kg P_2O_5 ha^{-1} was found at par with 40 kg P_2O_5 ha^{-1}. These results are in conformity with Kumar *et al*. (2015), Singh *et al*. (2017) and Patel *et al*. (2019).

Interaction effect of soil amendments and phosphorus on nitrogen uptake

It is apparent from the Table 4.11(b) & (c) that during 2021 and 2022, expect for N uptake in stover where significant interaction was observed only at pooled data, a significant interaction effect of amendments and phosphorus was observed on N uptake in seed and total N uptake. Maximum N uptake in seed, stover and total N uptake was recorded with treatment combination SA_3P_{60} which was at par with SA_3P_{40} while the minimum was recorded at SA_0P_0. It can be observed that nitrogen uptake in seed, stover and total N uptake were enhanced with increase in phosphorus levels, even so better uptake was noticed at SA_3 which is the conjoint application of lime and PSB, might have indirectly supplemented the nitrogen availability in rhizosphere by means of improving better root development, facilitating higher nodulation thereby boosting biological N fixation and a favourable soil condition encouraging better availability of nutrients. The results are in line with Singh and Singh (2022) who found significant interaction influence of liming materials and phosphorus; while Rathore *et al*. (2010) reported significant interaction of biofertilizers and phosphorus on nitrogen uptake.

4.3.2. Phosphorus uptake in seed and stover

4.3.2.1. Effect of soil amendments

An appraisal of data given in Table 4.12(a) and illustrated in Fig 4.17 clearly indicates that there was a positive effect of soil amendments on phosphorus uptake in seed, stover and total P uptake. From the pooled data, maximum value was recorded at SA_3 which enhanced the P uptake to an extent by 48.1% in seed, 71.8% in stover and 58.0% in total P uptake. A critical evaluation of data [Table 4.12(a)] revealed the responses to amendment levels by phosphorus uptake in seed, stover and total P uptake are in order as such: $SA_3 > SA_1 > SA_2 > SA_0$. However, irrespective of amendments treatment the pooled P uptake varied from 1.64 to 2.43 kg ha^{-1} in seed, 1.28 to 2.20 kg ha^{-1} in stover and 2.93 to 4.63 kg ha^{-1} in total P uptake. Borang and Sharma (2020) suggested that as nutrient uptake is the product of nutrient content and yield, with the increase in these attributes, the nutrient uptake was also increased. Similar results were reported by Amruta *et al*. (2015) and Uchoi and Sharma (2023).

4.3.2.2. Effect of phosphorus levels

It is apparent from the Table 4.12(a) and portrayed in Fig 4.17 that phosphorus uptake in seed, stover and total uptake enhanced with application of different levels of phosphorus. Application of 60 kg P_2O_5 ha^{-1} increased the phosphorus uptake to an extent of 75.0% in seed, 100.8% in stover and 86.3% in total P uptake over control. Irrespective of P doses the phosphorus uptake

Table 4.12(a): Effect of soil amendments and phosphorus on phosphorus uptake in seed and stover of black gram

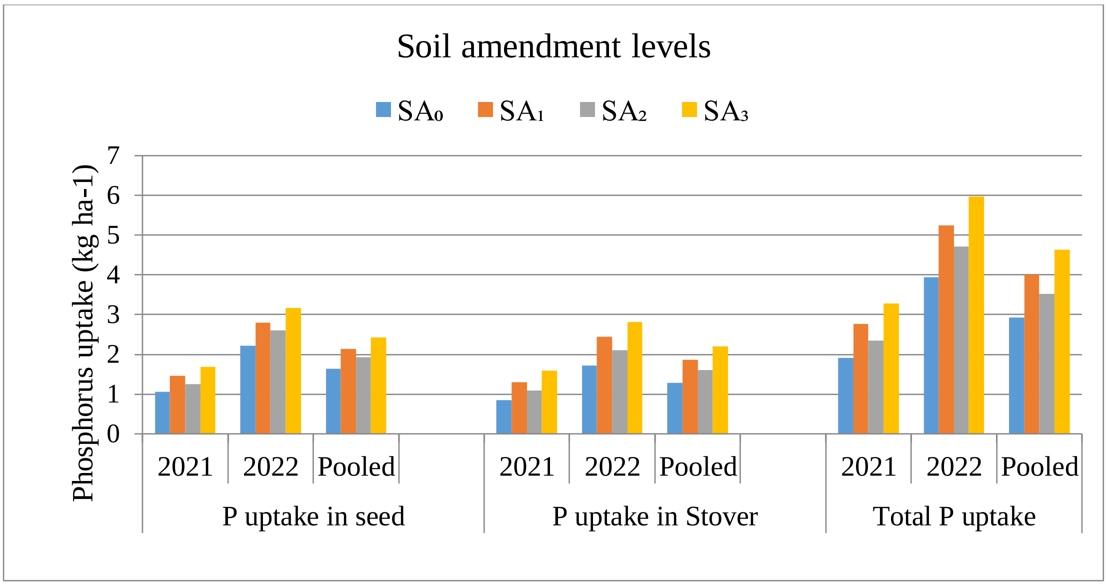
Treatments	Phosphorus uptake (kg ha^{-1})								
	Seed			Stover			Total		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	1.06	2.22	1.64	0.85	1.72	1.28	1.91	3.94	2.93
SA_1 (5% LR)	1.46	2.80	2.13	1.30	2.44	1.87	2.77	5.24	4.00
SA_2 (PSB)	1.25	2.61	1.93	1.09	2.11	1.60	2.34	4.72	3.53
SA_3 (5% LR + PSB)	1.69	3.16	2.43	1.59	2.81	2.20	3.28	5.97	4.63
SEm±	0.03	0.03	0.02	0.03	0.04	0.03	0.06	0.06	0.04
CD (P=0.05)	0.09	0.10	0.06	0.10	0.11	0.07	0.17	0.16	0.11
Phosphorus levels									
P_0	0.96	1.91	1.44	0.74	1.53	1.13	1.70	3.44	2.57
P_{20}	1.25	2.27	1.76	1.08	1.86	1.47	2.33	4.13	3.23
P_{40}	1.58	3.24	2.41	1.43	2.73	2.08	3.01	5.97	4.49
P_{60}	1.68	3.37	2.52	1.57	2.96	2.27	3.25	6.33	4.79
SEm±	0.03	0.03	0.02	0.03	0.04	0.03	0.06	0.06	0.04
CD (P=0.05)	0.09	0.10	0.06	0.10	0.11	0.07	0.17	0.16	0.11

Table 4.12(b): Interaction effect of soil amendments and phosphorus on phosphorus uptake in seed and stover of black gram

Soil amendments	Phosphorus uptake (kg ha^{-1})							
	Seed				Stover			
	Phosphorus levels							
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
2021								
SA_0	0.80	0.98	1.19	1.28	0.55	0.73	0.98	1.13
SA_1	1.06	1.32	1.68	1.78	0.86	1.17	1.51	1.69
SA_2	0.86	1.07	1.48	1.59	0.61	0.94	1.34	1.45
SA_3	1.13	1.62	1.97	2.05	0.95	1.48	1.90	2.03
SEm±	0.06				0.07			
CD (P=0.05)	0.18				0.19			
2022								
SA_0	1.61	1.89	2.64	2.73	1.16	1.42	2.06	2.23
SA_1	2.06	2.41	3.30	3.43	1.72	2.04	2.88	3.11
SA_2	1.75	2.21	3.19	3.28	1.35	1.76	2.53	2.81
SA_3	2.23	2.56	3.81	4.05	1.86	2.20	3.47	3.70
SEm±	0.07				0.08			
CD (P=0.05)	0.20				0.23			
Pooled								
SA_0	1.21	1.44	1.92	2.00	0.86	1.08	1.52	1.68
SA_1	1.56	1.87	2.49	2.61	1.29	1.61	2.19	2.40
SA_2	1.30	1.64	2.34	2.44	0.98	1.35	1.94	2.13
SA_3	1.68	2.09	2.89	3.05	1.41	1.84	2.68	2.87
SEm±	0.05				0.05			
CD (P=0.05)	0.13				0.15			

Table 4.12(c): Interaction effect of soil amendments and phosphorus on total phosphorus uptake of black gram

Soil amendments	Total phosphorus uptake (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	1.35	1.72	2.17	2.41
SA_1	1.92	2.49	3.19	3.47
SA_2	1.47	2.01	2.83	3.04
SA_3	2.08	3.10	3.87	4.09
SEm±	0.12			
CD (P=0.05)	0.34			
	2022			
SA_0	2.77	3.32	4.70	4.96
SA_1	3.78	4.46	6.18	6.53
SA_2	3.10	3.97	5.72	6.09
SA_3	4.09	4.76	7.28	7.75
SEm±	0.11			
CD (P=0.05)	0.32			
	Pooled			
SA_0	2.06	2.52	3.44	3.68
SA_1	2.85	3.47	4.68	5.00
SA_2	2.28	2.99	4.27	4.57
SA_3	3.09	3.93	5.57	5.92
SEm±	0.08			
CD (P=0.05)	0.23			



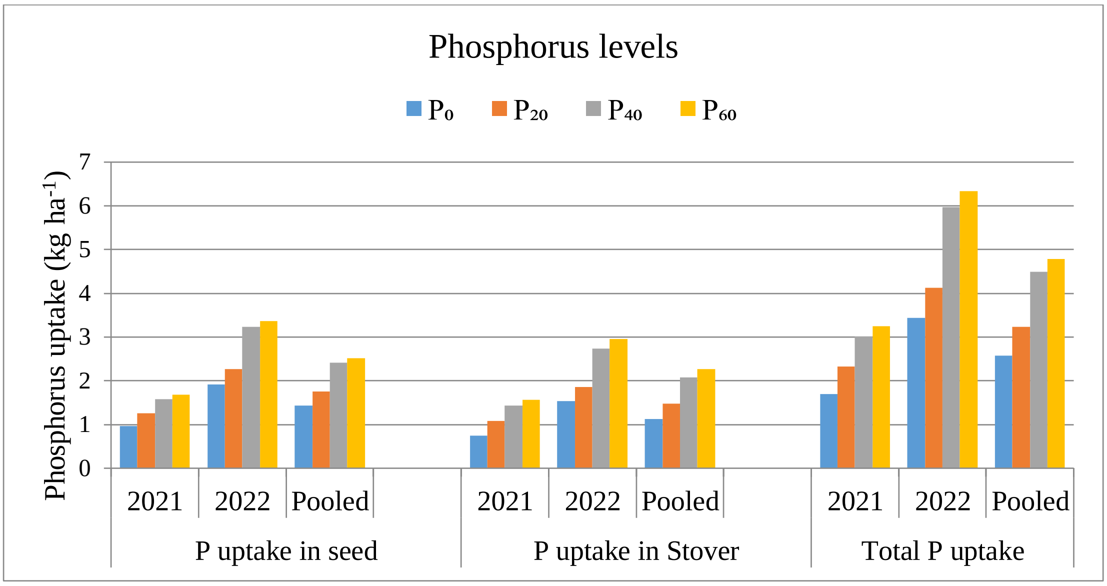


Fig 4.17: Effect of soil amendments and phosphorus on phosphorus uptake in black gram

ranged from 1.44 to 2.52 kg ha^{-1} in seed, 1.13 to 2.27 kg ha^{-1} in stover and 2.57 to 4.79 kg ha^{-1} in total P uptake. These finding are found relevant to Singh *et al*. (2017) and Patel *et al*. (2019).

Interaction effect of soil amendments and phosphorus on phosphorus uptake

From the Table 4.12(b) & (c) it is evident that maximum P uptake in seed, stover as well as total P uptake was registered with treatment combination SA_3P_{60} while minimum was recorded at SA_0P_0 (control). From the pooled data, application of 5% LR + PSB + 60 kg P_2O_5 ha^{-1} (SA_3P_{60}) increased the phosphorus uptake by 152.0% in seed, 233.7% in stover and 121.8% in total P uptake over SA_0P_0 combination. However phosphorus uptake in seed (in 2021), stover (in both 2021 and 2022) and total P uptake (in 2021) at SA_3P_{60} was found to be at par with SA_3P_{40}. An increasing trend in P uptake (in seed, stover as well as total P uptake) was noticed with increase in P levels this can be due to the fact that with increased in dose of phosphatic fertilizer the concentration of P in soil solution might have enhanced which probably allowed greater supply of P to plants hence influencing higher P uptake by plants, also the role of soil amendment as its counterpart might have contributed to the phenomena. These results are parallel with that of Singh and Singh (2022) who reported the interaction effect of liming materials and phosphorus; Singh and Yadav (2008) and Bhabai *et al*. 2019 found interaction of PSB and P on phosphorus uptake.

4.3.3. Potassium uptake in seed and stover

4.3.3.1. Effect of soil amendments

The data given in Table 4.13(a) and depicted in Fig 4.18 specified that application of soil amendments brought about a significant increase in potassium uptake in seed, stover and total K uptake with maximum pooled value being recorded at SA_3 which induced an increase of 58.5% in seed, 43.8% in stover and 47.1% in total K uptake over control. From the pooled data, sole application of lime (SA_1) augmented the potassium uptake in seed and stover by 35.2 and 27.9% respectively over control while sole application of PSB (SA_2) enhanced the potassium uptake to an extent of 13.0 and 15.3% respectively over control. Overall the responses to amendments by potassium uptake in seed, stover as well as total K uptake are in order as such: $SA_3>SA_1>SA_2>SA_0$. Thus, response of potassium uptake in seed and stover of black gram to SA_3 was better among all the soil amendments. However, irrespective of amendments treatment the pooled potassium uptake varied from 3.52 to 5.58 kg ha^{-1} in seed, 12.28 to 17.67 kg ha^{-1} in stover and 15.80 to 23.25 kg ha^{-1} in total K uptake. Similar findings were also reported by Rathore *et al*. (2010) and Odyuo and Sharma (2020).

4.3.3.2. Effect of phosphorus levels

It is apparent from the data given in Table 4.13(a) and delineated in Fig 4.18 that potassium uptake in seed, stover and total K uptake enhanced with application of different levels of phosphorus. During 2021 and 2022, maximum K uptake was recorded with 60 kg P_2O_5 ha^{-1} with a pooled value of 5.38 kg ha^{-1} in seed, 17.88 kg ha^{-1} in stover and 23.26 kg ha^{-1} in total K uptake; however in both the years of experimentation, in both seed and stover, the potassium uptake registered at P_{60} was found to be at par with P_{40}. While minimum was recorded at control with pooled value of 3.31 kg ha^{-1} in seed, 11.21 kg ha^{-1} in stover and 14.53 kg ha^{-1} in total K uptake. The phosphorus level P_{60} increased the potassium uptake by 62.5% in seed and 59.5% in stover over control. Enhancement in potassium uptake is attributed by increased yield as well as potassium content with application of phosphorus. These findings are consistent with those reported by Yadav *et al*. (2017) and Bhavya *et al*. (2018).

Table 4.13(a): Effect of soil amendments and phosphorus on potassium uptake in seed and stover of black gram

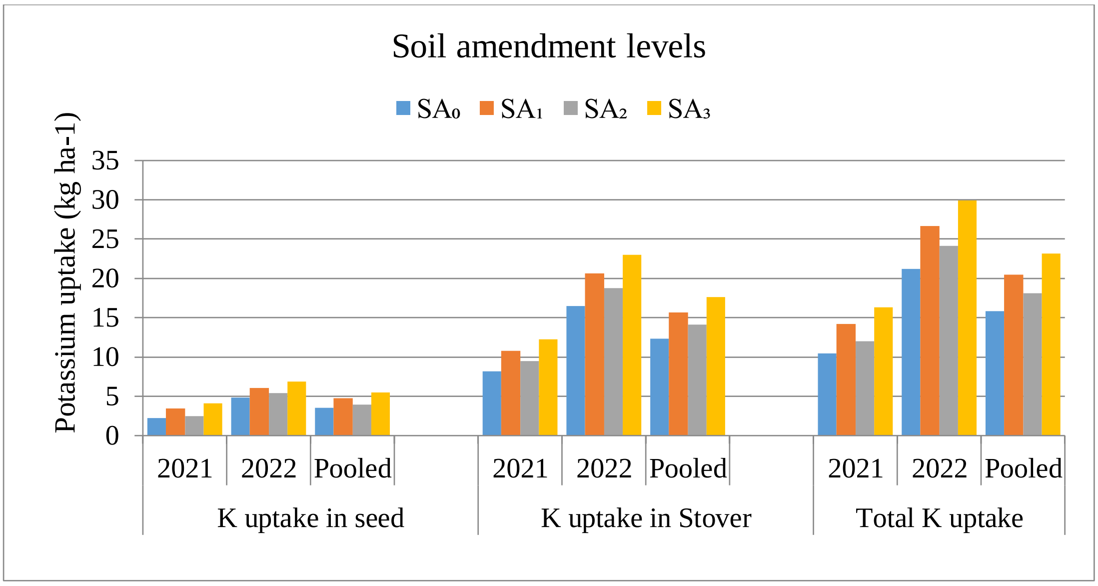
Treatments	Potassium uptake (kg ha^{-1})								
	Seed			Stover			Total		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	2.24	4.80	3.52	8.14	16.42	12.28	10.39	21.22	15.80
SA_1 (5% LR)	3.46	6.07	4.76	10.76	20.65	15.71	14.22	26.72	20.47
SA_2 (PSB)	2.50	5.46	3.98	9.50	18.81	14.16	12.01	24.26	18.13
SA_3 (5% LR + PSB)	4.13	7.03	5.58	12.28	23.07	17.67	16.41	30.10	23.25
SEm±	0.07	0.12	0.07	0.18	0.30	0.17	0.22	0.34	0.20
CD (P=0.05)	0.21	0.34	0.20	0.51	0.85	0.49	0.63	0.98	0.57
Phosphorus levels									
P_0	2.31	4.32	3.31	7.44	14.98	11.21	9.75	19.30	14.53
P_{20}	2.86	4.96	3.91	9.60	17.02	13.31	12.46	21.98	17.22
P_{40}	3.53	6.94	5.24	11.68	23.15	17.42	15.21	30.09	22.65
P_{60}	3.63	7.13	5.38	11.96	23.79	17.88	15.59	30.92	23.26
SEm±	0.07	0.12	0.07	0.18	0.30	0.17	0.22	0.34	0.20
CD (P=0.05)	0.21	0.34	0.20	0.51	0.85	0.49	0.63	0.98	0.57

Table 4.13(b): Interaction effect of soil amendments and phosphorus on potassium uptake in seed and stover of black gram

Soil amendments	Potassium uptake (kg ha^{-1})							
	Seed				Stover			
	Phosphorus levels							
	P_0	P_{20}	P_{40}	P_{60}	P_0	P_{20}	P_{40}	P_{60}
2021								
SA_0	1.84	2.11	2.43	2.58	6.36	7.51	9.24	9.46
SA_1	2.64	3.18	4.00	4.02	8.24	10.21	12.12	12.46
SA_2	1.85	2.23	2.92	3.01	6.62	8.74	11.23	11.42
SA_3	2.89	3.92	4.78	4.92	8.55	11.94	14.13	14.49
SEm±	0.15				0.35			
CD (P=0.05)	0.43				1.02			
2022								
SA_0	3.70	4.13	5.64	5.75	12.91	14.43	18.94	19.39
SA_1	4.63	5.29	7.15	7.20	16.29	18.27	23.92	24.14
SA_2	3.94	4.74	6.51	6.65	13.36	16.12	22.28	23.46
SA_3	5.02	5.68	8.49	8.93	17.37	19.26	27.46	28.17
SEm±	0.24				0.59			
CD (P=0.05)	0.68				1.71			
Pooled								
SA_0	2.77	3.12	4.03	4.16	9.63	10.97	14.09	14.43
SA_1	3.64	4.24	5.57	5.61	12.27	14.24	18.02	18.30
SA_2	2.89	3.48	4.72	4.83	9.99	12.43	16.75	17.44
SA_3	3.96	4.80	6.63	6.93	12.96	15.60	20.79	21.33
SEm±	0.14				0.34			
CD (P=0.05)	0.39				0.97			

Table 4.13(c): Interaction effect of soil amendments and phosphorus on total potassium uptake of black gram

Soil amendments	Total potassium uptake (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	8.21	9.62	11.68	12.04
SA_1	10.88	13.39	16.12	16.48
SA_2	8.47	10.96	14.15	14.43
SA_3	11.44	15.86	18.91	19.41
SEm±	0.43			
CD (P=0.05)	1.25			
	2022			
SA_0	16.60	18.56	24.58	25.14
SA_1	20.92	23.56	31.07	31.33
SA_2	17.30	20.86	28.79	30.11
SA_3	22.40	24.94	35.94	37.10
SEm±	0.68			
CD (P=0.05)	1.96			
	Pooled			
SA_0	12.41	14.09	18.13	18.59
SA_1	15.90	18.48	23.59	23.91
SA_2	12.89	15.91	21.47	22.27
SA_3	16.92	20.40	27.43	28.26
SEm±	0.40			
CD (P=0.05)	1.14			



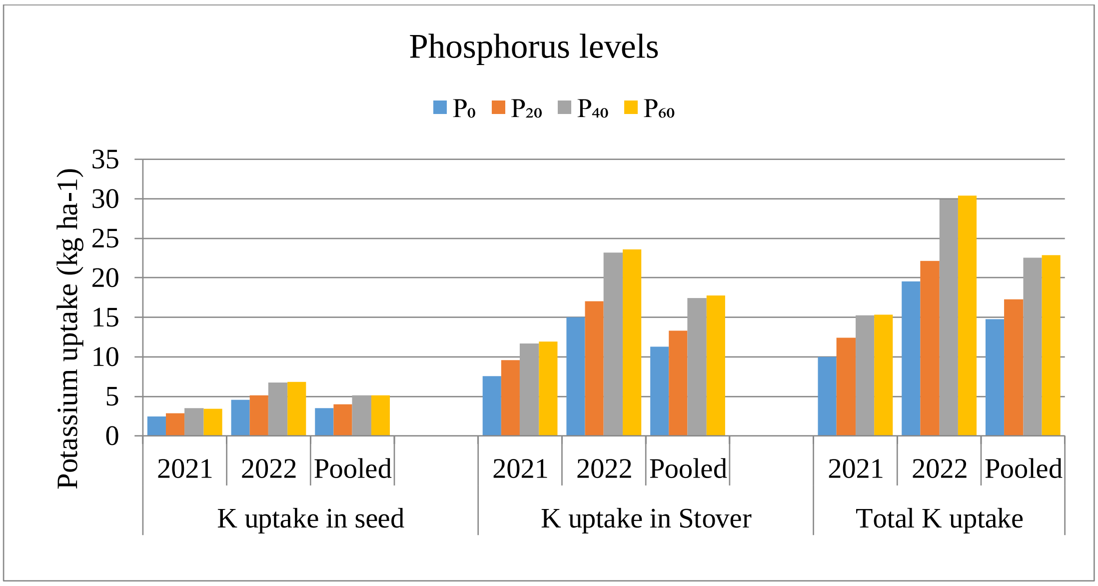


Fig 4.18: Effect of soil amendments and phosphorus on potassium uptake in black gram

Interaction effect of soil amendments and phosphorus on potassium uptake

It is apparent from the Table 4.13(b) & (c) that there was a significant interaction effect of soil amendments and phosphorus on K uptake in seed, stover and total K uptake during both the years of experimentation. From the pooled data, maximum K uptake seed, stover and total K uptake was recorded with treatment combination SA_3P_{60} while minimum was recorded at SA_0P_0(control). However, irrespective of soil amendments, K uptake in seed, stover and total K uptake at P_{60} was at par with P_{40}. The results are in close agreement with Singh and Singh (2022) who reported significant interaction of liming materials and phosphorus on potassium uptake of soybean; also Rathore *et al*. (2010) found significant interaction of phosphorus and biofertilizers on potassium uptake of *urd* bean.

4.3.4. Calcium uptake in seed and stover

4.3.4.1. Effect of soil amendments

From the data presented in Table 4.14(a) and depicted in Fig 4.19 it was observed that calcium uptake in seed, stover and total Ca uptake showed significant disparity among amendment treatments. It is apparent from the table that maximum calcium uptake in seed, stover as well as total Ca uptake was recorded in SA_3 and minimum was recorded at SA_0 in both the years. From the pooled data, combined application of lime and PSB (SA_3) enhanced the calcium uptake in seed by 72.7%, 63.2% in stover and 66.4% in total Ca uptake over control. Whereas, sole application of lime (SA_1) increased calcium uptake to an extent by 49.0% in seed, 39.7% in stover and 42.4% in total Ca uptake while PSB alone (SA_2) augmented the calcium uptake by 20, 16.9 and 17.8% in seed, stover and total Ca uptake over control. Thus, calcium uptake in seed and stover responded better to combine application of lime and PSB among all the amendments. Lime and PSB application enhanced seed and stover yield, as well as Ca content which ultimately increased Ca uptake by crop. A similar finding on calcium uptake in seed and stover of black gram was reported by Uchoi and Sharma (2023).

4.3.4.2. Effect of phosphorus levels

From the Table 4.14(a) it can be observed that phosphorus has a significant positive effect on calcium uptake in seed, stover and total Ca uptake. From the pooled data, it can be observed that during 2021 as well as 2022, maximum calcium uptake (0.88 kg ha^{-1} in seed and 2.15 kg ha^{-1} in stover) was recorded with 60 kg P_2O_5 ha^{-1} and minimum (0.56 kg ha^{-1} in seed and 1.26 kg ha^{-1} in stover) at control. Application of 60 kg P_2O_5 ha^{-1} increased the pooled calcium uptake to an extent of 57.1% in seed, 70.6% in stover and 66.4% in total Ca uptake over control. However, calcium uptake in seed, stover and total Ca uptake was found at par with 40 kg P_2O_5 ha^{-1}. This is in congruence with that of Singh and Singh (2022) and Uchoi and Sharma (2023).

Interaction effect of soil amendments and phosphorus on total Ca uptake

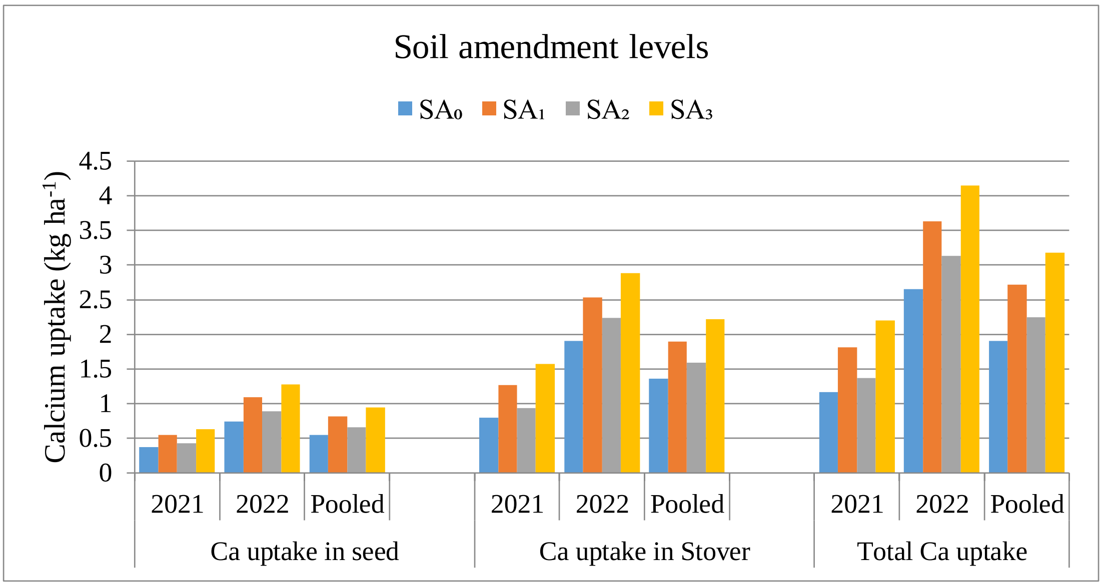
It is apparent from the Table 4.14(b) that the pooled data of total Ca uptake showed significant interaction effect of soil amendments and phosphorus. From the pooled data, maximum total Ca uptake was recorded with the treatment combination SA_3P_{40} which was at par with SA_3P_{60} while minimum was recorded at SA_0P_0 (control). A critical analysis of data showed that, PSB application (SA_2) improved total calcium uptake significantly under P_{60} level of phosphorus, while effect of PSB was insignificant under other tested level of phosphorus. Singh and Singh (2022) reported significant interaction of liming materials and phosphorus on calcium uptake of soybean.

Table 4.14(a): Effect of soil amendments and phosphorus on calcium uptake in seed and stover of black gram

Treatments	Calcium uptake (kg ha^{-1})								
	Seed			Stover			Total		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	0.37	0.74	0.55	0.80	1.91	1.36	1.17	2.65	1.91
SA_1 (5% LR)	0.55	1.09	0.82	1.27	2.53	1.90	1.81	3.63	2.72
SA_2 (PSB)	0.43	0.89	0.66	0.94	2.24	1.59	1.37	3.13	2.25
SA_3 (5% LR + PSB)	0.63	1.28	0.95	1.57	2.88	2.22	2.20	4.15	3.18
SEm±	0.02	0.03	0.02	0.04	0.08	0.05	0.05	0.09	0.05
CD (P=0.05)	0.05	0.08	0.04	0.12	0.24	0.13	0.14	0.25	0.14
Phosphorus levels									
P_0	0.37	0.75	0.56	0.80	1.73	1.26	1.17	2.48	1.82
P_{20}	0.47	0.88	0.67	1.07	2.00	1.54	1.54	2.88	2.21
P_{40}	0.56	1.18	0.87	1.35	2.89	2.12	1.91	4.07	2.99
P_{60}	0.57	1.19	0.88	1.36	2.94	2.15	1.94	4.13	3.03
SEm±	0.02	0.03	0.02	0.04	0.08	0.05	0.05	0.09	0.05
CD (P=0.05)	0.05	0.08	0.04	0.12	0.24	0.13	0.14	0.25	0.14

Table 4.14(b): Interaction effect of soil amendments and phosphorus on total Ca uptake of black gram

Soil amendments	Total Ca uptake (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	Pooled			
SA_0	1.39	1.76	2.20	2.28
SA_1	2.08	2.27	3.18	3.35
SA_2	1.50	1.98	2.69	2.83
SA_3	2.32	2.84	3.87	3.68
SEm±	0.10			
CD (P=0.05)	0.28			



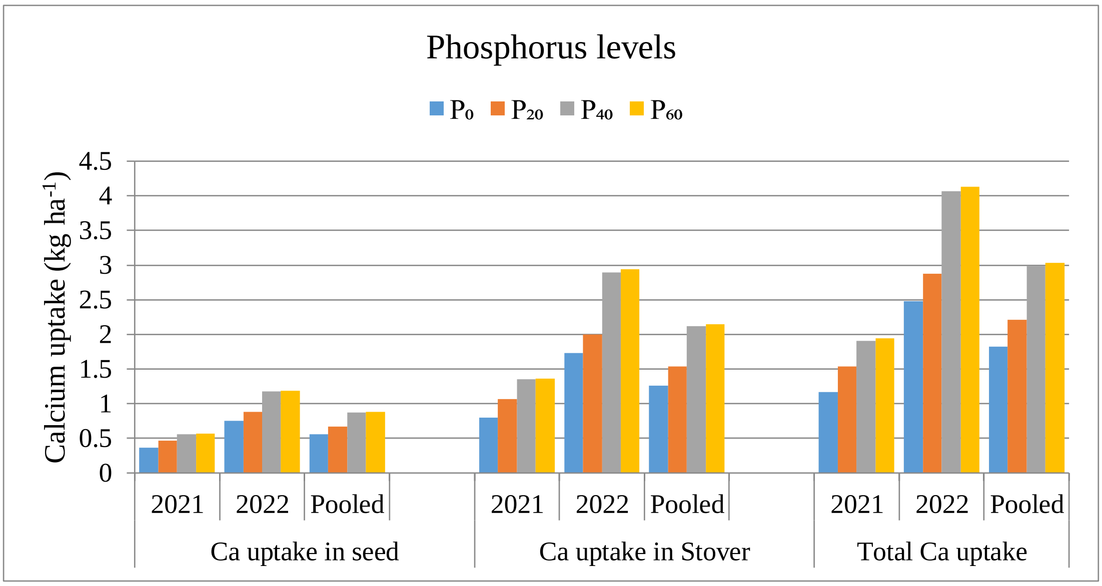


Fig 4.19: Effect of soil amendments and phosphorus on calcium uptake in black gram

4.3.5. Magnesium uptake in seed and stover

4.3.5.1. Effect of soil amendments

The results from the 4.15(a) and illustrated in Fig 4.20 revealed that there was a significant effect of soil amendments on magnesium uptake of black gram. Irrespective of year of experimentation and treatment, the magnesium uptake in seed and stover varied from 0.16 to 0.95 kg ha^{-1} and 0.47 to 2.40 kg ha^{-1}, respectively. During 2021 and 2022, maximum magnesium uptake in seed, stover and total Mg uptake was recorded at SA_3 while minimum at SA_0. From the pooled data, application of lime in conjunction with PSB (SA_3) enhanced the magnesium uptake by 127.5% in seed, 122.5% in stover and 122.9% in total Mg uptake over control; whereas, sole application of lime (SA_1) improved the magnesium uptake by 75.8, 78.7 and 77.0% while sole PSB (SA_2) increased the magnesium uptake by 13.7, 23.7 and 21.1% in seed, stover and in total Mg uptake over control. Hence, it could be inferred that magnesium uptake in seed and stover noted under SA_3 was superior to rest of the soil amendments. The results are in agreement with that of Rathod *et al*. (2017).

4.3.5.2. Effect of phosphorus levels

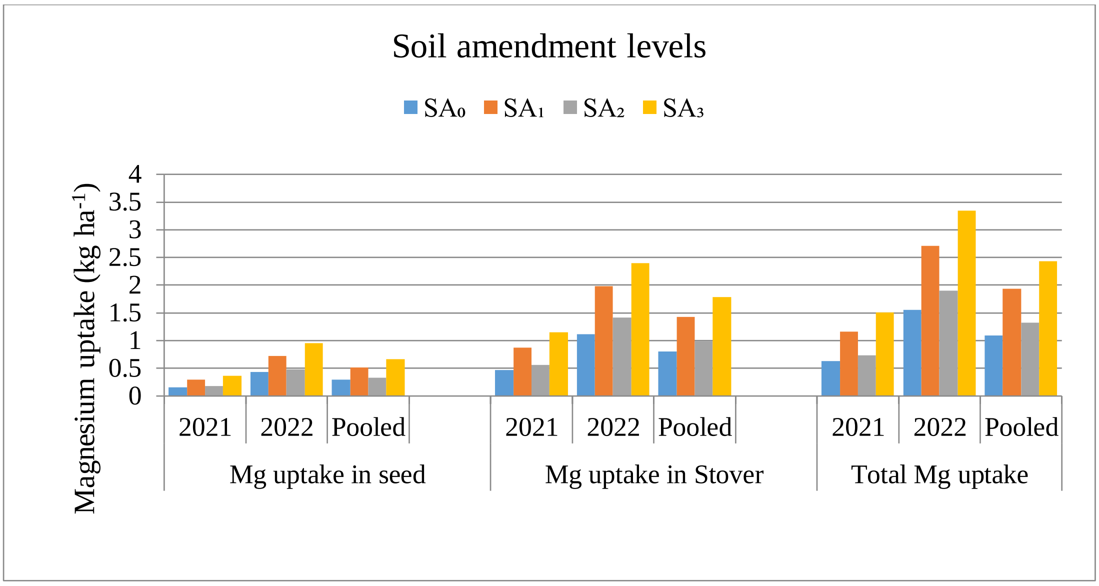
The data [4.15(a)] showed that in 2021 as well as 2022, maximum uptake in seed, stover and total uptake was recorded with the application of P_{60} (60 kg P_2O_5 ha^{-1}) and minimum at P_0 (control). From the pooled data, it can be observed that there was an increase in magnesium uptake in seed by 47.2%, 63.8% in stover and 56.1% in total Mg uptake at P_{60} over control. However, magnesium uptake in seed, stover and total Mg uptake was found at par with 40 kg P_2O_5 ha^{-1}. The present results are in collaboration with the findings Eutropia and Ndakidemi (2014).

Table 4.15(a): Effect of soil amendments and phosphorus on magnesium uptake in seed and stover of black gram

Treatments	Magnesium uptake (kg ha^{-1})								
	Seed			Stover			Total		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	0.16	0.43	0.29	0.47	1.12	0.80	0.63	1.55	1.09
SA_1 (5% LR)	0.29	0.72	0.51	0.87	1.98	1.43	1.16	2.71	1.93
SA_2 (PSB)	0.18	0.48	0.33	0.56	1.42	0.99	0.74	1.90	1.32
SA_3 (5% LR + PSB)	0.36	0.95	0.66	1.15	2.40	1.78	1.51	3.35	2.43
SEm±	0.02	0.02	0.02	0.04	0.07	0.04	0.05	0.08	0.05
CD (P=0.05)	0.05	0.07	0.04	0.12	0.19	0.11	0.15	0.22	0.13
Phosphorus levels									
P_0	0.20	0.51	0.36	0.54	1.35	0.94	0.74	1.86	1.30
P_{20}	0.23	0.56	0.39	0.72	1.49	1.11	0.95	2.05	1.50
P_{40}	0.27	0.75	0.51	0.89	2.00	1.44	1.16	2.74	1.95
P_{60}	0.28	0.77	0.53	0.91	2.09	1.50	1.19	2.86	2.03
SEm±	0.02	0.02	0.02	0.04	0.07	0.04	0.05	0.08	0.05
CD (P=0.05)	0.05	0.07	0.04	0.12	0.19	0.11	0.15	0.22	0.13

Table 4.15(b): Interaction effect of soil amendments and phosphorus on total Mg uptake of black gram

Soil amendments	Total Mg uptake (kg ha^{-1})			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	Pooled			
SA_0	0.93	0.97	1.19	1.27
SA_1	1.45	1.89	2.23	2.17
SA_2	0.94	1.08	1.59	1.67
SA_3	1.89	2.05	2.79	3.00
SEm±	0.09			
CD (P=0.05)	0.26			



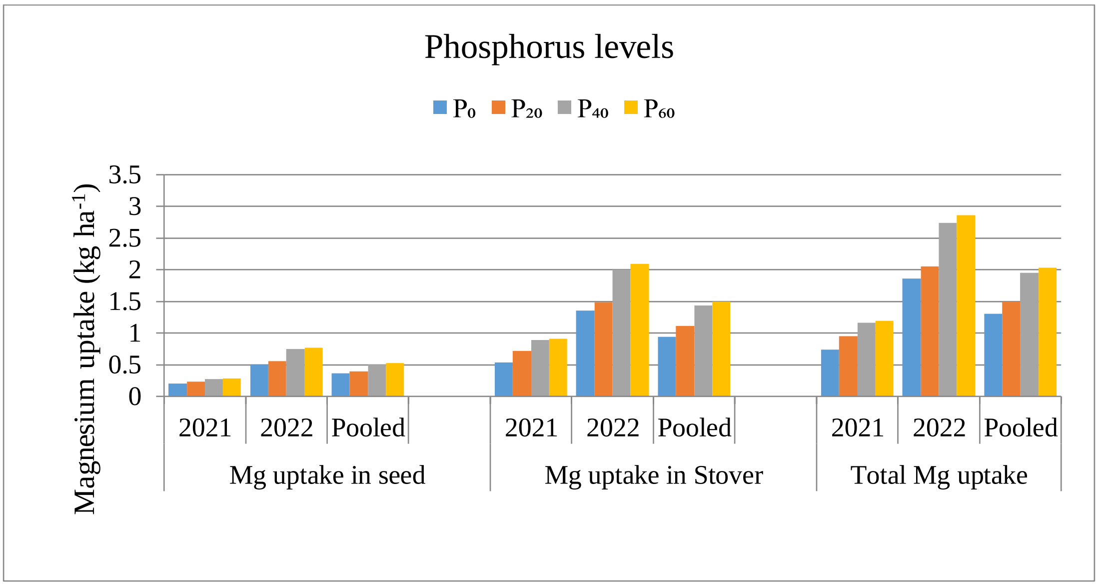


Fig 4.20: Effect of soil amendments and phosphorus on magnesium uptake in black gram

Interaction effect of soil amendments and phosphorus on total Mg uptake

It is apparent from the Table 4.15(b) that the pooled data of total Mg uptake exhibited significant interaction effect of soil amendments and phosphorus. From the pooled data, maximum total Mg uptake was recorded with the treatment combination SA_3P_{60} which was at par with SA_3P_{40} while minimum was recorded at SA_0P_0 (control).

4.4. Effect of soil amendments and phosphorus on soil properties

4.4.1. Soil pH

4.4.1.1. Effect of soil amendments

It is apparent from the Table 4.16 and illustrated in Fig 4.21 that during 2021 and 2022 maximum pH in post harvest soil was recorded in SA_3 with a pooled value of 4.70 which was at par with SA_1 (4.66) while minimum was recorded at SA_2 with a pooled value of 4.43 which was statistically at par with SA_0 (4.44). Further examination of data revealed that though statistically non-significant the pooled soil pH value at sole application of PSB was minutely lower than control; the decrease in pH could be due to the microbial production of organic acids or the release of protons (Satyaprakash *et al.*, 2017). On the other hand, application of lime had significant influence on soil pH; the increase in soil pH can be attributed to the probable displacement of Al^{3+}, H^+ and Fe^{3+} ions by Ca^{2+} ions present in lime (Kisinyo *et al.*, 2012). Also, lime when employed in soil reacts with water and effectuates the production of OH^- ions and Ca^{2+} ions which replaces H^+ and Al^{3+} from soil adsorption sites resulting to an increase in soil pH. Similar finding was reported by Chimdi *et al.* (2012) and Verde *et al.* (2013).

4.4.1.1. Effect of phosphorus levels

Data given in the Table 4.16 further revealed that different levels of phosphorus application did not have significant effect on pH of post harvest soil in both the years. Irrespective of P doses the pooled data of soil pH ranged from 4.49 to 4.62.

4.4.2. Electrical conductivity

4.4.2.1. Effect of soil amendments

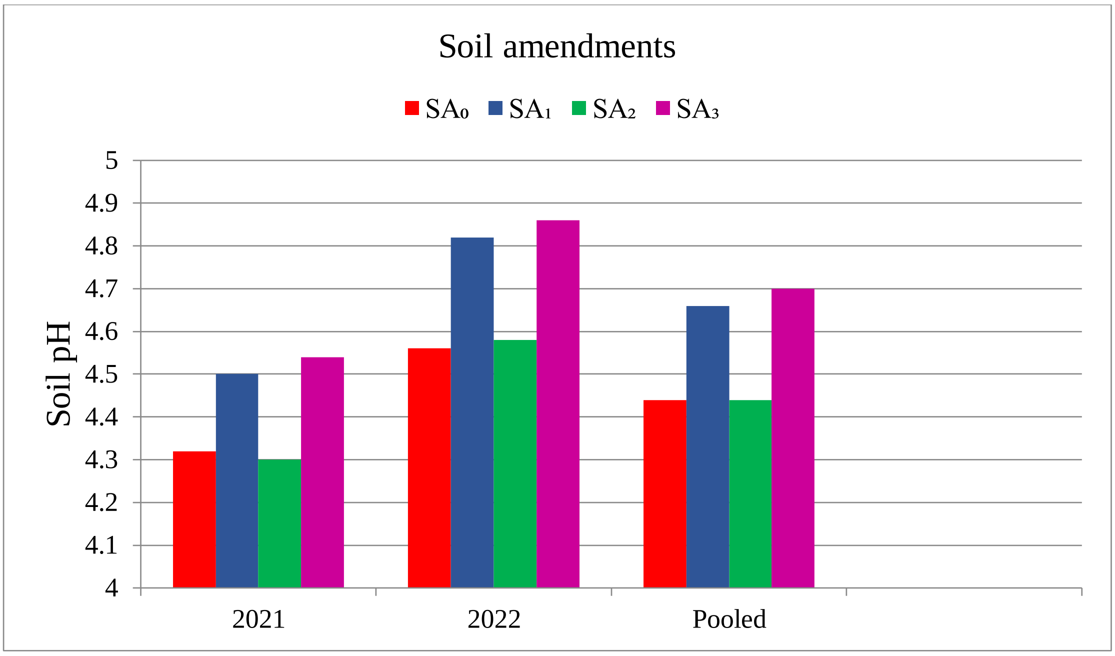
Data pertaining to electrical conductivity of post harvest soil during 2021 and 2022 have been presented in Table 4.16 and depicted in Fig 4.22. It is evident from the data that application of soil amendments brought about a significant influence on electrical conductivity of post harvest soil; however the increased in electrical conductivity was recorded exclusively in limed plots either applied alone or combined. From the pooled data, maximum value on electrical conductivity was noted at SA_3 (0.19 dSm^{-1}) which was at par with SA_1 (0.18 dSm^{-1}) while minimum value was noted at control (0.15 dSm^{-1}) and was at par with SA_2 (0.15 dSm^{-1}). The enhancement in EC with lime application could be due to its ability to enhance solubility of salts (Meena and Prakasha, 2020). Also, liming increase the availability of nutrient cations which possess the ability to carry electrical charge and conduct electrical current in the soil system might have enhanced the soil electrical conductivity. These results are in alignment with that of Lee *et al*. (2022).

4.4.2.2. Effect of phosphorus levels

The data presented in Table 4.16 further reflected that effect of phosphorus on electrical conductivity was found to be non-significant in both the years. However, irrespective of P levels the soil electrical conductivity of post harvest soil ranged from 0.16 to 0.18 dSm^{-1}.

Table 4.16: Effect of soil amendments and phosphorus on soil pH, electrical conductivity and organic carbon of post harvest soil

Treatments	Soil pH			Electrical conductivity (dSm^{-1})			Organic carbon ($g\ kg^{-1}$)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	4.32	4.56	4.44	0.15	0.15	0.15	20.30	20.70	20.50
SA_1 (5% LR)	4.50	4.82	4.66	0.18	0.19	0.18	20.55	20.98	20.76
SA_2 (PSB)	4.30	4.56	4.43	0.15	0.15	0.15	20.43	20.85	20.64
SA_3 (5% LR + PSB)	4.54	4.86	4.70	0.18	0.20	0.19	20.58	21.05	20.81
SEm±	0.04	0.04	0.03	0.008	0.004	0.004	0.12	0.13	0.09
CD (P=0.05)	0.12	0.10	0.08	0.02	0.01	0.01	NS	NS	NS
Phosphorus levels									
P_0	4.34	4.65	4.49	0.15	0.16	0.16	20.25	20.73	20.49
P_{20}	4.42	4.67	4.54	0.16	0.17	0.16	20.40	20.85	20.63
P_{40}	4.44	4.71	4.57	0.17	0.17	0.17	20.55	20.93	20.74
P_{60}	4.47	4.77	4.62	0.18	0.18	0.18	20.65	21.08	20.86
SEm±	0.04	0.04	0.03	0.008	0.004	0.004	0.12	0.13	0.09
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS



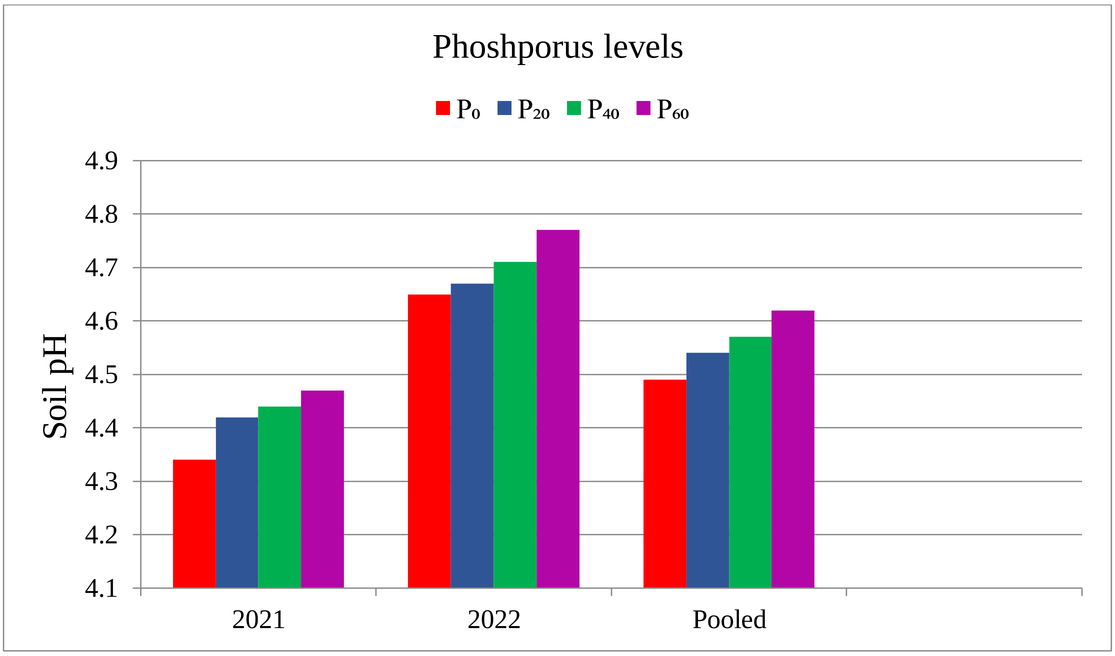
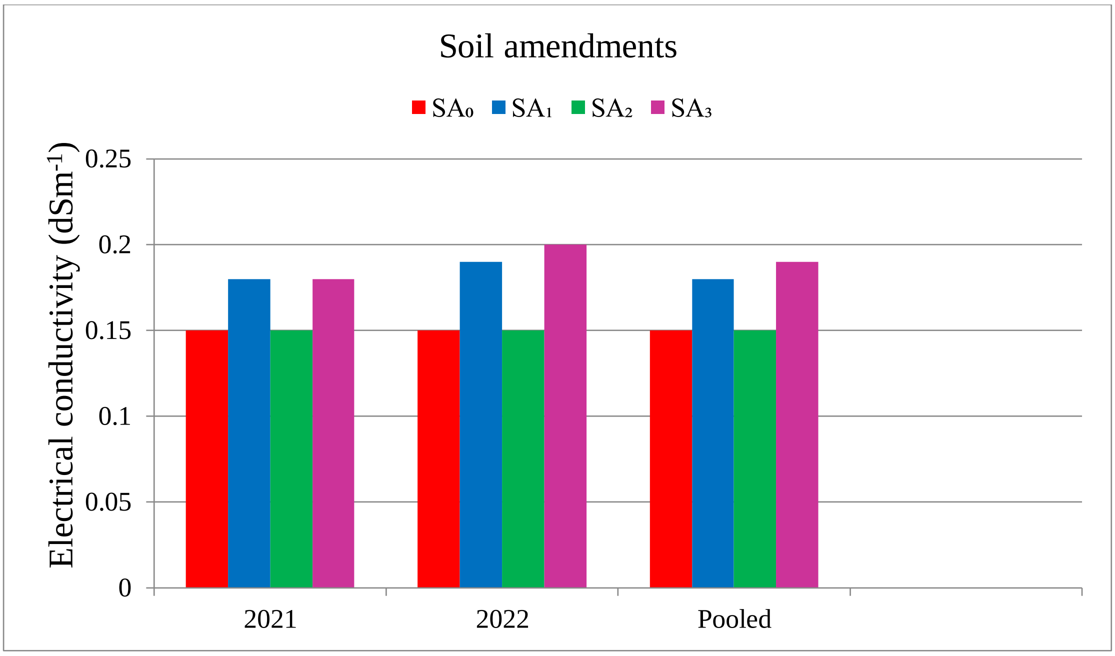


Fig 4.21: Effect of soil amendments and phosphorus on soil pH of experimental soil



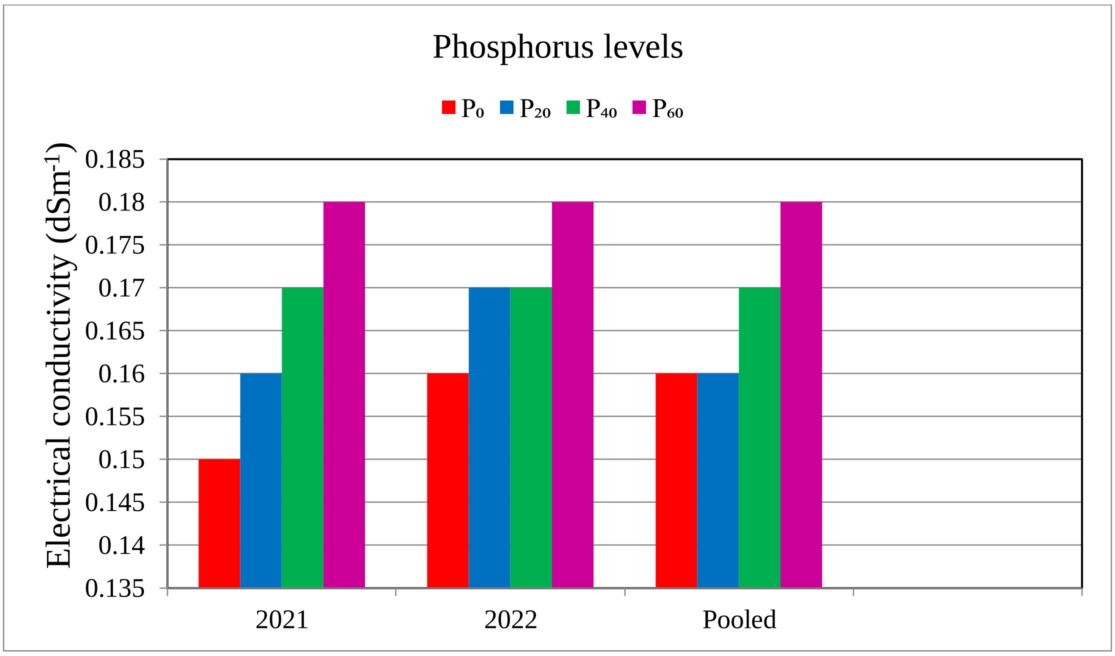
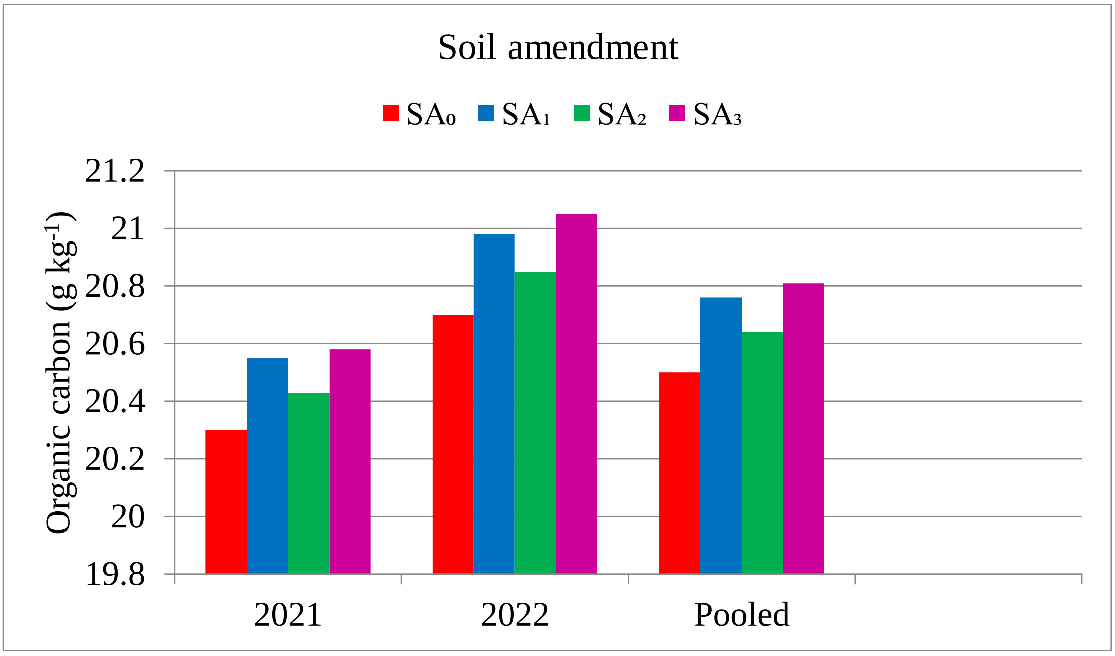


Fig 4.22: Effect of soil amendments and phosphorus on electrical conductivity of experimental soil



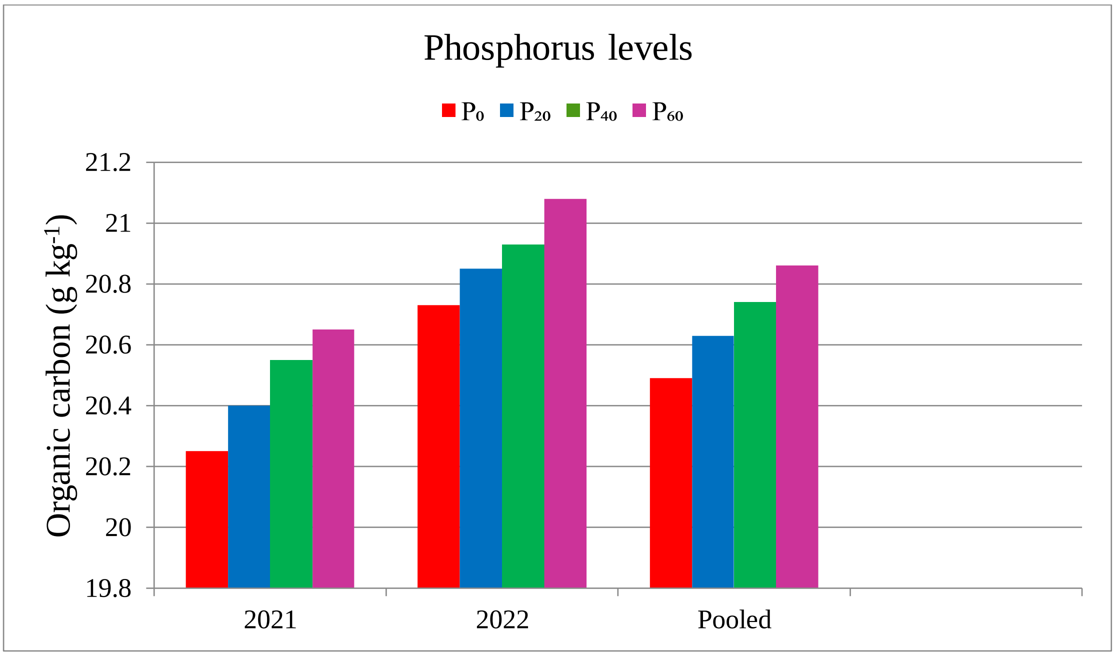


Fig 4.23: Effect of soil amendments and phosphorus on organic carbon of experimental soil

4.4.3. Organic carbon

4.4.3.1. Effect of soil amendments

It could be inferred from data presented in Table 4.16 that irrespective of soil amendment levels the pooled organic carbon of post harvest soil ranged from 20.50 to 20.81 g kg^{-1}. The maximum organic carbon was noted at SA_3 and minimum organic carbon was observed at SA_0. Organic carbon was slightly higher in amended soil compared with the control, but the differences were statistically non-significant ($P < 0.05$).

4.4.3.2. Effect of phosphorus levels

It is clear from the Table 4.16 and represented in Fig 4.23 that organic carbon increased slightly with the increasing P levels, but the disparity was not significant. However from the pooled data, irrespective of P levels the organic carbon varied from 20.49 to 20.86 g kg^{-1}. From the findings it can also be concluded that the effect of soil amendments and phosphorus on organic carbon was not significant; it could be due to no addition of any external input of organic manures during the experimentation.

4.4.4. Available NPK status of soil

4.4.4.1. Available nitrogen

4.4.4.1.1. Effect of soil amendments

A perusal data presented in Table 4.17(a) and depicted in Fig 4.24 revealed that application of soil amendments significantly increased the available nitrogen status of post harvest soil. During 2021 and 2022, the maximum available nitrogen in soil at harvest was recorded with the application of 5% LR + PSB (SA_3) with a pooled value of 290.60 kg ha^{-1} and minimum available nitrogen 249.83 kg ha^{-1} was registered at control. Liming enhanced the nitrogen fixation; improves the soil reaction which boosts nitrogen availability; favours higher microbial activities in the soils; accelerates the rate of decomposition of organic matter and mineralization of nitrogen (Ranjit *et al*., 2007).The result obtained in the present study is in agreement with the results of Odyuo and Sharma (2020) and Singh and Singh (2023). It could be inferred from the data given in Table 4.17(a) that the sole application of PSB recorded significantly higher available nitrogen in soil after harvest as compared to control; this can be ascribed to enhanced root residues and exudates integrated into the soil owing to seed inoculation with PSB. Also, PSB might have boosted the availability of phosphorus to plants which must have been employed in greater root development and nodulation; hence biological nitrogen fixation by legume crop might have been maximized. These results are substantiated with those reported by Barman *et al*. (2014) and Dkhar *et al.* (2019).

4.4.4.1.2. Effect of phosphorus levels

The data presented in Table 4.17(a) and illustrated in Fig 4.24 further indicated that available nitrogen in post harvest soil was significantly affected by the different phosphorus levels. During 2021 and 2022, maximum available nitrogen was noted with the application of 60 kg P_2O_5 ha^{-1} with a pooled value of 286.94 kg ha^{-1} which was found to be at par with 40 kg P_2O_5 ha^{-1} and minimum available nitrogen 248.27 kg ha^{-1} was recorded at control. Phosphorus fertilizer might have increased nodulation, thereby enhancing nitrogen fixation as well as nitrogen secretion by the legume crops which boost the nitrogen status in soil. These results are in accordance with those of Yakubu *et al*. (2010) and Amba *et al*. (2011).

4.4.4.2. Available phosphorus

4.4.4.2.1. Effect of soil amendments

It is evident from the Table 4.17(a) and delineated in Fig 4.25 that there was significant increase in available phosphorus of soil at harvest in response to application of soil amendments. Irrespective of the soil amendments treatment the pooled data on available phosphorus of post harvest soil ranged from 11.97 to 14.86 kg ha^{-1}. In both the years of experimentation, maximum available phosphorus was recorded at SA_3 while minimum at control. Available phosphorus was augmented by liming; because Ca^{2+} ions present in lime reduces P sorption by effectuating dissolution of complex iron and aluminium phosphates thereby making phosphate available in the form of monocalcium phosphate. Therefore increase in available P status due to lime application was understandable (Dixit and Sharma 2003). The results are in congruence with Muindi *et al.* (2015) and Guddisa *et al.* (2016).The data further reveals that in both the years of experimentation there was a significant increase in available phosphorus status with seed inoculation with PSB over control. Enhancement of available P can be ascribed to secretion of organic acid which solubilised the fixed phosphorus and convert it to plant available form (Chen *et al.*, 2006); and the action of organic acids has been accredited to their chelation property. Low available phosphorus in control plots might be due to no addition of any external input and its mining from the soil by crop. The results are in line with Singh *et al*. (2003), Nyekha *et al*. (2015) and Hassan *et al*. (2017).

4.4.4.2.2. Effect of phosphorus levels

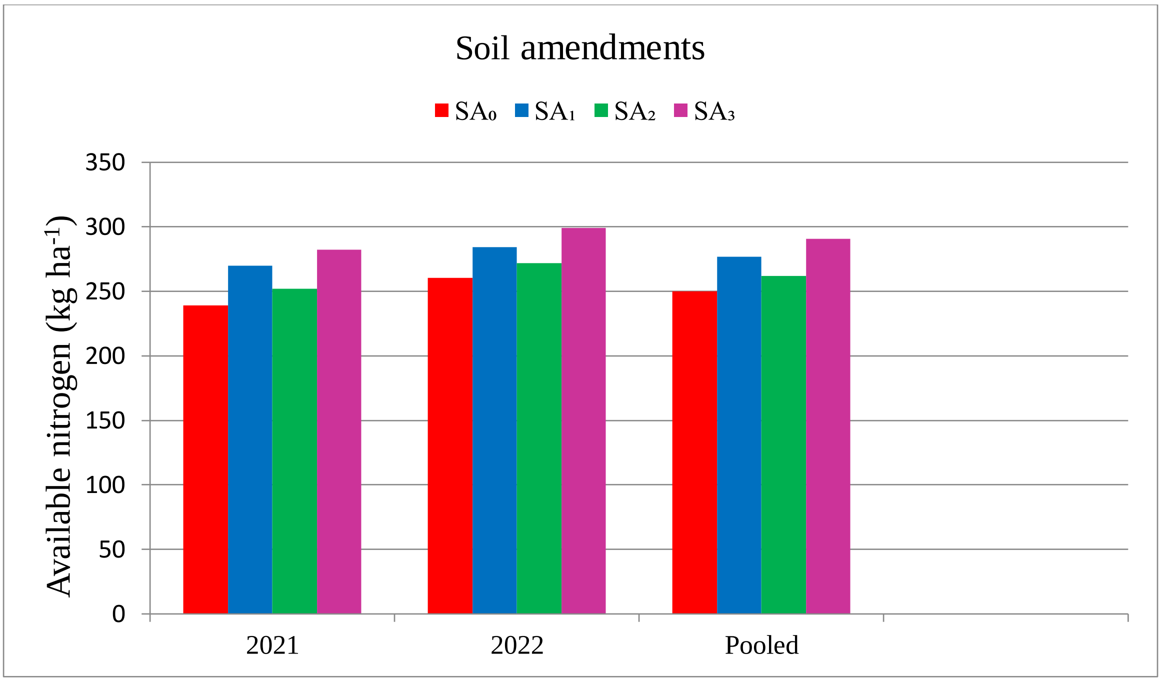
It is apparent from the Table 4.17(a) and illustrated in Fig 4.25 that application of different levels of phosphorus significantly influenced the availability of phosphorus status in post harvest soil in both the years. Maximum available phosphorus was recorded at 60 kg P_2O_5 ha^{-1} with a pooled value of 16.58 kg ha^{-1} and minimum available phosphorus at control (10.14 kg

Table 4.17(a): Effect of soil amendments and phosphorus on available nutrients of post harvest soil

Treatments	Available nutrients ($kg\ ha^{-1}$)								
	Nitrogen			Phosphorus			Potassium		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	239.38	260.29	249.83	11.50	12.44	11.97	175.47	177.30	176.38
SA_1 (5% LR)	269.70	284.33	277.01	13.00	14.29	13.65	177.19	179.68	178.43
SA_2 (PSB)	251.92	271.75	261.84	12.06	13.18	12.62	175.60	177.38	176.49
SA_3 (5% LR + PSB)	282.24	298.97	290.60	14.27	15.45	14.86	178.01	179.80	178.90
SEm±	5.00	6.00	3.91	0.17	0.12	0.10	0.75	0.70	0.51
CD (P=0.05)	14.45	17.32	11.05	0.49	0.34	0.29	2.16	2.03	1.45
Phosphorus levels									
P_0	245.65	250.88	248.27	9.84	10.44	10.14	175.76	177.68	176.72
P_{20}	259.24	272.83	266.04	10.69	12.36	11.53	176.29	178.34	177.31
P_{40}	263.42	292.65	278.04	14.20	15.49	14.84	177.00	178.83	177.91
P_{60}	274.92	298.97	286.94	16.09	17.07	16.58	177.22	179.30	178.26
SEm±	5.00	6.00	3.91	0.17	0.12	0.10	0.75	0.70	0.51
CD (P=0.05)	14.45	17.32	11.05	0.49	0.34	0.29	NS	NS	NS

Table 4.17(b): Interaction effect of soil amendments and phosphorus on available phosphorus of post harvest soil

Soil amendments	Available phosphorus kg ha^{-1}			
	Phosphorus levels			
	P_0	P_{20}	P_{40}	P_{60}
	2021			
SA_0	9.33	9.76	12.20	14.70
SA_1	9.74	11.40	14.79	16.07
SA_2	9.39	9.56	13.69	15.58
SA_3	10.91	12.05	16.11	18.01
SEm±	0.34			
CD (P=0.05)	0.98			
	2022			
SA_0	9.75	10.89	13.72	15.43
SA_1	10.85	12.99	15.92	17.40
SA_2	9.85	11.75	14.75	16.28
SA_3	11.30	13.74	17.57	19.19
SEm±	0.23			
CD (P=0.05)	0.67			
	Pooled			
SA_0	9.54	10.33	12.96	15.06
SA_1	10.29	12.20	15.36	16.73
SA_2	9.62	10.70	14.22	15.93
SA_3	11.11	12.89	16.84	18.60
SEm±	0.21			
CD (P=0.05)	0.58			



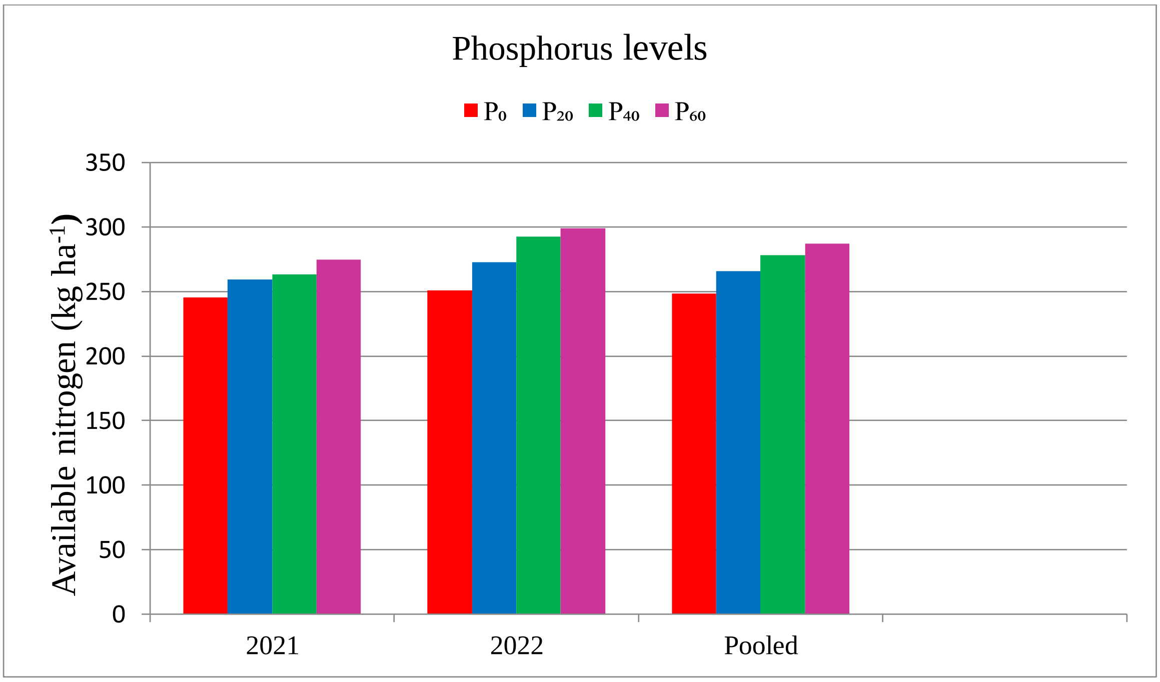
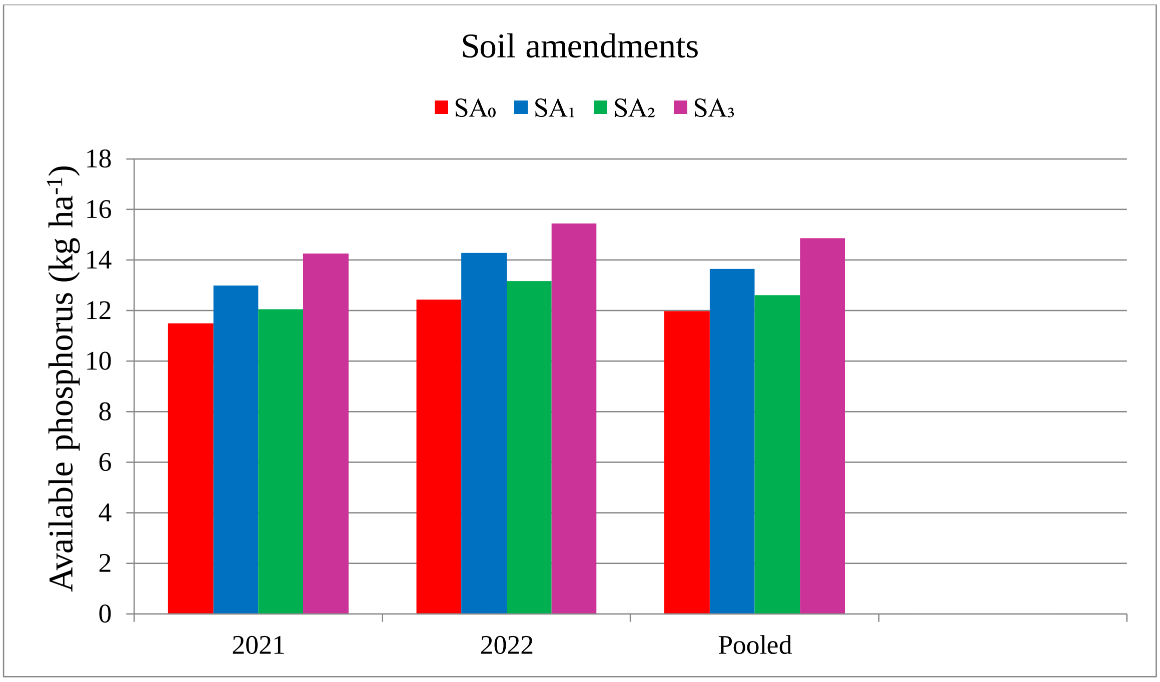


Fig 4.24: Effect of soil amendments and phosphorus on available nitrogen of experimental soil



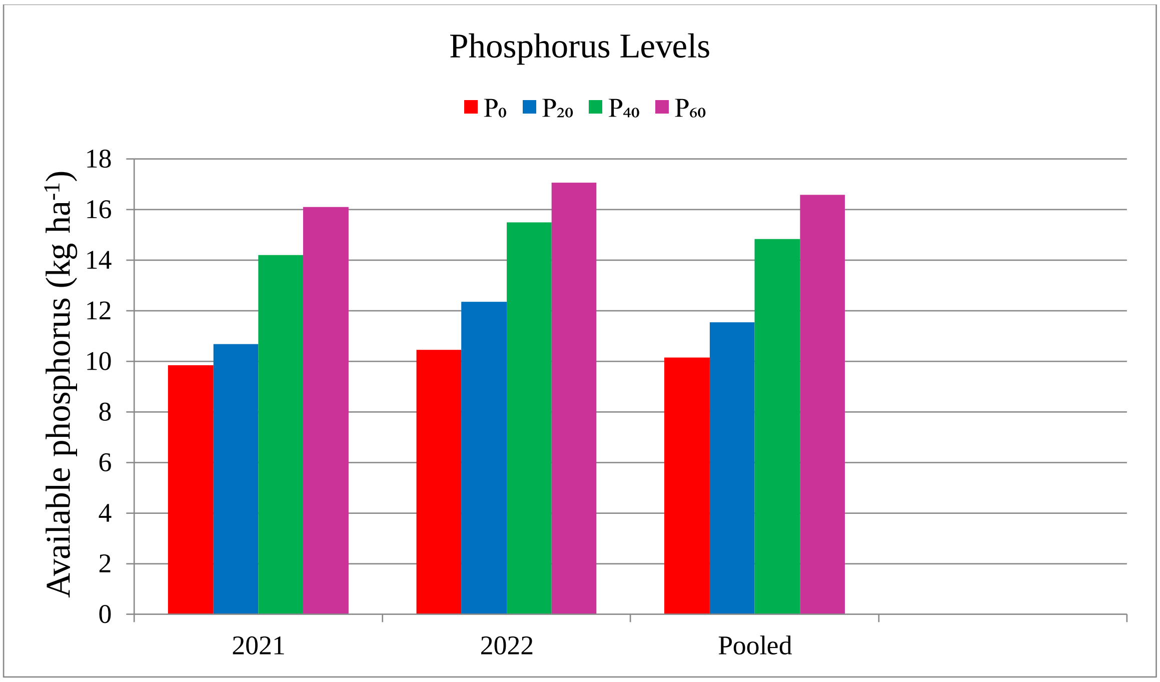
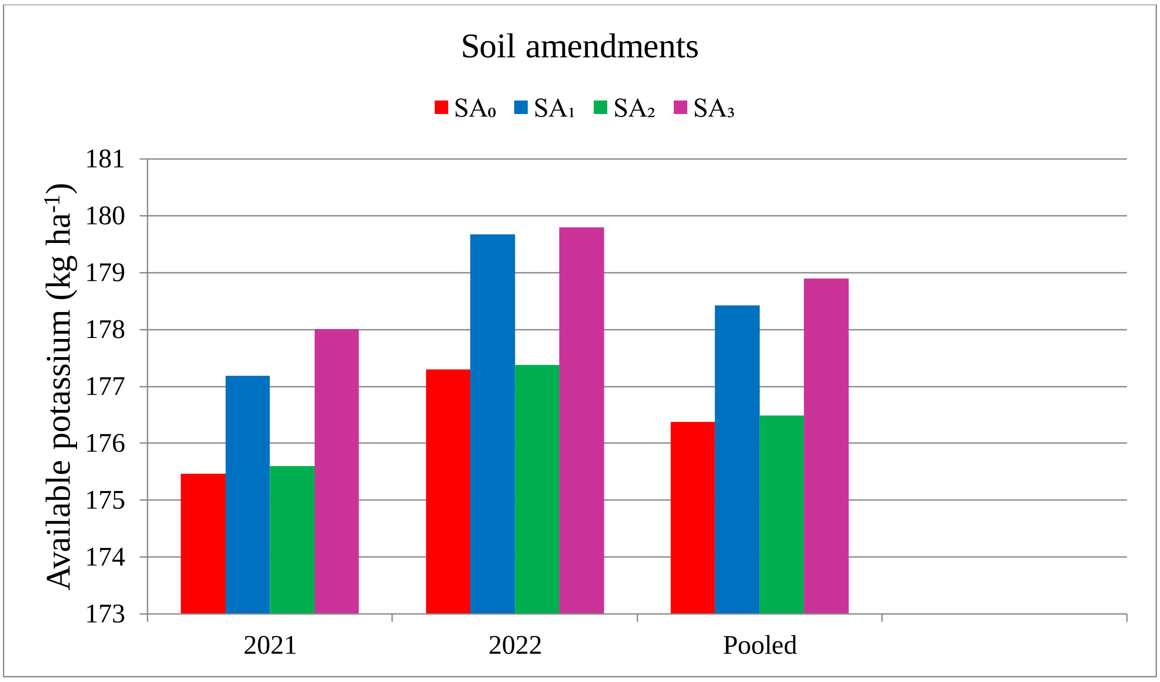


Fig 4.25: Effect of soil amendments and phosphorus on available phosphorus of experimental soil



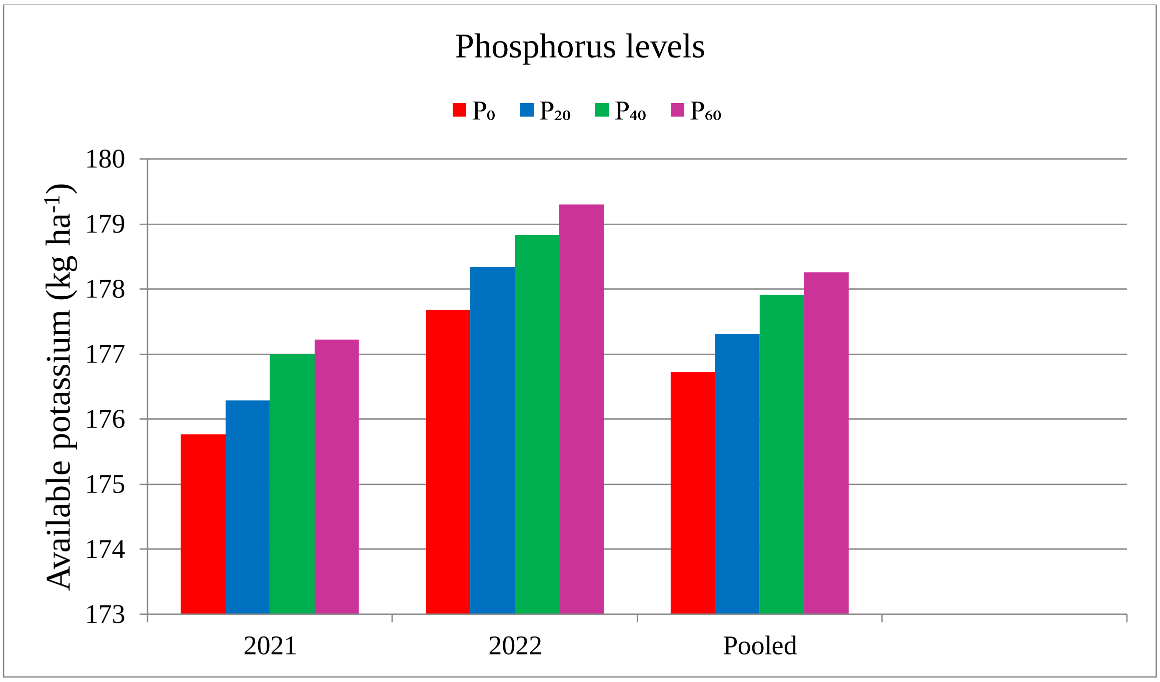


Fig 4.26: Effect of soil amendments and phosphorus on available potassium of experimental soil

ha^{-1}). The increase in available phosphorus with different levels of phosphorus might be due to residual effect of P fertilizers; owing to saturation of phosphorus adsorption sites with native soil phosphorus in P accumulated soil, resulting in lesser adsorption of applied P in soil possessing initial available P. The availability of P from reserved soil pool to the crop was also higher with the increase in initial soil available status. Both the magnitude of initial soil available P in soil and the levels of P applied to the soil resulted in increase in soil P fertility for crop growth (Archana *et al*., 2017). These findings are in conformity with Deo and Khaldelwal (2009) and Zohmingliana *et al*. (2018).

Interaction effect of soil amendments and phosphorus on available phosphorus

The interaction effect of soil amendments and phosphorus on available phosphorus in soil at harvest was found significant in both the years of experimentation. The data from 2021 and 2022 of experimentation are presented in Table 4.17 (b), irrespective of the treatment combination the pooled value of available phosphorus ranged from 9.54 to 18.60 kg ha^{-1}. Maximum available phosphorus was recorded at treatment combination SA_3P_{60} while minimum was recorded at SA_0P_0. The present study inferred that available phosphorus status inpost harvest was enhanced significantly when P fertilizer was applied in conjunction with soil amendments; availability of soil P was elevated as compare to when either of them was applied alone. This could be due to reduction of P sorption by liming enabling both the native and phosphorus fertilizer available for plant uptake (Kisinyo *et al*., 2013; The *et al*., 2006) also PSB solubilise of unavailable form of native P bringing more phosphorus to soil solution. The results are in close agreement with Muindi *et al*. (2015) who documented significant interaction of lime and phosphorus; Bhabai *et al*. (2019) reported significant interaction of PSB and phosphorus on soil available P.

4.4.4.3. Available potassium

4.4.4.3.1. Effect of soil amendments

It is evident from the Table 4.17(a) and illustrated in Fig 4.26 that soil amendments had significant influence on available potassium of post harvest soil. During 2021 and 2022, maximum available potassium was noted at SA_3 with a pooled value of 178.90 kg ha^{-1} which was at par with SA_2 (178.43 kg ha^{-1}) and minimum available potassium was recorded at control with a pooled value of 176.38 kg ha^{-1}. Significant enhancement in available potassium can be attributed to liming; due to the fact that releases of potassium from non-exchangeable fractions to available form get accelerated when acid soils are limed (Bishnoi *et al*., 1988); also, the enhancement of available K on lime application might be due to displacement of exchangeable potassium by calcium. Similar findings were narrated by Verde *et al*. (2013) and Odyuo and Sharma (2020). Further evaluation of data given in Table 4.17(a) revealed that the available potassium recorded at sole application of PSB treated seed (SA_1) was statistically at par with control (SA_0). Hence, it could be inferred that influence of PSB inoculated seed on soil available potassium was inconspicuous.

4.4.4.3.2. Effect of phosphorus levels

It is clear from the Table 4.17(a) that the different levels of phosphorus application could not significantly influence the available potassium after crop harvest. However, irrespective of P levels the pooled value of soil available potassium ranged from 176.72 to 178.26 kg ha^{-1}.

4.4.5. Exchangeable calcium

4.4.5.1. Effect of soil amendments

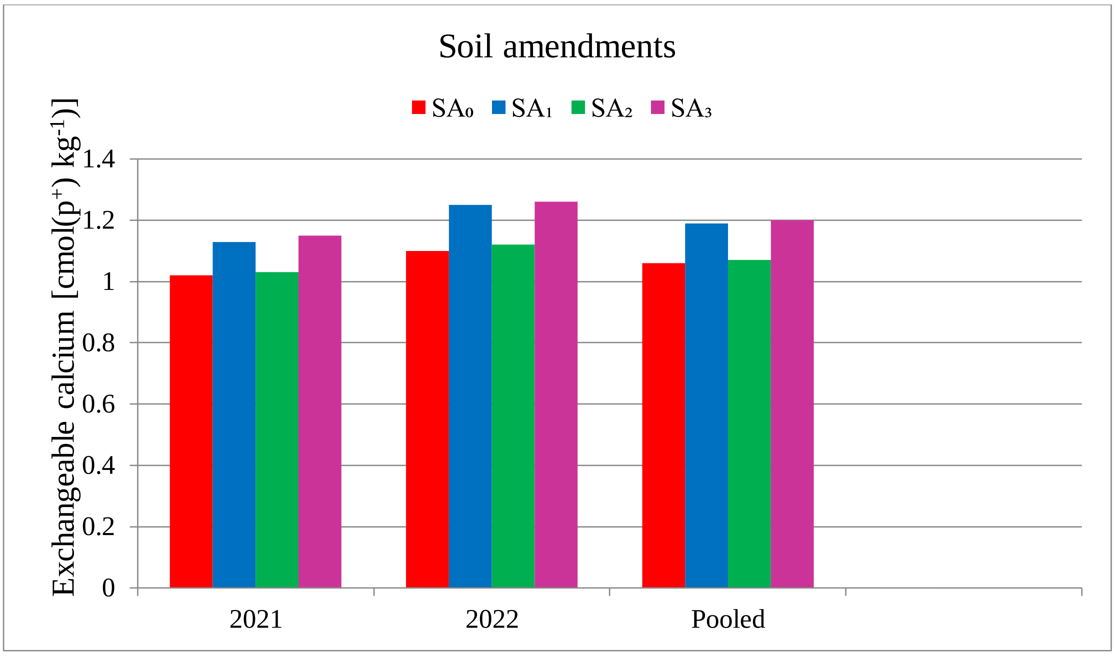
The data regarding to exchangeable calcium was tabulated in Table 4.18 and depicted in Fig 4.27. It is apparent from Table 4.3 that application of soil amendments significantly increased the exchangeable calcium of post harvest soil. During 2021 and 2022, irrespective of amendments treatment the pooled value of exchangeable calcium varied from 1.06 to 1.20 cmol(p^+)kg^{-1}. Maximum exchangeable calcium 1.20 cmol(p^+)kg^{-1} was reported at SA_3 which was found to be at par with SA_1 [1.19 cmol(p^+)kg^{-1}] while minimum was recorded at control [1.06 cmol(p^+)kg^{-1}] which was statistically at par with SA_2 (1.07cmol(p^+)kg^{-1}). The increase in exchangeable calcium might be ascribed to the release of Ca^{2+} ions when lime dissociates (Chimdi *et al*., 2012) and owing to $CaCO_3$ used as the liming material for present study might have contributed in boosting the calcium concentration in the soil solution. Furthermore, due to the increased base saturation of acid soils on liming, higher amount of calcium move from lime particles to the exchange sites of soil particles. This is due to increase in charge density and greater affinity for higher valent ions. The calcium being divalent cation and its higher concentration due to liming amplified its concentration on exchange complex. Similar results on increase in exchangeable calcium due to liming were reported by Guddisa *et al*. (2016) and Bekele *et al*. (2018). The exchangeable calcium at PSB sole amended plots was not statistically different to control. Thus it could be inferred that PSB had no influence on exchangeable calcium.

4.4.5.2. Effect of phosphorus levels

The data given in Table 4.18 further revealed that the different levels of phosphorus had no significant effect on exchangeable calcium. However, during 2021 and 2022, irrespective of application of different phosphorus levels the pooled exchangeable calcium of post harvest soil ranged from 1.08 to

Table 4.18: Effect of soil amendments and phosphorus on exchangeable nutrients of post harvest soil

Treatments	Exchangeable nutrients [cmol(p^+)kg^{-1}]					
	Calcium			Magnesium		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	1.02	1.10	1.06	0.61	0.72	0.66
SA_1 (5% LR)	1.13	1.25	1.19	0.70	0.75	0.73
SA_2 (PSB)	1.03	1.12	1.07	0.63	0.73	0.68
SA_3 (5% LR + PSB)	1.15	1.26	1.20	0.71	0.78	0.75
SEm±	0.04	0.04	0.03	0.04	0.04	0.03
CD (P=0.05)	0.11	0.11	0.08	NS	NS	NS
Phosphorus levels						
P_0	1.00	1.15	1.08	0.61	0.71	0.66
P_{20}	1.08	1.20	1.14	0.64	0.73	0.68
P_{40}	1.13	1.16	1.14	0.69	0.76	0.73
P_{60}	1.13	1.22	1.17	0.71	0.78	0.75
SEm±	0.04	0.04	0.03	0.04	0.04	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS



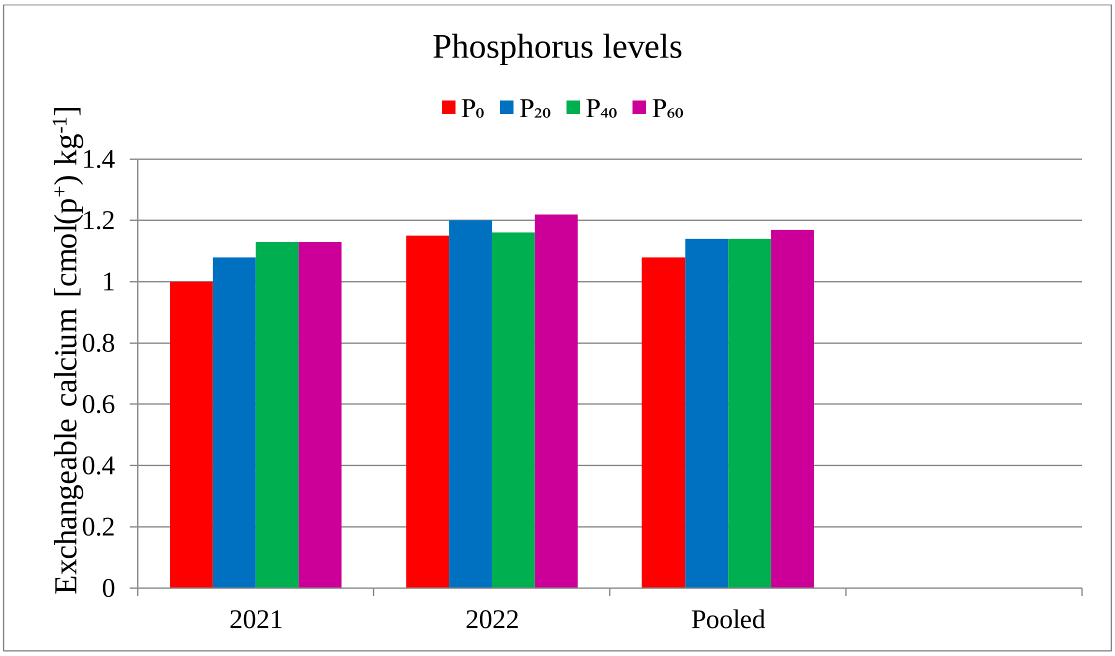
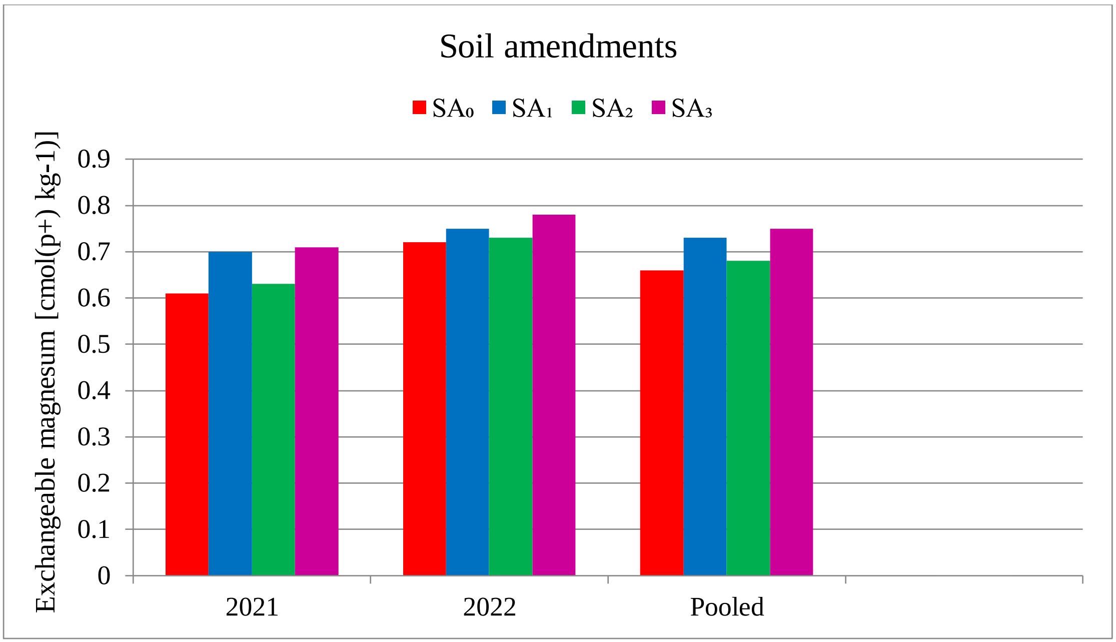


Fig 4.27: Effect of soil amendments and phosphorus on exchangeable calcium of experimental soil



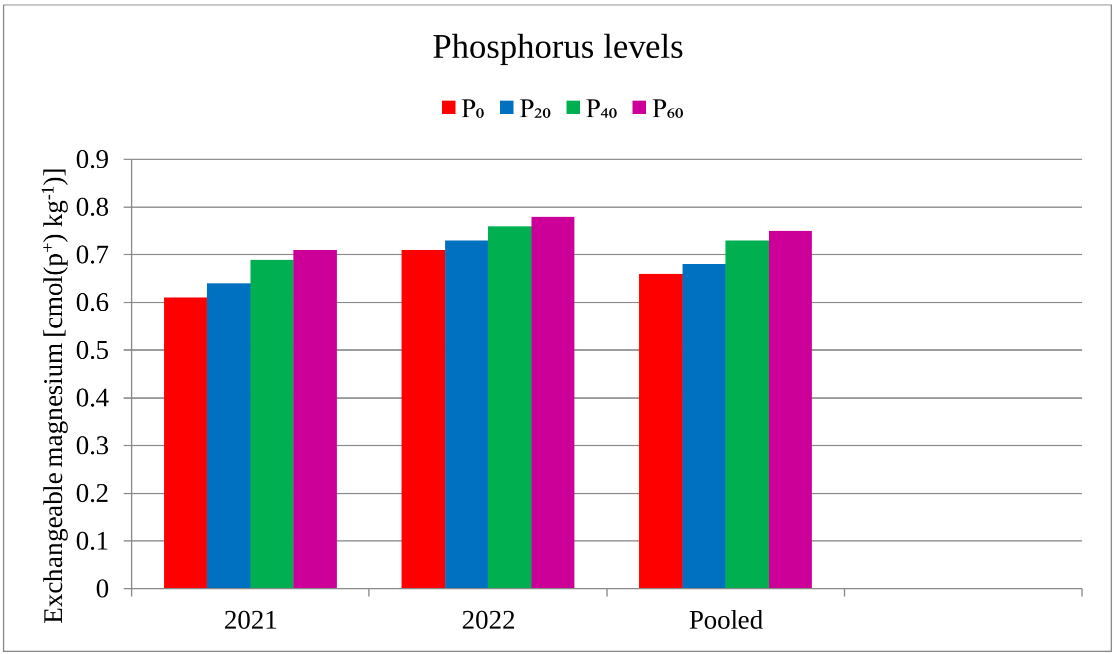


Fig 4.28: Effect of soil amendments and phosphorus on exchangeable magnesium of experimental soil

1.17 where the maximum value of exchangeable calcium was recorded at 60 kg P_2O_5 ha^{-1}.

4.4.6. Exchangeable magnesium

4.4.6.1. Effect of soil amendments

The data pertaining exchangeable magnesium of post harvest soil have been presented in Table 4.18 and represented in Fig 4.28. During both the years of experimentation, the maximum exchangeable magnesium was noted at SA_3 with apooled value of 0.75 cmol(p^+)kg^{-1} while minimum was recorded at control (0.66 cmol(p^+)kg^{-1}). The effect of soil amendments on exchangeable magnesium was statistically non-significant. This might be due to type of lime used which was calcitic limestone that contains calcium carbonate and because Mg is a poor competitor with Ca for exchange sites, it is often deficient in the topsoil because of the application of substantial amount of soluble Ca. Similar results was reported by Verde *et al*. (2013) and Singh and Singh (2022).

4.4.6.2. Effect of phosphorus levels

The data given in Table 4.18 clearly indicates that there was no significant influence on exchangeable magnesium of post harvest soil with application of phosphorus. However, irrespective of P levels the pooled value of magnesium varied from 0.66 to 0.75 cmol(p^+)kg^{-1}.

4.4.7. Total potential acidity

4.4.7.1. Effect of soil amendments

A perusal data presented in Table 4.19 and depicted in Fig 4.29 exhibited that application of soil amendments significantly reduced the total potential acidity of post harvest soil. However, irrespective of amendments the pooled total potential acidity of soil ranged from 17.84 to 19.96 cmol(p^+)kg^{-1}. During 2021 and 2022, the maximum total potential acidity was recorded at control (19.96 cmol(p^+)kg^{-1}) which was at par with SA_2 (19.83cmol(p^+)kg^{-1}), while minimum was recorded at SA_1 (17.84 cmol(p^+)kg^{-1}) which was found to be statistically at par with SA_3 (17.92 cmol(p^+)kg^{-1}). Among amended plots, reduction of total potential acidity was observed at limed plots in comparison with unlimed plots; it could be ascribed to depressed activity of Al^{+3} and H^+ due to neutralization upon liming as a result of the increase in Ca concentration and hydroxyl ions in soil solution. These results are in agreement with those of Rajneesh *et al*. (2018) and Tasung *et al*. (2023). From the data it was observed that the total potential acidity of post harvest soil in PSB (sole) amended soil was not significantly different to that of control.

4.4.7.2. Effect of phosphorus levels

From the data given in Table 4.19 it is apparent that during 2021 and 2022, irrespective of phosphorus levels, the pooled data of total potential acidity of post harvest soil ranged from 18.83 to 18.96 cmol(p^+)kg^{-1}. The data further revealed that application of levels of phosphorus could not bring about a significant effect on total potential acidity.

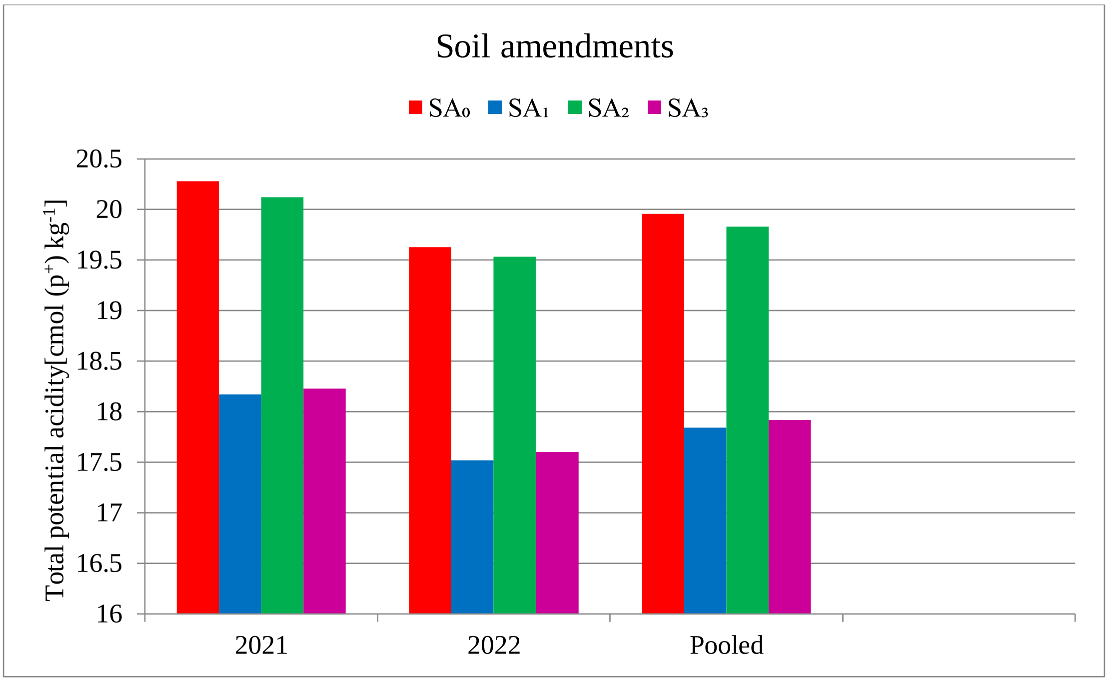
4.4.8. pH dependent acidity

4.4.8.1. Effect of soil amendments

The data presented in Table 4.19 and represented in Fig 4.30 indicated that pH dependent acidity was significantly lower in soil amended plots as compared to control. However, the decreased in pH dependent acidity was observed only in limed plots either applied alone or combined. During both the years of experimentation, maximum pH dependent acidity was registered at control with a pooled value of 16.58 cmol(p^+)kg^{-1} that was at par with SA_2

Table 4.19: Effect of soil amendments and phosphorus on soil acidity components of post harvest soil

Treatments	Soil acidity components [cmol(p^+) kg^{-1}]								
	Total potential acidity			pH dependent acidity			Exchangeable acidity		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Soil amendments									
SA_0 (Control)	20.28	19.63	19.96	16.70	16.47	16.58	3.58	3.17	3.38
SA_1 (5% LR)	18.17	17.52	17.84	15.46	15.18	15.32	2.71	2.33	2.52
SA_2 (PSB)	20.12	19.53	19.83	16.58	16.41	16.49	3.54	3.13	3.33
SA_3 (5% LR + PSB)	18.23	17.60	17.92	15.48	15.23	15.35	2.75	2.38	2.56
SEm±	0.18	0.17	0.12	0.22	0.23	0.16	0.12	0.11	0.08
CD (P=0.05)	0.52	0.48	0.35	0.64	0.66	0.45	0.34	0.33	0.23
Phosphorus levels									
P_0	19.17	18.48	18.83	15.96	15.69	15.83	3.21	2.79	3.00
P_{20}	19.25	18.67	18.96	16.00	15.92	15.96	3.25	2.75	3.00
P_{40}	19.20	18.63	18.92	16.12	15.93	16.02	3.08	2.71	2.90
P_{60}	19.18	18.50	18.84	16.14	15.75	15.95	3.04	2.75	2.90
SEm±	0.18	0.17	0.12	0.22	0.23	0.16	0.12	0.11	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS



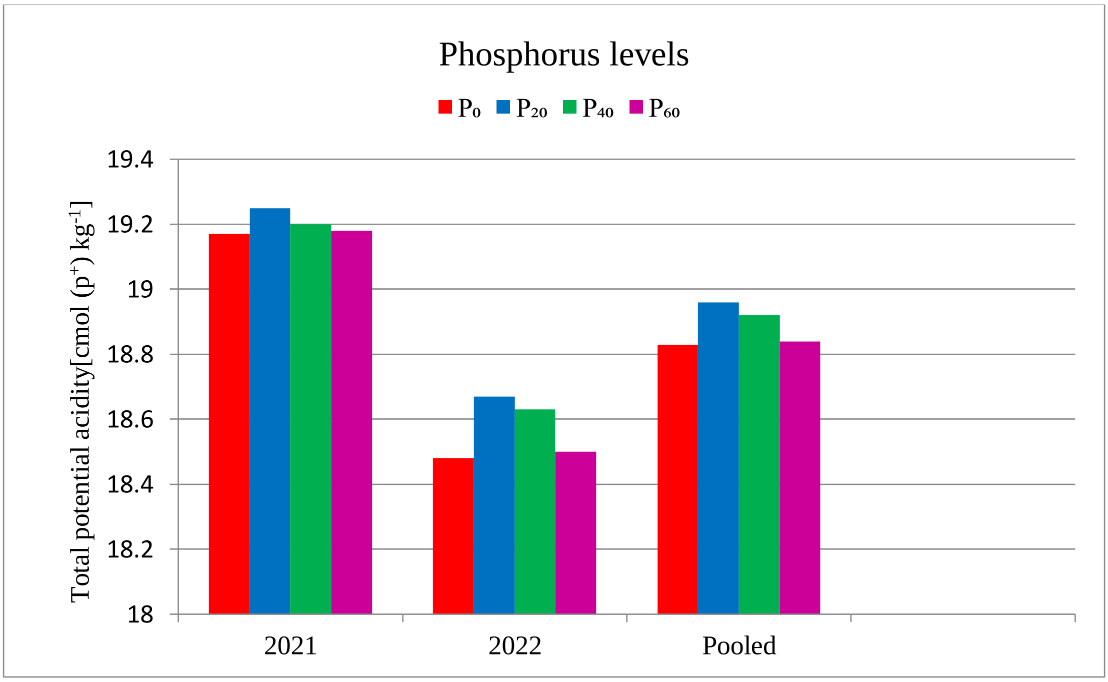
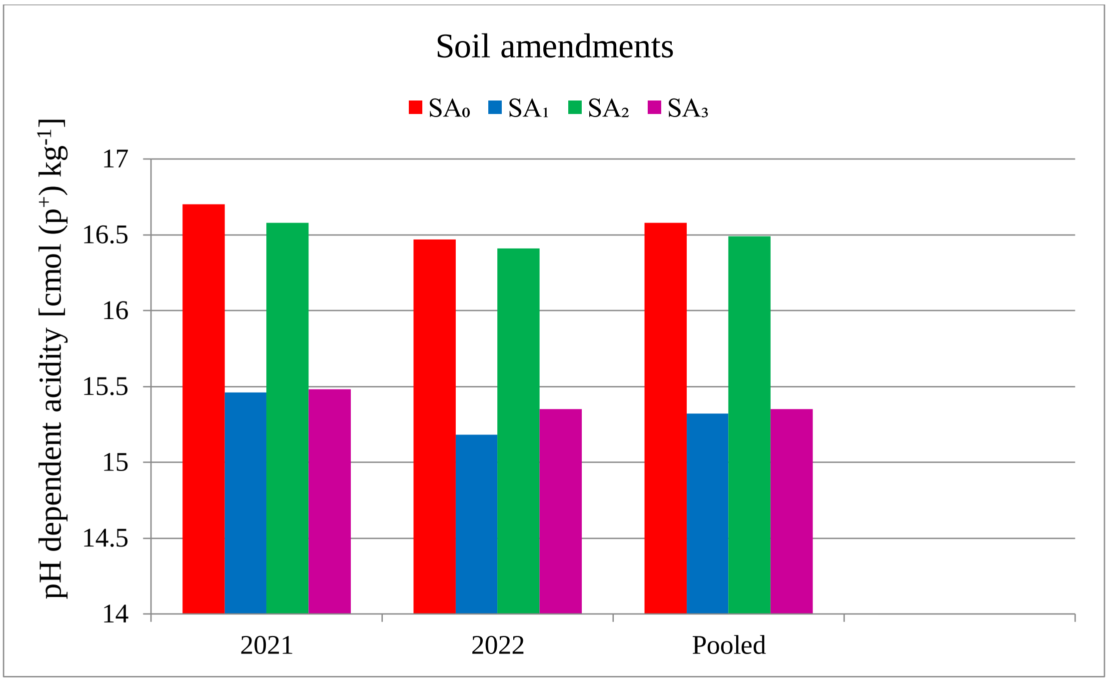


Fig 4.29: Effect of soil amendments and phosphorus on total potential acidity of experimental soil



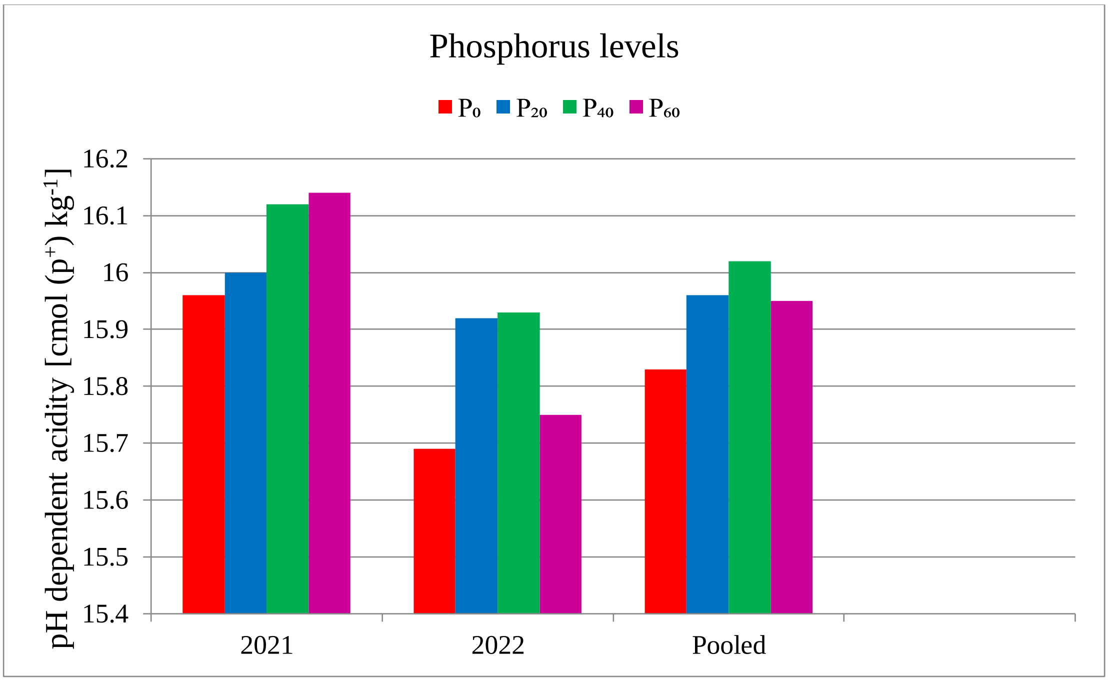


Fig 4.30: Effect of soil amendments and phosphorus on pH dependent acidity of experimental soil

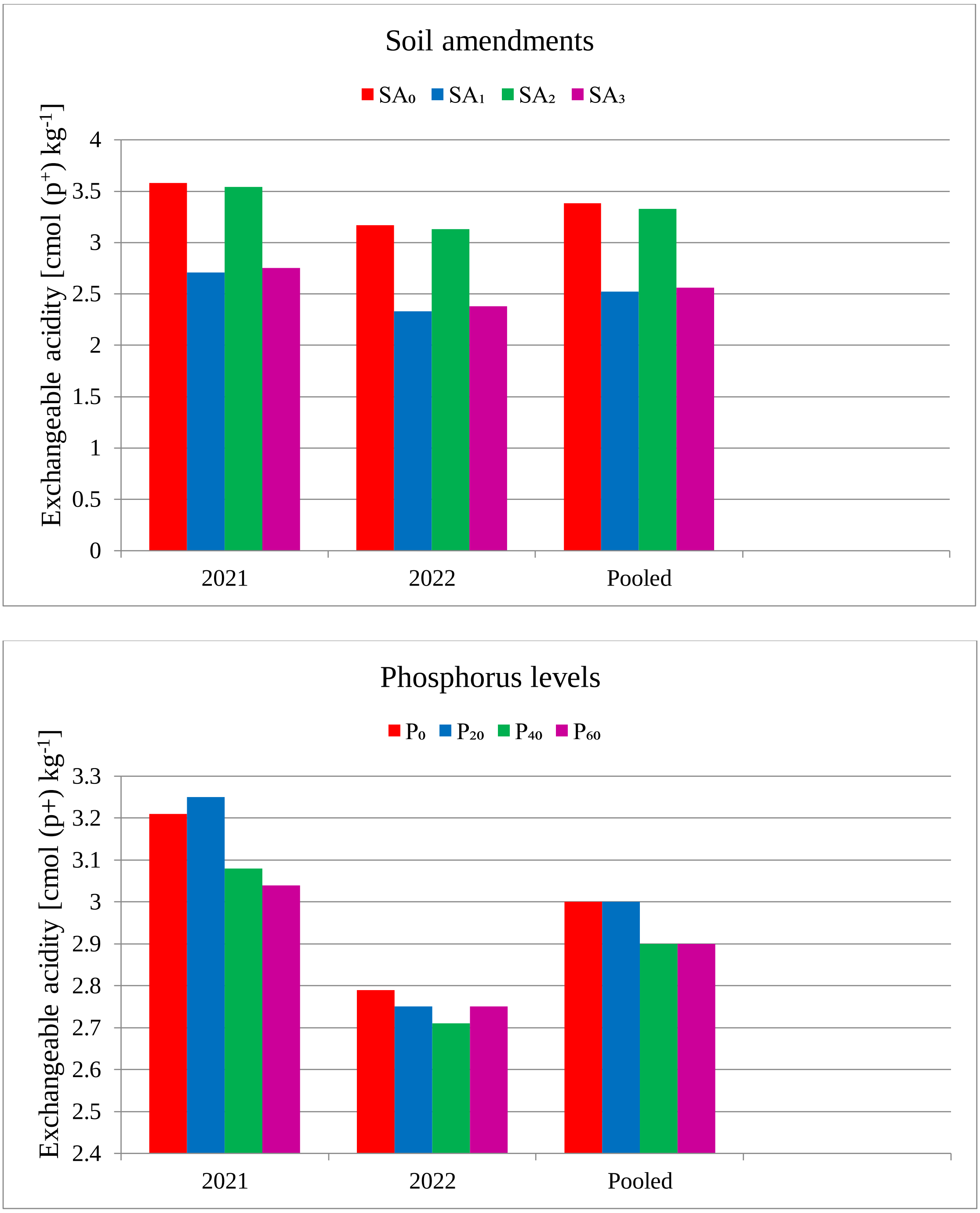


Fig 4.31: Effect of soil amendments and phosphorus on exchangeable acidity of experimental soil

[16.49 cmol(p^+)kg^{-1}] and minimum was recorded at SA_1 with a pooled value of 15.32 cmol(p^+)kg^{-1} that was at statistically at par with SA_3 [15.35cmol(p^+)kg^{-1}].

The reduction in pH dependent acidity could be attributed to the deprotonation of the pH-dependent charge sites as the soil pH raise due to liming. These results are in conformity with Dixit and Sharma (1993) and Rajneesh *et al*. (2018).

4.4.8.2. Effect of phosphorus levels

Further evaluation of the data given in Table 4.19 reflected that effect of levels of phosphorus on pH dependent acidity was statistically non-significant. However, irrespective of P levels the pooled value of pH dependent acidity of post harvest soil varies from 15.83 to 16.02 cmol(p^+)kg^{-1}.

4.4.9. Exchangeable acidity

4.4.9.1. Effect of soil amendments

From the data presented in Table 4.19 and illustrated in Fig 4.31 it can be observed that application of soil amendments significantly lowered the exchangeable acidity of post harvest soil; however the reduction can be observed only in lime amended plots either applied sole or in conjoint. From the pooled data, irrespective of amendment levels the exchangeable acidity ranged from 2.52 to 3.38 cmol(p^+)kg^{-1}. Maximum exchangeable acidity (3.38 cmol(p^+)kg^{-1}) was recorded at control which was at par with SA_2 (PSB) while minimum (2.52 cmol(p^+)kg^{-1}) was recorded at SA_1 (5% LR) that was at par with SA_3 (5% LR + PSB). The reduction in exchangeable acidity in lime amended plots (either alone or combined) can be ascribed to the displacement of Al^{+3} and H^+ from exchange sites by OH^- ions and Ca^{2+} ionsand decreasing solubility potential of Al when pH of the soil raisedue to liming. Further evaluation of data revealed that exchangeable acidity was decrease by 25.4% at SA_1 and 23.1% at SA_3 over control. A similar result on decrease in exchangeable acidity by liming was reported by Borah *et al.* (2000) and Ananthakumar *et al*. (2019). However, from the data it was observed that the exchangeable acidity at sole PSB amended plot did not exhibit any significant variation.

4.4.9.2. Effect of phosphorus levels

An evaluation of the data given in Table 4.19 and Fig 4.31 further indicated that application of phosphorus had no influence on exchangeable acidity. However, during 2021 and 2022, irrespective of P levels the pooled value of exchangeable acidity ranged from 2.90 to 3.00 cmol(p^+)kg^{-1}.

4.4.10. Exchangeable Al^{3+}

4.4.10.1. Effect of soil amendments

The data pertaining exchangeable aluminium of post harvest soil have been presented in Table 4.20 and delineated in Fig 4.32. During 2021 and 2022, maximum exchangeable Al^{3+} of post harvest soil was registered at SA_0 with a pooled value of 2.25cmol(p^+)kg^{-1} that was at par with SA_2 [2.19 cmol(p^+)kg^{-1}] while minimum was recorded at SA_3 with a pooled value of 1.81 cmol(p^+)kg^{-1} and was at par with SA_1 [1.88 cmol(p^+)kg^{-1}]. Exchangeable aluminium was significantly lower in lime amended plots compared to control. This decrease may be attributed to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as $Al(OH)^3$, as the soil was limed (Havlin *et al*., 1999). Moreover, an increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides thus reducing concentration of Al in soil solution (Ritchie, 1989). These results are conformity with the findings reported by Muindi *et al*. (2015) and Tasung *et al*. (2023). The exchangeable Al was slightly lower in PSB amended plots

Table 4.20: Effect of soil amendments and phosphorus on exchangeable Al^{3+} and H^{+} of post harvest soil

Treatments	Exchangeable Al^{3+} [cmol(p^{+})kg^{-1}]			Exchangeable H^{+} [cmol(p^{+})kg^{-1}]		
	2021	2022	Pooled	2021	2022	Pooled
Soil amendments						
SA_0 (Control)	2.38	2.13	2.25	1.21	1.04	1.13
SA_1 (5% LR)	2.00	1.75	1.88	0.71	0.58	0.65
SA_2 (PSB)	2.29	2.08	2.19	1.25	1.04	1.15
SA_3 (5% LR + PSB)	1.96	1.67	1.81	0.79	0.71	0.75
SEm±	0.12	0.10	0.08	0.14	0.12	0.09
CD (P=0.05)	0.34	0.30	0.22	0.40	0.35	0.26
Phosphorus levels						
P_0	2.21	1.92	2.06	1.00	0.88	0.94
P_{20}	2.17	1.83	2.00	1.08	0.92	1.00
P_{40}	2.17	2.00	2.08	0.92	0.71	0.81
P_{60}	2.08	1.88	1.98	0.96	0.88	0.92
SEm±	0.12	0.10	0.08	0.14	0.12	0.09
CD (P=0.05)	NS	NS	NS	NS	NS	NS

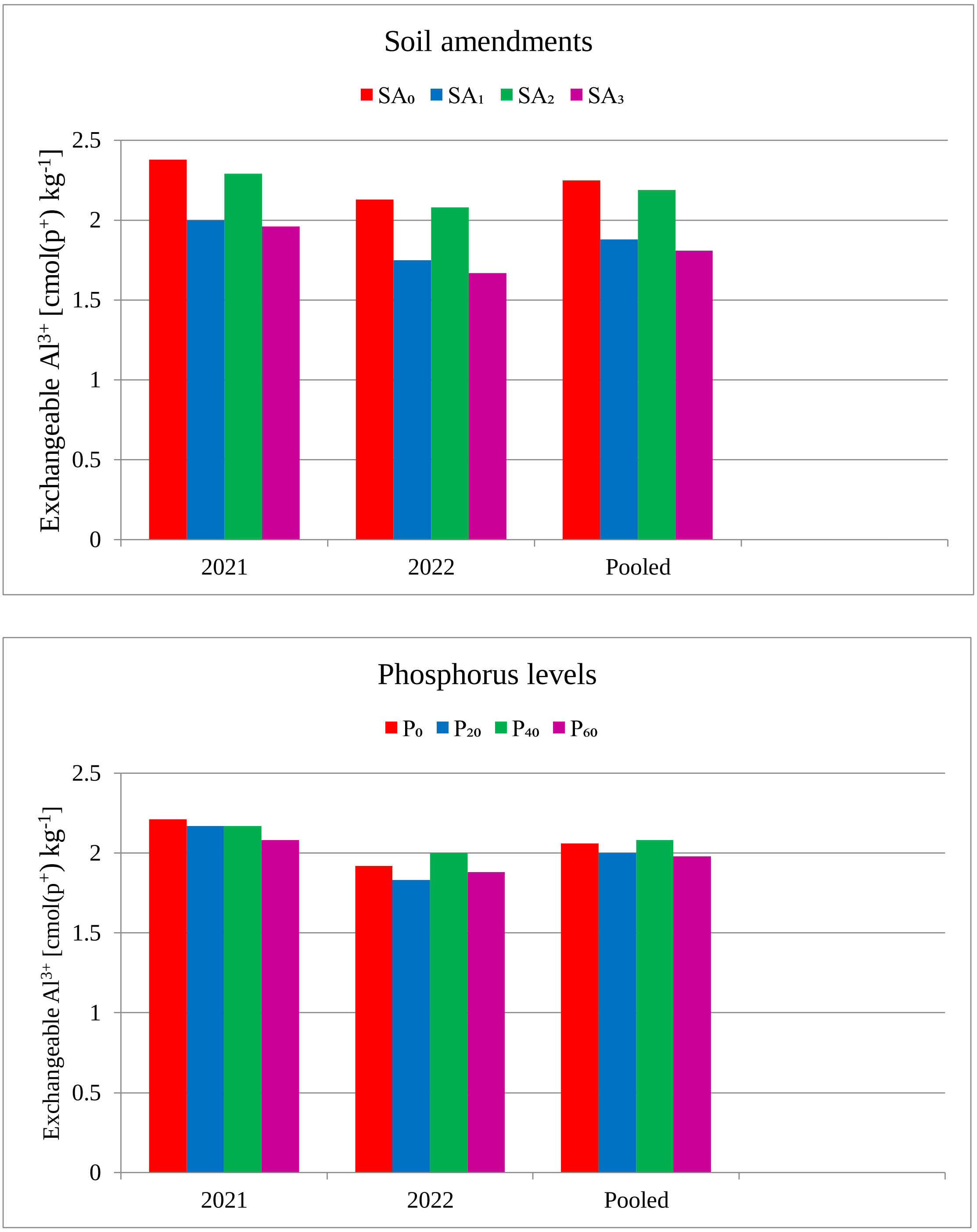
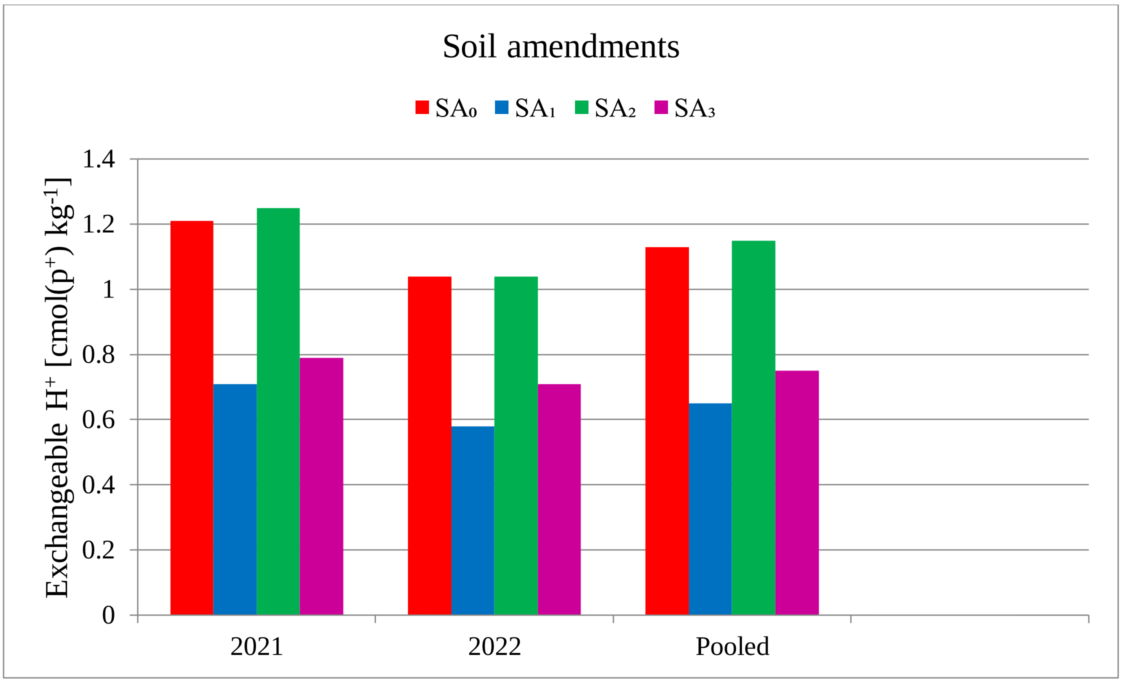


Fig 4.32: Effect of soil amendments and phosphorus on exchangeable aluminium of experimental soil



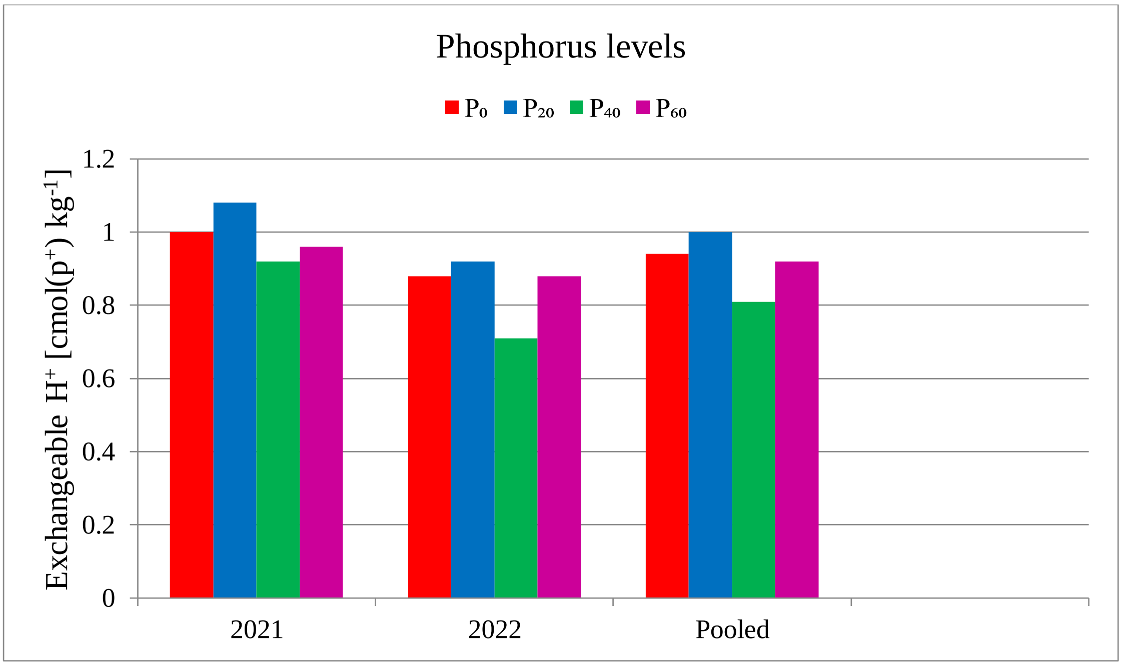


Fig 4.33: Effect of soil amendments and phosphorus on exchangeable hydrogen of experimental soil

compared with the control, but the variation was insignificant when PSB was applied alone and statistically significant when PSB was applied in combination.

4.4.10.2. Effect of phosphorus levels

It is evident from the Table 4.20 that phosphorus application could not significantly influence the exchangeable Al^{3+} of post harvest soil. Irrespective of P levels the exchangeable aluminium ranged from 1.98 to 2.08 cmol(p^+)kg^{-1}.

4.4.11. Exchangeable H^+

4.4.11.1. Effect of soil amendments

It is apparent from the Table 4.20 and depicted in Fig 4.33 that the application of soil amendments had significant influence on exchangeable H^+. A critical evaluation of data revealed that the plots treated with amendment containing lime either sole or combined exhibited remarkable reduction in exchangeable H^+. During both the years of experimentations, maximum exchangeable H^+ was recorded at SA_2 with a pooled value of 1.15 cmol(p^+)kg^{-1} that was statistically at par with control [1.13 cmol(p^+)kg^{-1}] while minimum was recorded at SA_1 with a pooled value of 0.65 cmol(p^+ kg^{-1} which was at par with SA_3 [0.75 cmol(p^+)kg^{-1}]. The decreased in exchangeable H^+ observed in exclusively lime treated plots this might be due to the fact that $CaCO_3$ was used as the liming material for the current study and thus the Ca^{2+} cations in lime replace the H^+ ions on the exchange site and CO_3^{-2} anions neutralize the H^+ ion released from the exchange sites. These findings are in accordance with Odyou and Sharma (2020) and Uchoi and Sharma (2023). The exchangeable H^+ was slightly higher at PSB (sole) amended plots compared to control, but the difference was insignificant; the enhanced exchangeable H^+ might be due to secretion of weak organic acids by PSB which can be easily dissociated resulting in release of protons. These results are in agreement with those of Satyaprakash *et al*. (2017).

4.4.11.2. Effect of phosphorus levels

Further evaluation of the data given in Table 4.20 revealed that the effect phosphorus on exchangeable H^+ was statistically non-significant ($P < 0.05$). However during 2021 and 2022, irrespective of P levels the pooled value of exchangeable H^+ of post harvest soil ranged from 0.81 to 1.00 cmol(p^+)kg^{-1}.

4.4.12. Microbial biomass carbon

4.4.12.1. Effect of soil amendments

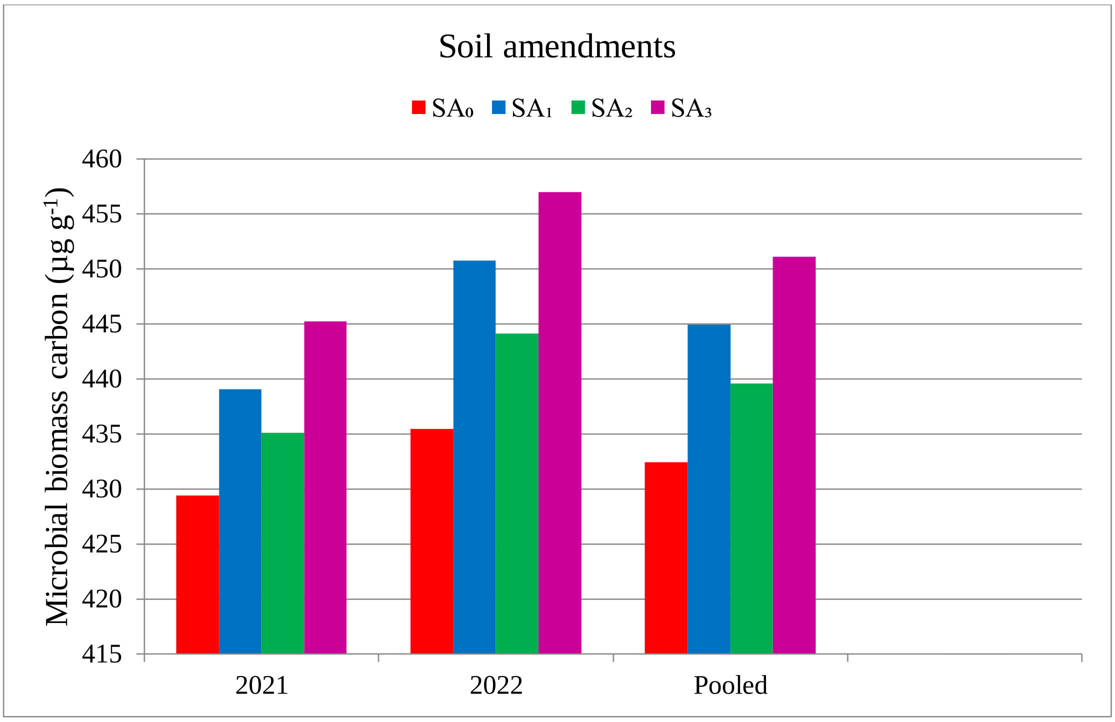
The data pertaining microbial biomass carbon of post harvest soil have been presented in Table 4.21 and illustrated in Fig 4.34. It is evident that microbial biomass was enhanced significantly with application of soil amendments. During 2021 and 2022, maximum microbial biomass carbon was noted at SA_3 with a pooled value of 451.11 µg g^{-1} while minimum was recorded at SA_0 with a pooled value of 432.44 µg g^{-1}. However, during 2021, SA_1 was found to be at par with SA_2. Jokinen *et al.* (2006) reported the increase in microbial activity in amended soil was probably ascribed to increase in soil pH, which created a more hospitable environment for soil microorganisms. Furthermore, PSB enhanced the availability of nutrients by solubilising the insoluble nutrients which serve as a substrate for the microbes, thus microbial inoculation showed increase in microbial cells in soil over uninoculated control treatment. These results are in close agreement with that of Gogoi *et al*. (2010), Hassan *et al*. (2017) and Dkhar *et al.* (2019).

4.4.12.2. Effect of phosphorus levels

Further evaluation of data given in Table 4.21 revealed that the microbial biomass carbon of soil at harvest significantly increased with

Table 4.21: Effect of soil amendments and phosphorus on microbial biomass carbon

Treatments	Microbial biomass carbon (µg g^{-1})		
	2021	2022	Pooled
Soil amendments			
SA_0 (Control)	429.40	435.48	432.44
SA_1 (5% LR)	439.05	450.79	444.92
SA_2 (PSB)	435.10	444.13	439.61
SA_3 (5% LR + PSB)	445.24	456.98	451.11
SEm±	3.01	1.61	1.71
CD (P=0.05)	8.69	4.64	4.83
Phosphorus levels			
P_0	412.67	425.74	419.20
P_{20}	432.20	442.79	437.50
P_{40}	446.50	453.96	450.23
P_{60}	457.41	464.88	461.15
SEm±	3.01	1.61	1.71
CD (P=0.05)	8.69	4.64	4.83



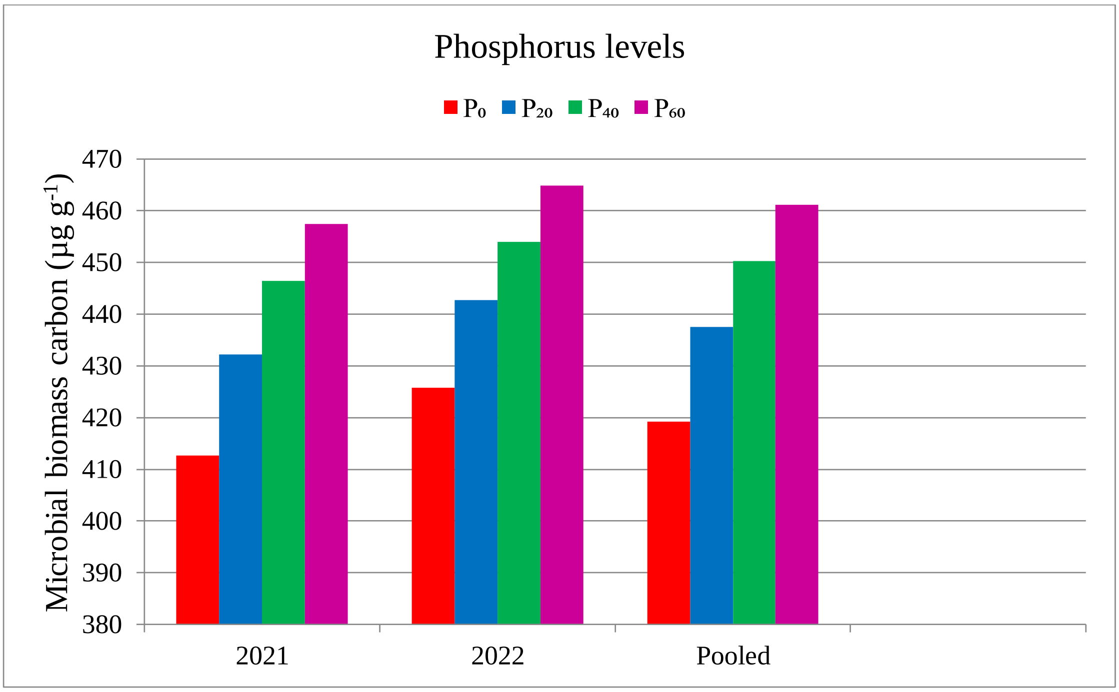


Fig 4.34: Effect of soil amendments and phosphorus on microbial biomass carbon of experimental soil

increasing levels of phosphorus. During 2021 and 2022, maximum microbial biomass carbon was noted at 60 kg P_2O_5 ha^{-1} with a pooled value of 461.15 µg g^{-1} while minimum was noted at control with a pooled value of 419.20 µg g^{-1}. The microbial biomass carbon increased with increase in dose of inorganic fertilizers, may be attributed primarily to increase in microbial population (Hasebe *et al*., 1985) and furthermore to the formation of root exudates, mucigel soughed off cells and underground roots from previous crops which also play a pivotal role in increasing biomass carbon (Goyal *et al*., 1992). Again, it might be due to the enhancing effect of P fertilization on soil organic matter level and also because more cellular components were synthesized. Similar results were reported by Souza *et al*. (2013) and Mohammad *et al*. (2017).

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

A field investigation entitled, "Effect of soil amendments and phosphorus on performance of black gram (*Vigna mungo* L. Hepper) in acidic soil of Nagaland" was conducted during the *kharif* season of 2021 and 2022 at the experimental farm of the Department of Soil Science, School of Agricultural Sciences, Medziphema campus, Nagaland University. The main findings of the investigation are summarized in the following heads.

Effect of soil amendments and phosphorus on growth and yield of black gram

1. Plant height of black gram was significantly increased with the application of soil amendments. During 2021 and 2022, from the pooled data, maximum plant height at 25 DAS (12.51 cm and was at par with SA_1), 50 DAS (35.44 cm) and at harvest (40.79 cm) was recorded with SA_3. However, in 2021 at 25 DAS, the maximum height was recorded at SA_1 with value of 10.17 cm that was at par with SA_3. Phosphorus application significantly increased the plant height with the advancement of days. The maximum pooled value of plant height at 25 DAS (13.05 cm and was at par with 40 kg P_2O_5 ha^{-1}), 50 DAS (35.71 cm) and at harvest (41.38 cm) was registered at 60 kg P_2O_5 ha^{-1}, except for plant height at 25th day in 2021 the maximum plant height was noted at 40 kg P_2O_5 ha^{-1} which was statistically at par with 60 kg P_2O_5 ha^{-1}. Soil amendment and phosphorus showed significant interaction at pooled data on 50th day and at harvest. From the pooled data, the plant height at 50 DAS (40.44 cm) and at harvest (47.13 cm) showed significant increase in plant stature and highest plant height was observed with the treatment combination SA_3P_{60}.
2. It was observed that number of branches was significantly higher in amended plots over control. However, during the initial days of plant

growth the influence of PSB on number of branches was not very distinct. During both the years of experimentation, maximum number of branches per plant at 25, 50 DAS and at harvest was observed at SA_3 with a pooled value of 1.01, 1.90 and 2.07, respectively, while minimum was recorded at control (0.57, 1.43 and 1.57, respectively). However in both the years of experimentation, during the initial growth stage (i.e., at 25 DAS), the number of branches noted at SA_2 (0.58 and 0.73, respectively) was statistically at par with SA_0 (0.50 and 0.63, respectively); and during 2021, on 50th day and at harvest, number of branches at SA_3 was at par with SA_1. Phosphorus level 60 kg P_2O_5 ha^{-1} significantly increased the number of branches per plant and at harvest (from the pooled data) the increase was to an extent 62.6% higher over control. However, during 2021 at all growth stages number of branches recorded at 60 kg P_2O_5 ha^{-1} was found to be at par with 40 kg P_2O_5 ha^{-1}.

3. Number of pods plant^{-1} was significantly enhanced with the application of soil amendments. From the pooled data, maximum number of pods plant^{-1} (13.08) increased to an extent by 23.7% over control with the application of 5% LR + PSB (SA_3). Application of phosphorus @60 kg P_2O_5 ha^{-1} significantly increased number of pods plant^{-1} (13.28) to an extent by 40.0% over control which was at par with 40 kg P_2O_5 ha^{-1}. Interaction effect of soil amendments and phosphorus on number of pods plant^{-1} was found significant during 2022 and at pooled data. Irrespective of years of experimentation, the treatment combination SA_3P_{60} marked the maximum number of pods plant^{-1} over rest of the treatment combination.

4. It was observed that pod length of black gram was significantly augmented in amended plots compared with control. From the pooled data, maximum pod length was recorded at SA_3 with a pooled value of 4.48 cm while minimum was recorded at control with a pooled value of 4.14 cm which was at par with SA_2 (4.23 cm). The significant increased in pod length was

observed only in lime treated plots either sole or combined while pod length of black gram was enhanced slightly in sole PSB treated plots but was statistically not different to control. Combined application of lime and PSB significantly augmented the pod length by 8.2% over control. Application of phosphorus significantly influenced the pod length of black gram. Maximum pooled pod length was registered with the application of 60 kg P_2O_5 ha^{-1} (4.50 cm) and was at par with 40 kg P_2O_5 while minimum at control (3.99 cm).

5. The seed pod^{-1} was significantly higher in amended plots and SA_3 level increased to an extent of 10.2% over control. From the pooled data, maximum seed pod^{-1} was recorded with the application of 5% LR + PSB (SA_3). Effect of phosphorus on seed pod^{-1} was recorded maximum at 60 kg P_2O_5 ha^{-1} (with a pooled value of 6.84) which was found to be at par with 40 kg P_2O_5 ha^{-1}. Treatment combination of soil amendments and phosphorus significantly increased the number of seed pod^{-1} of black gram. From pooled data, maximum seed was obtained with SA_3P_{60} (7.13) and was at par with SA_3P_{40}.
6. The effect of soil amendment and phosphorus on test weight of black gram was not significant. However, irrespective of treatments the test weight of black gram varied from 41.63 to 41.97 g.
7. Soil amendment exerted significant effect on seed yield of black gram. From the pooled data, maximum seed yield (627.69 kg ha^{-1}) was obtained with 5% LR + PSB application and acquired an increase to an extent by 29.9% over control. Effect of phosphorus on seed yield of black gram was found to be significant. Maximum pooled seed yield (641.73 kg ha^{-1}) obtained with 60 kg P_2O_5 ha^{-1}which was 45.3% higher than control and was statistically at par with 40 kg P_2O_5 ha^{-1} (640.00 kg ha^{-1}). It was observed that the seed yield of black gram increased with the increasing levels of phosphorus while the yield plateaued at 40 kg P_2O_5 ha^{-1}. The

interaction of soil amendments and phosphorus was significant with maximum seed yield obtained at treatment combination SA_3P_{60} which was at par with SA_3P_{40}.

8. On the basis of response curve the optimum dose of phosphorus was 49.35 kg P_2O_5 ha^{-1} for acquiring better production of seed yield of black gram in acidic soil of Nagaland.
9. The effect of soil amendment on stover yield was found to be significant. From the pooled data, SA_3 increased the stover yield to an extent by 35.7% over control. Application of phosphorus @ 60 kg P_2O_5 ha^{-1} significantly increased the stover yield by 55.9% over control. Treatment combination of soil amendments and phosphorus significantly increased the stover yield of black gram. From pooled data, maximum stover yield was obtained with SA_3P_{60} (1406.16 kg ha^{-1}) which was at par with SA_3P_{40}.

Effect of soil amendments and phosphorus on nutrient composition

1. Nitrogen content in seed and stover was significantly augmented with the application of soil amendments. Maximum pooled N content in seed (3.48%) and stover (1.33%) was recorded with the application of 5% LR + PSB (SA_3) and minimum at control (3.15% in seed and 1.21% in stover). Application of phosphorus on nitrogen content in seed and stover was found significant. In both years of experimentation, an apparent increase in N content in seed and stover was observed with increasing levels of P, with maximum N content in seed and stover was recorded at P_{60} (3.55 and 1.32 %, respectively) while minimum value was recorded at control (3.11 and 1.19%, respectively).
2. Protein content in seed of black gram was significantly higher in amended plots. From the pooled data, maximum protein content (21.75%) was obtained with application of SA_3 which recorded an increase to an extent of 10.5% higher over control. In both the years of experimentation, the protein

content in response to amendment levels was in order as such; $SA_3>SA_1>SA_2>SA_0$. Application of phosphorus significantly enhanced the protein content. From the pooled data, the maximum value of protein content (22.18%) was recorded at 60 kg P_2O_5 ha^{-1} and minimum was recorded at control (19.43%).

3. Phosphorus content in seed and stover was significantly increased with the application of soil amendments. The maximum pooled phosphorus content in seed (0.37%) and stover (0.18%) was noted with the application of 5% LR + PSB (SA_3) while minimum value was noted at control (0.33% in seed and 0.14% in stover). The effect of levels of phosphorus on phosphorus content in seed and stover was found to be significant. During 2021 and 2022, maximum P content in seed and stover was registered at 60 kg P_2O_5 ha^{-1} with a pooled value of 0.38 and 0.18%, respectively, while minimum at control with a pooled value of 0.32 and 0.14%, respectively.
4. Potassium content in seed and stover were influenced markedly by soil amendments. During 2021 and 2022, maximum potassium content was registered at SA_3 with a pooled value of 0.87% in seed and 1.47% in stover while minimum was registered at control (0.70 and 1.38%, respectively) which was found to be at par with SA_2 in both seed and stover. However, the enhancement in potassium content in seed and stover was observed only in lime amended plots either applied alone or in combined. A critical evaluation of the data further revealed that potassium content at PSB sole amended plots (SA_2) was not statistically different to that of control. The effect of phosphorus application on potassium content in seed and stover of black gram was statistically significant. Irrespective of years of experimentation, the potassium content in seed and stover in response to phosphorus application ranged from 0.65 to 0.89% and 1.27 to 1.57%, respectively. The potassium content in seed and stover obtained at

phosphorus level P_{60} was superior to the preceding lower level of P but was found to be statistically at par with P_{40}.

5. Calcium content in seed and stover was significantly enhanced with the application of soil amendments. During 2021 and 2022, calcium content in seed and stover ranged from 0.112 to 0.147% and 0.149 to 0.185%, respectively; wherein the maximum pooled calcium content in seed (0.147%) and stover (0.185%) was recorded at SA_3. It was also observed that calcium content in seed and stover noted at SA_2 was at par with control. The effect of phosphorus on calcium content in seed and stover was found to be non-significant.
6. Magnesium content in seed and stover was significantly higher in amended plots. The responses of magnesium content in seed as well as stover to soil amendments showed similar trend as that of calcium content. From the pooled data, maximum magnesium content in seed and stover was recorded SA_3 (0.099 and 0.146%, respectively) while minimum was recorded at control (0.057 and 0.089%, respectively) that was at par with SA_2 in both seed and stover. The effect of phosphorus on magnesium content in seed and stover was found to be non-significant.

Effect of soil amendments and phosphorus on nutrient uptake

1. Nitrogen uptake in seed, stover and total N uptake was significantly higher in amended plots over control. From the pooled data, maximum value was recorded at SA_3 which increased the nitrogen uptake by 43.2% in seed, 50.3% in stover and 46.1% in total N uptake over control. The effect of soil amendments on nitrogen uptake in seed, stover and total uptake of black gram was in order as such: SA_3>SA_1>SA_2> SA_0. Application of 60 kg P_2O_5 ha^{-1} increased the nitrogen uptake to an extent of 66.5% in seed, 71.9% in stover and 68.7% in total uptake over control. Treatment combination of soil amendments and phosphorus significantly increased the nitrogen uptake

of black gram. From pooled data, maximum N uptake in seed, stover and total N uptake was recorded with treatment combination SA_3P_{60} which was at par with SA_3P_{40} while the minimum was recorded at SA_0P_0.

2. Phosphorus uptake in seed, stover and total P uptake was enhanced significantly with the application of soil amendments. The maximum pooled phosphorus uptake was registered at SA_3which enhanced the P uptake to an extent of 48.1% in seed, 71.8% in stover and 58.0% in total P uptake. The superiority of amendments may be arranged as: SA_3>SA_1>SA_2>SA_0. Application of 60 kg P_20_5 ha^{-1} increased the phosphorus uptake to an extent of 75.0% in seed, 100.8% in stover and 86.3% in total P uptake over control. Treatment combination SA_3P_{60} attained the maximum phosphorus uptake in seed, stover as well as total P uptake while minimum was recorded at SA_0P_0 (control).
3. Application of soil amendments brought about a significant increased in potassium uptake in seed, stover and total K uptake with maximum pooled value being recorded at SA_3 which induced an increase of 58.5% in seed, 43.8% in stover and 47.1% in total K uptake over control. From the pooled data, sole application of lime (SA_1) augmented the potassium uptake in seed and stover by 35.2 and 27.9% respectively over control while sole application of PSB (SA_2) enhanced the potassium uptake to an extent of 13.0 and 15.3% respectively over control. Overall the responses to amendments by potassium uptake in seed, stover as well as total K uptake are in order as such: SA_3>SA_1>SA_2>SA_0. Thus, response of potassium uptake in seed and stover of black gram to SA_3 was better among all the soil amendments. Potassium uptake in seed, stover and total K uptake increased with application of different levels of phosphorus. During 2021 and 2022, maximum K uptake was recorded with 60 kg P_2O_5 ha^{-1} with a pooled value of 5.38 kg ha^{-1}in seed, 17.88 kg ha^{-1}in stover and 23.26 kg ha^{-1}in total K uptake; however in both the years of experimentation, in both seed and

stover, the potassium uptake registered at P_{60} was found to be at par with P_{40}. While minimum was recorded at control with pooled value of 3.31 kg ha^{-1}in seed, 11.21 kg ha^{-1}in stover and 14.53 kg ha^{-1}in total K uptake. The phosphorus level P_{60} increased the potassium uptake by 62.5% in seed and 59.5% in stover over control.

4. Calcium uptake in seed, stover and total Ca uptake showed significant disparity among amendment treatments. Maximum calcium uptake in seed, stover as well as total Ca uptake was recorded in SA_3 and minimum was recorded at SA_0 in both the years. From the pooled data it can be observed that SA_3 enhanced the calcium uptake in seed by 72.7%, 63.2% in stover and 66.4% in total Ca uptake. Application of 60 kg P_2O_5 ha^{-1} increased the calcium uptake to an extent of 57.1% in seed, 70.6% in stover and 66.4% in total Ca uptake over control. However, calcium uptake in seed, stover and total Ca uptake was found at par with 40 kg P_2O_5 ha^{-1}. From the pooled data, maximum total Ca uptake was recorded with the treatment combination SA_3P_{40} which was at par with SA_3P_{60} while minimum was recorded at SA_0P_0 (control).
5. Magnesium uptake in seed, stover as well as total Mg uptake was significantly influenced with the application of soil amendments. From the pooled data, it can be observed that magnesium uptake was increased to an extent by 127.5% in seed, 122.5% in stover and 122.9% in total Mg uptake at SA_3 compared to control. Application of 60 kg P_2O_5 ha^{-1} increased the magnesium uptake in seed by 47.2%, 63.8% in stover and 56.1% in total Mg uptake. From the pooled data, maximum total Mg uptake was recorded with the treatment combination SA_3P_{60} which was at par with SA_3P_{40} while minimum was recorded at SA_0P_0 (control).

Effect of treatments on soil properties

1. Soil pH of post harvest soil was significantly higher in amended plots especially in lime amended plots either applied alone or combined. Maximum pooled pH was recorded in SA_3 with a value of 4.70 which was at par with SA_1 (4.66) while minimum was recorded atSA_2 with a value of 4.43 which was statistically at par with SA_0 (4.44). Phosphorus application did not have significant affect on pH of post harvest soil during both the years of experimentation.
2. Application of soil amendments brought about a significant influence on electrical conductivity of post harvest soil; however the increased in electrical conductivity was recorded exclusively in limed plots. Maximum pooled value on electrical conductivity was noted at SA_3 (0.19 dSm^{-1}) which was at par with SA_1 (0.18 dSm^{-1}) while minimum value was noted at control (0.15 dSm^{-1}) and was at par with SA_2 (0.15 dSm^{-1}). The effect of phosphorus on electrical conductivity was found to be non-significant in both the years of experimentation.
3. Organic carbon was slightly higher in amended soil compared with the control, but the differences were statistically non-significant ($P < 0.05$). The effect of phosphorus on organic carbon was not significant.
4. Application of soil amendments significantly increased the available nitrogen status of post harvest soil. During 2021 and 2022, the maximum available nitrogen in soil at harvest was recorded with the application of 5% LR alongside seed inoculated PSB (SA_3) with a pooled value of 290.60 kg ha^{-1} and minimum available nitrogen (249.83 kg ha^{-1}) was registered at control. Available nitrogen in post harvest soil was significantly affected by the different phosphorus levels. From the pooled data, maximum available nitrogen was noted with the application of 60 kg P_2O_5 ha^{-1} with a pooled value of 286.94 kg ha^{-1} which was found to be at par with 40 kg P_2O_5 ha^{-1} and minimum available nitrogen 248.27 kg ha^{-1} was recorded at control.

5. There was significant increased in available phosphorus of soil at harvest in response to application of soil amendments. Maximum pooled available phosphorus was recorded at SA_3 (14.86 kg ha^{-1}) while minimum at control (11.97 kg ha^{-1}). Application of 60 kg P_2O_5 ha^{-1} recorded the maximum available phosphorus with a pooled value of 16.58 kg ha^{-1} and minimum was recorded at control (10.14 kg ha^{-1}). The interactioneffect of soil amendments and phosphorus on available phosphorus in soil at harvest was found significant in both the years of experimentation. From the pooled data, maximum available phosphorus (18.60 kg ha^{-1}) was recorded at treatment combination SA_3P_{60}while minimum (9.54 kg ha^{-1}) was recorded at SA_0P_0.
6. Soil amendments had significant influence on available potassium of post harvest soil. During 2021 and 2022, maximum available potassium was noted at SA_3 with a pooled value of 178.90 kg ha^{-1}which was at par with SA_2 (178.43 kg ha^{-1}) and minimum available potassium was recorded at control with a pooled value of 176.38 kg ha^{-1}. The different levels of phosphorus application could not affect available potassium significantly after crop harvest.
7. Application of soil amendments significantly increased the exchangeable calcium of post harvest soil. During 2021 and 2022, irrespective of amendments treatment the pooled value of exchangeable calcium varied from 1.06 to 1.20 cmol(p^+)kg^{-1}. Maximum exchangeable calcium was reported at SA_3 which was found to be at par with SA_1 (1.19 cmol(p^+)kg^{-1}) while minimum was recorded at control which was statistically at par with SA_2 (1.07cmol(p^+)kg^{-1}). The effect of phosphorus on exchangeable calcium was not statistically significant.
8. The effect of soil amendments on exchangeable magnesium was statistically non-significant. However, from the pooled data, the maximum exchangeable magnesium was noted at SA_3 with a pooled value of 0.75

cmol(p^+)kg^{-1} while minimum was recorded at control (0.66 cmol(p^+)kg^{-1}). Also, there was no significant influence on exchangeable magnesium of post harvest soil with application of phosphorus.

9. Application of soil amendments significantly reduced the total potential acidity of post harvest soil. During 2021 and 2022, the maximum total potential acidity was recorded at control (19.96 cmol(p^+)kg^{-1}) which was at par with SA_2 (19.83cmol(p^+)kg^{-1}), while minimum was recorded at SA_1 (17.84 cmol(p^+)kg^{-1}) which was found to be statistically at par with SA_3 (17.92 cmol(p^+)kg^{-1}). Thereby, application of 5% LR (SA_1) decreased the total potential acidity by 10.6% over control. The effect of different levels of phosphorus could not bring about a significantly affect on total potential acidity.
10. pH dependent acidity was significantly lower in amended plots as compared to control. However, the decreased in pH dependent acidity was observed only in limed plots either applied alone or combined. During both the years of experimentation, maximum pH dependent acidity was registered at control with a pooled value of 16.58 cmol(p^+)kg^{-1} that was at par with SA_2 [16.49 cmol(p^+)kg^{-1}] and minimum was recorded at SA_1 with a pooled value of 15.32 cmol(p^+)kg^{-1} that was at statistically at par with SA_3 [15.35cmol(p^+)kg^{-1}]. The effect of phosphorus levels on pH dependent acidity was statistically non-significant.
11. Application of soil amendments significantly lowered the exchangeable acidity of post harvest soil; however the reduction can be observed only in lime amended plots either applied sole or in conjoint. Irrespective of amendment levels, the pooled data of exchangeable acidity ranged from 2.52 to 3.38 cmol(p^+)kg^{-1}. During 2021 and 2022, maximum exchangeable acidity was recorded at control which was at par with SA_2 (PSB) while minimum was recorded at SA_1 (5% LR) that was at par with SA_3 (5% LR + PSB). Further evaluation of data revealed that exchangeable acidity was

decrease by 25.4% at SA_1 and 23.1% at SA_3 over control. Phosphorus application had no influence on exchangeable acidity.

12. Exchangeable aluminium of post harvest soil was significantly reduced in amended plots as compared to control. During 2021 and 2022, maximum exchangeable Al^{3+} of post harvest soil was registered at SA_0 with a pooled value of 2.25cmol(p^+)kg^{-1} that was at par with SA_2 [2.19 cmol(p^+) kg^{-1}] while minimum was recorded at SA_3 with a pooled value of 1.81 cmol(p^+) kg^{-1} and was at par with SA_1 [1.88 cmol(p^+)kg^{-1}]. Phosphorus application could not significantly affect the exchangeable Al^{3+} of post harvest soil.
13. Application of soil amendments had significant influence on exchangeable H^+. It was observed that the plots treated with amendment containing lime either sole or combined exhibited remarkable reduction in exchangeable H^+. During both the years of experimentations, the maximum exchangeable H^+ was recorded at SA_2 with a pooled value of 1.15cmol(p^+)kg^{-1} that was statistically at par with control [1.13cmol(p^+)kg^{-1}] while minimum was recorded at SA_1 with a pooled value of 0.65 cmol(p^+)kg^{-1} which was at par with SA_3 [0.75 cmol(p^+)kg^{-1}]. The effect phosphorus on exchangeable H^+ was statistically non-significant ($P < 0.05$).
14. Microbial biomass was enhanced significantly with application of soil amendments. During 2021 and 2022, maximum microbial biomass carbon was noted at SA_3 with a pooled value of 451.11 µg g^{-1} while minimum was recorded at SA_0 with a pooled value of 432.44 µg g^{-1}. However, during 2021, SA_1 was found to be at par with SA_2. Also, there was significant increased in microbial biomass carbon of soil at harvest with the application of phosphorus. It was observed that there was an increase in microbial biomass carbon with the increasing P doses and maximum microbial biomass carbon was noted at 60 kg P_2O_5 ha^{-1} with a pooled value of 461.15 µg g^{-1} while minimum was noted at control with a pooled value of 419.20 µg g^{-1}.

CONCLUSIONS

The following conclusions were drawn from the summary of present study:

1. Plant growth, yield attributes, seed yield, stover yield, protein content nutrient content and uptake of black gram were enhanced significantly with application of soil amendment and phosphorus. SA_3 (5% lime of LR +PSB) performed comparatively better than rest of the soil amendment levels. Among the P levels, phosphorus application @ 60 kg ha^{-1} recorded comparatively higher values, however was at par with 40 kg P_2O_5 ha^{-1} on account of yield attributes and yield of black gram.

2. The optimum level of phosphorus calculated on the basis of pooled grain yield of black gram was found to be 49.35 kg P_2O_5 ha^{-1}.

3. Application of soil amendments significantly increased the soil pH, EC, available N, P, K, exchangeable calcium and soil microbial biomass carbon, and reduced soil acidity components. Application of phosphorus significantly enhanced the soil available nitrogen, phosphorus and soil microbial biomass carbon of post harvest soil.

4. Hence, application of 50 kg P_2O_5 ha^{-1} along with soil amendments (5% lime of LR + PSB) is recommended for getting better yield of black gram under acidic soil condition of Nagaland.

5. From the present study it can be concluded that in such acidic soil application of inorganic P fertilizers without lime will be less beneficial for black gram production since the availability of P in the soil are restricted for plant uptake. Therefore, application of phosphorus along with lime + PSB might be a sustainable approach to enhance the efficiency of phosphatic fertilizer and to reduce adverse effect of soil acidity.

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APPENDICES

APPENDICES

Appendix I: Effect of soil amendments and phosphorus on plant height of black gram at 25 DAS

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.53	0.27	0.68	0.28	0.14	0.19	3.32	Replication	4	0.81	0.20	0.36	2.53
SA	3	8.02	2.67	6.83*	26.39	8.80	12.00*	2.92	SA	6	34.40	5.73	10.20*	2.25
P	3	57.34	19.11	48.86*	88.05	29.35	40.03*	2.92	P	6	145.38	24.23	43.10*	2.25
SA×P	9	5.42	0.60	1.54	8.31	0.92	1.26	2.21	SA×P	18	13.72	0.76	1.36	1.78
Error	30	11.74	0.39		22.00	0.73			Error	60	33.73	0.56		
Total	47	83.04			145.02				Total	95	717.84			

Appendix II: Effect of soil amendments and phosphorus on plant height of black gram at 50 DAS

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	1.86	0.93	0.86	1.39	0.69	0.46	3.32	Replication	4	3.25	0.81	0.63	2.53
SA	3	237.56	79.19	73.09*	994.36	331.45	221.67*	2.92	SA	6	1231.92	205.32	159.24*	2.25
P	3	751.48	250.49	231.21*	871.21	290.40	194.22*	2.92	P	6	1622.70	270.45	209.76*	2.25
SA×P	9	17.65	1.96	1.81	24.24	2.69	1.80	2.21	SA×P	18	41.89	2.33	1.81*	1.78
Error	30	32.50	1.08		44.86	1.50			Error	60	77.36	1.29		
Total	47	1041.05			1936.06				Total	95	5903.93			

Appendix III: Effect of soil amendments and phosphorus on plant height of black gram at harvest

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.11	0.06	0.08	1.00	0.50	0.33	3.32	Replication	4	1.11	0.28	0.25	2.53
SA	3	210.24	70.08	96.42*	1161.24	387.08	258.37*	2.92	SA	6	1371.48	228.58	205.47*	2.25
P	3	865.94	288.65	397.12*	971.72	323.91	216.21*	2.92	P	6	1837.66	306.28	275.31*	2.25
SA×P	9	9.63	1.07	1.47	28.69	3.19	2.13	2.21	SA×P	18	38.32	2.13	1.91*	1.78
Error	30	21.81	0.73	0.08	44.94	1.50			Error	60	66.75	1.11		
Total	47	1107.73			2207.59				Total	95	5949.88			

*Significant at 5%

Appendix IV: Effect of soil amendments and phosphorus on number of branches per plant of black gram at 25 DAS

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.002	0.001	0.08	0.02	0.01	0.71	3.32	Replication	4	0.02	0.01	0.45	2.53
SA	3	1.28	0.43	40.29*	1.73	0.58	37.73*	2.92	SA	6	3.01	0.50	38.78*	2.25
P	3	2.40	0.80	75.47*	2.90	0.97	63.33*	2.92	P	6	5.30	0.88	68.30*	2.25
SA×P	9	0.05	0.01	0.57	0.07	0.01	0.49	2.21	SA×P	18	0.12	0.01	0.52	1.78
Error	30	0.32	0.01		0.46	0.02			Error	60	0.78	0.01		
Total	47	4.06			5.18				Total	95	9.97			

Appendix V: Effect of soil amendments and phosphorus on number of branches per plant of black gram at 50 DAS

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.02	0.01	0.30	0.002	0.001	0.04	3.32	Replication	4	0.02	0.004	0.17	2.53
SA	3	0.80	0.27	10.58*	2.28	0.76	33.01*	2.92	SA	6	3.09	0.51	21.28*	2.25
P	3	5.14	1.71	67.81*	4.54	1.51	65.59*	2.92	P	6	9.68	1.61	66.75*	2.25
SA×P	9	0.01	0.00	0.06	0.08	0.01	0.40	2.21	SA×P	18	0.10	0.01	0.22	1.78
Error	30	0.76	0.03		0.69	0.02			Error	60	1.45	0.02		
Total	47	6.73			7.60				Total	95	15.88			

Appendix VI: Effect of soil amendments and phosphorus on number of branches per plant of black gram at harvest

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.01	0.01	0.24	0.01	0.003	0.10	3.32	Replication	4	0.02	1.50	0.16	2.53
SA	3	0.68	0.23	9.29*	2.83	0.94	27.38*	2.92	SA	6	3.51	0.005	19.86*	2.25
P	3	5.02	1.67	68.33*	6.25	2.08	60.48*	2.92	P	6	11.27	0.59	63.74*	2.25
SA×P	9	0.03	0.003	0.12	0.10	0.01	0.33	2.21	SA×P	18	0.13	1.88	0.24	1.78
Error	30	0.73	0.02		1.03	0.03			Error	60	1.77	0.01		
Total	47	6.48			10.22				Total	95	18.20			

*Significant at 5%

Appendix VII: Effect of soil amendments and phosphorus on number of pods per plant of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.28	0.14	0.88	2.78	1.39	2.85	3.32	Replication	4	3.06	0.76	2.37	2.53
SA	3	33.10	11.03	69.94*	54.67	18.22	37.39*	2.92	SA	6	87.77	14.63	45.35*	2.25
P	3	81.94	27.31	173.14*	143.32	47.77	98.01*	2.92	P	6	225.26	37.54	116.38*	2.25
SA×P	9	1.43	0.16	1.01	12.70	1.41	2.90*	2.21	SA×P	18	14.13	0.79	2.43*	1.78
Error	30	4.73	0.16		14.62	0.49			Error	60	19.35	0.32		
Total	47	121.48			228.09				Total	95	433.05			

Appendix VIII: Effect of soil amendments and phosphorus on pod length of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.09	0.04	1.13	0.01	0.00	0.08	3.32	Replication	4	0.09	0.02	0.55	2.53
SA	3	0.68	0.23	5.87*	0.88	0.29	6.08*	2.92	SA	6	1.56	0.26	5.99*	2.25
P	3	1.95	0.65	16.90*	1.63	0.54	11.24*	2.92	P	6	3.58	0.60	13.74*	2.25
SA×P	9	0.06	0.01	0.17	0.07	0.01	0.16	2.21	SA×P	18	0.13	0.01	0.17	1.78
Error	30	1.15	0.04		1.46	0.05			Error	60	2.61	0.04		
Total	47	3.92			4.05				Total	95	8.04			

Appendix IX: Effect of soil amendments and phosphorus on seed per pod

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.01	0.003	0.21	0.001	0.001	0.12	3.32	Replication	4	0.01	0.002	0.19	2.53
SA	3	4.15	1.38	93.39*	1.37	0.46	104.09*	2.92	SA	6	5.52	0.92	95.84*	2.25
P	3	7.83	2.61	176.39*	4.70	1.57	356.46*	2.92	P	6	12.53	2.09	217.59*	2.25
SA×P	9	0.36	0.04	2.71*	0.12	0.01	3.11*	2.21	SA×P	18	0.48	0.03	2.80*	1.78
Error	30	0.44	0.01		0.13	0.004			Error	60	0.58	0.01		
Total	47	12.79			6.32				Total	95	20.19			

*Significant at 5%

Appendix X: Effect of soil amendments and phosphorus on test weight

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.08	0.04	0.05	0.28	0.14	0.41	3.32	Replication	4	0.36	0.09	0.16	2.53
SA	3	0.36	0.12	0.15	0.78	0.26	0.76	2.92	SA	6	1.14	0.19	0.33	2.25
P	3	0.72	0.24	0.30	0.84	0.28	0.82	2.92	P	6	1.56	0.26	0.46	2.25
SA×P	9	0.04	0.004	0.01	0.04	0.005	0.01	2.21	SA×P	18	0.08	0.005	0.01	1.78
Error	30	23.77	0.79		10.31	0.34			Error	60	34.08	0.57		
Total	47	24.96			12.26				Total	95	37.25			

Appendix XI: Effect of soil amendments and phosphorus on grain yield

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	2488.81	1244.41	1.67	524.00	262.00	0.43	3.32	Replication	4	3012.81	753.20	1.11	2.53
SA	3	111959.23	37319.74	50.17*	163074.01	54358.00	88.41*	2.92	SA	6	275033.24	45838.87	67.47*	2.25
P	3	158778.98	52926.33	71.15*	661897.07	220632.36	358.85*	2.92	P	6	820676.05	136779.34	201.34*	2.25
SA×P	9	14854.18	1650.46	2.22*	20082.89	2231.43	3.63*	2.21	SA×P	18	34937.07	1940.95	2.86*	1.78
Error	30	22316.88	743.90		18444.77	614.83			Error	60	40761.64	679.36		
Total	47	310398.08			864022.73				Total	95	2607743.33			

Appendix XII: Effect of soil amendments and phosphorus on stover yield

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	10207.74	5103.87	2.24	3199.34	1599.67	0.37	3.32	Replication	4	13407.07	3351.77	1.02	2.53
SA	3	574420.61	191473.54	84.13*	693531.75	231177.25	53.60*	2.92	SA	6	1267952.36	211325.39	64.15*	2.25
P	3	891728.52	297242.84	130.60*	2647780.30	882593.43	204.64*	2.92	P	6	3539508.82	589918.14	179.06*	2.25
SA×P	9	45986.71	5109.63	2.25*	94697.13	10521.90	2.44*	2.21	SA×P	18	140683.84	7815.77	2.37*	1.78
Error	30	68276.85	2275.89		129389.73	4312.99			Error	60	197666.58	3294.44		
Total	47	1590620.43			3568598.24				Total	95	10679817.63			

*Significant at 5%

Appendix XIII: Effect of soil amendments and phosphorus on N content in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.01	0.005	1.49	0.01	0.003	1.19	3.32	Replication	4	0.02	0.004	1.35	2.53
SA	3	1.16	0.39	117.84*	0.43	0.14	51.35*	2.92	SA	6	1.59	0.27	87.18*	2.25
P	3	1.09	0.36	111.16*	1.54	0.51	182.56*	2.92	P	6	2.63	0.44	144.09*	2.25
SA×P	9	0.04	0.005	1.42	0.03	0.003	1.06	2.21	SA×P	18	0.07	0.004	1.25	1.78
Error	30	0.10	0.003		0.08	0.003			Error	60	0.18	0.003		
Total	47	2.40			2.09				Total	95	4.69			

Appendix XIV: Effect of soil amendments and phosphorus on N content in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.00	0.00	0.01	0.001	0.001	0.19	3.32	Replication	4	0.001	0.0003	0.09	2.53
SA	3	0.06	0.02	5.48*	0.19	0.06	23.31*	2.92	SA	6	0.25	0.04	13.01*	2.25
P	3	0.18	0.06	16.66*	0.07	0.02	8.67*	2.92	P	6	0.25	0.04	13.29*	2.25
SA×P	9	0.01	0.002	0.45	0.003	0.0003	0.11	2.21	SA×P	18	0.02	0.001	0.30	1.78
Error	30	0.11	0.004		0.08	0.003			Error	60	0.19	0.003		
Total	47	0.37			0.34				Total	95	1.20			

Appendix XV: Effect of soil amendments and phosphorus on P content in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.0002	0.0001	0.50	0.001	0.0003	2.93	3.32	Replication	4	0.0008	0.0002	1.29	2.53
SA	3	0.02	0.01	27.38*	0.01	0.004	40.30*	2.92	SA	6	0.03	0.005	31.60*	2.25
P	3	0.03	0.01	49.43*	0.03	0.01	96.07*	2.92	P	6	0.06	0.01	64.66*	2.25
SA×P	9	0.001	0.0001	0.30	0.0001	0.00002	0.16	2.21	SA×P	18	0.001	0.00004	0.26	1.78
Error	30	0.01	0.0002		0.003	0.0001			Error	60	0.01	0.0002		
Total	47	0.06			0.05				Total	95	0.26			

*Significant at 5%

Appendix XVI: Effect of soil amendments and phosphorus on P content in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.00003	0.00002	0.12	0.00004	0.00002	0.28	3.32	Replication	4	0.0001	0.00002	0.17	2.53
SA	3	0.01	0.003	20.62*	0.01	0.004	52.66*	2.92	SA	6	0.02	0.0033	30.92*	2.25
P	3	0.01	0.004	29.79*	0.01	0.004	52.09*	2.92	P	6	0.02	0.0039	36.96*	2.25
SA×P	9	0.00	0.00001	0.10	0.0002	0.00002	0.33	2.21	SA×P	18	0.0003	0.00002	0.18	1.78
Error	30	0.00	0.0001		0.002	0.0001			Error	60	0.01	0.0001		
Total	47	0.03			0.02				Total	95	0.07			

Appendix XVII: Effect of soil amendments and phosphorus on K content in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.002	0.001	0.35	0.00	0.002	0.69	3.32	Replication	4	0.01	0.002	0.54	2.53
SA	3	0.42	0.14	52.86*	0.10	0.03	10.57*	2.92	SA	6	0.53	0.09	29.56*	2.25
P	3	0.05	0.015	5.80*	0.051	0.017	5.23*	2.92	P	6	0.10	0.016	5.49*	2.25
SA×P	9	0.00	0.000	0.12	0.01	0.00	0.29	2.21	SA×P	18	0.01	0.00	0.21	1.78
Error	30	0.08	0.003		0.10	0.003			Error	60	0.18	0.003		
Total	47	0.55			0.27				Total	95	1.39			

Appendix XVIII: Effect of soil amendments and phosphorus on K content in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.001	0.000	1.89	0.00	0.001	1.43	3.32	Replication	4	0.00	0.001	1.53	2.53
SA	3	0.01	0.00	14.34*	0.12	0.04	49.82*	2.92	SA	6	0.13	0.02	41.64*	2.25
P	3	0.00	0.001	5.75*	0.009	0.003	3.70*	2.92	P	6	0.01	0.002	4.17*	2.25
SA×P	9	0.00	0.000	0.14	0.00	0.00	0.41	2.21	SA×P	18	0.00	0.00	0.35	1.78
Error	30	0.01	0.000		0.02	0.001			Error	60	0.03	0.001		
Total	47	0.02			0.16				Total	95	1.86			

*Significant at 5%

Appendix XIX: Effect of soil amendments and phosphorus on Ca content in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.0004	0.0002	1.43	0.001	0.0004	2.56	3.32	Replication	4	0.001	0.0003	2.02	2.53
SA	3	0.01	0.002	13.01*	0.01	0.005	33.57*	2.92	SA	6	0.02	0.003	23.68*	2.25
P	3	0.001	0.0003	2.11	0.001	0.0002	1.20	2.92	P	6	0.001	0.0002	1.64	2.25
SA×P	9	0.0004	0.00004	0.31	0.001	0.0001	0.38	2.21	SA×P	18	0.001	0.0001	0.35	1.78
Error	30	0.004	0.0001		0.004	0.0001			Error	60	0.01	0.0001		
Total	47	0.01			0.02				Total	95	0.06			

Appendix XX: Effect of soil amendments and phosphorus on Ca content in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.0001	0.00003	0.12	0.0003	0.0002	0.31	3.32	Replication	4	0.0004	0.0001	0.24	2.53
SA	3	0.01	0.005	18.41*	0.01	0.002	4.02*	2.92	SA	6	0.02	0.004	8.78*	2.25
P	3	0.001	0.0004	1.46	0.003	0.001	1.99	2.92	P	6	0.004	0.0007	1.81	2.25
SA×P	9	0.0002	0.00003	0.09	0.01	0.001	1.12	2.21	SA×P	18	0.01	0.0003	0.78	1.78
Error	30	0.01	0.0003		0.02	0.001			Error	60	0.02	0.0004		
Total	47	0.02			0.03				Total	95	0.10			

Appendix XXI: Effect of soil amendments and phosphorus on Mg content in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.0001	0.0001	0.30	0.00002	0.00001	0.07	3.32	Replication	4	0.0001	0.00004	0.20	2.53
SA	3	0.01	0.003	13.70*	0.02	0.01	53.43*	2.92	SA	6	0.03	0.01	30.80*	2.25
P	3	0.0001	0.00002	0.10	0.00004	0.00001	0.09	2.92	P	6	0.0001	0.00002	0.10	2.25
SA×P	9	0.002	0.0002	0.83	0.001	0.0001	0.68	2.21	SA×P	18	0.002	0.0001	0.77	1.78
Error	30	0.01	0.0002		0.005	0.0002			Error	60	0.01	0.0002		
Total	47	0.02			0.03				Total	95	0.08			

*Significant at 5%

Appendix XXII: Effect of soil amendments and phosphorus on Mg content in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.0001	0.00003	0.09	0.00	0.00	0.002	3.32	Replication	4	0.0001	0.00001	0.05	2.53
SA	3	0.02	0.01	23.18*	0.03	0.01	49.91*	2.92	SA	6	0.05	0.01	35.18*	2.25
P	3	0.0002	0.0001	0.22	0.0001	0.00003	0.15	2.92	P	6	0.0003	0.00005	0.19	2.25
SA×P	9	0.002	0.0002	0.63	0.002	0.0002	0.76	2.21	SA×P	18	0.003	0.0002	0.69	1.78
Error	30	0.01	0.0003		0.007	0.0002			Error	60	0.02	0.0003		
Total	47	0.03			0.04				Total	95	0.11			

Appendix XXIII: Effect of soil amendments and phosphorus on N uptake in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	2.37	1.19	1.40	0.11	0.06	0.06	3.32	Replication	4	2.48	0.62	0.70	2.53
SA	3	248.80	82.93	98.25*	333.05	111.02	119.01*	2.92	SA	6	581.85	96.98	109.15*	2.25
P	3	298.76	99.59	117.98*	1241.00	413.67	443.47*	2.92	P	6	1539.75	256.63	288.85*	2.25
SA×P	9	24.43	2.71	3.22*	43.26	4.81	5.15*	2.21	SA×P	18	67.69	3.76	4.23*	1.78
Error	30	25.32	0.84		27.98	0.93			Error	60	53.31	0.89		
Total	47	599.68			1645.40				Total	95	4063.62			

Appendix XXIV: Effect of soil amendments and phosphorus on N uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	1.28	0.64	0.91	0.23	0.12	0.07	3.32	Replication	4	1.51	0.38	0.31	2.53
SA	3	125.63	41.88	59.33*	274.66	91.55	53.03*	2.92	SA	6	400.29	66.72	54.86*	2.25
P	3	210.85	70.28	99.58*	632.31	210.77	122.08*	2.92	P	6	843.16	140.53	115.55*	2.25
SA×P	9	12.18	1.35	1.92	30.43	3.38	1.96	2.21	SA×P	18	42.61	2.37	1.95*	1.78
Error	30	21.17	0.71		51.80	1.73			Error	60	72.97	1.22		
Total	47	371.12			989.43				Total	95	2744.28			

*Significant at 5%

Appendix XXV: Effect of soil amendments and phosphorus on P uptake in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.03	0.02	1.52	0.06	0.03	2.14	3.32	Replication	4	0.09	0.02	1.86	2.53
SA	3	2.66	0.89	77.76*	5.54	1.85	132.50*	2.92	SA	6	8.20	1.37	107.88*	2.25
P	3	3.84	1.28	112.32*	18.51	6.17	442.71*	2.92	P	6	22.35	3.73	294.13*	2.25
SA×P	9	0.23	0.03	2.28*	0.63	0.07	5.02*	2.21	SA×P	18	0.86	0.05	3.79*	1.78
Error	30	0.34	0.01		0.42	0.01			Error	60	0.76	0.01		
Total	47	7.11			25.16				Total	95	74.71			

Appendix XXVI: Effect of soil amendments and phosphorus on P uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.04	0.02	1.34	0.01	0.003	0.17	3.32	Replication	4	0.04	0.01	0.66	2.53
SA	3	3.61	1.20	90.27*	7.76	2.59	141.38*	2.92	SA	6	11.36	1.89	119.85*	2.25
P	3	5.01	1.67	125.54*	17.06	5.69	310.83*	2.92	P	6	22.07	3.68	232.78*	2.25
SA×P	9	0.27	0.03	2.25*	0.78	0.09	4.73*	2.21	SA×P	18	1.05	0.06	3.69*	1.78
Error	30	0.40	0.01		0.55	0.02			Error	60	0.95	0.02		
Total	47	9.32			26.15	0.003			Total	95	62.55			

Appendix XXVII: Effect of soil amendments and phosphorus on K uptake in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.03	0.02	0.25	0.27	0.14	0.82	3.32	Replication	4	0.31	0.08	0.66	2.53
SA	3	27.40	9.13	139.04*	32.31	10.77	64.50*	2.92	SA	6	59.71	9.95	85.55*	2.25
P	3	13.88	4.63	70.43*	71.57	23.86	142.89*	2.92	P	6	85.45	14.24	122.43*	2.25
SA×P	9	1.83	0.20	3.10*	4.32	0.48	2.88*	2.21	SA×P	18	6.16	0.34	2.94*	1.78
Error	30	1.97	0.07		5.01	0.17			Error	60	6.98	0.12		
Total	47	45.11			113.49				Total	95	340.82			

*Significant at 5%

Appendix XXVIII: Effect of soil amendments and phosphorus on K uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	2.18	1.09	2.89	1.80	0.90	0.86	3.32	Replication	4	3.98	1.00	1.40	2.53
SA	3	111.95	37.32	98.88*	285.58	95.19	90.96*	2.92	SA	6	397.53	66.26	93.06*	2.25
P	3	158.89	52.96	140.35*	696.59	232.20	221.87*	2.92	P	6	855.48	142.58	200.26*	2.25
SA×P	9	8.52	0.95	2.51*	28.82	3.20	3.06*	2.21	SA×P	18	37.34	2.07	2.91*	1.78
Error	30	11.32	0.38		31.40	1.05			Error	60	42.72	0.71		
Total	47	292.87			1044.19				Total	95	3532.73			

Appendix XXIX: Effect of soil amendments and phosphorus on Ca uptake in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.01	0.003	0.78	0.05	0.02	2.91	3.32	Replication	4	0.05	0.01	2.31	2.53
SA	3	0.48	0.16	48.69*	1.98	0.66	79.25*	2.92	SA	6	2.45	0.41	70.63*	2.25
P	3	0.32	0.11	32.86*	1.70	0.57	68.20*	2.92	P	6	2.02	0.34	58.23*	2.25
SA×P	9	0.04	0.004	1.28	0.13	0.01	1.76	2.21	SA×P	18	0.17	0.01	1.62	1.78
Error	30	0.10	0.003		0.25	0.01			Error	60	0.35	0.01		
Total	47	0.94			4.11				Total	95	11.16			

Appendix XXX: Effect of soil amendments and phosphorus on Ca uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.03	0.02	0.81	0.11	0.06	0.69	3.32	Replication	4	0.15	0.04	0.71	2.53
SA	3	4.29	1.43	67.81*	6.12	2.04	24.61*	2.92	SA	6	10.42	1.74	33.38*	2.25
P	3	2.57	0.86	40.50*	13.81	4.60	55.50*	2.92	P	6	16.37	2.73	52.45*	2.25
SA×P	9	0.24	0.03	1.25	1.15	0.13	1.54	2.21	SA×P	18	1.39	0.08	1.48	1.78
Error	30	0.63	0.02		2.49	0.08			Error	60	3.12	0.05		
Total	47	7.76			23.68				Total	95	68.59			

*Significant at 5%

Appendix XXXI: Effect of soil amendments and phosphorus on Mg uptake in seed of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.001	0.0005	0.11	0.002	0.001	0.13	3.32	Replication	4	0.003	0.001	0.12	2.53
SA	3	0.33	0.11	26.89*	2.09	0.70	93.99*	2.92	SA	6	2.42	0.40	69.88*	2.25
P	3	0.05	0.02	4.32*	0.61	0.20	27.60*	2.92	P	6	0.67	0.11	19.24*	2.25
SA×P	9	0.03	0.003	0.84	0.12	0.01	1.87	2.21	SA×P	18	0.16	0.01	1.50	1.78
Error	30	0.12	0.004		0.22	0.01			Error	60	0.35	0.01		
Total	47	0.55			3.05				Total	95	7.44			

Appendix XXXII: Effect of soil amendments and phosphorus on Mg uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.004	0.002	0.09	0.02	0.01	0.23	3.32	Replication	4	0.03	0.01	0.19	2.53
SA	3	3.45	1.15	55.27*	11.74	3.91	74.48*	2.92	SA	6	15.19	2.53	69.02*	2.25
P	3	1.06	0.35	16.90*	4.83	1.61	30.65*	2.92	P	6	5.89	0.98	26.74*	2.25
SA×P	9	0.33	0.04	1.73	0.82	0.09	1.74	2.21	SA×P	18	1.15	0.06	1.74	1.78
Error	30	0.63	0.02		1.58	0.05			Error	60	2.20	0.04		
Total	47	5.46			18.99				Total	95	46.82			

Appendix XXXIII: Effect of soil amendments and phosphorus on N total uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	6.63	3.32	1.20	0.56	0.28	0.06	3.32	Replication	4	7.19	1.80	0.50	2.53
SA	3	726.90	242.30	87.62*	1201.81	400.60	89.12*	2.92	SA	6	1928.71	321.45	88.55*	2.25
P	3	1010.14	336.71	121.76*	3643.29	1214.43	270.15*	2.92	P	6	4653.43	775.57	213.64*	2.25
SA×P	9	68.47	7.61	2.75*	143.25	15.92	3.54*	2.21	SA×P	18	211.72	11.76	3.24*	1.78
Error	30	82.96	2.77		134.86	4.50			Error	60	217.82	3.63		
Total	47	1895.10			5123.77				Total	95	13393.76			

*Significant at 5%

Appendix XXXIV: Effect of soil amendments and phosphorus on P total uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.14	0.07	1.69	0.07	0.03	0.96	3.32	Replication	4	0.21	0.05	1.35	2.53
SA	3	12.45	4.15	100.25*	26.36	8.79	241.71*	2.92	SA	6	38.81	6.47	166.40*	2.25
P	3	17.62	5.87	141.88*	71.05	23.68	651.42*	2.92	P	6	88.66	14.78	380.15*	2.25
SA×P	9	0.98	0.11	2.64*	2.74	0.30	8.39*	2.21	SA×P	18	3.73	0.21	5.33*	1.78
Error	30	1.24	0.04		1.09	0.04			Error	60	2.33	0.04		
Total	47	32.43			101.31				Total	95	271.08			

Appendix XXXV: Effect of soil amendments and phosphorus on K total uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	2.73	1.36	2.41	3.04	1.52	1.10	3.32	Replication	4	5.77	1.44	1.48	2.53
SA	3	247.75	82.58	146.00*	509.20	169.73	122.96*	2.92	SA	6	756.96	126.16	129.66*	2.25
P	3	266.52	88.84	157.06*	1214.72	404.91	293.32*	2.92	P	6	1481.24	246.87	253.72*	2.25
SA×P	9	17.26	1.92	3.39*	53.14	5.90	4.28*	2.21	SA×P	18	70.39	3.91	4.02*	1.78
Error	30	16.97	0.57		41.41	1.38			Error	60	58.38	0.97		
Total	47	551.23			1821.52				Total	95	6015.71			

Appendix XXXVI: Effect of soil amendments and phosphorus on Ca total uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.05	0.03	1.01	0.10	0.05	0.57	3.32	Replication	4	0.16	0.04	0.68	2.53
SA	3	7.62	2.54	94.61*	15.04	5.01	55.51*	2.92	SA	6	22.66	3.78	64.47*	2.25
P	3	4.70	1.57	58.38*	25.18	8.39	92.94*	2.92	P	6	29.89	4.98	85.02*	2.25
SA×P	9	0.41	0.05	1.69	1.69	0.19	2.08	2.21	SA×P	18	2.10	0.12	1.99*	1.78
Error	30	0.81	0.03		2.71	0.09			Error	60	3.52	0.06	0.68	2.53
Total	47	13.60			44.72				Total	95	131.72			

*Significant at 5%

Appendix XXXVII: Effect of soil amendments and phosphorus on Mg total uptake in stover of black gram

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.005	0.002	0.08	0.04	0.02	0.27	3.32	Replication	4	0.04	0.01	0.21	2.53
SA	3	5.93	1.98	62.44*	23.63	7.88	109.01*	2.92	SA	6	29.56	4.93	94.81*	2.25
P	3	1.58	0.53	16.66*	8.88	2.96	40.99*	2.92	P	6	10.47	1.74	33.57*	2.25
SA×P	9	0.51	0.06	1.80	1.39	0.15	2.13	2.21	SA×P	18	1.90	0.11	2.03*	1.78
Error	30	0.95	0.03		2.17	0.07			Error	60	3.12	0.05		
Total	47	8.99			36.10				Total	95	89.84			

Appendix XXXVIII: Effect of soil amendments and phosphorus on soil pH of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.09	0.05	2.38	0.02	0.01	0.64	3.32	Replication	4	0.11	0.03	1.64	2.53
SA	3	0.55	0.18	9.31*	0.93	0.31	21.05*	2.92	SA	6	1.49	0.25	14.34*	2.25
P	3	0.12	0.04	1.96	0.11	0.04	2.45	2.92	P	6	0.22	0.04	2.17	2.25
SA×P	9	0.13	0.01	0.75	0.05	0.01	0.37	2.21	SA×P	18	0.18	0.01	0.59	1.78
Error	30	0.59	0.02		0.44	0.01			Error	60	1.04	0.02		
Total	47	1.49	0.05		1.55				Total	95	4.97			

Appendix XXXIX: Effect of soil amendments and phosphorus on EC of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.003	0.002	2.39	0.0005	0.0002	1.62	3.32	Replication	4	0.004	0.001	2.25	2.53
SA	3	0.01	0.005	6.92*	0.02	0.01	52.35*	2.92	SA	6	0.04	0.01	15.19*	2.25
P	3	0.004	0.001	2.15	0.0009	0.0003	1.98	2.92	P	6	0.01	0.001	2.12	2.25
SA×P	9	0.002	0.0002	0.29	0.0004	0.0000	0.30	2.21	SA×P	18	0.002	0.0001	0.29	1.78
Error	30	0.02	0.001		0.005	0.0002			Error	60	0.02	0.0004		
Total	47	0.04			0.03				Total	95	0.08			

*Significant at 5%

Appendix XL: Effect of soil amendments and phosphorus on organic carbon of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.16	0.08	0.44	0.05	0.02	0.12	3.32	Replication	4	0.21	0.05	0.28	2.53
SA	3	0.58	0.19	1.05	0.85	0.28	1.44	2.92	SA	6	1.42	0.24	1.25	2.25
P	3	1.10	0.37	2.01	0.77	0.26	1.31	2.92	P	6	1.87	0.31	1.65	2.25
SA×P	9	0.59	0.07	0.36	0.45	0.05	0.26	2.21	SA×P	18	1.04	0.06	0.31	1.78
Error	30	5.48	0.18		5.89	0.20			Error	60	11.37	0.19		
Total	47	7.91			8.01				Total	95	20.38			

Appendix XLI : Effect of soil amendments and phosphorus on available N of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	6.53	3.27	0.01	45.64	22.82	0.05	3.32	Replication	4	52.17	13.04	0.04	2.53
SA	3	12915.56	4305.19	14.33*	9955.67	3318.56	7.69*	2.92	SA	6	22871.23	3811.87	10.41*	2.25
P	3	5258.53	1752.84	5.83*	16964.48	5654.83	13.10*	2.92	P	6	22223.01	3703.83	10.12*	2.25
SA×P	9	485.16	53.91	0.18	3244.59	360.51	0.84	2.21	SA×P	18	3729.75	207.21	0.57	1.78
Error	30	9015.08	300.50		12945.98	431.53			Error	60	21961.06	366.02		
Total	47	27680.87			43156.35				Total	95	78633.00			

Appendix XLII: Effect of soil amendments and phosphorus on available P of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.91	0.46	1.31	0.19	0.09	0.58	3.32	Replication	4	1.10	0.28	1.08	2.53
SA	3	53.01	17.67	50.68*	62.07	20.69	127.97*	2.92	SA	6	115.09	19.18	75.16*	2.25
P	3	311.10	103.70	297.38*	323.07	107.69	666.03*	2.92	P	6	634.18	105.70	414.17*	2.25
SA×P	9	7.76	0.86	2.47*	5.71	0.63	3.92*	2.21	SA×P	18	13.47	0.75	2.93*	1.78
Error	30	10.46	0.35		4.85	0.16			Error	60	15.31	0.26		
Total	47	383.25			395.89				Total	95	810.08			

*Significant at 5%

Appendix XLIII: Effect of soil amendments and phosphorus on available K of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	13.26	6.63	0.99	13.13	6.57	1.11	3.32	Replication	4	26.39	6.60	1.04	2.53
SA	3	281.64	93.88	13.95*	69.17	23.06	3.89*	2.92	SA	6	350.81	58.47	9.24*	2.25
P	3	55.04	18.35	2.73	17.34	5.78	0.98	2.92	P	6	72.39	12.06	1.91	2.25
SA×P	9	88.79	9.87	1.47	1.66	0.18	0.03	2.21	SA×P	18	90.45	5.03	0.79	1.78
Error	30	201.89	6.73		177.76	5.93			Error	60	379.65	6.33		
Total	47	640.62			279.07				Total	95	1096.14			

Appendix XLIV: Effect of soil amendments and phosphorus on exchangeable Ca^{2+} of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.02	0.01	0.69	0.01	0.004	0.26	3.32	Replication	4	0.03	0.01	0.48	2.53
SA	3	0.18	0.06	3.43*	0.26	0.09	5.17*	2.92	SA	6	0.43	0.07	4.29*	2.25
P	3	0.13	0.04	2.43	0.04	0.01	0.75	2.92	P	6	0.16	0.03	1.61	2.25
SA×P	9	0.09	0.01	0.58	0.09	0.01	0.62	2.21	SA×P	18	0.18	0.01	0.60	1.78
Error	30	0.52	0.02		0.50	0.02			Error	60	1.01	0.02		
Total	47	0.93			0.89				Total	4	0.03	0.01	0.48	2.53

Appendix XLV: Effect of soil amendments and phosphorus on exchangeable Mg^{2+} of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.05	0.02	1.33	0.05	0.02	1.42	3.32	Replication	4	0.10	0.02	1.37	2.53
SA	3	0.09	0.03	1.59	0.03	0.01	0.66	2.92	SA	6	0.12	0.02	1.15	2.25
P	3	0.08	0.03	1.38	0.04	0.01	0.83	2.92	P	6	0.12	0.02	1.12	2.25
SA×P	9	0.01	0.00	0.06	0.01	0.00	0.08	2.21	SA×P	18	0.02	0.00	0.07	1.78
Error	30	0.55	0.02		0.49	0.02			Error	60	1.04	0.02		
Total	47	0.77			0.62				Total	95	1.55			

*Significant at 5%

Appendix XLVI: Effect of soil amendments and phosphorus on TPA of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.32	0.16	0.41	0.08	0.04	0.12	3.32	Replication	4	0.40	0.10	0.28	2.53
SA	3	48.19	16.06	41.53*	49.31	16.44	49.19*	2.92	SA	6	97.50	16.25	45.08*	2.25
P	3	0.05	0.02	0.04	0.31	0.10	0.31	2.92	P	6	0.36	0.06	0.16	2.25
SA×P	9	5.20	0.58	1.49	4.51	0.50	1.50	2.21	SA×P	18	9.71	0.54	1.50	1.78
Error	30	11.60	0.39		10.03	0.33			Error	60	21.63	0.36		
Total	47	65.36			64.24				Total	95	139.10			

AppendixXLVII: Effect of soil amendments and phosphorus on pH dependent acidity of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.04	0.02	0.03	0.63	0.31	0.50	3.32	Replication	4	0.66	0.17	0.27	2.53
SA	3	16.43	5.48	9.36*	18.28	6.09	9.75*	2.92	SA	6	34.71	5.79	9.56*	2.25
P	3	0.28	0.09	0.16	0.50	0.17	0.27	2.92	P	6	0.78	0.13	0.22	2.25
SA×P	9	9.24	1.03	1.75	7.08	0.79	1.26	2.21	SA×P	18	16.32	0.91	1.50	1.78
Error	30	17.55	0.58		18.75	0.62			Error	60	36.30	0.60		
Total	47	43.54			45.24				Total	95	90.08			

AppendixXLVIII: Effect of soil amendments and phosphorus on exchangeable acidity of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.14	0.07	0.42	0.28	0.14	0.89	3.32	Replication	4	0.42	0.10	0.65	2.53
SA	3	8.35	2.78	17.17*	7.54	2.51	15.98*	2.92	SA	6	15.90	2.65	16.59*	2.25
P	3	0.35	0.12	0.73	0.04	0.01	0.09	2.92	P	6	0.40	0.07	0.41	2.25
SA×P	9	1.27	0.14	0.87	0.92	0.10	0.65	2.21	SA×P	18	2.19	0.12	0.76	1.78
Error	30	4.86	0.16		4.72	0.16			Error	60	9.58	0.16		
Total	47	14.98			13.50				Total	95	32.24			

*Significant at 5%

AppendixXLIX: Effect of soil amendments and phosphorus on exchangeable Al^{3+} of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.28	0.14	0.84	0.22	0.11	0.87	3.32	Replication	4	0.50	0.13	0.85	2.53
SA	3	1.56	0.52	3.08*	1.93	0.64	5.11*	2.92	SA	6	3.49	0.58	3.95*	2.25
P	3	0.10	0.03	0.20	0.18	0.06	0.48	2.92	P	6	0.28	0.05	0.32	2.25
SA×P	9	1.09	0.12	0.72	0.71	0.08	0.63	2.21	SA×P	18	1.80	0.10	0.68	1.78
Error	30	5.05	0.17		3.78	0.13			Error	60	8.83	0.15		
Total	47	8.08			6.83				Total	95	16.41			

Appendix L: Effect of soil amendments and phosphorus on exchangeable H^{+} of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	0.04	0.02	0.09	0.13	0.06	0.36	3.32	Replication	4	0.17	0.04	0.21	2.53
SA	3	2.81	0.94	4.13*	1.97	0.66	3.79*	2.92	SA	6	4.78	0.80	3.98*	2.25
P	3	0.18	0.06	0.27	0.31	0.10	0.59	2.92	P	6	0.49	0.08	0.41	2.25
SA×P	9	1.92	0.21	0.94	1.46	0.16	0.94	2.21	SA×P	18	3.39	0.19	0.94	1.78
Error	30	6.79	0.23		5.21	0.17			Error	60	12.00	0.20		
Total	47	11.74			9.08				Total	95	21.33			

Appendix LI: Effect of soil amendments and phosphorus on microbial biomass carbon of post harvest soil

SOV	DF	2021			2022			F tab	SOV	DF	Pooled			F tab
		SS	MSS	F cal	SS	MSS	F cal				SS	MSS	F cal	
Replication	2	177.46	88.73	0.82	91.21	45.60	1.47	3.32	Replication	4	268.67	67.17	0.96	2.53
SA	3	1599.31	533.10	4.91*	3057.00	1019.00	32.86*	2.92	SA	6	4656.31	776.05	11.11*	2.25
P	3	13462.45	4487.48	41.30*	10053.49	3351.16	108.07*	2.92	P	6	23515.93	3919.32	56.12*	2.25
SA×P	9	50.24	5.58	0.05	129.34	14.37	0.46	2.21	SA×P	18	179.58	9.98	0.14	1.78
Error	30	3259.94	108.66		930.29	31.01			Error	60	4190.23	69.84		
Total	47	18549.40			14261.32				Total	95	35043.19			

*Significant at 5%