PHOSPHORUS USE EFFICIENCY AS INFLUENCED BY LIMING MATERIALS IN SOYBEAN [*Glycine max* (L.) Merrill] IN A DYSTRUDEPT OF NAGALAND

Thesis

submitted to

NAGALAND UNIVERSITY

in partial fulfillment of requirements for the Degree

of

DOCTOR OF PHILOSOPHY

in

Agricultural Chemistry and Soil Science

by

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2022

DECLARATION

I, L.Soemndro Singh, 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 had 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 (Agriculture) in Agricultural Chemistry and Soil Science.

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CERTIFICATE – I

This is to certify that the thesis entitled "**Phosphorus use efficiency as influenced by Liming Materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland**" submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agricultural Chemistry and Soil Science is the record of research work carried out by Mr. L.Somendro Singh, Registration No. Ph.D/ACSS/00116 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 AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

This is to certify that the thesis entitled **"Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland"** Submitted by Mr. L. Somendro Singh, Admission No. Ph.- 225/17, Registration No.Ph.D/ACSS/00116 to the NAGALAND UNIVERSITY in partial fulfillment of the requirement for the award of degree of Philosophy in Agricultural Chemistry and Soil Science has been Examined by the Advisory Board and External examiner on 26/7/22

The performance of the student has been found Satisfactory/~~Unsatisfactory.~~

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Acknowledgements

I take the opportunity to express my deep sense of gratitude and indebtedness to my dignified supervisor, Prof. P. K Singh, Professor, Department of Agricultural Chemistry and Soil Science, SASRD, Nagaland University, Medziphema, for his unstinted help, dignified support, valuable suggestions, untiring guidance and assistance throughout the period of investigation and for giving his best in the preparation of this manuscript without which it would have not been possible to accomplish this stupendous task.

I accolade my deep sense of honor to the Dean, SASRD, Nagaland University, Medziphema for providing his necessary help during the investigation period.

I extend my sincere thanks to the Director, ICAR Research Complex for NEH Region, Umiam for giving permission Ph.D study leave.

To the members of advisory committee, Prof. S.K. Sharma, Professor and Prof. Y.K. Sharma, Professor, Department of Agricultural Chemistry and Soil Science; Dr. A.P. Singh, Assistant *Professor, Department of Agronomy;* Prof. M. Dutta, *Professor, Department of Soil and Water Conservation, SASRD, Nagaland University, Medziphema, I am greatly indebted for their inspiring suggestion, help and advice.*

I am very much grateful and feel indebted to prof. A. K. Singh, Professor, Department of Agricultural Chemistry and Soil Science, SASRD, Nagaland University, Medziphema for his valuable suggestion and guidance during the field experimentation and laboratory work.

I owe my sincere thanks to Prof. Indira Sarangthem, Dean, collage of Agriculture, Central Agriculture University, Imphal and prof. A. Herojit Singh, *professor, Department of Agricultural Chemistry and Soil Science, collage of Agriculture, Central Agriculture University, Imphal for valuable suggestion and guidance during the laboratory work and preparation of this manuscript.*

I am thankful to the non teaching staff and field workers, Department of Agricultural Chemistry and Soil Science, SASRD, Nagaland University, Medziphema for their constant service during the field experimental period and laboratory work.

My sincere thanks to all my friends and colleagues specially Mr. Langhnyei Angh, Mr.Badap, Mr. Rajkishor Singh and Anil Singh

Mere words are insufficient to express my heartfelt gratitude to my parents, my beloved wife and son and loved ones who are a constant and never ending source of inspiration and encouragement during the entire course of this study. They always stood by me and without their prayers and moral support I would have not achieve this goal.

Date: 08/04/22

Place: Medziphema

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LIST OF ABBREVIATIONS

@	At the rate of
ºC	Degree Celsius
/	Per
%	Percentage
µg	Microgram
:	Ratio
Rs	Rupee(s)
AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of variance
Ca	Calcium
cm	Centimetre
CD	Critical Difference
cv.	Cultivar
E	East
et al.	And others
Fe	Iron
Fig.	Figure
g	Gram
ha	Hectare
i.e.	That is
K	Potassium
Kg	Kilogram

m	Metre
Mg	Magnesium
Mn	Manganese
N	North
N	Nitrogen
No.	Number
NS	Non Significant
NU	Nagaland University
OC	Organic carbon
P	Phosphorus
PUE	Phosphorus Use Efficiency
q	Quintal
S	Sulphur
S	Significant
Sl. No.	Serial Number
SEm±	Standard Error Mean
t	Tonne
SPD	Split Plot Design
SSP	Single Super Phosphate
Viz.	Namely
Zn	Zinc

ABSTRACT

A research investigation entitled "Phosphorus use efficiency as influenced by liming materials in soybean {*Glycine max (*L.) Merrill} in a dystrudept of Nagaland" was carried out at the research farm of SASRD, Nagaland University, Medziphema during *kharif* season in 2018 and 2019. The experiment was laid out in a split plot design (SPD) on soybean variety JS-335 with liming materials i.e., no liming material, wood ash @ 0.4 LR, paper mill sludge @ 0.4 LR and calcium silicate @ 0.4 LR ($M_{0,}$ $M_{1,}$ M_2 and M_3 respectively$_{)}$ in main plot and phosphorus levels i.e., 0, 40, 60 and 80 kg P_2O_5 ha^{-1} (P_0, P_{40}, P_{60} and P_{80}) in sub plot consisting of 16 treatments and each treatment replicated three time. The highest plant height (63.63 cm), number of leaves (33.75), number of branches (6.73), root length (52.33 cm), root dry weight (4.22 gm) and number of root nodules (102.50) were found in the plot receiving calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. The number of pods per plant was significantly influenced by calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1} alone and their interaction (calcium silicate @ 0.4 LR + 80 kg P_2O_5 ha^{-1}). The seed test weight was found to be significant among the treatments. The grain and stover yield of soybean was significantly increased with increasing dosage of phosphorus and different liming materials and the highest grain yield of 2012.04 kg ha^{-1} and stover yield of 2623.59 kg ha^{-1} was recorded with application of calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. Synergistic interaction effect was observed between liming materials and phosphorus on grain and stover yield of soybean during both years of research investigation. There was also significant increased in the nutrient concentration and uptake of nitrogen, phosphorus, potassium, sulphur, calcium and magnesium in both the grain and stover with higher doses of phosphorus with calcium silicate @ 0.4 LR. The highest total nutrient uptake of 211.29 N kg ha^{-1}, 16.82 P kg ha^{-1}, 103.35 K kg ha^{-1}, 11.32 S kg ha^{-1}, 25.97 Ca kg ha^{-1} and 15.01 Mg kg ha^{-1} were

recorded with combined application of calcium silicate @ 0.4 LR with 80 kg P_2O_5 ha^{-1}. The application of phosphorus upto 80 kg P_2O_5 ha^{-1} along with liming materials was found to be significantly effective in increasing the qualitative parameter viz. protein and oil content of soybean seed. The highest protein content (39.67 %) and oil content (18.11 %) was recorded in the plot receiving CS @ 0.4 LR + 80 P_2O_5 kg ha^{-1}. Water holding capacity of post harvest soil was increased significantly with application of liming materials and phosphorus alone than initial value (47.62 %). Application of liming materials of CS @ 0.4 LR increased with pH–5.41, the initial pH of the experimental plot was 5.31. The highest OC % was found in the plots receiving CS @ 0.4 LR (1.17 %) and 80 kg P_2O_5 ha^{-1} (1.24 %). Available K, micro nutrients Fe, Mn, Zn, exchange acidity and exchangeable Al^{3+} status decreased in post harvest soil, where as the available N, P, S & exchangeable Ca^{2+}, Mg^{2+} and CEC status in soil increased by application of liming materials and phosphorus and their interaction. The soil microbial biomass carbon of 319.79 $\mu g\, g^{-1}$ and soil respiration of 8.30 μg C g^{-1} hr^{-1} was highest with the treatment M_3P_{80} while the lowest was observed in control (M_0P_0) with 274.72 $\mu g\, g^{-1}$ and 6.42 μg Cg^{-1} hr^{-1}, respectively. Phosphorus fractions, soluble or loosely bound P, Ca-P and organic-P mg kg^{-1} were increased with application of liming material and phosphorus alone and also their interaction. The Al-P mg kg^{-1}, Fe-P mg kg^{-1}, reductant-P mg kg^{-1} and occuluded-P mg kg^{-1} were decreased with liming materials alone or with phosphorus than initial values. Liming materials application did not have any significant influence on agronomic efficiency of P (AEP %), physiological efficiency of P (PEP %), apparent recovery phosphorus (ARP %) and phosphorus use efficiency (PUE %). Phosphorus application had significant effect on AEP %, PEP %, ARP % and PUE %. Agronomic efficiency of P, physiological efficiency of P, apparent recovery P and phosphorus use efficiency were found the highest 12.21 kg kg^{-1} in the treatment 60 kg P_2O_5 ha^{-1}, 121.18 kg kg^{-1} in the treatment 80 kg P_2O_5 ha^{-1}, 15.01 % and

15.31 % in the treatment 40 kg P_2O_5 ha^{-1}, respectively. Soybean responds very well in the different liming materials (wood ash, paper mill sludge and calcium silicate) with the increased application of phosphorus (40, 60 and 80 kg P_2O_5 ha^{-1}). Application of calcium silicate @ 0.4 LR with 80 kg P_2O_5 ha^{-1} was found to best for soybean cultivation in a Dystrudept of Nagaland.

Keywords: Soybean, liming materials, acid soil, phosphorus and phosphorus use efficiency

CHAPTER I

INTRODUCTION

INTRODUCTION

The acidic soil develop physical, chemical, nutritional and biological constraints for crop production in terms of soil crusting (affecting seed germination), high infiltration rate, low water holding capacity, high permeability, low pH, low cation exchange capacity low base saturation (16-67%), high Al, Fe, and Mn saturation percentage, high P fixing capacity (92%) (Pattnayak and Misra, 1989). The Effects of soil acidity are many; the most important being the retardation of plant growth through toxicity of aluminum (Al) and Hydrogen (H) ions, unavailability of other plant nutrients, mainly nitrogen and phosphorus, and reduction of microbial activity in the soil (Ano & Ubochi, 2007).

Soybean {Glycine max (L.) Merrill} is known as ‘Golden bean’ and miracle crop of 20^{th} century (Govindarao, 2010). Soybean is the world’s most important legume in terms of production and trade and has been a dominant oilseed since the 1960s. Soybean posses a high nutritional quality protein (40 %), which is rich in valuable amino acid lycine (5 %), soybean being the richest, cheapest and easiest source of best quality proteins and fats and having a vast multiplicity of uses as food and industrial products is sometimes called a “wonder crop”. In addition to its nutritional values, soybean is also used as important nitrogen (N_2)-fixing crop throughout the world for the restoration and maintenance of soil fertility in a sustainable way and consequently the improvement of crop yields (Smaling *et al*., 2008). Soybean has the capacity to fix about 70-120 N ha^{-1} through symbiosis (Tisdale and Nelson, 1985). The nitrogen requirement of soybean is substantially fulfilled through symbiotic nitrogen fixation with rhizobium. In India, it is now the second largest oilseed after groundnut. Total area of soybean in India is 11.67 million ha with production of 8.59 mt during year 2015-16 with an average national yield of

737 kg ha^{-1}. Soybean occupied 42 % of India's total oilseeds and 25 % of edible oil production (*Source:* - Agricultural Statistic at a Glance 2016, *Directorate of Economics & Statistics,* Ministry of Agriculture, Govt. of India). In Nagaland, it was estimated that the area, production and productivity of soybean during the year 2015-2016 was 24.68 thousand ha, 31.17 thousand tonne and 1254 kg ha^{-1} respectively (Statistical Handbook of Nagaland, *Directorate of Economics & Statistics Govt. of Nagaland, 2017*). Low phosphorus in soil is a major constraint for soybean growth and production, which are atmospheric nitrogen (N_2) dependent (Bordeleau and Prévost 1994) because phosphorus is particularly important for symbiotic N_2 fixation in legumes (Zahran 1999). When phosphorus rate in soil is low, this process can be strongly undermined and thus becomes a principal yield-limiting nutrient (Pereira and Bliss 1989). Most leguminous plants require a neutral or slightly acidic soil for growth (Brockwell *et al*.,1991). Soybeans thrive in the pH range of 6.0 to 6.8. Soil phosphorus tests provide an indication of the level of soil phosphorus in plant. The test provides an index of phosphorus measurement that can be taken up by plant (Watson and Mullen, 2007).

Liming is the addition of a compound containing calcium or calcium plus magnesium to the acid soils that are capable of reducing the acidity of the soil (Barber, 1984). Liming of acid soil is the way to raise pH, base status, cation exchange capacity, inactive Al, Fe and Mn in soil solution and reduce P fixation (Sahu and Patnaik, 1990, Misra and Pattanayak, 2002). The main aim of soil liming is to neutralize acidic inputs and recovering the buffering capacity to the soil (Ulrich, 1983). Liming materials that have potential use in agricultural include organic liming material (Fly ash, wood ash, organic residue of various crops etc.). Applications of industrial wastes as fertilizer and soil amendment have become popular in agriculture.

Paper mill sludge is produced as a by-product of paper production that disposal of this material presents a problem for the mill (Mahmood and Elliot, 2006). Paper mill sludge (PMS) is the of cheap alternative sources of liming materials that contains $CaCO_3$ (Torkashvand, 2010; Kar *et al.,* 2014) but the quantity of required PMS depends on the paper manufacturing processes, soil type, crop species and cultivars (Caires *et al.,* 2005).

Wood ash, the residue remaining from the combustion of bark, sawdust, and yard waste for energy generation for forestry product operations, is an effective liming material on acid agricultural soils (Arshad, *et al*., 2012). Wood ash contains many nutrients that were adsorbed from the soil during tree growth. Whenever wood is burned, oxides and hydroxides of calcium, magnesium, potassium, sodium, etc. are formed. These alkaline compounds are effective in neutralizing soil acidity. Therefore wood ash can also be used as a liming material (Lickacz, 2002). Studies by Demeyer *et al*., (2000) shows that wood ash causes the increase of soil pH and a decrease in soil acidity. Therefore, liming practice should less expensive and be available within easy reach of farmers besides its suitability. Research has shown that several industrial byproducts and organic residues which are potential lime sources can be used if available at an affordable distance. Such materials includes converter slag from steel industries (*Torkashvand* and Shahram, 2007), Paper mill sludge (Sahu and Mitra, 1996, Sahu and Nanda, 1998, Pattanayak *et al*., 2011), cement kiln waste, precipitated $CaCO_3$ from fertilizer industries, wood ash (Lickacz, 2002) from the combustion of bark, sawdust, and yard waste for energy generation for forestry product operations which have been successfully used as soil amendments.

Phosphorus is the most important essential element in plant nutrition, next to nitrogen. Although phosphorus is abundant in many soils, paradoxically it is a major critical nutrient for plant growth because of its least solubility in solution phase and high inaccessibility to plant roots for uptake (Hinsinger, 2001). Phosphorus is one of the most limiting nutrients in agricultural cropping systems (Roberts and Johnston, 2015; Guignard *et al*., 2017; Khan *et al*., 2018).

It is estimated that P deficiencies can be found in nearly 67 % of world land designated for crop production (Dhillon *et al*., 2017). Also, P use efficiency (PUE) for cereal production in the world is too low, varying between 15 and 30 % (Dhillon *et al*., 2017). Phosphorus deficiency is one of the major crop production constraints in acidic soils. About 80 % of the applied phosphorus fertilizers are lost due to low acquisition and use efficiency of plant those results in significant loss of applied phosphorus causing serious environmental problems. The availability of phosphorus is influenced by soil organic matter, pH, and exchangeable and soluble Al, Fe, and Ca (Smithson, 1999). The total phosphorus content in Indian soils is reported to vary from 44 mg kg^{-1} to more than 3500 mg kg^{-1}, however, for most agricultural soils, it ranges within the limit of 120 to 2166 mg kg^{-1} (Tomar, 2000). To overcome crop-limiting factor of phosphorus application of lime and alternative liming materials, inorganic and organic sources of phosphorus for enhanced phosphorus acquisition can be the viable options for phosphorus management in acid soils.

Phosphorus use efficiency (PUE) as defined as yield increase per kg of fertilizer P added, is related to P sources, environmental factors, soil and crop management (Bationo and Kumar, 2002). The Phosphorus use efficiency was higher at lower doses of applied P with the maximum value (21.3%) recorded SSP @ 30 kg P_2O_5 ha^{-1} (Majumdar *et al.*, 2007). It significantly reduced indicating that PUE decreases at higher doses of P due to the fact that plants grown in extremely P deficient soil exhibit greater P sorption at lower doses of P (Venkatesh *et al.*, 2002. There is a commonly held belief that P fertilizer is very inefficient because P recovery by crops in the year it is applied is often only 10-15%. The residual fertilizer P not recovered by the crop is believed to be permanently tied-up or "fixed" in the soil in forms not available to plants (Roberts and Johnston, 2015). Limitation of grain crop productivity by phosphorus (P) is widespread and will probably increase in the future. Enhanced P efficiency can be achieved by improved uptake of phosphate from soil (P-acquisition efficiency) and by improved productivity per unit P taken up (P-use efficiency). Improved P-use efficiency which can be achieved by plants that have overall lower P concentrations, and by optimal distribution and redistribution of P in the plant allowing maximum growth and biomass allocation to harvestable plant parts (Veneklaas *et at* 2012).Application of inorganic phosphorus at right rate, time, and type and at right place can increase phosphorus use efficiency in crops (Thakuria *et al*., 2016). Hence, the purpose of the present investigation is to evaluate the "Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland" with following objectives:

1. To study the effect of liming materials and phosphorus levels on crop growth, yield, quality parameters and nutrient uptake by soybean.
2. To study the effect of liming materials and phosphorus levels on soil properties.
3. To study the effect of liming materials on soil phosphorus fractions.
4. To study the phosphorus use efficiency in soybean**.**

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Soil acidity

Soil acidity is largely associated with the presence of hydrogen ion and aluminium ions in exchangeable forms (Brady, 2001). Thus, the higher concentrations of these ions in the soil solution are the acidity. Most of acids soils have been found to be low in fertility, have poor physical, chemical and biological properties. Generally, soil has natural buffering capacity by which they are able to resist change in soil pH upon marginal increases in their acidity or alkalinity (Black, 1968). The absorption of H^+ ions by soil colloids takes place by two processes (Bolt, 1976) viz. non-selective and preferential adsorption. Generally acid soils are poor in available nutrients owing to the adverse effect of soil acidity, low base saturation, microbial and nutrient imbalance (Mandal *et al*., 1975 and Tripathi *et al*., 1982.). The small amount of control that can be exerted over phosphate availability seems to be associated with liming. Liming is one of the processes, which govern the practical control of phosphorus availability. The simplest mechanism processes is the exchange of $H_2PO_4^-$ by hydroxyl groups. With due consideration of pH, lime obviously decreases the amount of fixed phosphorus (Amarasiri and Olsens, 1973).

Several agricultural practices have been recommended to overcome the problem of acid soil infertility. Among them, the most common and widely used method is liming, which is defined as the application of ground calcium and or magnesium carbonate, hydroxides, and oxides aiming at increasing the soil pH, modifying its physical, chemical and biological properties (Edmeades and Ridley, 2003).

Amelioration of soil acidity through liming is a common practice (Quoggio *et al*., 1993). Besides lime, some others materials are also used as acid soil amendment, such as gypsum, phosphate rock (Alva *et al*., 1990; Mclay *et al*., 1995 and He *et al*., 1996) and some industrial byproducts like basic slag (Bhat *et al*., 2007), paper mill sludge (Sahu and Nanda, 1998: Pattanayak *et al*., 2011), press mud (James and Pandian, 2017) have suggested. The main management practice to ameliorate acid soils is the surface application of lime and calcareous materials (Bolan *et at*., 2003). The main aim of the soil liming is to neutralize acidic inputs and recovering the buffering capacity to the soil (Ulrich, 1983). To minimize the cost involvement in liming and to make the particle effective and efficient (Pattanayak *et al*., 2011) suggested for application of paper mill sludge.

2.2 Efficiency of Phosphorus

The different phosphorus utilization efficiencies were calculated from established formulae by Fageria and Baligar (2005) and Goodroad and Jellum (1988) as below:

Agronomic efficiency of phosphorus (kg kg^{-1}): It is described as the economic production obtained per unit of phosphorus applied. Agronomic efficiency of phosphorus was calculated using the formula as

$$\text{AEP (kg kg}^{-1}\text{)} = \frac{\text{Yield in P treated plot – Yield in control plot}}{\text{Amount of P added}}$$

Physiological efficiency of phosphorus (kg kg^{-1}): It represents the ability of plant to transform phosphorus acquired from fertilizer into economic yield (grain). Physiological efficiency of phosphorus was calculated using the formula as

$$\text{PEP (kg kg}^{-1}\text{)} = \frac{\text{Yield in P treated plot – Yield in control plot}}{\text{P uptake in P treated plot - P uptake in control plot}}$$

Apparent Recovery Efficiency (%): It indicates the quantity of nutrient uptake per unit of nutrient applied. Apparent Recovery Efficiency was calculated using the formula as

$$\text{ARE (\%)} = \frac{\text{Uptake of P in P treated plot – uptake of P in control plot}}{\text{Amount of P added}} \times 100$$

Phosphorus use efficiency (%): The Phosphorus use efficiency (PUE) as defined as yield increased per kg fertilizer P added is related to P sources, environmental factor, soil and crop management (Bationo and Kumar, 2002). Low phosphorus use efficiency (PUE) is one of the main problems of acidic soil that limit the crop growth.

Phosphorus use efficiency was calculated using the formula as described by Goodroad and Jellum (1988) as

PUE (%) = PEP x ARE

Venkatesh *et al.* (2002) Phosphorus use efficiency by maize increased up to 60 kg P_2O_5 ha^{-I}, thereafter it significantly reduced indicating that PUE decreases at higher doses of P due to the fact that plants grown in extremely P deficient soil exhibit greater P sorption at lower doses of P. The PUE increased in order when P was applied along with FYM/lime or FYM + lime, which indicates that FYM and lime have helped in release of P from soil and also reduced P fixation. Application of 60 kg P_2O_5 ha^{-1} along with lime and FYM resulted in maximum PUE of 29.67 %.

Majumdar *et al.* (2007) a field experiment was conducted for five consecutive years on a phosphorus deficient Typic Hapludalf and found that the phosphorus use efficiency was higher at lower doses of applied P with the maximum value (21.3%) recorded with SSP @ 30 kg P_2O_5 ha^{-1} plus FYM.

Rahim *et al*. (2010) concluded that wheat growth increased significantly with the use of P. it is clear that elevated P application has significant influence the PUE of wheat plant.

Devi *et al*. (2012) observed that maximum agronomic efficiency of phosphorus was observed from 60 kg P_2O_5 ha^{-1} owing to greater grain production per unit of phosphorus applied. Apparent phosphorus recovery was highest when using 40 kg P_2O_5 ha^{-1} level of phosphorus. In the same trend PUE was also increased upto 60 kg P_2O_5 ha^{-1} and declined at higher level.

Dalshad *et al*. (2013) observed that the results of PUE demonstrated the superiority of superphosphate fertilizer over the other sources of P fertilizer in case soybean cultivars. The high mean values of PUE (55.556 %) were recorded by the application of superphosphate @ 75 Kg P ha^{-1}, while the low mean values was (4.622 %) over control recorded by the application of NPK (20:20:20).

Shabnam and Iqbal (2016) conducted an experiment on phosphorus use efficiency by wheat plants grown in acidic soil. The results revealed that lower PUE was seen at higher P rates. The maximum PUE of 7.75 % was observed at 60 mg/kg P rate for wheat and it decreased significantly at higher P rates. The minimum of 4.17 % was obtained with 30 mg/kg P application.

Results are in conformity with those of Rahim *et al*. 2010 who concluded that wheat growth increased significantly with the use of P. it is clear that elevated P application has significant influence the PUE of wheat plant.

2.3 Type of liming materials

Materials like carbonate, oxide, hydroxide of calcium and magnesium compound are referred as agricultural lime which neutralizes soil acidity (Adams, 1984). Liming materials are classified as naturally occurring and industrial wastes. Among the naturally occurring lime sources, calcitic, dolomitic and stromatolytic lime stones are importance. Several industrial waste such as steel mill sludge (42 % CaO), blast furnace sludge from steel industries, paper sludge from paper mills (40 % CaO), press mud from sugar mill (33 % CaO), cement kiln waste and precipitated calcium carbonate from fertilizer factories have potential for use as liming materials for acid soil amendments which are eco friendly (Mishra and Pattanayak, 2002). Research has shown that several industrial byproducts and organic residues which are potential lime sources can be used if available at an affordable distance. Such materials includes converter slag from steel industries (*Torkashvand* and Shahram, 2007), Paper mill sludge (Sahu and Mitra, 1996, Sahu and Nanda, 1998, Pattanayak *et al*., 2011), cement kiln waste, precipitated $CaCO_3$ from fertilizer industries, wood ash (Lickacz, 2002) from the combustion of bark, sawdust, and yard waste for energy generation for forestry product operations which have been successfully used as soil amendments.

Studies made by Pradhan and Mishra (1982) showed application of paper mill sludge (PMS) and organic amendments caused a rise in soil pH. Paper mill sludge is produced as a by-product of paper production that disposal of this material presents a problem for the mill (Mahmood and Elliot, 2006). Paper mill sludge from paper mill be used for amelioration of acid soil successfully and economically (Sewaram *et al*., 1992). Paper mill sludge is the of cheap alternative sources of liming materials that contains $CaCO_3$ (Torkashvand, 2010; Kar *et al.*, 2014) but the quantity of required PMS depends on the paper manufacturing processes, soil type, crop species and cultivars (Caires *et al.*, 2005).

Wood ash, the residue remaining from the combustion of bark, sawdust, and yard waste for energy generation for forestry product operations, is an effective liming material on acid agricultural soils (Arshad *et al*., 2012). Wood ash contains many nutrients that were adsorbed from the soil during tree growth. Whenever wood is burned, oxides and hydroxides of calcium, magnesium, potassium, sodium, etc. are formed. These alkaline compounds are effective in neutralizing soil acidity. Therefore wood ash can also be used as a liming material (Lickacz, 2002). Studies by Demeyer *et al*., (2000) shows that wood ash causes the increase of soil pH and a decrease in soil acidity. Therefore, liming practice should less expensive and be available within easy reach of farmers besides its suitability.

2.4 Effect of liming materials on soil properties, crop growth and yield of soybean

Simson *et al*. (1980) observed that maximum soil pH was achieved in less than 1 week after application of the lime-sludge, while the pH of soils treated with finely-ground agricultural limestone increased continuously throughout the 24 week incubation period.

Ohno and Erich (1990) reported that wood ashes have variable calcium carbonate equivalence (CCE) ranging from 26 to 59 %, indicating that the acid-neutralizing value of wood ash varies considerably from source to source, and available P and K fractions varied from 43 to 56 % and from 39 to 82 %, respectively.

Muse and Mitchell (1994) stated that paper mill by product at equivalent rates based on CCE resulted in mean pH values significantly higher than values achieved with agricultural lime and also all materials such Paper mill by product, lime by-products (waste lime, grit, and dregs) as increased Mehlich-1 extractable P, K, and Mg in a field study conducted on an acid.

Vityakon and Seripong (1995) observed that the lime sludge had a high calcium carbonate equivalent (9l.3 %), it increased soil pH, Bray II extractable P and exchangeable Ca and decreased exchangeable Al and H contents, as application rate increased.

Demeymer *et al*. (2000) shows that wood ash causes the increase of soil pH and a decrease in soil acidity.

Gagnon *et al*. (2001) reported that microbial activity is stimulated by addition of paper mill sludge. Microbial biomass, CO_2 evolution and the activity of several enzymes (fluorescein diacetate, acid phosphatase, arylsulfatase and urease) were increased after application of raw sludge with a C:N ratio of 109:1 to a fredericton sandy loam.

Gaskin and Morris (2004) indicated that lime mud has potential to be used as an agricultural liming material because of its capability to neutralize soil acidity (increase soil pH) and add calcium and magnesium to the soil.

Hazarika *et al*. (2007) found that application of lime sludge (@ 40 % of the lime requirement) as liming material in acid soils of Meghalaya increased grain yield of maize, turmeric, and groundnut to the tune of 72-86 % over farmers' practice (no lime).

Mohammadi *et al*. (2010) showed that paper mill sludge significantly increased pH, which was proportional to the application rate of paper mill sludge. The application of 2 % sludge (based on soil dry mass) remarkably increased shoot dry matter and P, K, Fe, Mn, K and P uptake.

Arshad *et al.* (2012) concluded that wood ash applied at rates equivalent to agricultural lime improved some soil chemical and physical properties and increased crop production relative to agricultural lime..

Nottidge and Nottidge (2012) observed that soil pH increased significantly from 4.80 to 6.40, while levels of exchangeable Al^{3+} correspondingly decreased from initial values of 2.50 cmol kg^{-1} to 0.21 cmol kg^{-1} when 4 t ha^{-1} of wood ash was applied. Significant increases ($P < 0.01$) in soil Ca, P, K, status relate to patterns of growth, nodulation, nitrogen accumulation and grain yield of soybean.

Sharifi *et al*. (2013) suggested that wood ash can be used as a valuable liming and nutrient source for conventional and organic agriculture; however, wood ash properties, such as dry matter, CCE and K content, and soil properties, such as cation exchange capacity, clay content and soil organic matter, should be taken into consideration to tailor the lime and K recommendations.

Kumar *et al*. (2014) reported that liming at 300 kg ha^{-1} (furrow application) led to 32% yield increase of maize over the control under an acidic Alfisol (pH 4.6) of Meghalaya, Northeastern India

Osundare (2014) reported that application of the liming materials resulted in significant increases in soil pH, organic carbon, total nitrogen, available P and the exchangeable bases. On the contrary, liming resulted in significant decreases in exchangeable acidity after cropping.

Melese *et al*. (2015) reported that wood ash application gave a better yield than the lime application because of the additional nutrients such as P, K, Mg and micronutrients essential to plant growth.

Melese and Yli-Halla (2016) state that lime and wood ash applications in acidic soils can effectively ameliorate H^+ and Al^{3+} toxicity and P deficiency.

Behera *et al.* (2017) observed that the calcium silicate source applied @ 0.2 LR and the ST @ 0.2 LR when applied mixed with FYM recorded highest average growth rate of 3.9 cm day^{-1}. Liming of soil and their combined application with FYM resulted in increasing root length, cob length, diameter and seed weight cob respectively.

Verde *et al*. (2018) observed 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.

2.5 Effect of liming on soil properties, crop growth and grain yield of soybean

Liming is an important for management of acid soils for it has considerable influence on crop yield and soil environment besides neutralizing soil acidity. The direct and residual effects of lime were reported by many workers (Prasad *et al*., 1983 and Misra, 2004). Role of lime is dual, as soil amendment (Foy, 1984) and plant nutrients supplying material (Prasad *et al*., 1983). It improves base saturation effective CEC (Patiram *et al*., 1990), lime potential and increase availability of N, P, Ca and Mg in soil (Bishnoi *et al*., 1988; Sahu and Patnaik, 1990; Pattanayak *et al*., 2011). The decrease in exchangeable acidity with liming may be attributed to the neutralizing of exchangeable Al^{3+} and H^{+} where as the reduction in pH dependent and total acidity would be due to neutralization of hydroxyle Al and Fe (Mclean and Bhumbla, 1964) Other reasons may be that on limning Al^{3+}, Fe^{3+} and Mn^{2+} which are dominant in acid soil get reduced and consequently.

Liming of acid soil is found to improve the physical condition of soil. Barade *et al*., (1998) conducted a field experiment where limning improved soil aggregation, maximum water holding capacity and hydraulic capacity of soil. Prasad and Singh (1980) also observed beneficial effect of liming and FYM on soil aggregation. An increase in soil pH is known under the many soil crop lime situations (Bishnoi *et al*., 1988; Gupta *et al*., 1989; Dixit *et al*., 1993) and has been attributed to increase in degree of base saturation and a decrease in exchangeable H^{+} and Al^{3+} (Sahu and Patnaik, 1990 and Bishnoi *et al*., 1988) observed that lime and organic matter additions in highly weather acid and laterite soils resulted in an increase in the ECE and pH values, which are essential for crop productivity. By increasing lime level there was rise in soil pH (Singh and Sanyal, 2000). The soil pH under lower dose or lime was comparable to that under full dose of lime which gradually decreased with lime probably on account of uptake and downward movements of lime due to leaching. Similar observations were made by Gupta *et al*., (1989).

Yargodin (1984) observed that liming makes phosphorous available in the soil and promotes root development, carbohydrate and nitrogen metabolism in plants.

Quaggio *et al*, (1993) found that application of lime in soybean increase pH, decrease toxic concentrations of Al and Mn, increase N, P, K and S uptake and also supply Ca and Mg.

Ghosh *et al*. (2006) conducted a field investigation conducted in the district of Bankura (West Bengal) during *kharif* 1998 and 1999 showed that liming tended to exhibit better nodulation and higher seed yield with more oil content than control.

Bhat *et al*. (2007) reported that on an average, calcite and basic slag caused an increase in grain yield to the extent of 21.9 and 31.0 % over the no lime treatment, respectively. Results of the analysis of residual soil showed that total acidity, exchange acidity and hydrolytic acidity recorded a decrease upon liming.

Okpara *et al.* (2007) showed an increase in soybean nodule formation upon lime application due to favorable conditions for *Bradyrhizobium* spp. Proliferation.

Cabral *et al*., (2008) Wood ash a pronounced increase on soil extractable potassium and phosphorous was observed, indicating that besides the liming effect this waste can contribute to improve soil fertility by supplying significant available amounts of these nutrients.

Andric *et al.* (2012) reported increased soybean yield by 44% as a result of lime application.

Bekere *et al*. (2013) reported that the combined effect of liming and bradyrhizobium inoculation significantly increased nodule number, nodule volume, nodule dry weight per soybean plant compared to unlimed and non-inoculated.

Kisinyo *et al*. (2013) found that lime increased soil pH and available P due to reduction in Al levels and P sorption.

Verde *et al*., (2013) reported that 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 yields.

Buni (2014) was carried out field experiment and results showed that soil pH increased from 5.03 to 6.72 by applying 3750 kg ha^{-1} lime and the exchangeable acidity reduced significantly. Moreover, liming significantly ($P \leq 0.05$) increased. Cation Exchange Capacity (CEC), available phosphorus and decreased available micronutrients except Cu.

Nduwumuremyi (2014) reported that the application of lime believed to enhance soil health status through improving soil pH, base saturation, Ca and Mg. It reduces Al and Mn toxicity and increases both P uptake in high P fixing soil and plant rooting system.

Benvindo (2014) reported that lime alone (2 ton ha^{-1}) increased significantly soil pH (15.9%), extractable Ca (64.4%) and Mg (23.1%), and reduced exchangeable acidity by 3.5 times.

Buni (2014) observed that soil pH increased from 5.03 to 6.72 by applying 3750 kg ha^{-1} lime and the exchangeable acidity reduced significantly. Moreover, liming significantly ($P \leq 0.05$) increased cation exchange capacity (CEC), available phosphorus and decreased available micronutrients except Cu.

Jackson (2014) reported that the application of lime significantly increase soil pH and available P. The highest mean amount of P was 8.3 mg P kg^{-1} was generated by CaO and the lowest was 7.1 mg P kg^{-1} generated by $CaCO_3$.

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

Rastija *et al*. (2014) reported that liming with dolomite considerably affected soil chemical properties and raised soil pH from initially acid or very acid to neutral or slightly alkaline reaction. Application of the highest dolomite rates raised the phosphorus availability by 8 % in the soils rich in phosphorus to 45% in the soils very poor in available phosphorus. Potassium availability was independent of liming.

Dey and Nath (2015) observed that application of recommended dose of NPK (20:60:42 kg ha^{-1} of NPK) along with lime (10 % of actual LR was followed) resulted in 153 percent yield increase over control for groundnut crop. Post harvest soil analysis also showed improved status of organic C, N and P in treated plots, but available K status declined emphasising the need for close monitoring and appropriate K application in such soils.

Wijanarko and Taufiq (2016) showed that liming by mixing dolomite with soil within 20 cm depth resulted in 8 % higher plant height compared to that applied on the soil surface. The highest yield was obtained when liming at rate equivalent to 10 % of Al saturation was mixed with soil within 20 cm depth.

Behera *et al*, (2017) observed that the maximum concentration of the major nutrients follows the order as N>K>P>Mg>Ca>S with application paper mill sludge with STD & FYM. Among the major nutrients, the recovery of P was maximum ranging from 26-66 %, followed by K from 22 to 55 per cent, N from 17 to 36 per cent and S from 6.2 to 28.7 per cent. The maximum uptake of the N (74.8 kg ha^{-1}) was observed in paper mill sludge source applied @ 0.2 LR with STD & FYM but the maximum uptake of the K (32.2 kg ha^{-1}) & S (7.1 kg ha^{-1}) was observed in calcium silicate source applied @ 0.2 LR integrated with STD and FYM.

Lynrah and Nongmaithem (2017) revealed that application of lime @ 1.5 t ha^{-1} gave highest values of growth and yield attributes. Application of lime @ 1.5 t ha^{-1} recorded highest seed (2.71 1.5 t ha^{-1}) and stover yield (2.79 1.5 t ha^{-1}). The uptake of N P K by soybean was also found to be highest under application of lime @ 1.5 t ha^{-1}.

Opala (2017) investigated that liming significantly reduced the exchangeable acidity in the soils and the effect of lime on available P was not significant but available P increased with increasing P rates.

2.6 Effect of phosphorus on soil properties, crop growth and yield of soybean

Amarasiri And Olsens (1973) concluded that for any level of phosphorus, liming decreased soluble P and labile P until the pH reached about 6.5. Limed soil had a higher maximum adsorption capacity for phosphorus than the unlimed soil. Adsorption of P by the freshly precipitated Fe and Al hydroxides apparently caused the greater inactivation of added phosphorus in the limed soils.

Debnath and Mandal (1982) reported about the transformation of applied phosphorus in acid soil into different P fractions. The fractions were in decreasing order of Al-P, Fe-P, Ca- P but with the passage of time Fe-P increased consistently, whereas Al-P and Ca-P increased up to 15 to 30 days and decreased thereafter.

Miles *et al*. (1984) reported that highly significant yield responses to lime and P were noted. Up to 460 kg P ha^{-1} were required in order to obtain a leveling-off of dry matter response to P.

Nimje and Seth (1986) conducted an experiment at IARI New Delhi rainy season, they concluded that dry matter yield of whole plant, N, P, K content and uptake at flowering and harvesting stage of soybean, enhanced due to increasing levels of phosphorus of 40 kg P_2O_5 and FYM.

Caradus and Snaydon (1988) found that external P supply to white clover was shown to have a greater effect on root elongation rate than on root production rate. Population with many small roots i.e. low root weight/number ratio was generally the most responsive to P, measured by shoot weight. Populations collected from low- P soil had lower root elongation rates, shorter average root lengths and their root production rates were more responsive to P than from high P soils.

Sairam *et al*. (1989) studied the effect of phosphorus levels and inoculation with Rhizobium on nodulation, leghaemoglobin content and reported that Rhizobium culture and application up to 90 kg P/ha improved nodulation and higher leghaemoglobin content root nodules along with an increase in nitrogen uptake, available soil nitrogen content and dry matter production.

Jayapaul and Ganesharaja (1990) conducted experiment at Agricultural College Research Institute, Madurai (TN) to study the response of soybean varieties to nitrogen andpPhosphorus application and reported that application of N up to 75 kg ha^{-1} and P_2O_5 up to 80 kg ha^{-1} gave higher yield.

Shahid *et al*. (1990) conducted a field experiment on soybean and observed that plant height, number of pod bearing branches $plant^{-1}$, number of pods $plant^{-1}$, pod length, number of seeds pod^{-1}, biological yield and harvest index of soybean increased significantly with P application.

Singh and Bajpai (1990) reported that the soybean was given a basal dressing of 20 kg N ha^{-1} + 0-100 kg P_2O_5 and 0-40 kg K_2O ha^{-1}. The increasing P rates increased the number and dry weight of nodules per plant. It observed increase in nodulation due to phosphorus application to soybean.

Westermann (1992) observed that plant P uptake was increased by P fertilization and decreased by increasing lime concentration, the soil-test P concentration or P fertilization rate.

Marschner (1995) reported that phosphorus stimulated root development, improved flower formation and seed production, promoted more uniform and earlier crop maturity, increases the nitrogen N-fixing capacity of legumes, improves seed quality, and increases resistance to plant diseases.

Patel and Chandravanshi (1996) observed in a field experiment that application of 90 kg P_2O_5 ha^{-1} gave significantly higher number of pods $plant^{-1}$, seed yield and straw yield in two successive years over lower levels of phosphorus.

Pradhan *et al*. (1996) reported that application of 0, 40 and 80 kg P_2O_5 ha^{-1} as single superphosphate gave soybean seed yield of 0.62, 0.88 and 0.90t ha^{-1}, respectively.

Tamboli (1996) had reported that the application of phosphorus resulted in higher root volume in legume plants like pegionpea, pea, chickpea and groundnut

Bhakare and Sonar (1998) found that application of 100 kg P_2O_5 ha^{-1} to soybean showed increase in soil available N, P and K which could be attributed to higher P fertilization and a leguminous crop soybean having the tendency to fix the atmospheric N and defoliation, thereby increasing organic matter and other available nutrients & higher P uptake by soybean which was significantly influenced by increasing levels of phosphorus and found highest in 100 kg P_2O_5 ha^{-1} treatment. The soil available status was also increasing with increase in the application of phosphorus.

Kundu and Basak (1999) studied that the dissolution effect of super phosphate and rock phosphate in their mixtures in the ratios of 3:1, 1:1 and 1:3 as well as the effect of mixture on available P in an acid soil incubated for 150 days under two moisture regimes, *viz.*, 50 per cent water holding capacity and submergence. All the mixtures increased the available P. Rock phosphate efficiency increased with increased proportion of super phosphate.

Carsky *et al.* (2001) stated that Phosphorus deficiency can limit nodulation by legume and P fertilizer application can overcome the deficiency.

Majumdar *et al.* (2001) reported that all the P levels significantly increased the grain and straw yields, pods/plant, 100 seed weight, oil and protein content and their yields and N, P and S uptake by soybean. Application of 60 kg P_2O_5 ha^{-1}along with 40 kg S ha^{-1} was the optimum dose of P and S for getting the highest yield of soybean.

Sharma *et al.* (2001) found that the application of 60 kg P_2O_5 ha^{-1}significantly improved plant height, branches $plant^{-1}$, nodules $plant^{-1}$, nodules dry weight $plant^{-1}$and dry matter accumulation $plant^{-1}$ and also significantly increased seed yield of soybean over 30 kg P_2O_5 ha^{-1}.

Shah *et al.* (2001) observed that phosphorus uptake efficiency and yield of soybean was increased with increase in phosphorus application in an experiment with 0, 40, 60 and 80 kg P_2O_5 ha^{-1}.

Sahoo and Panda, (2001) found that plant height, grain yield, biomass yield and P uptake efficiency of soybean increases at high levels of P application.

Khandwe and Sharma (2002) observed that by applying phosphorus to soybean increased significantly plant height and branches per plant up to 60 kg P_2O_5 ha^{-1}.

Kausadikar *et al.* (2003) reported from a field experiment that application of P at 90 kg P_2O_5 ha^{-1} gave the highest number of pods $plant^{-1}$, 100 seed weight, crude protein, seed yield and straw yield.

Singh and Rai (2003) conducted a field trial on wheat grown in sandy clay loam soil studied the influence of different levels of phosphorus in fertilizers of 0, 30, 60, and 90 Kg P_2O_5 ha.$^{-1}$ and phosphate solubilising micro organism on nutrient uptake by wheat. It was observed that highest phosphorus uptake of 111.27 Kg P_2O_5 ha.$^{-1}$ level of P and it was superior to rest of the levels of phosphorus. However, increase in nitrogen uptake was due to addition of 90 Kg P_2O_5 ha^{-1} along with phosphate solubilising micro organism. As phosphorus fertilization augmented the higher productivity, it also resulted in higher nitrogen accumulation in plant.

Kaul (2004) found that the plant height, branches $plant^{-1}$, leaves $plant^{-1}$, dry weight of root nodules and dry weight per plant were significantly influenced with the application of nitrogen, phosphorus and potassium @ 40:80:40 kg NPK ha^{-1}.

Guppy *et al.* (2005) reported that the incorporation of organic matter in soils that are able to rapidly sorb applied phosphorus fertilizers reportedly increased phosphorus availability to plants. Incubation of organic matter in soil reduced phosphorus sorption in soil.

Shipratewari and Pal (2005) carried out an experiment with soybean. And presented that application of 90 kg P_2O_5 ha^{-1}significantly increased the uptake of P and K in both grain and straw. There was no significant difference between 60 and 90 kg P_2O_5 in nutrient uptake.

Anetor and Akinrinde (2006) reported that P fertilizer addition was more prominent in the first cropping while lime and P application enhanced soybean growth and yield in the second cropping. Lime and its combination improved soil pH and available P.

Majumdar *et al*. (2007) carried out an experiment with soybean that the grain and straw yields, pods $palnt^{-1}$, 100-seed weight, oil and protein content and their yields and N, P and S uptake increased significantly with P alone (60 kg P_2O_5 ha^{-1}).

Devi *et al*. (2012) conducted a field experiment to sources and levels of phosphorus and found 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.

Sentimenla *et al*. (2012) reported that on the basis experimental findings, it is suggested that application of 60 kg P_2O_5 ha^{-1} was beneficial for higher productions and quality of soybean. Application of 60 kg P_2O_5 ha^{-1} produced significantly higher seed (2.88 t ha^{-1}), stover (3.74 t ha^{-1}) and protein content (40.98 %).

Bhattacharjee *et al*. (2013) conducted an experiment on acidic soils of northeast India and observed that growth, yield parameters and seed protein of soybean responded positively to higher dose of P (90 kg P_2O_5 ha^{-1}).

Ashoka *et al*. (2014) observed that lime and P increased biomass production, P concentrations of shoot and root, and its uptake by Indian spinach and available P. 1000 kg lime plus 100 kg P were adequate for plant growth. Available P was strongly and positively correlated (R^2 = 0.909, P = 0.000) with P uptake by plant. Results indicated that lime and phosphorus could be used in combination to enhance plant growth.

Ching *et al.* (2014) reported that the organic amendments increased soil pH, and, at the same time, they reduced exchangeable acidity, exchangeable Al, and exchangeable Fe. As the soil pH increased, the organic amendments effectively fixed Al and Fe instead of P.

Tamene *et al.* (2017) stated that P is known as the master key to agriculture, lack of available P in the soil limits the growth of both cultivated and uncultivated plants. In acidic soils there are very high contents of Fe and Al bonded P fractions compared to the other fractions which could be due to the high content of Fe/Al-oxides, low pH and advanced stage of weathering of the soils that control the plant available P, and the high content of Al and Fe oxides and hydroxides are the main factors for the strong P fixation in acidic soils.

Jiguang and Biao (2019) conducted an experiment on a global meta-analysis of soil respiration and results showed that P addition did not significantly change soil respiration and heterotrophic respiration across all ecosystems, but this P addition effect varied among ecosystem types ($p < 0.05$). Specifically, P addition significantly increased soil respiration by 17.4% in tropical forest and by 31.7% in cropland, depressed R s by 13.7% in wetland ($p < 0.05$), and had minor effect in other ecosystems (grassland, boreal forest, and temperate forest).

Tiwari *et al*. (2019) observed that the soybean seed yield increased with increase in the phosphorus levels upto 60 kg P_2O_5 ha^{-1}.

2.7 Combined effects of lime and phosphorus on soil properties, crop growth and yield of soybean

Jasmin and Heeney *(*1961) observed that increments in lime application increased soil pH and available phosphorus and decreased the exchangeable potassium and also reduced the total nitrogen, phosphorus and potassium present in the plant tissue at time of sampling and increased calcium. magnesium was not affected.

Akbari *et al.* (1981) reported that the availability of P decreased (11 to 9.9 ppm) with 15 per cent lime up to a certain limit but increased thereafter and the effect of lime application was apparent only beyond 5 per cent $CaCO_3$ level, although further increase in lime application from 10 to 20 per cent could not affect P fixation.

Haynes and Ludecke (1981) reported that liming resulted in an increase in exchangeable Ca and thus in percentage base saturation, with concomitant decreases in levels of exchangeable AI, Fe and Mn. Liming had no consistent effect on measured CEC values. Increasing lime rates significantly reduced concentrations of Mg, K and Na in saturation paste extracts but had no effect on exchangeable Mg, K and Na levels. Correlations between available phosphate indices and yield of both legumes were weak or non significant. However, high significant positive correlation coefficients were found between available phosphate and plant uptake of P.

Fageria *et al.* (1995) reported that increasing levels of applied P significantly increased nutrient uptake. With some exceptions, increasing levels of lime tend to reduce uptake of P, Zn, Cu, Mn, and Fe and increase the uptake of Ca and Mg in all the crop species. Decrease in K uptake, due to high lime, is probably due to antagonistic effects of Ca and Mg and reduced micronutrients uptake is probably due to increased soil pH resulting in decreased availability of these elements to plants.

Navale and Gaikwad (1998) observed that the seed yield of soybean increased with FYM along with 40 kg N ha^{-1} and 80 kg P_2O_5 ha^{-1}.

Ranjit *et al.* (2006) stated that increased dry matter yield of groundnut due to liming is attributed to the beneficial effect of ameliorating the soil, which increased the Ca saturation and availability of major nutrients, especially nitrogen. Addition of $CaCO_3$ increased soil pH and might have accelerated the process of mineralization of nitrogen which in turn promoted the uptake of nitrogen by groundnut. Application of 100 % LR recorded higher total phosphorus uptake (25.76 kg ha^{-1}) than other levels. The application of phosphorus influenced the phosphorus uptake significantly.

Uzoho *et al*. (2010) reported that plant height, leaf area, dry matter yield, nutrient uptake (N and P) and residual soil properties (pH, Ca, Mg and P) increased with treatments up to 30 kg P_2O_5 ha^{-1} and 1.5 t ha^{-1} lime combined rates.

Benvindo (2014) observed that integrated application of 5 ton ha^{-1} of goat manure with 2 ton ha^{-1} of lime plus 30 kg ha^{-1} P_2O_5 increased significantly soil pH (14.1 %), Ca (87.7 %), Mg (30.8 %), K (3.7 times) CEC (73.7 %) available P (38.0 %) and 59.3 % on microbial biomass.

Sarker *et al*. (2014) carried out to investigate the yield of Indian spinach (*Basella alba* L.) and their uptake and availability of phosphorus from lime and phosphorus amended acidic soil. Both lime and Phosphorus and their combinations had significant (P < 0.001) effects on shoot and root biomass, shoot and root P concentrations, P uptake by Indian spinach and P availability. 1000 kg lime plus 100 kg P were adequate for plant growth.

Suryantini (2014) stated that a positive correlation was reported between the number of nodules and soybean grain yield. Inorganic fertilizers increased nodulation and grain yield but the highest yields were generally obtained in the treatment of inorganic fertilizer combined with lime or manure.

Amsalu and Beyene (2020) reported that the soil chemical properties, except Mg, were significantly ($P \leq 0.05$) affected by increasing rates of lime and/or P addition. The highest lime rate resulted in an increase in soil pH, exchangeable Ca and Cu, and a decrease in the levels of exchangeable acidity and Al, Fe, Mn, and Zn. The lime and P interaction effects were significant ($P \leq 0.05$) on exchangeable Ca, Al, and Yield.

Ameyu and Asfaw (2020) reported a combined application of phosphorous 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 P kg 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.

2.8 Effect of liming material and phosphorus on phosphorus fractions

Soil phosphorus exists in both inorganic and organic forms. In most agricultural soils, 50-75 % of P is in organic form, although this fraction can vary from 10-90 % (Sharpley and Rekolainen, 1977). Inorganic P forms are associated with hydrous sesquioxides and amorphous and crystalline Al and Fe compounds in acidic, noncalcareous soils and with Ca-compounds in alkaline, calcareous soils. The inorganic phosphates in soils have been classified into easily soluble phosphate (ES-P), aluminium phosphates (Al-P), iron phosphates (Fe-P), reductant soluble phosphates (RS-P) and calcium phosphates (Ca-P) (Chang and Jackson, 1957). Strong acid soils, usually highly weathered, are dominant in Al-P, Fe-P and RS-P. Neutral and slightly acid soils usually contain all five fractions in comparable amounts. Alkaline and calcareous soils are often dominant in Ca-P. Phosphorus bound to aluminium (Al-P), iron (Fe-P) and calcium (Ca-P) constitutes the major active forms of inorganic P. Relatively less active are the occluded and reductant-soluble forms of P. Datta *et al*. (1989) reported that phosphorus in all forms exists in all soils, but Al-P and Fe-P are more abundant in acid soils, while Ca-P dominates in neutral to alkaline soils.

Chang and Jackson (1957) using different extractants sub-divided the inorganic phosphate into a number fractions, viz. water soluble, Al, Fe, Ca, occluded Fe and occluded Al. Ayres (1972) concluded that apatite and lattice fixation are primary sources of non-extractable Phosphorus, where as P associated with hydrated sesquioxides is its secondary source (Mukherjee *et al*., 1979). Kuo (1996) using different extractants sub-divided the inorganic phosphate into a number fractions, viz. Soluble and loosely bound P, Al-Phosphate, Fe-Phosphate, Reductant-soluble P and Ca-Phosphate. Concentrations of five inorganic P fractions, which include of soluble / loosely bound P, aluminum (Al)-P, iron (Fe)-P, calcium (Ca)-P, and occluded-P, were obtained by following a sequential chemical fractionation procedure. Soluble or loosely bound P, Al-P, and Fe-P were the main sources contributing to plant-available P, whereas Fe-P and Al-P were the two most important sources for contribution to plant-available P (Wang and Zhang, 2012).

Tripathi (1970) found that Fe-P and Al-P were higher in the new alluvial soils than in the old alluvial, hill and forest soils.

Khan and Mandal (1973) found from an experiment that the organic phosphorus constituted about 34.7 % of the total amount and both total and organic phosphorus were found to be significantly correlated with organic matter.

Mandal *et al*. (1975) found that Al-P, Fe-P, Ca-P, reductant soluble P and occluded P fractions constituted about 7.2, 27.8, 46.6, 16.2, and 2.2 per cent, respectively, of the total inorganically bound phosphorus in rice soils of West Bengal (India). The fractions of inorganic P, Ca-P dominated over all other fractions.

Perumal and Velayutham (1977) observed that Al-P and Fe-P constituted 55 % of total P while Ca-P formed only 12 %. The P forms were distributed as follows:Unidentified P > Fe-P > Al-P > Ca-P = reductant soluble P> saloid-P

Singh and Sinha (1977) found over 50% of the total P in the form of occluded P in highly weathered acid soils of Bihar.

Sahrawat (1977) found that in Alfisols of India with pH ranging from 5.5 to 6.8, the order of soil P distribution was Fe-P > Ca-P > Al-P.

Vijayachandran and Raj (1978) reported up to 40 % of P in reductant soluble form in acid soils of south India.

Bowman and Cole (1978) observed the distribution of different inorganic P forms in 20 surface soil samples belonging to Alfisols and Vertisols orders and reported that in Alfisols the most dominant form was Fe-P followed by Ca-P and Al-P. In Vertisols, however, the order of the distribution was Ca-P > Fe-P > Al-P.

Tomar *et al*. (1986) showed that recovery percentage of the total inorganic P into saloid-P, Al-P, Fe-P and Ca-P was only 27-53 % and the remaining fractions were either in occuluded from fixed in lattice.

Singh and Sarkar (1986) observed from an experiment that addition of phosphate enhanced the saloid-P, Al-P, Fe-P and Ca-P of soil.

Agrawal *et al*. (1987) conducted a long term fertilizer experiment and observed that graded doses of NPK fertilizers increased the saloid-P, Al-P, Fe-P, reductant soluble-P and available P status of soil. The Ca-P remained at the original level. The Al-P and Fe-P fractions increased significantly due to phosphate application.

Singh and Datta (1987) found the phosphorus fractions were correlated with organic carbon, base saturation and total nitrogen and inorganic-P increased in the solum contributing up to 99 % of total-P

Tandon (1987) discussed the distribution of different forms of P in Indian soils and concluded that in acid soils the increase in Al-P and Fe-P was less than the decrease in Ca-P, mainly because of the predominance of reductant soluble and occluded P forms. Fertilizer application was found to increase the Al-P and Fe-P fractions of the soil.

Patiram *et al*. (1990) found that in acid soils of Sikkim, among the different forms of P, Fe-P was dominated, being approximately 1.5 times of Al-P or Ca-P, but Al-P and Ca-P did not differ much. They also reported that residual P was highly related to total and organic P but had the negative relationship with other forms of inorganic P. Perumal and Velayutham (1977) observed that Al-P and Fe-P constituted 55 % of total P while Ca-P formed only 12 %. The P forms were distributed as follows: Unidentified P > Fe-P > Al-P > Ca-P = reductant soluble P > saloid-P.

Patiram *et al*. (1992) observed that the surface layers of some acid hill soils north-west contented fairly rich in total P reserve (average 493 ppm). The mineral, organic and residual P, on an average, constituted about 49.6, 45.6 and 33.6 percent of total P.

Huffman *et al*., (1996) as a consequence phosphorus fixation tends to be more pronounced in clay soils than in the coarser textured ones. Soil texture has a greater effect on P transformation.

Dutta and Mukhopadhyay (2007) showed that the different inorganic forms of soil P decreased in the order, Al-P > Fe-P > reductant-soluble-P > Ca-Poccluded-P > saloid-P.

Majumdar *et al*. (2007) carried out an experiment with soybean with application of different source of P (SSP and RP) that total and organic P increased significantly with different source of P. Among inorganic fraction, significantly increased in saloid-P, Al-P and Ca-P but depletion in reductant-soluble and occluded-P was observed.

Chandrakala *et al*. (2017) carried out an experiment with P fractions and P management and found that total-P, organic-P, reductant-P, soluble-P, occluded-P and calcium-P fractions increased with the increased gradient strips from very low to very high applied with levels of P where as saloid-P, aluminium-P and iron-P decreased with the P fertility gradients and dose of P addition increased.

Kiflu *et al*. (2017) conducted an experiment on fractionation and availability of P in acid soils under different rates of lime and found that the application of lime significantly affected the different P fractions. Organic-P forms were significantly lower for higher levels of lime application and application of lime increased Ca-P and decreased Al-P and Fe-P for acid soil.

Amruth *et al*. (2017) carried out an experiment on effect of Phosphorus levels on phosphorus availability and phosphorus fractions in soil and found significantly higher amount of all inorganic and organic forms of P in soil were recorded in application of higher dose of P i.e. 50 kg ha^{-1}. The results also revealed that significantly higher availability of phosphorus was recorded in 50 kg ha^{-1}.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled "**Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland**" was carried out during *kharif* season of 2018 and 2019 at the experimental research farm of School of Agricultural Sciences and Rural Development (SASRD), Medziphema campus, Nagaland University. The details of experimental, materials used and the research methodology adopted during the investigation for recording the various observation and analysis are described below.

3.1 General information

3.1.1 Location

The experimental farm is located in the foothills of Nagaland at an elevation of 301 m above mean sea level with geographical location of 20˚45'43" N latitude and 93˚53'04" E longitude.

3.1.2. Climatic condition

The experimental site lies in humid sub-tropical zone with moderate temperature and medium to high rainfall. The mean temperature ranges from 21º C to 32º C during summer while in winter it varies between 13º C to 26º C which rarely goes below 8º C. The average annual rainfall varies from 200 to 250 cm during April to September whereas the remaining period from September to March is virtually dry because of scanty rainfall.

The periodical data of temperature, relative humidity, rainfall and sun shine hours for the period of the experimentation viz. from July to December 2018 and July to December 2019 were obtained from Metrological Unit, ICAR Nagaland Centre, Jharnapani, Nagaland. The data are presented in the Table 3.1

Table 3.1 Meteorological data during the experimental period (July to December 2018 and July to December 2019)

Month /Year	Temperature (^oC)				Relative humidity (%)				Sunshine hours		Rainfall (mm)	
	Minimum		Maximum		Minimum		Maximum					
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
July	23.8	23.8	35.8	36.4	71.71	71.77	91.65	93.48	3.1	3.1	239.5	271.3
August	23.7	23.5	36.8	37.7	71.39	72.52	94.23	92.65	3.8	4.9	302.8	274.3
September	22.7	22.1	35.3	36.4	66.7	72.1	93.6	93.8	5.3	4.1	115.7	173.5
October	17.7	18.1	33.9	33.3	66.71	72.87	95.68	95.35	6	5.9	64	244.8
November	10.2	11.3	31.2	32	53.5	64.2	96.73	97.4	7	7	13.3	52.9
December	8.1	7.3	27.9	28	55.84	62.16	96.45	97.03	6.3	6.1	50	0.9

Source: Metrological Unit, ICAR Nagaland Centre, Jharnapani, Nagaland

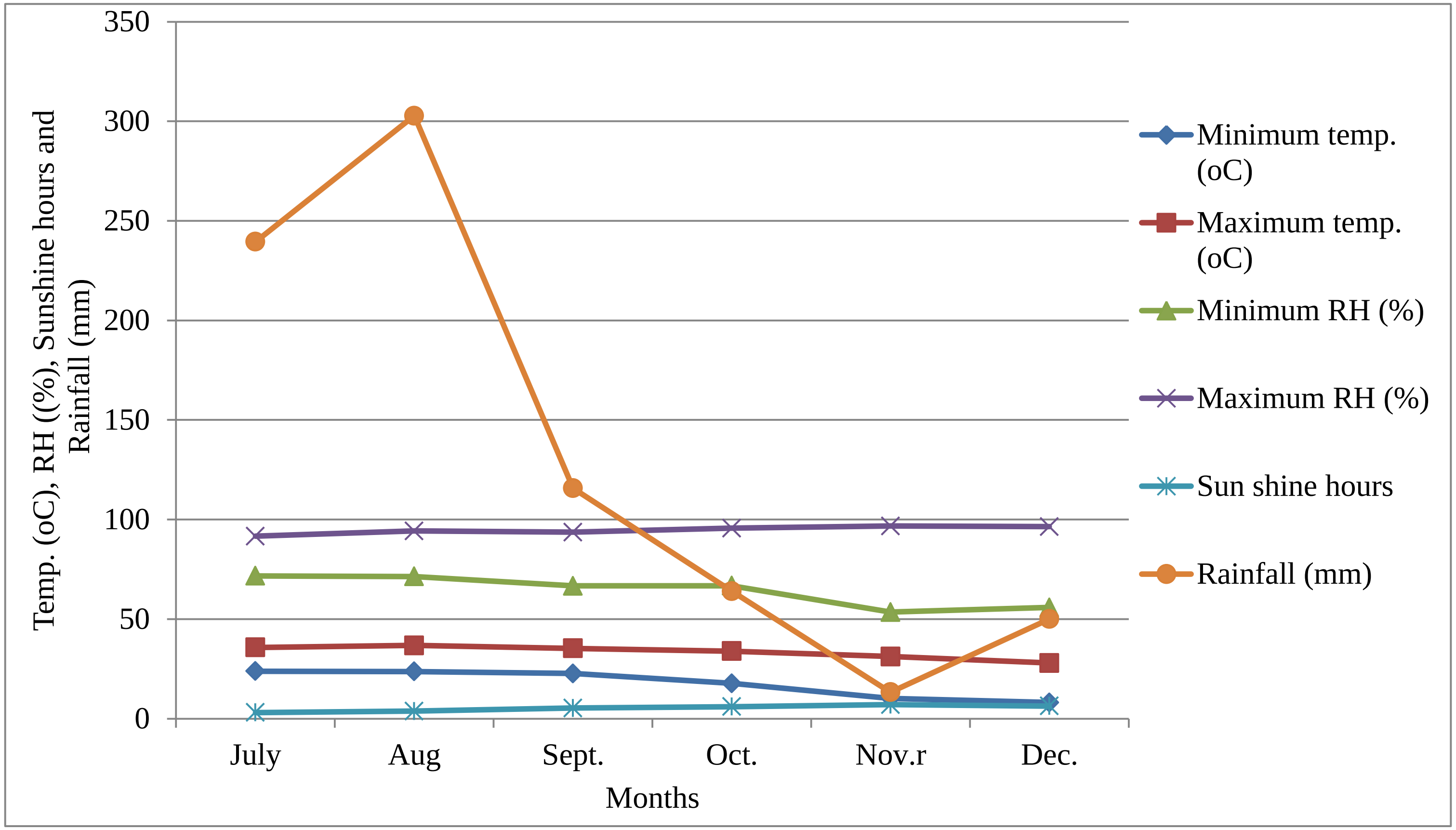


Fig. 1 (a) Metrological data during the period of experimentation for the year 2018

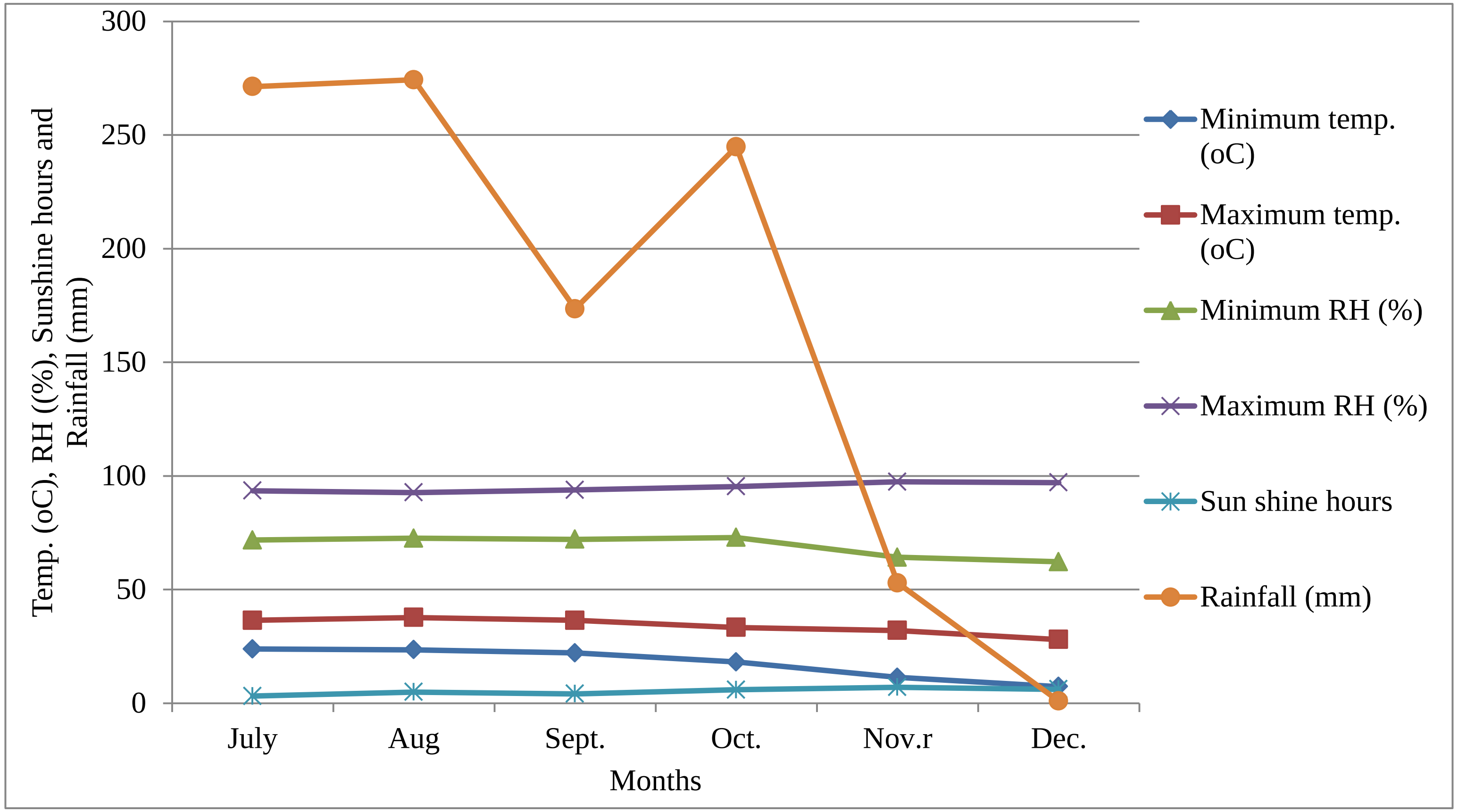


Fig. 1 (b) Metrological data during the period of experimentation for the year 2019

3.1.3 Soil of the experimental field

Soil sample was collected from 0-15 cm depth randomly from several spots of the experimental field before starting the experiment. A homogenous composite sample was then prepared for chemical, physical and biological analysis. Result of initial soil analysis is given in Table 3.2.

3.2 Detail of experiment and techniques

3.2.1 Design and plan of layout

The field experiment was laid out in a Split Plot Design (SPD) with sixteen (16) treatments which were replicated thrice. The experimental field was divided into three blocks where each block as sub-divided into sixteen plots measuring 4.5 m x 1.2 m whereby the treatments are placed in randomized manner in each the blocks.

The details of the experiment conducted consist of the following components:

a)	Crop	:	Soybean {*Glycine max* (L.) Merrill}
b)	Variety	:	JS-335
c)	Experimental design	:	Split plot design
d)	Plot size	:	4.05 m x 1.2 m
e)	Row to Row	:	45cm
f)	Plant to plant	:	10cm
g)	Total number of treatment	:	16
h)	Total number of replication	:	3
i)	Total number of plots	:	48
j)	Number of replication	:	3

The details of the plan and layout of the experimental field are given in Fig. 2

Table 3.2 Initial soil status of the experimental plot

Sl.	Soil Parameters	Value	Method
Chemical Properties			
1.	Soil pH	5.31	1:2.5 soil : water ratio by pH meter, Jackson, 1973
2.	Organic carbon %	0.91	Walkley and Black method, 1934
3.	Available nitrogen (kg ha^{-1})	240.69	Alkaline $KMnO_4$ method, Subbiah and Asija, 1956
4.	Available phosphorus (kg ha^{-1})	10.82	Bray and Kurtz, 1982
5.	Available potassium (kg ha^{-1})	229.93	Flame photometer, Hanway and Heidel, 1952
6.	Available sulphur (mg kg-^{1})	1.17	Turbidimetric method using $BaCl_2$, Chesin and Yien, 1951
7.	Cation Exchange Capacity (CEC) [cmol(p+)kg^{-1}]	8.11	Normal ammonium acetate method, Black, 1965
8.	Exchangeable Ca^{2+} [cmol(p+) kg^{-1}]	1.90	Versenate titration method, Jackson, 1973
9.	Exchangeable Mg^{2+} [cmol(p+) kg^{-1}]	0.67	Versanate titration method, Jackson ,1973
10.	Exchangeable Al^{3+} [cmol(p+) kg^{-1}]	1.06	1 *N* potasium chloride extract soil, Jayman and Sivasubramaniam, 1974
11.	Exchange Acidity [cmol(p+) kg^{-1}]	2.86	Barium acetate extraction, Mehlich, 1945; Parker, 1929
12	Lime requirement [t $CaCO_3$ ha^{-1}]	9.88	Woodruff Buffer method, 1948
13.	DTPA-Fe (mg kg^{-1})	43.72	DTPA extractable method, Lindsay and Norvell, 1978
14.	DTPA-Mn (mg kg^{-1})	29.78	DTPA extractable method, Lindsay and Norvell, 1978
15.	DTPA-Zn (mg kg^{-1})	1.19	DTPA extractable method, Lindsay and Norvell, 1978
Phosphorus fractions			
17.	Soluble or loosely bound P (mg kg^{-1})	4.16	Chang and Jackson, 1957 as modified by Kuo, 1996
18.	Al-P (mg kg^{-1})	51.13	Chang and Jackson, 1957 as modified by Kuo, 1996

Sl.	Soil Parameters	Value	Method
19.	Fe-P (mg kg^{-1})	40.37	Chang and Jackson, 1957 as modified by Kuo, 1996
20.	Ca-P (mg kg^{-1})	13.50	Chang and Jackson, 1957 as modified by Kuo, 1996
21.	Reductant-P (mg kg^{-1})	78.67	Chang and Jackson, 1957 as modified by Kuo, 1996
22.	Occuluded-P (mg kg^{-1})	56.50	Chang and Jackson, 1957 as modified by Kuo, 1996
Physical properties			
23.	Soil textural class	Sandy cay loam	Bouyoucos hydrometer method, Piper, 1950
24.	Bulk density (g cc^{-1})	1.02	core method as described by Black,1965
25.	Water holding capacity of soil (%)	47.62	Keen raczkowski method, Piper, 1950
Biological properties			
26.	Soil microbial biomass carbon (µg g^{-1})	274.13	Fumigation-extraction method (Vance *et al*., 1987).
27.	Soil respiration (µg C $g^{-1}h^{-1}$)	6.37	Alkali entrapment method (Macfayden, 1970).

3.2.3 Treatment details

The recommended dose of NK was applied in all the plots irrespective of the treatment.

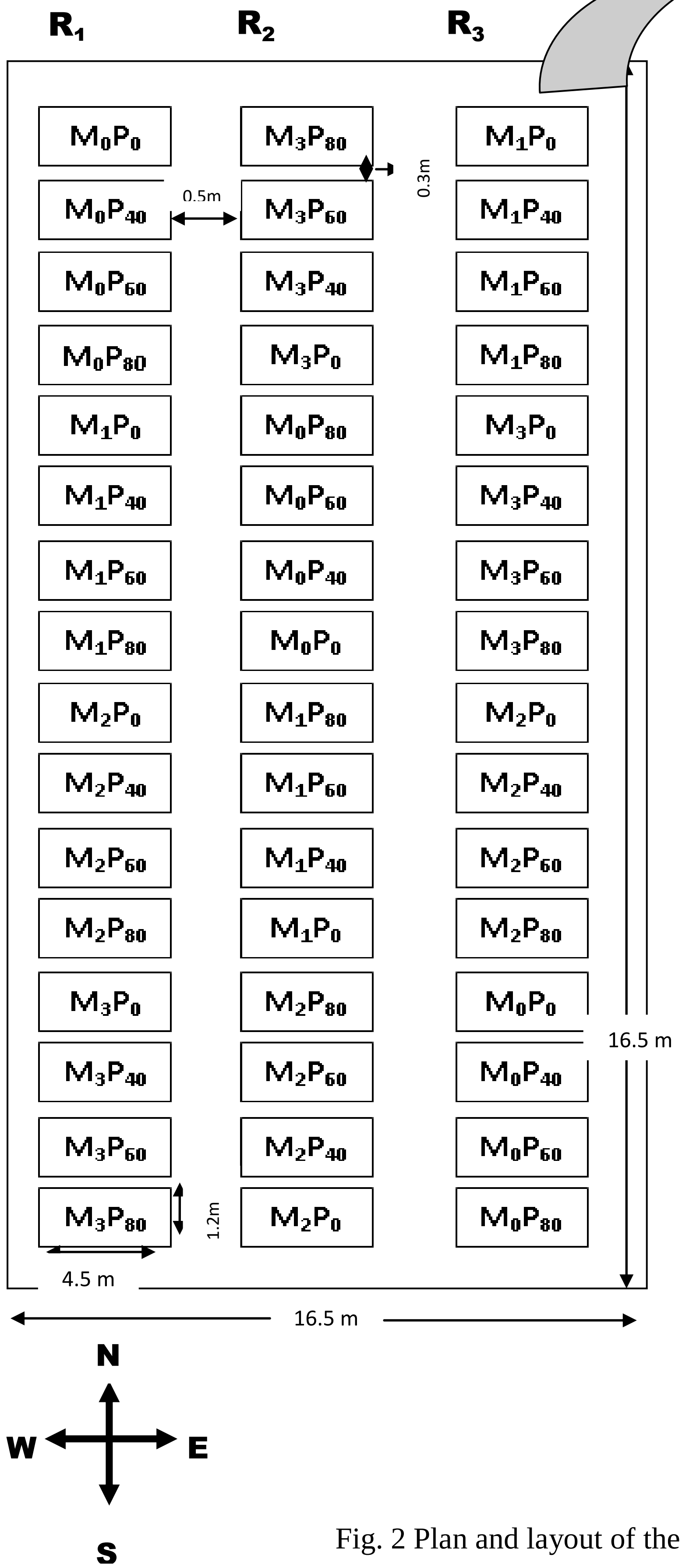
The details of treatment with their notations were as follows:

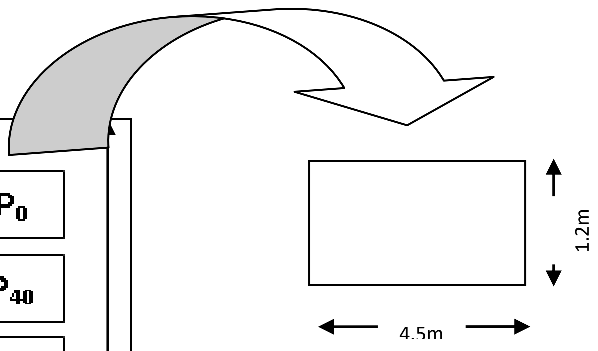
Factors	Treatments	Notations
A. Main plot treatment	No liming material	M_0
(Liming Materials)	Wood ash @ 0.4 LR	M_1
	Paper mill sludge @ 0.4 LR	M_2
	Calcium silicate @ 0.4 LR	M_3
B. Sub plot treatment	0 kg P_2O_5 ha^{-1}	P_0
(Level of Phosphorus)	40 kg P_2O_5 ha^{-1}	P_{40}
	60 kg P_2O_5 ha^{-1}	P_{60}
	80 kg P_2O_5 ha^{-1}	P_{80}

3.2.4 Treatment combinations

The treatment combinations with their notations were as follows:

Symbol used	Treatment	Symbol used	Treatment
T_1	M_0P_0 (Control)	T_9	M_2P_0
T_2	M_0P_{40}	T_{10}	M_2P_{40}
T_3	M_0P_{60}	T_{11}	M_2P_{60}
T_4	M_0P_{80}	T_{12}	M_2P_{80}
T_5	M_1P_0	T_{13}	M_3P_0
T_6	M_1P_{40}	T_{14}	M_3P_{40}
T_7	M_1P_{60}	T_{15}	M_3P_{60}
T_8	M_1P_{80}	T_{16}	M_3P_{80}





Liming Materials
(Main plot treatment)

M_0- No liming Materials

M_1- Wood ash @ 0.4 LR

M_2- Paper mill sludge @ 0.4 LR

M_3- Calcium silicate @ 0.4 LR

Phosphorus levels
(Sub plot treatment)

P_0- 0 kg P_2O_5 ha^{-1}

P_1- 40 kg P_2O_5 ha^{-1}

P_2-6 0 kg P_2O_5 ha^{-1}

P_3- 80 kg P_2O_5 ha^{-1}

Fig. 2 Plan and layout of the experiment

3.3 Cultivation details

3.3.1 Preparation of field

The preparatory tillage operation was given to the experimental field by ploughing with tractor drawn cultivator followed by harrowing and breaking clods by manually. The set of sixteen treatments were imposed on same layout and replicated three, thus making a total of 48 plots. Allotment of the each treatment was done by restricted randomization.

3.3.2 Test crop

Soybean cv. JS-335 was used as test crop which is very suitable variety in the North Eastern India. It is erect semi-determinate variety grows to a height of 58-60 cm. It matures in 95-110 days and average yield about 18-24 q grain ha^{-1}.

3.3.3 Seed treatment and sowing

The seeds were treated with Bavistin @ 2.5 g kg^{-1} seed of soybean to prevent the crop from seed and soil borne pathogens. The crop was sown through line sowing. The row to row and plant to plant spacing was 45 cm x 10 cm for soybean. The seed rate used for soybean crop is 40 kg ha^{-1}. The soybean was shown on 29th July 2018 and 30th July 2019 for 1st and 2nd year of the experiment respectively.

3.3.4 Fertilizer application

Whole of phosphorus P_0-0 kg ha^{-1}, P_{40}-40 P_2O_5 kg ha^{-1}, P_{60}- 60 P_2O_5 kg ha^{-1} and P_{80}-80 P_2O_5 kg ha^{-1} were applied at time of sowing as basal application in form of single super phosphate as per treatments. A constant dose of 20 and 30 kg ha^{-1} of N and K_2O was applied in all plots as basal in the form of urea and murate of potash respectively.

3.3.5 Liming

Liming materials M_0 - no liming material, M_1 - wood ash @ 0.4 LR, M_2 - paper mill sludge (@ 0.4 LR and M_3 - calcium silicate @ 0.4 LR were applied at the time sowing as per treatment. Neutralizing value of paper mill sludge, wood ash and calcium silicate are 86 %, 75 % and 72 %, respectively.

3.3.6 Weed control and thinning

Weeding the experimental plots was done by manual weeding as and when weeding was needed. At 15 days after sowing the thinning was done in order to maintain proper plant density.

3.3.7 Plant protection measures

Plant protection measures were adopted as and when needed during crop growth period. Chlorpyriphos @ 1.5 liters ha^{-1} was applied at 40 days after sowing to reduce the infestation of leaf defoliator insects in soybean in first year (2018) of experiment.

3.3.8 Harvesting, threshing and winnowing

Soybean crop were harvested by manual labour with the help of sickles. Produce from net plots were left in the respective plot for 2 to 3 days in order to sun dried the produce. Thereafter threshing was done and after manual winnowing, the seed and stover yields was recorded in kg $plot^{-1}$ and then converted in to q ha^{-1}.

3.4 Biometric observations

The five plants of each plot of the experimental field were randomly selected excluding the border rows and were tagged. All the characters under study were recorded from these plants.

3.4.1 Plant growth parameters

For determining the vegetative growth characters, five plants from each plot were selected randomly and tagged for recording the growth attributes parameters viz. plant height, number of leaves per plant, number of branches per plant, numbers of root nodules per plant, root length and root dry weight at different days after sowing (30 DAS, 60 DAS and 90 DAS).

3.4.1.1 Plant height (cm)

Five plants from each plot were randomly selected and tagged for recording the plant height at different growth stage in centimeter from the base of the plant to the tip of the tallest leaf and expressed the mean values. The plant height was recorded at 30 DAS, 60 DAS and 90 DAS. The average plant height was worked out by dividing the summation with five and expressed in cm.

3.4.1.2 Number of leaves per plant

The number of leaves per plant of the randomly selected five plants from each plot was recorded and expressed the mean values. The number of leaves per plant was recorded at 30 DAS, 60 DAS and 90 DAS. The average number of leaves per plant was worked out by dividing the summation with five.

3.4.1.3 Number of branches per plant

The number of branches per plant of the randomly selected five plants from each plot was recorded and expressed the mean values. The number of branches per plant was recorded at 30 DAS, 60 DAS and 90 DAS. The average number of branches per plant was worked out by dividing the summation with five.

3.4.1.4 Number of root nodules per plant

The number of root nodules per plant of the randomly selected five plants from each plot was recorded and expressed the mean values. The number of root nodules per plant was recorded at 30 DAS, 60 DAS and 90 DAS. The average number of root nodules per plant was worked out by dividing the summation with five.

3.4.1.5 Root length (cm)

Root length of the randomly selected 5 plants from each plot was recorded and expressed the mean values. The root length was recorded at 30 DAS, 60 DAS and 90 DAS. The average root length was worked out by dividing the summation with five.

3.4.1.6 Root dry weight (g)

Root dry weight of the randomly selected 5 plants from each plot was recorded for root dry weight and expressed the mean values. The Root dry weight was recorded at 30 DAS, 60 DAS and 90 DAS. The average root dry weight was worked out by dividing the summation with five.

3.4.2 Yield attributes

3.4.2.1 Number of pod per plant

The total number of pods per plant was counted from five randomly selected plants from each plot at harvest and the average number of pods per plant was recorded for each treatment.

3.4.2.2 Number of seeds per pod

Five selected plants were taken and the number of seeds per pod was counted after harvesting and average number of seeds per pod were counted for each plot.

3.4.2.3 Seed index (100 grains weight)

100 grains drawn randomly from each harvested plot were carefully counted for each treatment and the weight was expressed in grams.

3.4.3 Yield

3.4.3.1 Grain yield (kg ha^{-1})

The produce was threshed, winnowed and clean separately for each plot. The seed weight of each plot was recorded in kg and then subsequently converted into kg ha^{-1}.

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

The yield of stover was calculated by subtracting seed yield of net plot from the stover yield along with seeds intake before threshing and then converted into kg ha^{-1}.

3.5 Determination of soil physico-chemical properties

Soil samples were collected from each plot after harvesting of soybean at soil depths (0-15 cm) from the experimental field. Soil samples were air dried in shade and stored in polythene bags for further analysis. The air dried samples were carefully and gently grind with the wooden pestle to break soil lumps (clods) and were passed through sieve of 2 mm diameter. The sieved samples were mixed thoroughly and stored in polythene bags, properly labeled and preserved for subsequent analysis. The following standard methods were used for analysis of the soil sample.

3.5.1 Soil physical properties

3.5.1.1 Soil texture

The sand, silt and clay content of the soil samples were determined by Bouyoucos Hydrometer method as described by Piper (1950).

3.5.1.2 Bulk density (g cc^{-1})

The bulk density of experimental soil was determined by core method as described by Black (1965).

3.5.1.3 Water holding capacity (%)

The water holding capacity of the soil was determined by Keen Raczkowski box method as described by Piper (1950).

3.5.2 Soil chemical properties

3.5.2.1 Soil pH

Hydrogen ion activity expressed as pH at harvest was determined by 1:2.5 soil : water ratio by pH meter, as described by Jackson (1973).

3.5.2.2 Organic carbon (%)

Organic carbon at 0-15 cm soil depth at harvest was estimated by chromic acid titration method, as described Walkley and Black (1934).

3.5.2.3 Cation exchange capacity [cmol(p+)kg^{-1}]

The Cation Exchange Capacity of the soil was determined by successive extraction of soil with neutral 1N ammonium acetate by Black (1965).

3.5.2.4 Available nitrogen (kg ha^{-1})

Available nitrogen in soil was determined by alkaline $KMnO_4$ method (Subbiah and Asija, 1956).

3.5.2.5 Available phosphorus (kg ha^{-1})

Available phosphorous in the soil was determined by Bray’s 1 method (Bray and Kurtz, 1945).

3.5.2.6 Available potassium (kg ha^{-1})

Available potassium was determined by extracting the soil with neutral normal ammonium acetate solution and estimated by flame photometer, Hanway and Heidek (1952).

3.5.2.7 Available sulphur (mg kg^{-1})

Available sulphur was determined by extracting the soil with 0.15 per cent $CaCl_2$ solution and determined colorimetrically by turbidimetric method using $BaCl_2$ (Chesin and Yien, 1951).

3.5.2.8 Exchangeable calcium and magnesium [cmol(p+) kg^{-1}]

The Ca^{2+} and Mg^{2+} were estimated by EDTA complexometric titration method (Jackson, 1973).

3.5.2.9 Exchangeable aluminum [cmol(p+) kg^{-1}]

The exchangeable aluminum in soil was determined by using 1 *N* potasium chloride extract soil (Jayman and Sivasubramaniam, 1974).

3.5.2.10 Exchange acidity [cmol(p+) kg^{-1}]

The exchange acidy was estimated by Barium acetate extraction (Mehlich, 1945).

3.5.2.11 Available micronutrients (Fe, Mn and Zn)

The micronutrients were extracted by using 0.005 M DTPA (Diethyl triamine Penta acetic acid), 0.01M Calcium chloride dehydrate and 0.1M Triethanol amine buffered at 7.3 pH (Lindsay and Norvell, 1978) and concentrations were analyzed by atomic absorption spectrophotometer .

3.5.2.12 Lime requirement (t ha^{-1})

The lime requirement of the acid soil was determined by Woodruff Buffer method, 1948. A 10 gm of soil was taken in a plastic beaker. To this 10 ml of distilled water was added, stirred, 2 drops of $CaCl_2$ was added, pH of the soil suspension was taken with the help of a pH meter. This pH was noted as salt pH (pHs). Then 10 ml of Woodruff buffer solution was added to it, stirred and pH was measured after 30 minutes. This was called as buffer pH.

3.5.2.13 Inorganic phosphorus fractions (mg kg^{-1})

Inorganic phosphorus fractions were determined using the methods outlined originally by Chang and Jackson (1957) and modified by Kuo (1996). Chang and Jackson (1957) suggested six inorganic-P fractions of soil in their original fractionation scheme. Modifications suggested by Peterson and Cory (1966) and Williams *et al*., (1967) were adopted in two stages of fractionation procedure of Chang and Jackson (1957). The procedure follows the extraction of the soil with 1N NH_4Cl, 0.5N NH_4F, 0.1N NaOH, 0.5N H_2SO_4, 0.3N sodium citrate (with solid sodium dithionite) and finally with 0.1N NaOH for the extraction of easily soluble-P, Al-phosphate, Fe-phosphate, Ca-phosphate, reductant soluble phosphate, and occluded phosphate respectively.

3.5.2.14 Organic phosphorus fractions (mg kg^{-1})

Organic phosphorus fractions were calculated by subtracting inorganic phosphorus fractions from total phosphorus.

2.5.3 Soil biological properties

3.5.3.1 Soil respiration (μg C g^{-1} h^{-1})

Soil respiration was determined by AA method as described by Kirita and Hozumi, 1966.

3.5.3.2 Soil Microbial Biomass Carbon (μg g^{-1})

Total microbial biomass carbon was determined by Chloroform fumigation incubation method as described by Jenkinson and Powlson, 1976.

3.6 Plant analysis

Plant samples (straw and grain) were collected from each plot after threshing separately then dried in oven at 45 °C until a constant dry weight obtained. The dried plant samples were then grounded to powder and used for determination of N, P, K, Ca, Mg and S concentration following chemical analysis.

3.6.1 Estimation of nitrogen in seeds and stover

0.5 gm powdered sample was digested with concentrated H_2SO_4 presence of digested mixture ($CuSO_4$ + K_2SO_4) till the digest gave clear blue green colour. The digested sample was further diluted carefully with distill water to known volume. Then a known volume of aliquot was transferred to distillation unit (Micro Kjedahl apparatus) and liberated ammonia was trapped in boric acid containing mixed indicator. Later it was titrated against standard H_2SO_4 and amount of ammonia liberated was estimated in the form of nitrogen as per the Microkjeldahl methods as described by Jackson (1973).

3.6.2 Digestion of plant samples for other nutrients

0.5 gm of powdered sample was pre-digested with concentrated HNO_3 overnight. Further predigested sample was treated with di-acid (HNO_3: $HClO_4$ in the ratio 10:4) mixture and kept on hot plate for digestion till colorless. After complete digestion precipitate was dissolved in 6N HCl and transferred to the 100 ml volumetric flask through Whatman No. 44 filter paper and finally the volume of extract was made to 100 ml with distilled water and preserved for further analysis..

3.6.2.1 Estimation of phosphorus in seeds and stover (%)

Phosphorus content was determined by vanadomolybdo-phosphoric acid yellow colour complex method as described by Jackson (1973). An aliquot of 10 ml was taken, 10 ml of vanadomolybdate yellow reagent was added and volume was made up to 50 ml, after half hour colour intensity was measured by Spectrophotometer at wavelength 420 nm.

3.6.2.2 Estimation of potassium in seeds and stover (%)

Potassium content of plant was determined by flame-photometric method, using di-acid digestion system respectively by Jackson (1973).

3.6.2.3 Estimation of calcium, magnesium and sulphur in seeds and stover (%)

The samples were digested in diacid mixure [HNO_3 : $HClO_4$ (3:2)]. The sulphur was estimated spectrophotometrically, calcium and magnesium by EDTA titration method (Jackson, 1973).

3.7 Nutrient uptake (kg ha^{-1})

The uptake of different nutrients was separately carried out for seed and stover sample multiplying nutrient content (%) in seed and stover and their corresponding yield data.

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

3.8 Quality parameters

3.8.1 Protein content (%)

The nitrogen content of seed was determined using KEL plus system as described by Subbiah and Asija (1956). The factor 6.25 was used to calculate the protein content of soybean seed.

3.8.2 Estimation of oil content (%)

The oil content of soybean seeds was estimated by adopting a Soxhlet Ether Extraction method described by AOAC, 1960. The percent of oil present in a sample was calculated with the help of following formula.

$$\text{Oil content (\%)} = \frac{W2 - W1}{X} \times 100$$

Where,

W1 = Initial weight of beaker

W2 = Final weight of beaker (beaker + oil)

X = Weight of the sample taken for extraction

3.9 Phosphorus utilization efficiencies

The different phosphorus utilization efficiencies were calculated from established formulae as below:

3.9.1 Agronomic efficiency of phosphorus (AEP):

$$\text{AEP (kg kg}^{-1}\text{)} = \frac{\text{Yield in P treated plot – Yield in control plot}}{\text{Amount of P added}}$$

3.9.2 Physiological efficiency of phosphorus (PEP):

$$\text{PEP (kg kg}^{-1}\text{)} = \frac{\text{Yield in P treated plot – Yield in control plot}}{\text{P uptake in P treated plot - P uptake in control plot}}$$

3.9.3Apparent Recovery Efficiency (ARE):

$$\text{ARE (\%)} = \frac{\text{Uptake of P in P treated plot – uptake of P in control plot}}{\text{Amount of P added}} \times 100$$

3.9.4 Phosphorus use efficiency (PUE):

PUE (%) = PEP x ARE

3.10 Analysis of data

All the observed data were statistically analyzed by method of analysis of variance prescribed by Gomez and Gomez (1984). To obtain the analysis of variance, standard error of means i.e., SE (m) ± were determined in all the cases, while critical difference (CD) at 5 % level of significance was estimated only in cases where "F" test was found significant.

A

B

Plate1. A. Ploughing of Experimental plot by tractor

B. Field preparation and layout

A

B

Plate 2. A. Application liming materials and fertilizers

B. Sowing of seeds

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The details of results and discussion of the present investigation entitled "**Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland**" conducted at the research farm of School of Agricultural Sciences and Rural Development (SASRD), Medziphema campus, Nagaland University during *kharif* season of 2018 and 2019 are presented in this chapter. The related to the effect of liming materials, phosphorus levels and their interaction on growth and yield attributes of soybean, yields, oil and protein content and their yield in grain, nutrients content and uptake in grain and strover, total nutrients uptake in soybean, physico-chemical properties of post harvest soil, phosphorus fractions, phosphorus use efficiency etc. were statistically analysed and presented with help of tables and diagrams where necessary under the following heads.

4.1. Effect on growth attributes of soybean

Growth attributes of soybean such as plant height, number of leave per plant, number of branches per plant, numbers of root nodules per plant, root length and root dry weight are discussed under the following heads:

4.1.1. Effect on plant height

4.1.1.1. Effect of liming materials on plant height

The data on plant height as influence by different treatments are presented in table 4.1.1 (a) and Fig. 3. There was significant difference due to liming materials at all stages of the crop growth in both years. The maximum plant height was recorded with application of CS @ 0.4 LR with corresponding values of 25.80 cm and 24.22 cm, 46.98 cm and 44.43 cm and 55.90 cm and 56.68 cm at 30 DAS, 60 DAS and 90 DAS in the year 2018 and 2019, respectively.

The pooled data revealed that the application of CS @ 0.4 LR recorded the maximum plant height with corresponding values of 25.01 cm at 30 DAS, 45.71 cm at 60 DAS and 56.29 cm at 90 DAS. The increased in plant height with application of liming material i.e. CS @ 0.4 LR might be due to significant increase in nodulation, nitrogenise activity and efficient nutrients uptake. A similar trend was also observed by Kumar *et al*. (2014).

4.1.1.2. Effect of phosphorus on plant height

As evident from the data in the table 4.1.1 (a) and Fig. 3, there was an increase in the plant height with the advancement of days and appreciable difference between various treatments. The treatment 80 kg P_2O_5 ha^{-1} recorded the maximum plant height with corresponding value of 26.87 cm and 25.70 cm, 50.53 cm and 45.90 cm and 57.92 cm and 58.23 cm at 30 DAS, 60 DAS and 90 DAS in the year 2018 and 2019, respectively. The pooled data revealed that the application of 80 kg P_2O_5 ha^{-1} recorded the maximum plant height with corresponding values of 26.28 cm at 30 DAS, 48.22 cm at 60 DAS and 58.208 cm at 90 DAS. The data has also revealed that increasing levels of phosphorus increases the plant height significantly.

This positive growth respor Plate 6.Stages of crop at 30, 60 and 90 DAS soil may be related with better availability of P as the rate of P application increased (Ameyu, 2020). The result so obtained could due to the nutrients which were responsible for increased cell division, cell enlargement, growth, photosynthesis and protein synthesis which are responsible for increased plant height. This was also similar with findings of Sharma *et al.* (2001).

4.1.1.3. Interaction effect of liming materials and phosphorus on plant height

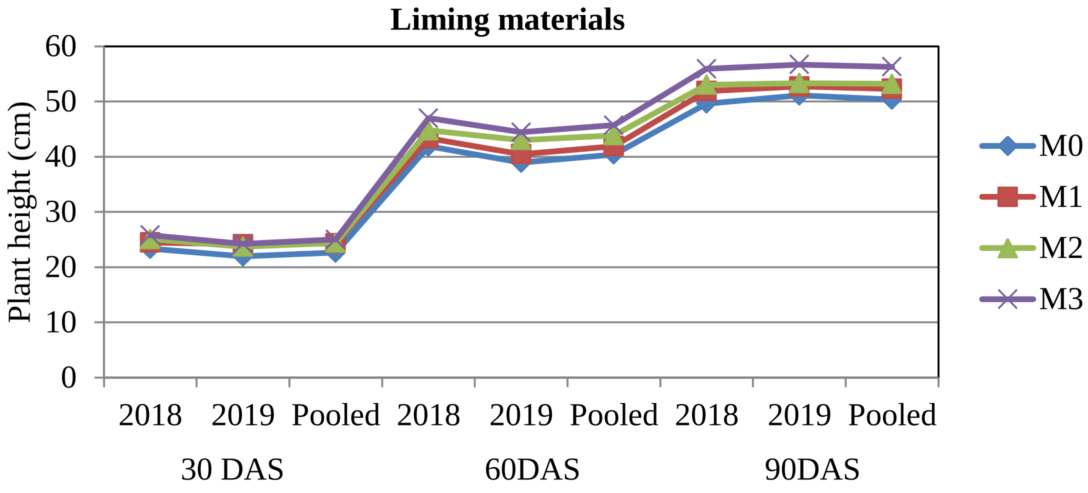
From the table 4.1.1 (b) and Fig. 3, it is evident that application of treatment combination M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) recorded the maximum plant height with corresponding value of 28.40 cm and 26.40 cm at

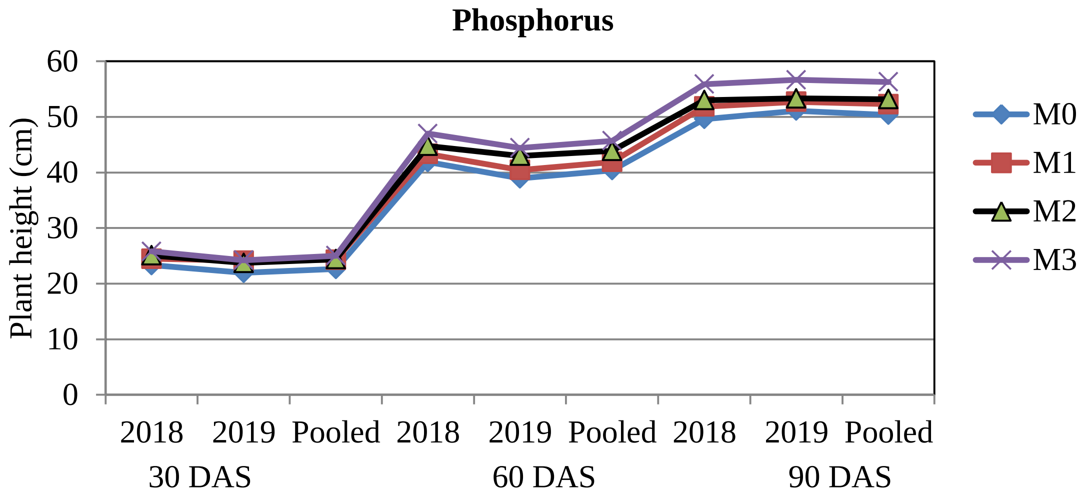
Table 4.1.1 (a) Effect of liming materials and phosphorus levels on plant height of soybean at different days after sowing

Treatments	**Plant height (cm)**								
	30 DAS			**60 DAS**			**90 DAS**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	23.32	21.95	22.63	41.88	38.93	40.41	49.60	51.10	50.35
M_1	24.47	24.13	24.30	43.33	40.47	41.90	51.87	52.72	52.29
M_2	25.08	23.72	24.40	44.77	43.00	43.88	53.02	53.33	53.18
M_3	25.80	24.22	25.01	46.98	44.43	45.71	55.90	56.68	56.29
SEm±	***0.40***	***0.46***	***0.31***	***0.89***	***0.77***	***0.59***	***0.98***	***0.79***	***0.63***
CD (P=0.05)	***1.39***	***1.59***	***0.94***	***3.09***	***2.65***	***1.81***	***3.39***	***2.75***	***1.94***
P_0	22.45	20.98	21.72	37.03	36.42	36.73	45.72	46.50	46.11
P_{40}	24.27	23.22	23.74	43.35	40.52	41.93	51.87	53.52	52.69
P_{60}	25.08	24.12	24.60	46.05	44.00	45.03	54.88	55.58	55.23
P_{80}	26.87	25.70	26.28	50.53	45.90	48.22	57.92	58.23	58.08
SEm±	***0.33***	***0.42***	***0.27***	***0.63***	***0.69***	***0.47***	***0.73***	***0.62***	***0.48***
CD (P=0.05)	***0.95***	***1.24***	***0.76***	***1.84***	***2.00***	***1.32***	***2.14***	***1.82***	***1.37***

Table 4.1.1 (b) Interaction effect of liming materials and phosphorus levels on plant height of soybean at different days after sowing

Treatments	**Plant height (cm)**								
	30 DAS			**60 DAS**			**90 DAS**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	21.07	20.47	20.77	34.47	33.80	34.13	44.47	45.80	45.13
M_0P_{40}	23.00	20.80	21.90	41.47	38.07	39.77	48.60	51.07	49.83
M_0P_{60}	23.73	21.87	22.80	44.13	41.67	42.90	51.27	53.00	52.13
M_0P_{80}	25.47	24.67	25.07	47.47	42.20	44.83	54.07	54.53	54.30
M_1P_0	22.53	21.33	21.93	35.40	35.53	35.47	45.40	46.53	45.97
M_1P_{40}	24.00	24.33	24.17	42.93	40.40	41.67	51.47	53.40	52.43
M_1P_{60}	24.87	25.07	24.97	45.60	42.80	44.20	54.13	54.80	54.47
M_1P_{80}	26.47	25.80	26.13	49.40	43.13	46.27	56.47	56.13	56.30
M_2P_0	22.80	20.93	21.87	37.53	39.40	38.47	46.33	45.73	46.03
M_2P_{40}	24.87	23.40	24.13	43.67	41.00	42.33	52.67	54.00	53.33
M_2P_{60}	25.53	24.60	25.07	46.20	45.33	45.77	55.20	55.33	55.27
M_2P_{80}	27.13	25.93	26.53	51.67	46.27	48.97	57.87	58.27	58.07
M_3P_0	23.40	21.20	22.30	40.73	36.93	38.83	46.67	47.93	47.30
M_3P_{40}	25.20	24.33	24.77	45.33	42.60	43.97	54.73	55.60	55.17
M_3P_{60}	26.20	24.93	25.57	48.27	46.20	47.23	58.93	59.20	59.07
M_3P_{80}	28.40	26.40	27.40	53.60	52.00	52.80	63.27	64.00	63.63
SEm±	***0.65***	***0.85***	***0.53***	***1.26***	***1.37***	***0.93***	***1.47***	***1.25***	***0.96***
CD (P=0.05)	***1.90***	***2.47***	***1.52***	***3.68***	***4.00***	***2.65***	***4.28***	***3.65***	***2.74***





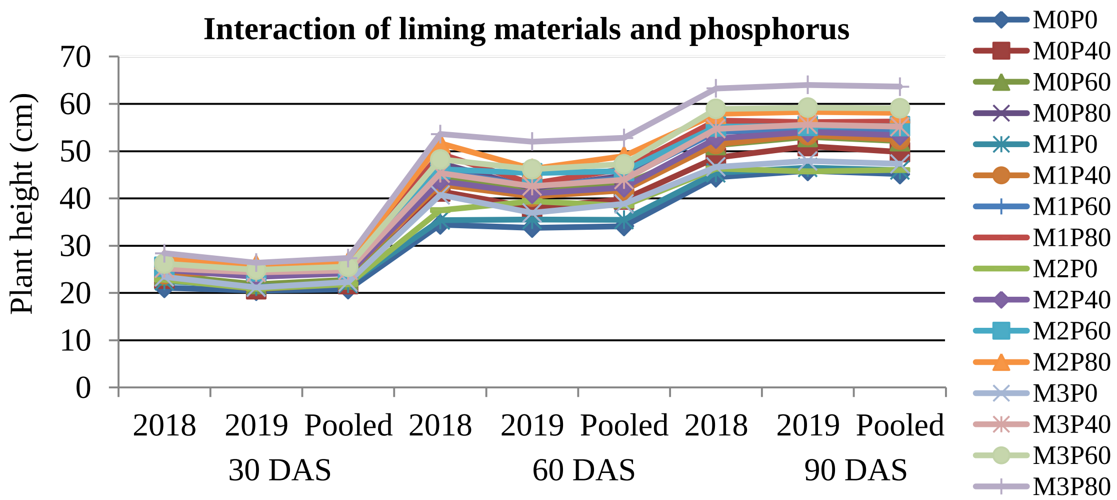


Fig.3. Effect of liming materials, phosphorus levels and interaction on plant height of soybean at different days after sowing

30 DAS, 53.60 cm and 52.00 cm at 60 DAS and 63.27 cm and 64.00 cm at 90 DAS in the year 2018 and 2019, respectively. The pooled data indicates the maximum plant height was observed with receiving treatment combination M_3P_{80} with corresponding value of 27.40 cm, 52.80 cm and 63.63 cm at 30 DAS, 60 DAS and 90 DAS, respectively. The minimum plant height was recorded with treatment combination of M_0P_0 (control) with the corresponding value of 21.07 cm and 20.47 cm, 34.47 cm and 33.80cm and 44.15 and 45.80 cm at 30, 60 and 90 DAS in year 2018 and 2019 while pooled data of 20.77 cm at 30 DAS, 34.47 cm at 60 DAS and 45.13 cm 90 DAS, respectively. A positive interaction effect between liming materials and phosphorus in increasing the plant height was observed.

The increased in the plant height might be due to better root development and nodulation which facilitates better nutrients utilization resulting in better growth of soybean (Bhattacharjee, 2013). Ashoka *et al.* (2014) also observed that application of lime @ 1000 kg and phosphorus up to 100 kg P_2O_5 ha^{-1} recorded higher plant height in soybean.

4.1.2. Effect on number of leaves per plant

4.1.2.1. Effect of liming materials on number of leaves per plant

The effect of liming materials on the number of leaves per plant has been presented in table 4.1.2 (a) and Fig. 4. From the results it was observed that different liming materials increase the number of leaves per plant. Application of CS @ 0.4 LR (M_3) recorded the highest number of leaves per plant with corresponding values 7.97 and 7.85 at 30 DAS, 24.02 and 21.18 plant at 60 DAS and 31.05 and 27.48 at 90 DAS during 2018 and 2019, respectively. The minimum number of leaves per plant was observed with M_0 (no liming material) which recorded 6.57 and 5.78 at 30 DAS, 19.38 and

17.57 at 60 DAS and 26.30 and 23.87 at 30 DAS during the year 2018 and 2019, respectively. The pooled data revealed that application of CS @ 0.4 LR significantly increased the numbers of leaves per plant over treatment WA @ 0.4 LR and PMS @ 0.4 LR and no liming material.

The results are in concurrence with the findings Melese *et al*. (2015) who reported that application of different liming materials had a significant influence on growth and yield attributes of soybean over no liming material. Behera *et al.* (2017) also reported that application of CS @ 0.2 LR recorded significantly better growth and yield attributes of maize.

4.1.2.2. Effect of phosphorus on number of leaves per plant

The results on number of leaves per plant have been presented in table 4.1.2 (a) and Fig. 4. The number of leaves per plant was higher in plot receiving treatment P_{80} (80 kg P_2O_5 ha^{-1}) with record value of 8.28 and 8.03 leaves per plant at 30 DAS, 25.73 and 22.68 leaves per plant at 60 DAS and 32.65 and 28.98 leaves per plant at 90 DAS during year of 2018 and 2019 as compared to other treatment at all stages of growth. The lowest number of leaves per plant was recorded with the P_0 (0 kg P_2O_5 ha^{-1}) treatment. The pooled data revealed that the maximum number of leaves per plant was the highest with application of treatment P_{80} with corresponding value of 8.16, 24.21 and 30.82 leaves per plant at 30 DAS, 60 DAS and 90 DAS respectively. The treatment P_{80} was found to be significant over other treatments at 30 DAS, 60 DAS and 90 DAS.

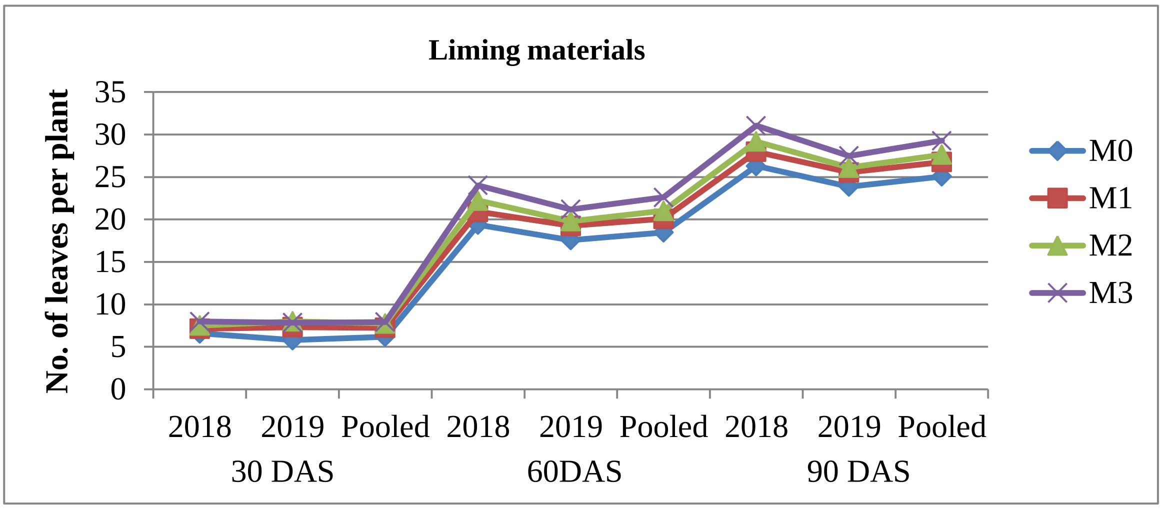
Shah *et al.* (2001) reported that significantly higher growth and yield attributes were observed with application of phosphorus 80 kg P_2O_5 ha^{-1} in soybean. The increased in the number of leaves might be due to the fact that the increased availability of phosphorus as the soil was low in phosphorus (Carsky *et al*. 2001).

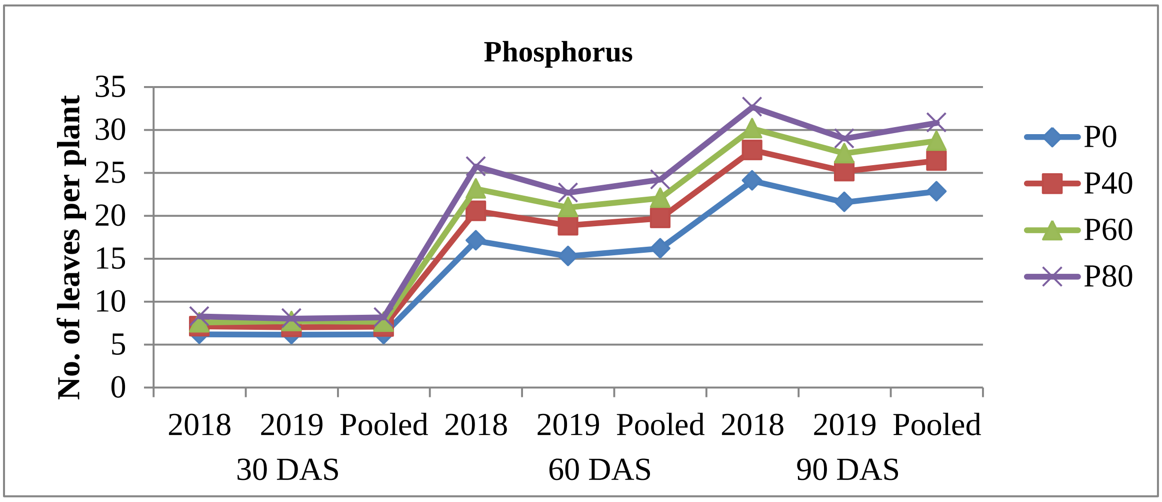
Table 4.1.2 (a) Effect of liming materials and phosphorus levels on number of leaves per plant of soybean at different days after sowing

Treatments	**Number of leaves plant^{-1}**								
	30 DAS			**60 DAS**			**90 DAS**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	6.57	5.78	6.18	19.38	17.57	18.48	26.30	23.87	25.08
M_1	7.13	7.32	7.23	20.90	19.25	20.08	27.98	25.55	26.77
M_2	7.50	8.00	7.75	22.22	19.80	21.01	29.18	26.10	27.64
M_3	7.97	7.85	7.91	24.02	21.18	22.60	31.05	27.48	29.27
SEm±	***0.24***	***0.34***	***0.21***	***0.88***	***0.37***	***0.48***	**0.84**	**0.37**	**0.46**
CD (P=0.05)	***0.85***	***1.18***	***0.65***	***3.06***	***1.28***	***1.48***	**2.92**	**1.28**	**1.42**
P_0	6.20	6.17	6.18	17.10	15.28	16.19	24.08	21.58	22.83
P_{40}	7.12	7.03	7.08	20.55	18.87	19.71	27.63	25.17	26.40
P_{60}	7.57	7.72	7.64	23.13	20.97	22.05	30.15	27.27	28.71
P_{80}	8.28	8.03	8.16	25.73	22.68	24.21	32.65	28.98	30.82
SEm±	***0.18***	***0.44***	***0.24***	***0.53***	***0.29***	***0.30***	**0.54**	**0.29**	**0.31**
CD (P=0.05)	***0.51***	***1.29***	***0.68***	***1.56***	***0.83***	***0.86***	**1.58**	**0.83**	**0.87**

Table 4.1.2 (b) Interaction effect of liming materials and phosphorus levels on number of leaves per plant of soybean at different days after sowing

Treatments	Number of leaves plant^{-1}								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	5.40	4.10	4.75	15.87	13.20	14.53	22.80	19.50	21.15
M_0P_{40}	6.13	5.90	6.02	18.67	17.27	17.97	25.73	23.57	24.65
M_0P_{60}	7.07	6.10	6.58	20.53	19.27	19.90	27.60	25.57	26.58
M_0P_{80}	7.67	7.03	7.35	22.47	20.53	21.50	29.07	26.83	27.95
M_1P_0	6.20	6.03	6.12	16.60	15.93	16.27	23.60	22.23	22.92
M_1P_{40}	6.87	7.37	7.12	19.53	18.67	19.10	26.53	24.97	25.75
M_1P_{60}	7.40	7.77	7.58	22.13	20.53	21.33	29.27	26.83	28.05
M_1P_{80}	8.07	8.10	8.08	25.33	21.87	23.60	32.53	28.17	30.35
M_2P_0	6.53	7.43	6.98	17.53	15.53	16.53	24.47	21.83	23.15
M_2P_{40}	7.47	7.63	7.55	21.87	19.80	20.83	28.93	26.10	27.52
M_2P_{60}	7.60	8.77	8.18	23.20	20.93	22.07	30.13	27.23	28.68
M_2P_{80}	8.40	8.17	8.28	26.27	22.93	24.60	33.20	29.23	31.22
M_3P_0	6.67	7.10	6.88	18.40	16.47	17.43	25.47	22.77	24.12
M_3P_{40}	8.00	7.23	7.62	22.13	19.73	20.93	29.33	26.03	27.68
M_3P_{60}	8.20	8.23	8.22	26.67	23.13	24.90	33.60	29.43	31.52
M_3P_{80}	9.00	8.83	8.92	28.87	25.40	27.13	35.80	31.70	33.75
SEm±	***0.35***	***0.89***	***0.48***	***1.07***	***0.57***	***0.61***	***1.08***	***0.57***	***0.61***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***





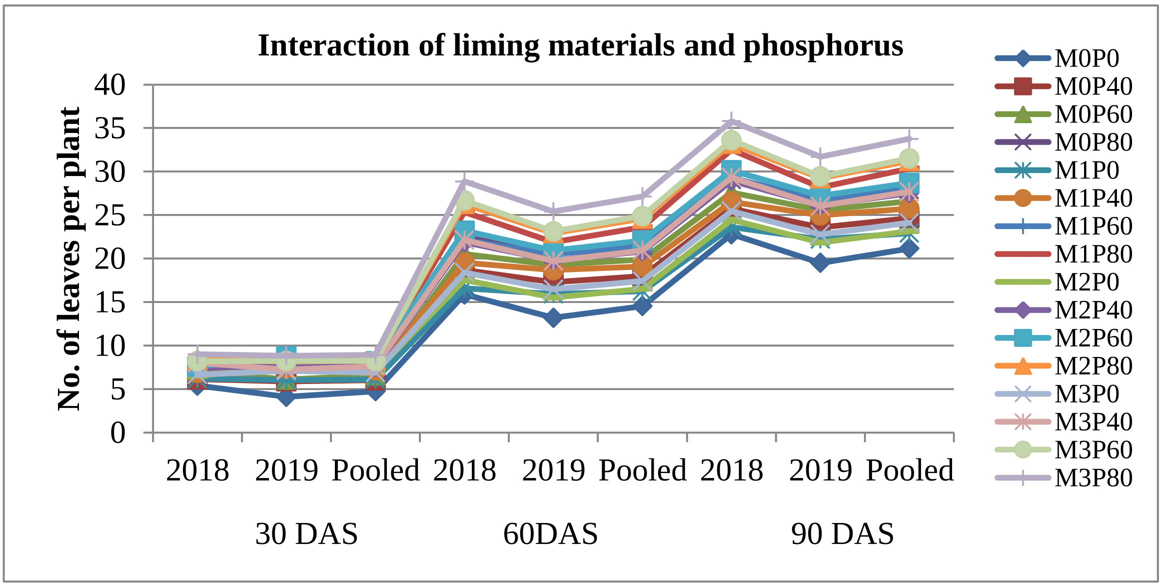


Fig. 4 Effect of liming materials, phosphorus levels and interaction on number of leaves per plant of soybean at different days after sowing

4.1.2.3. Interaction effect of liming materials and phosphorus on number of leaves per plant

The interaction effect of liming materials and phosphorus on number of leaves per plant has been presented on table 4.1.2 (b) and Fig.4. The highest number of leaves per plant was recorded in plots receiving treatment combination M_3P_{80} which recorded 9.00 and 8.83 at 30 DAS, 28.87 and 25.40 at 60 DAS and 35.80 and 31.70 at 9-0 DAS both in the year 2018 and 2019, respectively. The lowest number of leaves per plant was recorded with control plot (M_0P_0) having 5.40 and 4.10 leaves per plant at 30 DAS, 15.87 and 13.20 leaves per plant at 60 DAS and 22.80 and 19.50 leaves per plant at 90 DAS in the year 2018 and 2019, respectively. The pooled data showed that the maximum number of leaves per plant with the treatment combination M_3P_{80} which recorded 8.92, 27.13 and 33.52 at 30, 60 and 90 DAS, respectively. The interaction of liming materials and phosphorus levels did not exhibit any significant effect on the number of leaves per plant at 30, 60 and 90 DAS.

Ranjit *et al.* (2006) revealed that combined application of lime phosphorus with have significant interaction effect with maximum growth responses.

4.1.3. Effect on number of branches per plant

There were significant difference in branches per plant due to liming materials and phosphorus levels alone and their combination showed non significant at 30 DAS, 60 DAS and 90 DAS and presented in table 4.1.3 (a) and 4.1.3 (b) and fig. 5.

4.1.3.1. Effect of liming materials on number of branches per plant

The effects on liming materials on the number of branches per plant have been presented on table 4.1.3 (a) and fig. 5. As evident from the results obtained from the two year (2018 and 2019) data, the maximum number of branches per plant was observed with M_3 (CS @ 0.4 LR) at 30 DAS (1.10 and 1.53 branches per plant), at 60 DAS (4.88 and 4.83 branches per plant and at 90 DAS (6.58 and 6.62 branches per plant). The minimum number of branches per plant was recorded with M_0 (no liming materials) with 0.68 and 0.88, 4.22 and 3.98 and 5.92 and 5.55 branches per plant at 30, 60 and 90 DAS during both the year 2018 and 2019 respectively. As apparent from the pooled data of two year results M_3 recorded the maximum with 1.32, 4.86 and 6.60 branches per plant while the minimum was observed with M_0 with 0.78, 4.10 and 5.73 at 30, 60 and 90 DAS during both the year 2018 and 2019 respectively.

It was observed that application of liming materials have significant effect on number of branches per plant which might be due to higher uptake of nutrients from the soil as result of better root development with advancement of growth. The result is in conformity with the finding of Rakesh *et al.* (2014). The increase in crop growth rate with liming may result from better availability of nutrients due moderation of soil reaction.

4.1.3.2. Effect of phosphorus on number of branches per plant

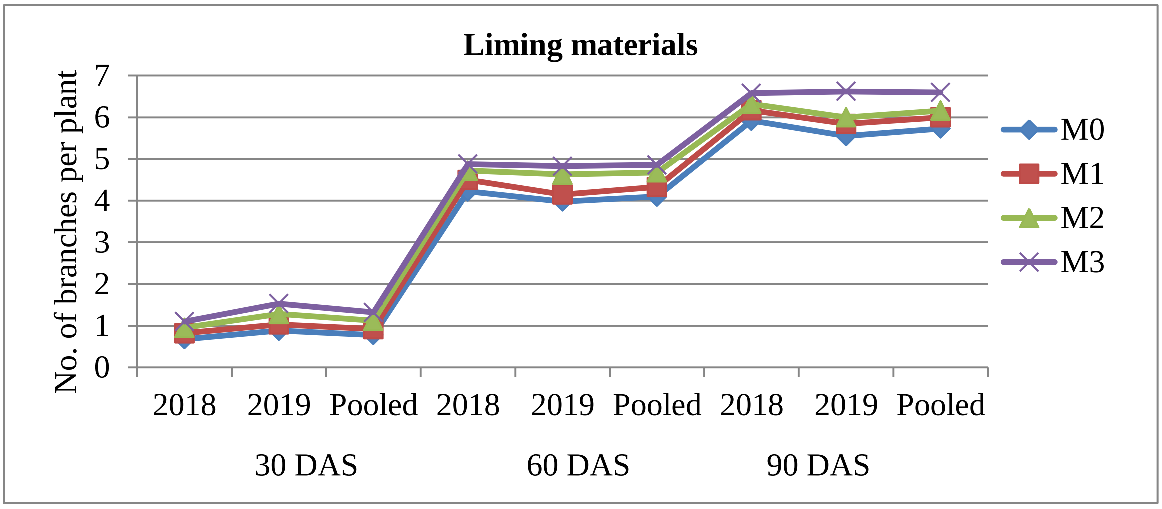
The effect of phosphorus levels on number of branches per plant of soybean at different days after sowing has been presented on table 4.1.3 (a) and fig. 5. The application of increase doses of phosphorus showed significant difference on number of branches per plant of soybean and application P_{80} (80 kg P_2O_5 ha^{-1}) gives the maximum number of branches per plant with 1.47, 1.53 and 1.50 at 30 DAS, 5.22, 5.13 and 5.18 at 60 DAS and 6.62, 6.48 and 6.55 branches per plant at 90 DAS during both the year 2018 and 2019 and pooled data, respectively whereas, the minimum number of branches per plant was recorded with P_0 (0 kg P_2O_5 ha^{-1}) with 0.50, 0.80 and 0.65 at 30 DAS, 4.02, 3.48 and 3.75 at 60 DAS and 5.62, 5.30 and 5.48 branches per plant at 90 DAS during both the year 2018 and 2019 and pooled data respectively.

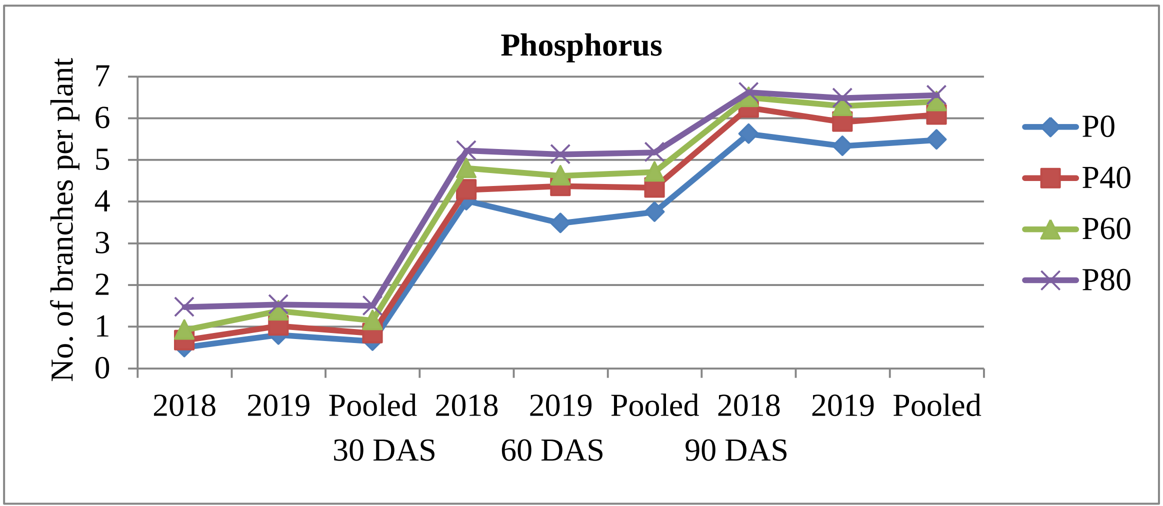
Table 4.1.3 (a) Effect of liming materials and phosphorus levels on number of branches per plant of soybean at different days after sowing

Treatments	Number of branches plant^{-1}								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0	0.68	0.88	0.78	4.22	3.98	4.10	5.92	5.55	5.73
M_1	0.82	1.03	0.92	4.50	4.15	4.33	6.17	5.84	6.00
M_2	0.95	1.28	1.12	4.72	4.63	4.68	6.32	6.00	6.16
M_3	1.10	1.53	1.32	4.88	4.83	4.86	6.58	6.62	6.60
SEm±	***0.07***	***0.09***	***0.06***	***0.13***	***0.18***	***0.11***	***0.11***	***0.17***	***0.10***
CD (P=0.05)	***0.23***	***0.31***	***0.17***	***0.44***	***0.63***	***0.34***	***0.39***	***0.59***	***0.32***
P_0	0.50	0.80	0.65	4.02	3.48	3.75	5.62	5.33	5.48
P_{40}	0.67	1.02	0.84	4.28	4.37	4.33	6.25	5.91	6.08
P_{60}	0.92	1.38	1.15	4.80	4.62	4.71	6.50	6.29	6.40
P_{80}	1.47	1.53	1.50	5.22	5.13	5.18	6.62	6.48	6.55
SEm±	***0.07***	***0.07***	***0.05***	***0.12***	***0.16***	***0.10***	***0.14***	***0.12***	***0.09***
CD (P=0.05)	***0.20***	***0.21***	***0.14***	***0.35***	***0.46***	***0.28***	***0.40***	***0.34***	***0.25***

Table 4.1.3 (b) Interaction effect of liming materials and phosphorus levels on number of branches per plant of soybean at different days after sowing

Treatments	Number of branches plant^{-1}								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	0.40	0.67	0.53	3.53	3.00	3.27	5.20	5.13	5.17
M_0P_{40}	0.53	0.80	0.67	4.07	4.07	4.07	5.87	5.47	5.67
M_0P_{60}	0.80	1.00	0.90	4.40	4.13	4.27	6.20	5.60	5.90
M_0P_{80}	1.00	1.07	1.03	4.87	4.73	4.80	6.40	6.00	6.20
M_1P_0	0.47	0.73	0.60	4.07	3.53	3.80	5.53	5.20	5.37
M_1P_{40}	0.60	0.93	0.77	3.93	4.00	3.97	6.20	5.77	5.98
M_1P_{60}	0.87	1.17	1.02	4.80	4.20	4.50	6.40	6.17	6.28
M_1P_{80}	1.33	1.27	1.30	5.20	4.87	5.03	6.53	6.23	6.38
M_2P_0	0.53	0.87	0.70	4.13	3.60	3.87	5.80	5.40	5.60
M_2P_{40}	0.73	1.13	0.93	4.47	4.67	4.57	6.33	5.93	6.13
M_2P_{60}	0.93	1.53	1.23	4.93	5.00	4.97	6.53	6.27	6.40
M_2P_{80}	1.60	1.60	1.60	5.33	5.27	5.30	6.60	6.40	6.50
M_3P_0	0.60	0.93	0.77	4.33	3.80	4.07	5.93	5.60	5.77
M_3P_{40}	0.80	1.20	1.00	4.67	4.73	4.70	6.60	6.47	6.53
M_3P_{60}	1.07	1.80	1.43	5.07	5.13	5.10	6.87	7.13	7.00
M_3P_{80}	1.93	2.20	2.07	5.47	5.67	5.57	6.93	7.27	7.10
SEm±	***0.14***	***0.15***	***0.10***	***0.24***	***0.31***	***0.20***	***0.27***	***0.23***	***0.18***
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**





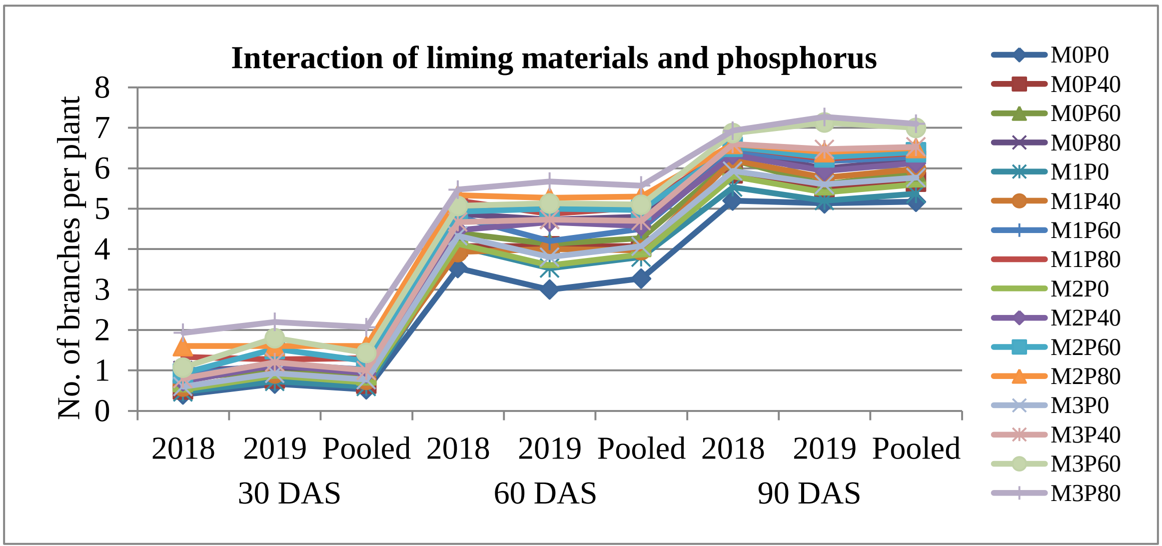


Fig. 5 Effect of liming materials, phosphorus levels and interaction on number of branches per plant of soybean at different days after sowing

The increased in the number of branches per plant of soybean could be attributed to the positive effect of phosphorus nutrition on vegetative growth. Singh and Rai (2003) concluded that application of 90 kg P_2O_5 ha^{-1} significantly increase the number of branches per plant of soybean. The finding of Majumdar *et al*. (2007) corroborated the results of this finding.

4.1.3.3. Interaction effect of liming materials and phosphorus on number of branches per plant

The interaction effect of liming materials and phosphorus on number of branches per plant has been presented on 4.1.3 (b) and fig. 5. It was evident that the highest number of branches per plant was obtained from treatment combination M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) with 1.93 and 2.20 at 30 DAS, 5.47 and 5.67 at 60 DAS and 6.93 and 7.27 branches per plant at 90 DAS during both the year 2018 and 2019 respectively. As apparent from the pooled data, the highest number of branches per plant at 30, 60 and 90 DAS with M_3P_{80} which recorded 2.07, 5.57 and 7.10 during the year 2018 and 2019 respectively. It was observed that the different treatment combinations did not have any significant effect on the number of branches per plant at different stage of growth of soybean.

The increased in the number of branches per plant might be due to better root development and nodulation which facilitates better nutrients utilization resulting in better growth of soybean (Bhattacharjee, 2013). Ashoka *et al*. (2014) also observed that application of lime @ 1000 kg and phosphorus up to 100 kg P_2O_5 ha^{-1} recorded higher number of branches per plant in soybean.

4.1.4. Effect on number of nodules per plant

4.1.4.1. Effect of liming materials on number of nodules per plant

The effect of liming materials on number of nodules per plant has been presented in table 4.1.4 (a) and fig. 6. Liming materials were significantly influenced the number of nodules per plant of soybean. Among the liming materials CS @ 0.4 LR got the highest number of nodules per plant followed by WA @ 0.4 LR, PMS @ 0.4 LR and no liming material. Application of CS @ 0.4 LR recorded the highest number of nodules per plant with corresponding values of 26.75, 25.33 and 26.04, 70.33, 55.33 and 62.83 and 35.92, 35.75 and 35.83 at 30, 60 and 90 DAS during both the year 2018 and 2019 and pooled data respectively, whereas, the minimum number of nodules per plant was recorded with M_0 (no liming material) with 7.83, 8.67 and 8.25 at 30 DAS, 19.25, 22.58 and 20.92 at 60 DAS and 14.75, 13.58 and 14.17 nodules per plant at 90 DAS during both the year 2018 and 2019 and pooled data respectively.

Okpara *et al*. (2007) observed that application of lime significantly increases the nodulation of soybean which might be due to higher activity of nitrogenase enzyme responsible for root nodulation and nitrogen fixation in legumes. Bekere *et al*. (2013) also reported the same results.

4.1.4.2. Effect of phosphorus on number of nodules per plant

The data on nodules per plant as influenced by phosphorus levels is presented in table 4.1.4 (a) and fig. 6. There was significant difference on nodules per plant due to phosphorus levels at different crop growth stage of soybean e,i. at 30 DAS, 60 DAS and 90 DAS. The data in respect of nodules is presented in the able4.1.4 (a) revealed that as the dose of phosphorus increased the root nodule count also increased. The highest nodule count was observed in the treatment P_{80} (80 kg P_2O_5 ha^{-1}) with corresponding values of 28.08, 26.75 and 27.42 at 30 DAS, 71.83, 67.58 and 69.71 at 60 DAS and 44.42, 39.25 and 41.83 at 90 DAS during both the year 2018 and 2019 and pooled data respectively, whereas, the minimum number of nodules per plant was recorded with P_0 (0 kg P_2O_5 ha^{-1}) with 9.58, 12.17 and 10.88 at 30 DAS, 20.25, 15.08 and 17.67 at 60 DAS and 18.67, 14.83 and 16.75 nodules per plant

Table 4.1.4 (a) Effect of liming materials and phosphorus levels on number of nodules per plant of soybean at different days after sowing

Treatments	Number of nodules plant^{-1}								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0	7.83	8.67	8.25	19.25	22.58	20.92	14.75	13.58	14.17
M_1	20.83	24.33	22.58	35.75	36.17	35.96	32.67	31.83	32.25
M_2	19.33	20.75	20.04	65.33	57.17	61.25	36.25	19.33	27.79
M_3	26.75	25.33	26.04	70.33	55.33	62.83	35.92	35.75	35.83
SEm±	**1.53**	**0.33**	**0.78**	**0.37**	**0.24**	**0.22**	**0.57**	**0.17**	**0.30**
CD (P=0.05)	**5.30**	**1.14**	**2.41**	**1.28**	**0.84**	**0.68**	**1.99**	**0.58**	**0.92**
P_0	9.58	12.17	10.88	20.25	15.08	17.67	18.67	14.83	16.75
P_{40}	15.83	18.08	16.96	38.42	27.17	32.79	19.42	18.83	19.13
P_{60}	21.25	22.08	21.67	60.17	61.42	60.79	37.08	27.58	32.33
P_{80}	28.08	26.75	27.42	71.83	67.58	69.71	44.42	39.25	41.83
SEm±	**0.32**	**0.34**	**0.23**	**0.53**	**0.24**	**0.29**	**0.43**	**0.17**	**0.23**
CD (P=0.05)	**0.93**	**1.00**	**0.66**	**1.56**	**0.69**	**0.83**	**1.27**	**0.49**	**0.66**

Table 4.1.4 (b) Interaction effect of liming materials and phosphorus levels on number of nodules per plant of soybean at different days after sowing

Treatments	Number of nodules plant^{-1}								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	3.33	3.67	3.50	8.33	7.33	7.83	6.67	5.33	6.00
M_0P_{40}	4.33	5.33	4.83	14.67	10.67	12.67	7.33	6.33	6.83
M_0P_{60}	10.33	12.33	11.33	15.33	30.67	23.00	18.67	17.33	18.00
M_0P_{80}	13.33	13.33	13.33	38.67	41.67	40.17	26.33	25.33	25.83
M_1P_0	14.33	15.33	14.83	18.33	11.67	15.00	22.67	21.33	22.00
M_1P_{40}	18.33	24.33	21.33	26.67	29.67	28.17	27.33	27.33	27.33
M_1P_{60}	22.33	26.33	24.33	48.33	50.67	49.50	33.67	32.33	33.00
M_1P_{80}	28.33	31.33	29.83	49.67	52.67	51.17	47.00	46.33	46.67
M_2P_0	5.33	14.33	9.83	23.67	23.67	23.67	22.00	9.33	15.67
M_2P_{40}	15.33	18.33	16.83	58.67	34.67	46.67	25.33	15.33	20.33
M_2P_{60}	22.33	22.33	22.33	88.67	90.67	89.67	45.67	18.33	32.00
M_2P_{80}	34.33	28.00	31.17	90.33	79.67	85.00	52.00	34.33	43.17
M_3P_0	15.33	15.33	15.33	30.67	17.67	24.17	23.33	23.33	23.33
M_3P_{40}	25.33	24.33	24.83	53.67	33.67	43.67	17.67	26.33	22.00
M_3P_{60}	30.00	27.33	28.67	88.33	73.67	81.00	50.33	42.33	46.33
M_3P_{80}	36.33	34.33	35.33	108.67	96.33	102.50	52.33	51.00	51.67
SEm±	***0.63***	***0.69***	***0.47***	***1.07***	***0.47***	***0.58***	***0.87***	***0.33***	***0.47***
CD (P=0.05)	***1.85***	***2.01***	***1.33***	***3.12***	***1.38***	***1.66***	***2.54***	***0.97***	***1.32***

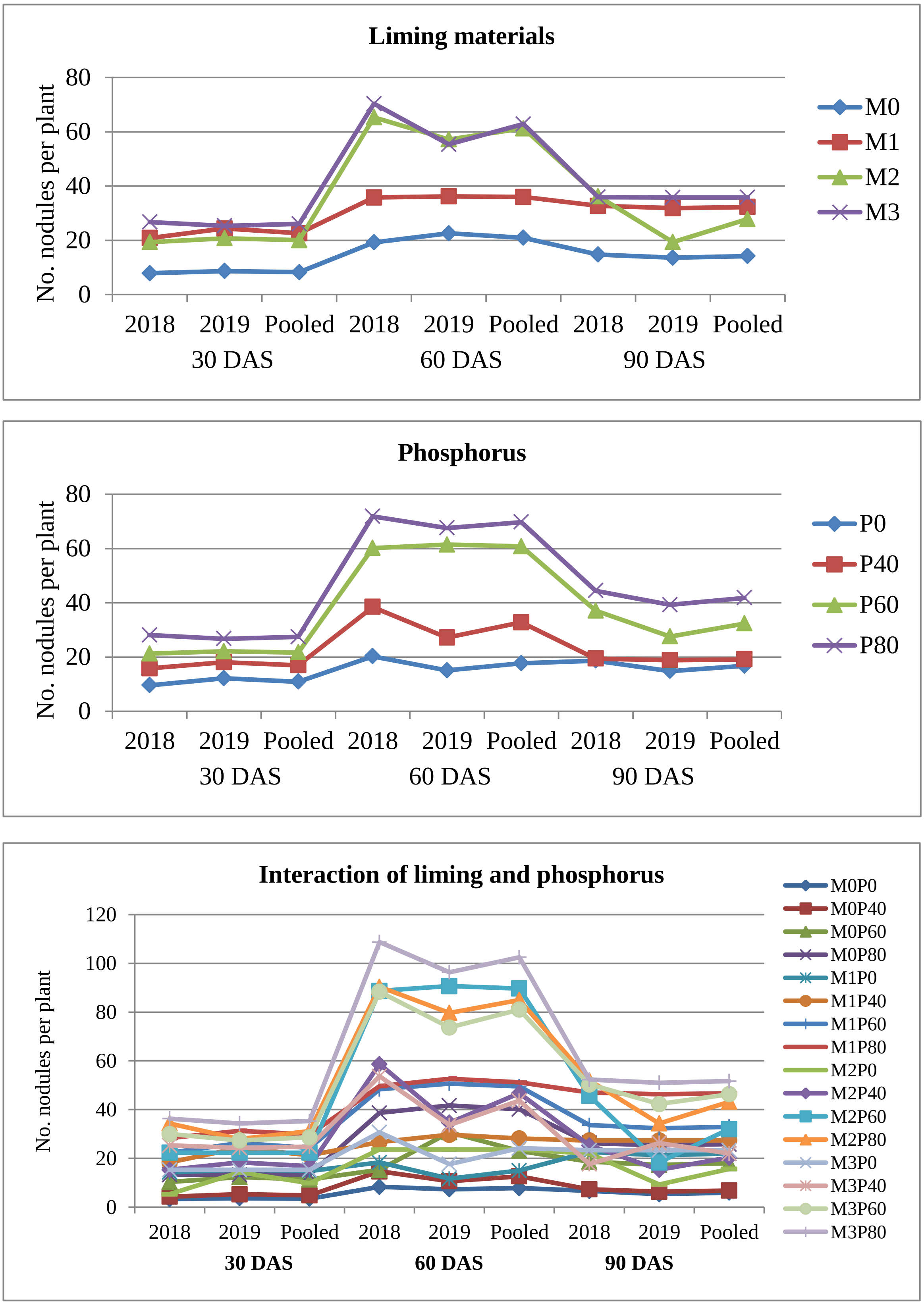


Fig. 6 Effect of liming materials, phosphorus levels and interaction on number of nodules per plant of soybean at different days after sowing

at 90 DAS during both the year 2018 and 2019 and pooled data respectively.

The number of nodule per plant increased with application of phosphorus which might be due to improve phosphorus availability in soil and enhanced symbiotic N_2 fixation. Similar results were obtained by Sharma *et al.* (2001) and Kaul (2004). Marschner (1995) also reported that phosphorus stimulated root development, improved flower formation and seed production, promoted more uniform and earlier crop maturity, increases the nitrogen N-fixing capacity of legumes, improves seed quality, and increases resistance to plant diseases.

4.1.4.3. Interaction effect of liming materials and phosphorus on number of nodules per plant

The results of interaction effect of liming materials and phosphorus on the number of nodules per plant have been presented on table 4.1.4 (b) and Fig. 6. The two year research investigation data revealed that application M_3P_{80} gives the highest number of nodules per plant which recorded 36.33 and 34.33 at 30 DAS, 108.67 and 96.33 at 60 DAS and 52.33 and 51.00 at 90 DAS during year 2018 and 2019, respectively. The lowest number of nodules per plant was obtained with M_0P_0 (control) which recorded 3.33 and 3.67 at 30 DAS, 8.33 and 7.33 at 60 DAS and 6.67 and 5.33 at 90 DAS during both the year 2018 and 2019 respectively. The pooled data revealed that the highest number of nodules per plant was obtained with application of M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) which recorded 35.33 at 30 DAS, 102.50 at 60 DAS and 51.67 at 90 DAS while the lowest was recorded with treatment M_0P_0 with 3.50 at 30 DAS, 7.83 at 60 DAS and 6.00 at 90 DAS respectively. The treatment combination M_3P_{80} was found to be significant over other treatment combinations.

The increased in the highest number of nodules per plant might be due to improved nitrogenise enzyme activity responsible for root nodulation and nitrogen fixation in legumes with application lime and also increased phosphorus availability in soil which enhanced symbiotic fixation with application of phosphorus. Benvindo (2014) also confirmed that lime and phosphorus application significantly increases the number of nodules per plant in soybean.

4.1.5. Effect on root length

4.1.5.1. Effect of liming materials on root length

The data on root length recorded at 30, 60 and 90 DAS are presented in table 4.1.5 (a) and Fig. 7. It was observed that liming materials significantly increased the root length at different growth stage of soybean at 30, 60 and 90 DAS. Among the liming materials, M_3 (CS @ 0.4 LR) exhibited significantly longest root length with corresponding values 21.75 cm and 20.00 cm at 30 DAS, 29.58 cm and 27.08 cm at 60 DAS and 39.58 cm and 38.25 cm at 90 DAS during both year 2018 and 2019, respectively. The lowest was observed with M_0 (no liming material) which recorded 15.08 cm and 13.17 cm at 30 DAS, 19.50 cm and 18.50 cm at 60 DAS and 22.50 cm and 21.17 cm at 90 DAS during both year 2018 and 2019 respectively. The pooled data of the two years results revealed that application M_3 (CS @ 0.4 LR) recorded the highest root length with an average of 20.88 cm, 28.33 cm and 38.92 cm while M_0 (no liming material) recorded the lowest with an average of 14.33 cm, 19.00 cm and 21.83 cm at 30, 60 and 90 DAS respectively. It was observed that treatment M_3 was significant over the treatment M_2, M_1 and M_0.

Liming enhances P uptake by alleviating Al toxicity and thereby improving root growth (Ameyu and Asfaw, 2020). The increased in the root length might be due to improved nitrogenise enzyme activity responsible for root nodulation and nitrogen fixation in legumes which improved root development with application lime (Benvindo, 2014). Similar finding on root length of soybean at different stage of growth were also reported by. Melese *et al*. (2015).

4.1.5.2. Effect of phosphorus on root length

The data on root length recorded at different growth stage of soybean at 30, 60 and 90 DAS are presented in table 4.1.5 (a) and Fig. 7. It was observed that phosphorus significantly increased the root length at different growth stage of soybean at 30, 60 and 90 DAS. Among the phosphorus levels, P_{80} (80 kg P_2O_5 ha^{-1}) exhibited significantly longest root length with corresponding values 21.17 cm, 20.00 cm and 20.58 cm at 30 DAS, 27.25 cm, 25.25 cm and 26.25 cm at 60 DAS and 39.67 cm, 38.33 cm and 39.00 cm at 90 DAS during the both the years 2018, 2019 and pooled data, respectively. The shortest root length was observed with the treatment P_0 (0 kg P_2O_5 ha^{-1}) with corresponding values 14.50 cm, 12.92 cm and 13.71 cm at 30 DAS, 21.75 cm, 20.58 cm and 21.17 cm at 60 DAS and 22.67 cm, 21.33 cm and 22.00 cm at 90 DAS during the both the years 2018, 2019 and pooled data, respectively.

Sentimenla *et al*. (2012) also reported that the growth attributes in soybean were significantly influenced by application of different levels of phosphorus.

4.1.5.3. Interaction effect of liming materials and phosphorus on root length

From the table 4.1.5 (b) and Fig. 7, it is evident that application of treatment combination M_3P_{80} recorded the maximum root length with corresponding value of 26.00 cm and 24.33 cm at 30 DAS, 31.67 cm and 29.33 cm at 60 DAS and 53.00 cm and 51.67 cm at 90 DAS in the year 2018 and 2019 respectively. The pooled data indicates the maximum root length was observed with plots receiving treatment combination M_3P_{80} with corresponding value of 25.17 cm, 30.50 cm and 52.33 cm at 30 DAS, 60 DAS and 90 DAS respectively while the minimum root length was recorded with treatment

Table 4.1.5 (a) Effect of liming materials and phosphorus levels on number of root length of soybean at different days after sowing

Treatments	**Root length (cm)**								
	30 DAS			**60 DAS**			**90 DAS**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	15.08	13.17	14.13	19.50	18.50	19.00	22.50	21.17	21.83
M_1	16.50	15.25	15.88	22.08	20.58	21.33	25.25	23.92	24.58
M_2	19.42	18.50	18.96	26.58	24.83	25.71	35.33	34.00	34.67
M_3	21.75	20.00	20.88	29.58	27.08	28.33	39.58	38.25	38.92
SEm±	***0.18***	***0.33***	***0.19***	***0.29***	***0.28***	***0.20***	***0.35***	***0.38***	***0.26***
CD (P=0.05)	***0.62***	***1.13***	***0.57***	***0.99***	***0.97***	***0.62***	***1.20***	***1.31***	***0.79***
P_0	14.50	12.92	13.71	21.75	20.58	21.17	22.67	21.33	22.00
P_{40}	17.92	16.42	17.17	23.17	21.75	22.46	26.92	25.58	26.25
P_{60}	19.17	17.58	18.38	25.58	23.42	24.50	33.42	32.08	32.75
P_{80}	21.17	20.00	20.58	27.25	25.25	26.25	39.67	38.33	39.00
SEm±	***0.23***	***0.29***	***0.19***	***0.21***	***0.22***	***0.15***	***0.20***	***0.37***	***0.21***
CD (P=0.05)	***0.68***	***0.84***	***0.53***	***0.61***	***0.64***	***0.43***	***0.58***	***1.07***	***0.59***

Table 4.1.5 (b) Interaction effect of liming materials and phosphorus levels on root length of soybean at different days after sowing

Treatments	Root length (cm)								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	12.00	10.33	11.17	15.67	16.33	16.00	19.67	18.33	19.00
M_0P_{40}	14.67	13.00	13.83	17.67	17.33	17.50	22.33	21.00	21.67
M_0P_{60}	16.33	14.00	15.17	21.67	19.67	20.67	23.67	22.33	23.00
M_0P_{80}	17.33	15.33	16.33	23.00	20.67	21.83	24.33	23.00	23.67
M_1P_0	13.33	11.67	12.50	19.67	18.00	18.83	20.67	19.33	20.00
M_1P_{40}	16.33	15.00	15.67	20.00	18.67	19.33	22.67	21.33	22.00
M_1P_{60}	16.33	15.33	15.83	23.33	21.67	22.50	26.00	24.67	25.33
M_1P_{80}	20.00	19.00	19.50	25.33	24.00	24.67	31.67	30.33	31.00
M_2P_0	15.33	15.00	15.17	23.33	23.00	23.17	23.00	21.67	22.33
M_2P_{40}	20.00	18.33	19.17	26.33	24.33	25.33	28.67	27.33	28.00
M_2P_{60}	21.00	19.33	20.17	27.67	25.00	26.33	40.00	38.67	39.33
M_2P_{80}	21.33	21.33	21.33	29.00	27.00	28.00	49.67	48.33	49.00
M_3P_0	17.33	14.67	16.00	28.33	25.00	26.67	27.33	26.00	26.67
M_3P_{40}	20.67	19.33	20.00	28.67	26.67	27.67	34.00	32.67	33.33
M_3P_{60}	23.00	21.67	22.33	29.67	27.33	28.50	44.00	42.67	43.33
M_3P_{80}	26.00	24.33	25.17	31.67	29.33	30.50	53.00	51.67	52.33
SEm±	***0.47***	***0.57***	***0.37***	***0.42***	***0.44***	***0.30***	***0.40***	***0.73***	***0.42***
CD (P=0.05)	***1.37***	***1.67***	***1.05***	***1.22***	***1.27***	***0.86***	***1.16***	***2.14***	***1.19***

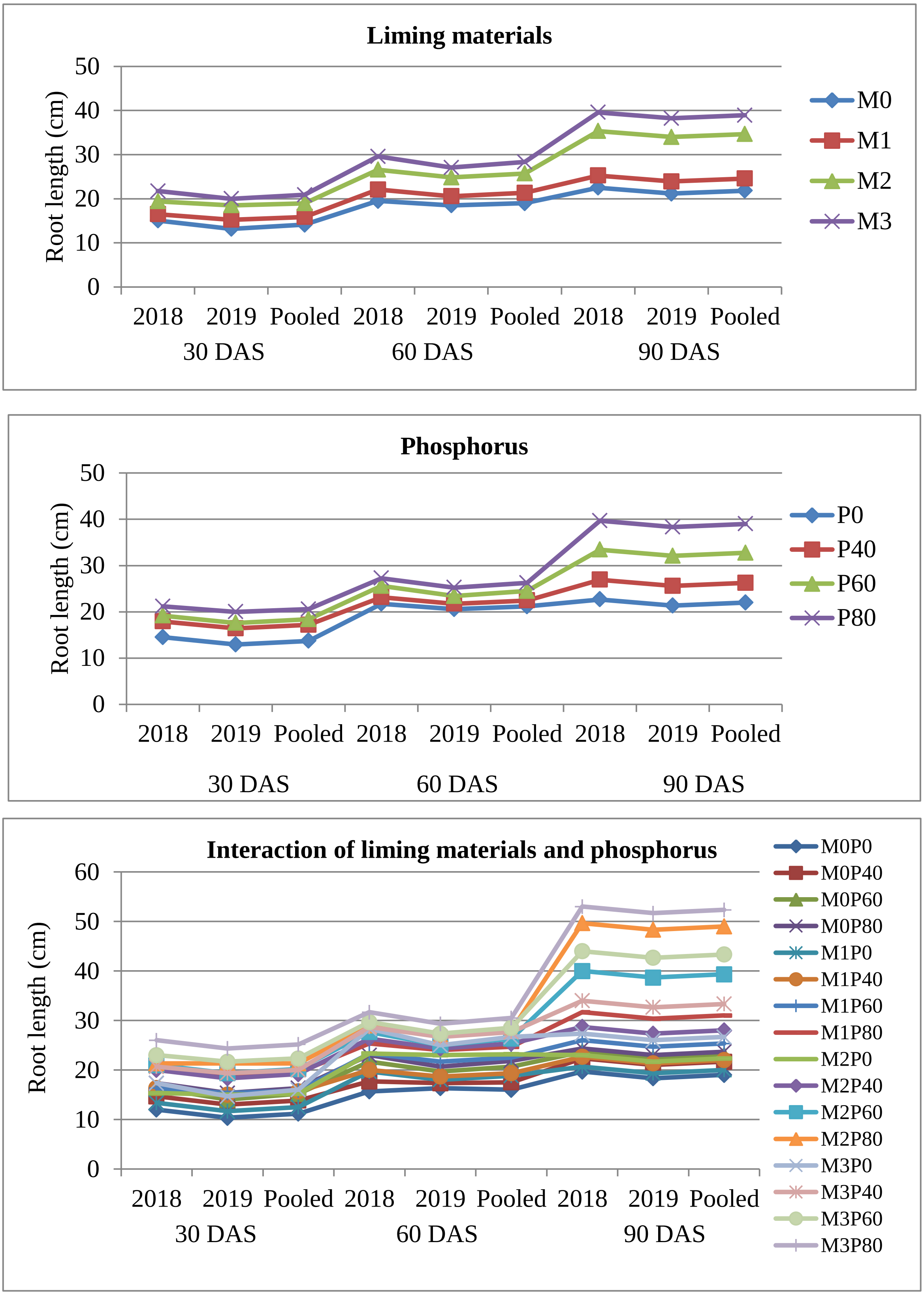


Fig. 7 Effect of liming materials, phosphorus levels and interaction on root length of soybean at different days after sowing

combination of M_0P_0 (control) with the corresponding value of 11.17 cm at 30 DAS, 16.00 cm at 60 DAS and 19.00 cm at 90 DAS respectively. A positive interaction effect between liming materials and phosphorus in increasing the root length was observed. It was found that treatment combination M_3P_{80} was significant over all the treatments.

The increased in root length might be due to combined application of liming materials and phosphorus which gives significantly better growth compared to application of liming materials and any levels of phosphorus alone. Ranjit *et al.* (2007) stated that increased the growth attributes of groundnut with combined application of lime (100 % LR) and phosphorus.

4.1.6. Effect on root dry weight

4.1.6.1. Effect of liming materials on root dry weight

The data on root dry weight recorded at different growth stages of soybean at 30, 60 and 90 DAS are presented in Table 4.1.6 and Fig. 8. It was observed that liming materials significantly increased the root dry weight over no liming material. Among the liming materials, application of M_3 (CS @ 0.4 LR) recorded the highest root dry weight with 1.52 g and 1.50 g at 30 DAS, 2.29 g and 2.22 g at 60 and 2.79 g and 2.65 at 90 DAS during both the year 2018 and 2019, respectively. The lowest was observed with M_0 which recorded 0.79 g and 0.76 g, 1.38 g and 1.45 g and 1.90 g and 1.72 g at 30, 60 and 90 DAS during year 2018 and 2019, respectively. The pooled data of the two years results revealed that application of M_3 recorded the highest root dry weight with an average value of 1.50 g, 2.25 g and 2.27 g while M_0 recorded the lowest with an average value of 0.78 g, 1.42 g and 1.81 g at 30, 60 and 90 DAS, respectively.

The increased in the root length might be due to improved nitrogenise enzyme activity responsible for root nodulation and nitrogen fixation in legumes which improved root development with application lime (Benvindo, 2014). Similar finding on root dry weight of maize at different stage of growth were also reported by Behera *et al.* (2017).

4.1.6.2. Effect of phosphorus on root dry weight

The effect of phosphorus on root dry weight has been presented on table 4.1.6 (a) and Fig. 8. It was observed that application of P_{80} recorded the highest root dry weight with 1.74 g and 1.70 g, 2.51g and 2.45 g and 3.42 g and 3.28 g at 30, 60 and 90 DAS during 2018 and 2019, respectively. The lowest root dry weight at different stages of growth was observed with P_0 which recorded 0.85 g and 0.82 g, 1.26 g and 1.35g and 1.59g and 1.23g at 30, 60 and 90 DAS during 2018 and 2019, respectively. As apparent from the pooled data, theaverage root dry weight was highest with application of P_{80} which recorded 1.72 g, 2.48 g and 3.35 g whereas the lowest was observed with P_0 having 0.83 g, 1.30g and 1.41 g at 30, 60 and 90 DAS during 2018 and 2019, respectively. Application of phosphorus was observed to have a significant effect on root dry weight with increasing doses of phosphorus. Treatment P_{80} was found to be significant over P_{60}, P_{40} and P_0

Increase in root dry weight of addition of phosphorus might be due to acute deficiency in the experimental acidic up land soils of Nagaland (Sentimenla *et al*. 2012). Similar result also has been observed by Kaul (2004). Bhattacharjee (2013) reported that soybean responded positively to higher dose of P (90 kg P_2O_5 ha^{-1}).

4.1.6.3. Interaction effect of liming materials and phosphorus on root dry weight

The results of interaction effect of liming materials and phosphorus on the root dry weight have been presented on table 4.1.6 (b) and Fig. 8. The two year research investigation data revealed that application M_3P_{80} gives the highest number of root dry weight which recorded 2.25 g and 2.22 g at 30

Table 4.1.6 (a) Effect of liming materials and phosphorus levels on root dry weight of soybean at different days after sowing

Treatments	**Root dry weight (g)**								
	30 DAS			**60 DAS**			**90 DAS**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	0.79	0.76	0.78	1.38	1.45	1.42	1.90	1.72	1.81
M_1	1.32	1.28	1.30	1.79	1.79	1.79	2.52	2.23	2.37
M_2	1.42	1.49	1.46	2.15	2.11	2.13	2.79	2.65	2.72
M_3	1.52	1.50	1.51	2.29	2.22	2.25	2.84	2.66	2.75
SEm±	***0.05***	***0.03***	***0.03***	***0.03***	***0.04***	***0.02***	***0.04***	***0.03***	***0.02***
CD (P=0.05)	***0.18***	***0.09***	***0.09***	***0.10***	***0.12***	***0.07***	***0.12***	***0.10***	***0.07***
P_0	0.85	0.82	0.83	1.26	1.35	1.30	1.59	1.23	1.41
P_{40}	1.04	1.13	1.08	1.75	1.70	1.73	2.17	2.00	2.08
P_{60}	1.42	1.39	1.40	2.08	2.08	2.08	2.88	2.75	2.82
P_{80}	1.74	1.70	1.72	2.51	2.45	2.48	3.42	3.28	3.35
SEm±	***0.05***	***0.03***	***0.03***	***0.02***	***0.03***	***0.02***	***0.05***	***0.03***	***0.03***
CD (P=0.05)	***0.15***	***0.08***	***0.08***	***0.06***	***0.09***	***0.05***	***0.14***	***0.08***	***0.08***

Table 4.1.6 (b) Interaction effect of liming materials and phosphorus levels on root dry weight of soybean at different days after sowing

Treatments	Root dry weight (g)								
	30 DAS			60 DAS			90 DAS		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	0.71	0.66	0.68	0.43	0.85	0.64	0.92	0.68	0.80
M_0P_{40}	0.81	0.77	0.79	1.47	1.43	1.45	1.64	1.31	1.48
M_0P_{60}	0.82	0.80	0.81	1.64	1.60	1.62	2.40	2.36	2.38
M_0P_{80}	0.84	0.82	0.83	1.97	1.93	1.95	2.64	2.54	2.59
M_1P_0	0.91	0.87	0.89	1.34	1.30	1.32	2.10	1.33	1.72
M_1P_{40}	1.01	0.95	0.98	1.66	1.60	1.63	2.38	2.21	2.30
M_1P_{60}	1.49	1.46	1.48	1.55	1.67	1.61	2.64	2.39	2.51
M_1P_{80}	1.88	1.85	1.87	2.62	2.57	2.60	2.97	2.97	2.97
M_2P_0	0.85	0.88	0.86	1.57	1.54	1.56	1.70	1.49	1.60
M_2P_{40}	0.99	1.43	1.21	1.94	1.90	1.92	2.64	2.48	2.56
M_2P_{60}	1.83	1.79	1.81	2.52	2.48	2.50	3.34	3.14	3.24
M_2P_{80}	2.01	1.90	1.95	2.55	2.50	2.53	3.69	3.52	3.60
M_3P_0	0.92	0.88	0.90	1.72	1.68	1.70	1.62	1.40	1.51
M_3P_{40}	1.36	1.35	1.36	1.94	1.85	1.90	2.00	2.00	2.00
M_3P_{60}	1.52	1.50	1.51	2.59	2.55	2.57	3.16	3.13	3.15
M_3P_{80}	2.25	2.22	2.24	2.90	2.80	2.85	4.37	4.07	4.22
SEm±	***0.10***	***0.06***	***0.06***	***0.04***	***0.06***	***0.04***	***0.09***	***0.05***	***0.05***
CD (P=0.05)	***0.30***	***0.17***	***0.17***	***0.12***	***0.18***	***0.11***	***0.27***	***0.15***	***0.15***

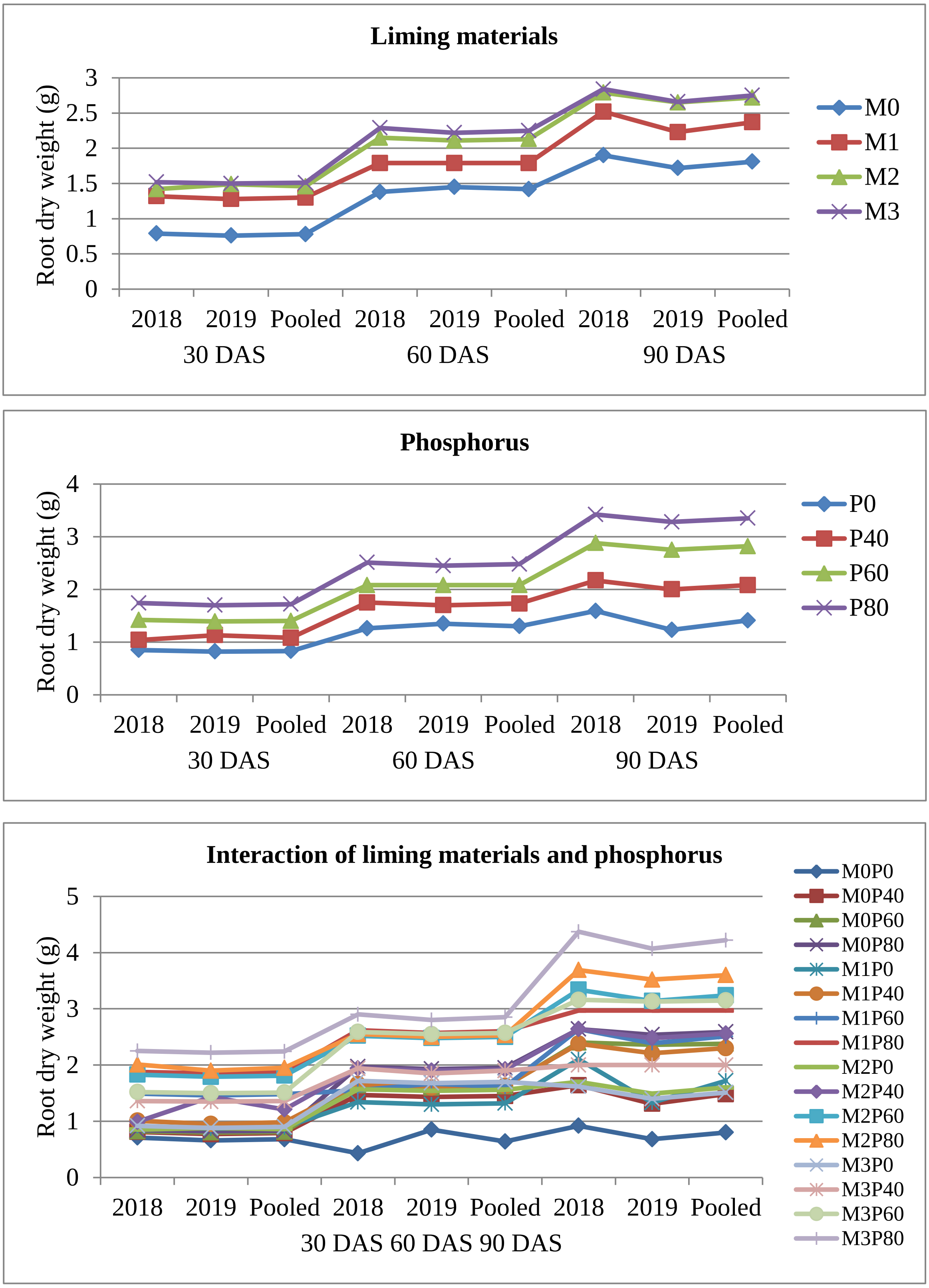


Fig. 8 Effect of liming materials, phosphorus levels and interaction on root dry weight of soybean at different days after sowing

DAS, 2.90 g and 2.80 g at 60 DAS and 4.37 g and 4.07 at 90 DAS during year 2018 and 2019, respectively. The lowest number of root dry weight was obtained with M_0P_0 (control) which recorded 0.71 g and 0.66 g at 30 DAS, 0.43 g and 0.85 g at 60 DAS and 0.92 g and 0.68 g at 90 DAS during both the year 2018 and 2019 respectively. The pooled data revealed that the highest root dry weight was obtained with application of M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) which recorded 2.24 at 30 DAS, 2.85 g at 60 DAS and 4.22 g at 90 DAS while the lowest was recorded with treatment M_0P_0 with 0.68 g at 30 DAS, 0.64 g at 60 DAS and 0.80 at 90 DAS respectively. The treatment combination CS @ 0.4 LR along 80 kg P_2O_5 ha^{-1} (M_3P_{80}) was found to be significant over other treatment combinations.

The increased in root dry weight might be due to better root development and nodulation which facilitates better nutrients utilization resulting in better growth of soybean (Bhattacharjee, 2013). Ashoka *et al.* (2014) also observed that application of lime @ 1000 kg and phosphorus up to 100 kg P_2O_5 ha^{-1} recorded higher number of branches per plant in soybean.

4.2. Effect on yield attributes of soybean

The effect of liming materials and phosphorus on yield attributes of soybean viz. number of pod per plant, number of seed per pod and seed test weight are presented under the following heads:

4.2.1. Effect on number of pods per plant

4.2.1.1. Effect of liming materials on number of pods per plant

Table 4.2.1 (a) and Fig. 9 presented the effect of liming material on number of pod per plant. As evident from the table, there was significant increased with the application liming materials. Among the liming materials, M_3 (CS @ 0.4 LR) recorded the highest number of pod per plant with 80.08 and 75.07 while M_0 (no liming materials) was recorded the lowest with 71.63

A

B

Plate 3. A and B vegetative stage of crop

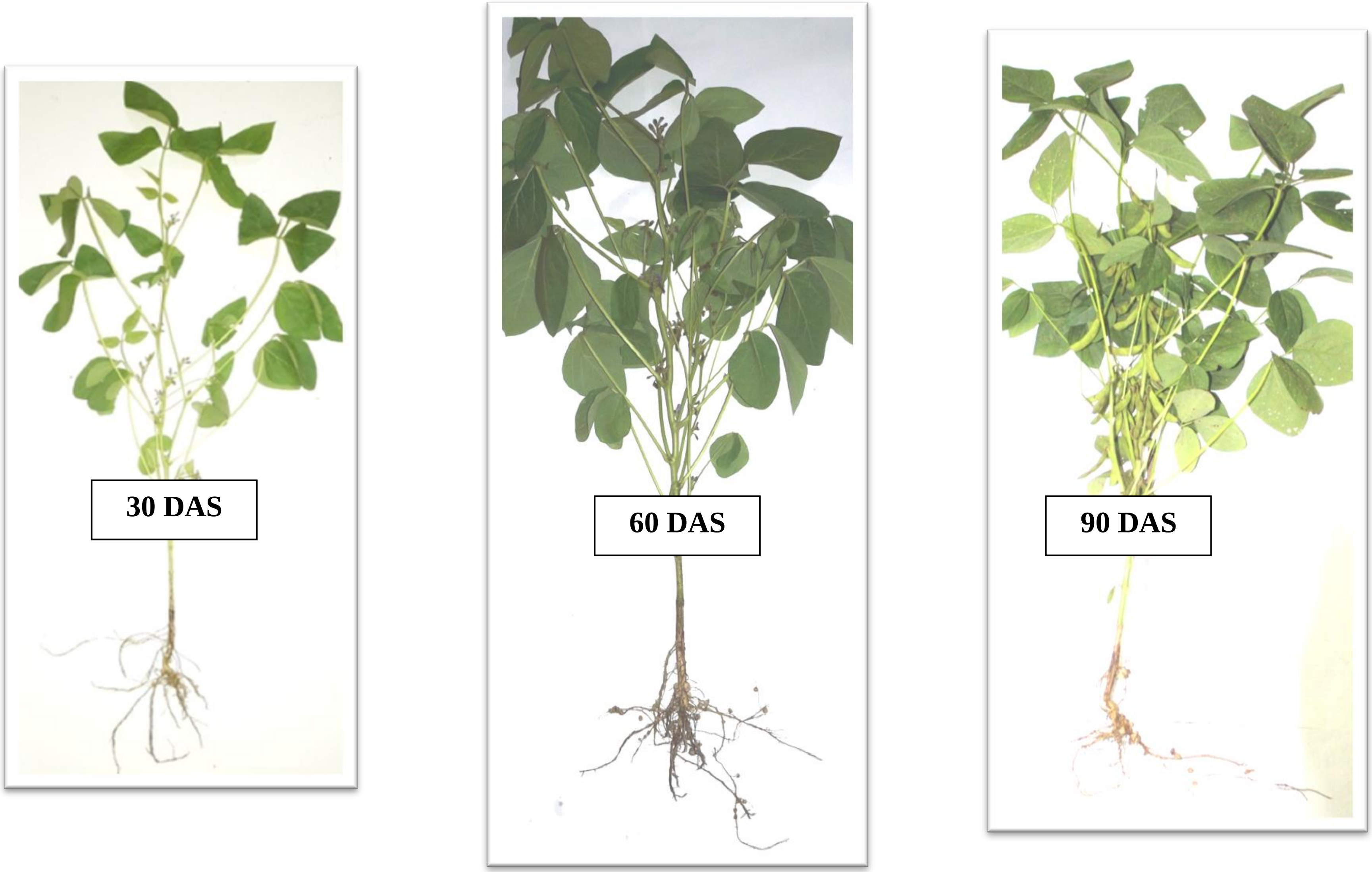


Plate 6.Stages of crop at 30, 60 and 90 DAS

and 65.38 during the year 2018 and 2019, respectively. It became apparent from the pooled data that M_3 (CS @ 0.4 LR) showed the highest number of pod per plant having 77.58 whereas M_0 (no liming materials) showed the lowest with 68.51.

The increased in the number of pod per plant might be due to improved liming through CS @ 0.4LR which promotes biological N_2 fixation and production of growth regulators (Hazarika *et al*. 2011). Kumar *et al*. (2014) reported that increasing levels of lime from 0 to 0.6 t ha^{-1} significantly increased yield attributes.

4.2.1.2 Effect of phosphorus on number of pods per plant

The number of pod per plant of soybean responded significantly to the application of phosphorus. It was shown in table 4.2.1 (a) and Fig. 9. The highest number of pod per plant produced in the plots receiving P_{80} (80 kg P_2O_5 ha^{-1}) having 86.37 and 78.87 while the lowest was observed in the pots receiving P_0 (80 kg P_2O_5 ha^{-1}) having 64.80 and 56.80 during 2018 and 2019, respectively. It is evident from the pooled data that P_{80} recorded the highest with 82.62 and P_0 recorded the lowest with 60.80 number of pod per plant on average.

The number of pods per plant increased with application of phosphorus which might be due to improve phosphorus availability in soil and enhanced symbiotic N_2 fixation. Similar results were obtained by Sharma *et al.* (2001) and Kaul (2004). Marschner (1995) also reported that phosphorus stimulated root development, improved flower formation and seed production, promoted more uniform and earlier crop maturity, increases the nitrogen N-fixing capacity of legumes, improves seed quality, and increases resistance to plant diseases.

Table 4.2.1 (a) Effect of liming materials and phosphorus levels on number of pod per plant, number of seed per pod and seed test weight of soybean

Treatments	**Seed test weight (g)**			**Number of pod plant^{-1}**			**Number of seed pod^{-1}**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	12.21	12.19	12.20	71.63	65.38	68.51	2.78	2.87	2.83
M_1	12.24	12.23	12.23	73.85	69.10	71.48	2.78	2.83	2.81
M_2	12.28	12.26	12.27	76.52	70.50	73.51	2.80	2.85	2.83
M_3	12.33	12.31	12.32	80.08	75.07	77.58	2.92	2.97	2.94
SEm±	***0.019***	***0.022***	***0.015***	***0.49***	***1.08***	***0.59***	***0.04***	***0.03***	***0.03***
CD (P=0.0.5)	***0.067***	***0.076***	***0.045***	***1.69***	***3.74***	***1.83***	**NS**	**NS**	**NS**
P_0	12.19	12.18	12.19	64.80	56.80	60.80	2.78	2.85	2.82
P_{40}	12.25	12.23	12.24	72.17	69.93	71.05	2.80	2.83	2.82
P_{60}	12.28	12.26	12.27	78.75	74.45	76.60	2.85	2.90	2.88
P_{80}	12.33	12.32	12.32	86.37	78.87	82.62	2.85	2.93	2.89
SEm±	***0.025***	***0.024***	***0.017***	***0.44***	***1.52***	***0.79***	***0.04***	***0.04***	***0.03***
CD (P=0.05)	***0.072***	***0.070***	***0.049***	***1.27***	***4.43***	***2.25***	**NS**	**NS**	**NS**

Table 4.2.1 (b) Interaction effect of liming materials and phosphorus levels on pod per plant, number of seed per pod and seed test weight of soybean

Treatments	Seed test weight (g)			Number of pod $plant^{-1}$			Number seed pod^{-1}		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	12.17	12.13	12.15	62.60	53.93	58.27	2.73	2.73	2.73
M_0P_{40}	12.20	12.17	12.18	68.80	67.80	68.30	2.73	2.93	2.83
M_0P_{60}	12.20	12.20	12.20	73.60	68.27	70.93	2.87	2.87	2.87
M_0P_{80}	12.27	12.27	12.27	81.53	73.20	77.37	2.80	2.93	2.87
M_1P_0	12.17	12.17	12.17	63.47	57.13	60.30	2.73	2.80	2.77
M_1P_{40}	12.23	12.20	12.22	70.07	69.07	69.57	2.73	2.73	2.73
M_1P_{60}	12.27	12.23	12.25	77.27	72.27	74.77	2.87	2.87	2.87
M_1P_{80}	12.30	12.30	12.30	84.60	77.93	81.27	2.80	2.93	2.87
M_2P_0	12.20	12.20	12.20	65.33	56.80	61.07	2.80	2.87	2.83
M_2P_{40}	12.27	12.23	12.25	73.00	71.53	72.27	2.80	2.80	2.80
M_2P_{60}	12.30	12.27	12.28	80.27	74.47	77.37	2.73	2.87	2.80
M_2P_{80}	12.33	12.33	12.33	87.47	79.20	83.33	2.87	2.87	2.87
M_3P_0	12.23	12.23	12.23	67.80	59.33	63.57	2.87	3.00	2.93
M_3P_{40}	12.30	12.30	12.30	76.80	73.00	74.90	2.93	2.87	2.90
M_3P_{60}	12.37	12.33	12.35	83.87	82.80	83.33	2.93	3.00	2.97
M_3P_{80}	12.40	12.37	12.38	91.87	85.13	88.50	2.93	3.00	2.97
SEm±	***0.050***	***0.048***	***0.034***	***0.87***	***2.01***	***1.09***	***0.07***	***0.07***	***0.05***
CD (P=0.05)	**NS**	**NS**	**NS**	***2.55***	***5.85***	***3.11***	**NS**	**NS**	**NS**

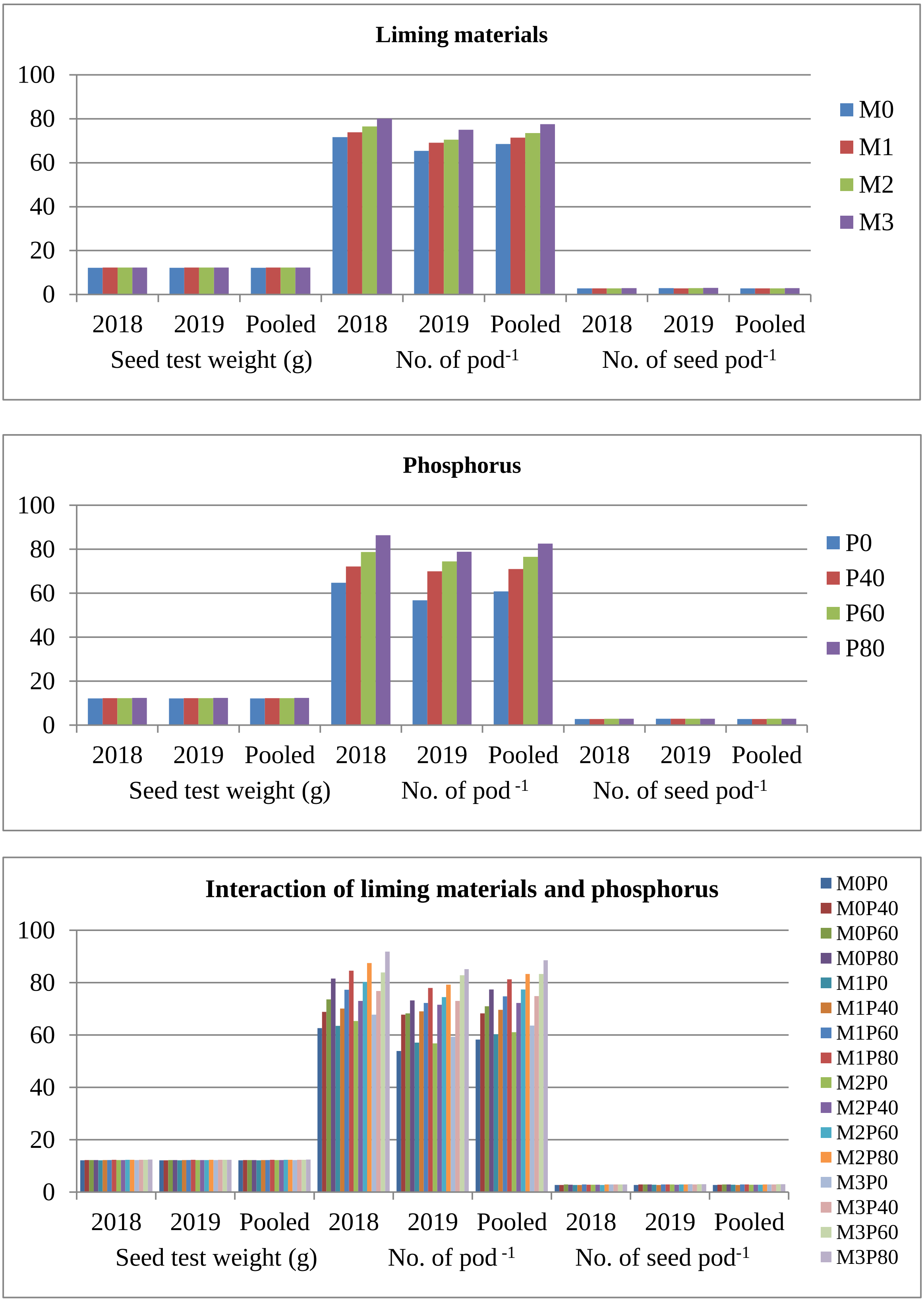


Fig. 9 Effect of liming materials, phosphorus levels and interaction on number of pod per plant, number of seed per pod and seed test weight of soybean

4.2.1.3. Interaction effect of liming materials and phosphorus on number of pods per plant

The interaction effect of liming materials and phosphorus on number of pods per plant has been presented on table 4.2.1 (b) and Fig.9. The highest number of pods per plant was recorded in plots receiving treatment combination M_3P_{80} which recorded 91.87 and 85.13 both in the year 2018 and 2019, respectively. The lowest number of pods per plant was recorded with control plot (M_0P_0) having 62.60 and 53.93 pods per plant in the year 2018 and 2019, respectively. M_3P_{80} was found to be significant over all other treatment combinations including control (M_3P_0).

The applied lime and P improved number of pod per plant, which might be due to lime and phosphorus enhanced vegetative growth, thereby, enabling the plant to bear higher number of pods than the untreated soil condition, and neutralizing soil acidity by lime, which in turn increases availability of P for plant uptake, through reduction in its fixation on acid soils as well as increases calcium availability in the soil (Kisinyo O., 2016). Temasgen *et al*. (2017) reported that the application of lime with P significantly increased number of pods per plant for soybeans. Pods per plant as influenced by interaction between lime and phosphorus has been reported by

4.2.2. Effect on number of seeds per pod

4.2.2.1. Effect of liming materials on number of seeds per pod

As evident from the table 4.2.1 (a) and Fig. 9, application of liming materials did not have any significant influence on the number of seeds per pod in soybean. However, application of M_3 recorded higher number of seeds per pod with 2.92 and 2.97 as compared of M_2, M_1 and M_0 which recorded 2.80 and 2.85, 2.78 and 2.83 and 2.78 and 2.87 during the year 2018 and 2019, respectively while in the pooled data, M_3 was 2.94.

4.2.2.2. Effect of phosphorus on number of seeds per pod

Application of Phosphorus did not have any significant effect on the number of seeds per pod in soybean. It was shown in table 4.2.1 (a) and Fig. 9, However, application of P_{80} recorded higher number of seeds per pod with 2.85 and 2.93 as compared of P_{60}, P_{40} and P_0 which recorded 2.85 and 2.90, 2.80 and 2.83 and 2.78 and 2.85 during the year 2018 and 2019, respectively while in the pooled data, P_3 was 2.89.

4.2.2.3. Interaction effect of liming materials and phosphorus on number of seeds per pod

The interaction effect between liming materials and phosphorus on the number of seeds per pod in soybean has been presented on table 4.2.1 (b) and Fig. 9. It was found that application of treatment M_3P_{80} recorded the highest number of seeds per pod with 2.93 and 3.00 during both the year 2018 and 2019, respectively. In the pooled data, M_3P_{80} recorded 2.97 while M_0P_0 recorded 2.73 on an average. It was observed that interaction between liming materials and phosphorus did not have any significant effect on the number of seeds per pod in soybean.

The results are conformity with the findings of Venkatesh *et al.,* (2002). Similar finding on the number of seeds per pod in soybean with combined application of lime and phosphorus has been reported by Suryantini (2014)

4.2.3. Effect on number of seed test weight

4.2.3.1. Effect of liming materials on seed test weight

The effect of liming materials on seed test weight has been presented on table 4.2.1 (a) and Fig. 9. It was observed that application of liming materials had a significant effect on seed test weight of soybean. Application of M_3 (CS @ LR) recorded the highest seed test weight with12.33 g and 12.31g while M_0 (no liming material) recorded the lowest with 12.21 g and 12.19 g during 2018 and 2019, respectively. From the pooled data, it was become evident that M_3 recorded higher seed test weight having 12.32 g as compared to M_2, M_1 and M_0 which recorded 12.27 g, 12.23 g and 12.20 g, respectively. Treatment M_3 was found to be significant over M_2, M_1 and $M_{0.}$

Lynrah and Nongmaithem (2017) reported that application of liming @ 1,5 t ha^{-1} recorded the highest seed test weight. The increased in the seed test weight could be due to improve the soil properties which improved the performance of all yield parameters.

4.2.3.2. Effect of phosphorus on seed test weight

The results revealed from table 4.2.1 (a) and Fig. 9 that increased the level of phosphorus application had a significant effect on seed test weight of soybean. Treatment P_{80} was found to give the higher seed test weight recorded 12.33 g and 12.32 g as compared to P_{60}, P_{40} and P_0 which recorded 12.28 g and 12.26 g, 12.25 g and 12.23 g and 12.29 g and 12.18 g during 2018 and 2019, respectively. In the pooled data, P_{80} recorded 12.32 g while P_0 recorded 12.19 g on an average. As evident from the results obtained treatment P_{80} was found to be significant over P_{60}, P_{40} and P_0.

The significant effect on seed test weight might be due to the fact that phosphorus increases the phosphorus availability resulting in improved growth and development which ultimately increased the seed weight through improved supply of assimilates to seed. Temasgen *et al*. (2017) reported that application of phosphorus at the rate of 30 kg ha^{-1} increased hundred seed weight of barley by 4.6% over the control treatment (no phosphorus).

4.2.3.3. Interaction effect of liming materials and phosphorus on seed test weight

The interaction effect between liming materials and phosphorus on seed test weight has been presented on 4.2.1 (b) and Fig. 9. The results revealed that

A

B

Plate 4. A. Pod forming stage of crop in first year 2018

B. Pod forming stage of crop in second year 2019

M_3P_{80} gave the highest seed test weight recorded 12.40 g and 12.37 g while M_0P_0 recorded the lowest with 12.17 and 12.13 during both the year 2018 and 2019, respectively. On an average highest seed test weight 12.38 g was recorded with M_3P_{80} while lowest 12.15 g with M_3P_{80} with pooled data. The interaction effect between liming materials and phosphorus was found to be non significant on seed test weight.

4.3. Effect on yield of soybean

The results on the effect of liming materials, phosphorus and their interaction on yield of soybean viz, grain and stover yield are presented under the following heads.

4.3.1. Effect on seed yield of soybean

4.3.1.1 Effect of liming materials on grain yield

The grain yield of soybean responded significantly to the application of liming material. The data of two years and pooled investigation (table 4.3.1 (a) and Fig. 10) indicated that liming material was significantly influenced the grain yield of soybean. Among the liming materials, CS @ 0.4 LR (M_3) recorded the highest seed yield with 2027.19 kg ha^{-1} and 1857.23 kg ha^{-1} while no liming material (M_0) was the lowest with 1755.49 kg ha^{-1} and 1670.67 kg ha^{-1} during 2018 and 2019, respectively. In the pooled data, CS @ 0.4 LR recorded an average mean of 1942.21 kg ha^{-1} while no liming material recorded 1713.08 kg ha^{-1}. Treatment CS @ 0.4 LR (M_3) was found to be significantly higher than other treatment PMS @ 0.4 LR (M_2), WA @ 0.4 LR (M_1) and no liming materials (M_0) in both the years of investigation.

Liming increased grain yield which might be due to the increase in soil pH, exchangeable bases, available P and reduction in exchangeable Al (Bishnoi

Table 4.3.1 (a) Effect of liming materials and phosphorus levels on grain and stover yield of soybean

Treatments	Grain Yield (kg ha^{-1})			Stover Yield (kg ha^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	1755.49	1670.67	1713.08	2306.67	2170.63	2238.65
M_1	1811.54	1731.55	1771.54	2452.50	2298.61	2375.56
M_2	1912.09	1830.36	1871.22	2541.67	2326.39	2434.03
M_3	2027.19	1857.23	1942.21	2578.33	2398.30	2488.32
SEm±	***31.54***	***20.59***	***18.83***	***24.19***	***19.28***	***15.47***
CD (P=0.05)	***109.15***	***71.27***	***58.04***	***83.72***	***66.73***	***47.67***
P_0	1657.63	1531.84	1594.73	2165.83	1988.18	2077.01
P_{40}	1837.77	1714.71	1776.24	2426.67	2266.47	2346.57
P_{60}	1959.85	1870.25	1915.05	2583.33	2395.44	2489.38
P_{80}	2051.06	1973.02	2012.04	2703.33	2543.85	2623.59
SEm±	***16.87***	***20.27***	***13.18***	***25.50***	***26.03***	***18.22***
CD (P=0.05)	***49.23***	***59.16***	***37.49***	***74.42***	***75.98***	***51.81***

et al., 1998; Gupta *et al*., 1989; Dixit *et al*., 1993). Similar results also found by Kisinyo *et al*., (2013). Ghosh *et al*. (2006) showed that liming tended to exhibit better nodulation and higher seed yield with more oil content than control.

4.3.1.2 Effect of phosphorus on grain yield

The response of different levels of phosphorus reveals that the higher level of P i.e. 80 kg P_2O_5 ha^{-1} (P_{80}) produced the highest significant grain yield of 2051.06 and 1973.02 kg ha^{-1} during the year 2018 and 2019, respectively. Whereas, the lowest was found with treatment 0 kg P_2O_5 ha^{-1} (P_0) having 1657.63 and 1531.84 kg ha^{-1} during the year 2018 and 2019, respectively. In the pooled data, 80 kg P_2O_5 ha^{-1} recorded an average mean of 2012.04 kg ha^{-1} while no phosphorus recorded 1594.73 kg ha^{-1} (table 4.3.1(a) and Fig. 9).

The increase in seed yield might be due to more number of of pods per plant, seeds per pod and hundred seed weight. Ilbas and Sahn (2005), Tapas and Gupta (2005) and Jain and Trivedi (2005) also reported that seed yield of soybean increase with inoculation and applying higher levels of phosphorus. The soil under study was deficient in available P and therefore significant response of soybean to the applied nutrients is quite understandable. The gradual increase in soybean yield with the graded level of phosphorus was might be due to an increase in root proliferation resulting nutrient uptake to increase the plant height, vigour and more number of pods and seeds. Similar result on increase in grain of soybean were reported by Naidu and Pillai (1993), Singh and Rai (2003), Singh and Singh (2004). Increase in grain yields on addition of P might be due to P acute deficiency in the experimental acidic soil. Gupta *et al*. (2008) also reported the beneficial effect of P application on blackgram.

Table 4.3.1 (b) Interaction effect of liming materials and phosphorus levels on grain and stover yield of soybean

Treatments	Grain yield kg ha^{-1}			Stover yield kg ha^{-1}		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	1576.19	1426.98	1501.59	2006.67	1846.83	1926.75
M_0P_{40}	1756.00	1666.76	1711.38	2300.00	2192.86	2246.43
M_0P_{60}	1836.43	1770.70	1803.56	2406.67	2284.13	2345.40
M_0P_{80}	1853.33	1818.25	1835.79	2513.33	2358.73	2436.03
M_1P_0	1632.67	1563.49	1598.08	2143.33	1924.60	2033.97
M_1P_{40}	1824.44	1722.22	1773.33	2400.00	2299.21	2349.60
M_1P_{60}	1840.54	1761.90	1801.22	2553.33	2381.75	2467.54
M_1P_{80}	1948.49	1878.57	1913.53	2713.33	2588.89	2651.11
M_2P_0	1669.00	1577.78	1623.39	2213.33	2053.17	2133.25
M_2P_{40}	1853.97	1734.13	1794.05	2486.67	2248.41	2367.54
M_2P_{60}	1983.33	1946.83	1965.08	2686.67	2454.76	2570.71
M_2P_{80}	2142.06	2062.70	2102.38	2780.00	2549.21	2664.60
M_3P_0	1752.67	1559.10	1655.88	2300.00	2128.11	2214.06
M_3P_{40}	1916.67	1735.71	1826.19	2520.00	2325.40	2422.70
M_3P_{60}	2179.11	2001.59	2090.35	2686.67	2461.11	2573.89
M_3P_{80}	2260.33	2132.54	2196.44	2806.67	2678.57	2742.62
SEm±	***33.73***	***40.53***	***26.37***	***50.99***	***52.06***	***36.44***
CD (P=0.05)	***98.46***	***118.31***	***74.98***	***148.84***	***151.96***	***103.61***

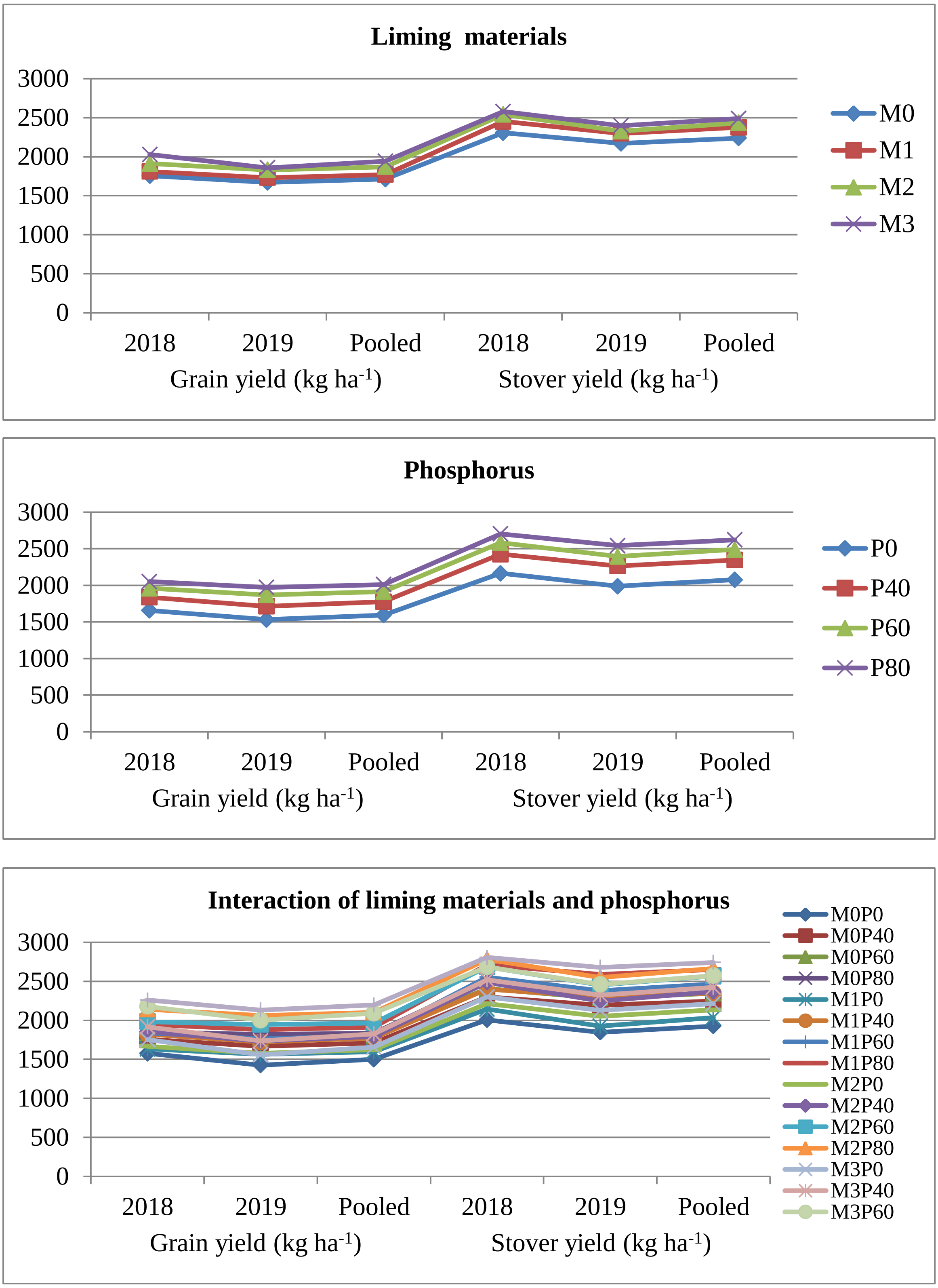


Fig. 10 Effect of liming materials, phosphorus levels and interaction on grain and stover yields of soybean.

4.3.1.3 Interaction effect of liming materials and phosphorus on grain yield

Table 4.3.1(b) and Fig. 10 showed the interaction effect between liming materials and phosphorus on grain yield of soybean. The interaction between liming materials and phosphorus was found to have a significant effect on seed yield. Application of liming material along with phosphorus increased seed yield than application of liming materials and phosphorus alone. The highest seeds yield was recorded with M_3P_{80} which recorded 2260.33 kg ha^{-1} and 2132.54 kg ha^{-1} while the lowest seeds yield was observed with M_0P_0 (control) which recorded 1576.19 kg ha^{-1} and 1426.98 kg ha^{-1} during the year 2018 and 2019, respectively. In the pooled data, M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) recorded an average mean of 2196.44 kg ha^{-1} while M_0P_0 recorded 1501.59 kg ha^{-1}.Treatment M_3P_{80} was found to be significantly higher than other treatment.

The positive response of soybean to the applied lime and P might be due to the probability of obtaining the available P from decomposed OM by microorganisms, when the pH value of the soil improved due to liming, which might have resulted in increased grain yield (Anetor, 2006). The results of the present study are in conformity with the work of Mesfin *et al.* (2014) who had reported the highest grain yield (1488.4 kg ha-1) of common bean from the combination of 30 kg P_2O_5 ha^{-1} and 0.4 t lime ha^{-1}. Nekesa *et al.* (2011) found that combined Diamonium Phosphate (DAP) and lime increased significantly soybean grain yields.

4.3.2. Effect on stover yield of soybean

4.3.2.1 Effect of liming materials on stover yield

The result on the effect of liming materials on stover yield has been presented on table 4.3.1(a) and Fig. 10. It was observed that application of liming materials had a significant influence on stover yield. Application of M_3 recorded higher stover yield with 2578.33 kg ha^{-1} and 2398.30 kg ha^{-1} as compared to M_2, M_1 and M_0 which recorded 2541.67 kg ha^{-1} and 2326.39 kg ha^{-1}, 2452.59 kg ha^{-1} and 2298.61 kg ha^{-1} and 2306.67 kg ha^{-1} and 2170.63 kg ha^{-1} during 2018 and 2019, respectively. In the pooled data, M_3 was recorded the highest stover yield an average mean of 2488.32 kg ha^{-1} while the lowest was recorded with M_0 having 2238.65 kg ha^{-1}.

The positive response of soybean to applied lime and P might be due to the improvement of soil pH in response to lime amendment, which enhanced growth and yield of the plant, as a result of increased availability of P that might have increased intensity of photosynthesis, flowering, seed formation and fruiting (Chalk, 2010). Ameyu and Asfaw (2020) also reported the similar results.

4.3.2.2 Effect of phosphorus on stover yield

Table 4.3.1(a) and Fig. 10 showed the results on the effect of phosphorus on stover yield. It was evident from data that with increasing in doses of phosphorus application, stover yield of soybean increased significantly. It is has been observed that application P_{80} (80 kg P_2O_5 ha^{-1}) recorded the highest stover yield with 2703.33 kg ha^{-1} and 2543.85 kg ha^{-1} where as the lowest stover yield was obtained with P_0 (0 kg P_2O_5 ha^{-1}) which recorded 2165.83 kg ha^{-1} and 1988.18 kg ha^{-1} during 2018 and 2019, respectively. In the pooled data, P_{80} recorded 2623.59 kg ha^{-1} while P_0 was 2077.01 kg ha^{-1}.

The higher value of stover yield at higher level of phosphorus is owing to significantly higher value of dry matter per plant beside the other growth and yield parameters. These finding are in conformity with the results of Sarkar, *et al.* (1997). The application of phosphorus enhanced to well develop root system and nodulation with consequent improved nitrogen fixation and better utilization of nutrients which in turn resulted in higher stover yield.

Plate 5. Harvesting Stages

4.3.2.3 Interaction effect of liming materials and phosphorus on stover yield

The result on the interaction effect of liming materials and phosphorus on stover yield has presented on Table 4.3.1(b) and Fig. 10. Increasing the level of phosphorus application with different liming materials has been found to have a significant influence on the stover yield. The highest stover yield was observed with M_3P_{80} (CS @.0.4 LR + 80 kg P_2O_5 ha^{-1}) which record 2806.67 kg ha^{-1} and 2678.57 kg ha^{-1} while lowest stover yield was observed with M_0P_0 (control) which record 2006.67 kg ha^{-1} and 1846.83 kg ha^{-1} during year 2018 and 2019, respectively. In the pooled data, M_3P_{80} recorded an average mean of 2742.62 kg ha^{-1} and M_0P_0 recorded 1926.75 kg ha^{-1}.

The combined application of liming material and phosphorus could have facilitated higher nutrient availability and uptake by plant resulting in improved growth and yield. Suryantini (2012) revealed that liming along with phosphorus increased the stover yield of soybean.

4.4. Effect on quality attributes

The results on the effect of liming materials, phosphorus and their interaction on quality attributes of soybean viz, protein content and protein yield and oil content and oil yield in seeds are presented below:

4.4.1. Effect on protein content and protein yield

4.4.1.1 Effect of liming materials on protein content and protein yield

Table 4.4.1 (a) and Fig. 11 presented the effect of liming materials on protein content. From the results obtained, it was apparent that liming materials had significant influence on protein content. M_3 recorded higher protein content which recorded 38.42 % and 34.61 % as compared with M_2 (37.83 % and 32.81 %), M_1 (37.74 % and 35.44 %) and M_0 (35.77 % and 33.52 %)

during 2018 and 2019, respectively. In the pooled data, M_3 had an average protein content of 37.52 % while $M_{2,}$ M_1 and M_0 had 36.82 %, 36.59 % and 34.64 % respectively.

The results indicated that CS @ 0.4 LR (M_3) recorded significantly higher protein yield which recorded 779.95 kg ha^{-1} and 684.58 kg ha^{-1} as compared to PMS @ 0.4 LR (M_2), WA @ LR (M_1) and no liming materials (M_0) which recorded 724.32 kg ha^{-1} and 658.83 kg ha^{-1}, 684.17 kg ha^{-1} and 615.73 kg ha^{-1} and 631.90 kg ha^{-1} and 565.67 kg ha^{-1} during 2018 and 2019, respectively. In the pooled data, M_3 recorded an average protein yield of 732.27 kg ha^{-1} while M_2, M_2 and M_0 were 691.57 kg ha^{-1}, 649.95 kg ha^{-1} and 598.78 kg ha^{-1} respectively. The significant increased in the protein yield could be due to increased in the seed yield with liming materials application.

The increased protein yield could be attributed to the fact that liming increased the seed yield and that the protein yield is directly related with seed yield. Similar result on protein yield with liming has been reported by Ghosh *et al*. (2006).

4.4.1.2 Effect of phosphorus on protein content and protein yield

The effect of phosphorus on protein content and yield has been presented table 4.4.1 (a) and Fig. 11. It has been observed that increasing doses of phosphorus application increased the protein content in significantly. It was evident that with increased level of phosphorus application up to 80 kg P_2O_5 ha^1 increased the protein content. The maximum protein content was observed with P_{80} (80 kg P_2O_5 ha^1) which recorded 38.48 % and 38.04 % during 2018 and 2019 respectively while in the pooled it had 38.28 %. The lowest protein content was observed with P_0 (0 kg P_2O_5 ha^1) which recorded 35.49 % and 31.81 % during 2018 and 2019 respectively while in the pooled data it was 33.65 %.

The maximum protein yield was observed with P_{80} which recorded 789.97 kg ha^{-1} and 752.05 kg ha^{-1} with pooled data as 771.01 kg ha^{-1} during the both year 2018 and 2019, respectively. The lowest protein yield was observed with P_0 which recorded 590.12 kg ha^{-1} and 489.19 kg ha^{-1} during 2018 and 2019 respectively while in the pooled data it was 539.65 kg ha^{-1}. Application of phosphorus was found to have significant effect on the protein yield. It has been observed that P_{80} was significant over $P_{60,}$ P_{40} and $P_{0.}$

The increase in protein content on addition of phosphorus was probably due to increase in amino acid. The improved protein content and yield might be due to higher N uptake as result of increased nodulation and N-fixation by nodules (Majumdar *et al*. 2001). The present findings of the study on protein content and yield are in conformity with the observation of Kausadikar *et al.* (2003) and Sentimenla *et al.* (2012).

4.4.1.3 Interaction effect of liming materials and phosphorus on protein content and protein yield

The interaction effect of liming materials and phosphorus on protein content and yield has been presented in table 4.4.1 (b) and Fig. 11. The result revealed that the interaction between liming materials and phosphorus have significant effect on protein content. The maximum protein content was observed with treatment M_3P_{80} having 39.10 % and 39.17 % with pooled data as 39.14 % whereas, the lowest was observed with M_0P_0 (control) which recorded 30.04 % and 27.19 % and pooled data of 28.61 % during 2018 and 2019, respectively.

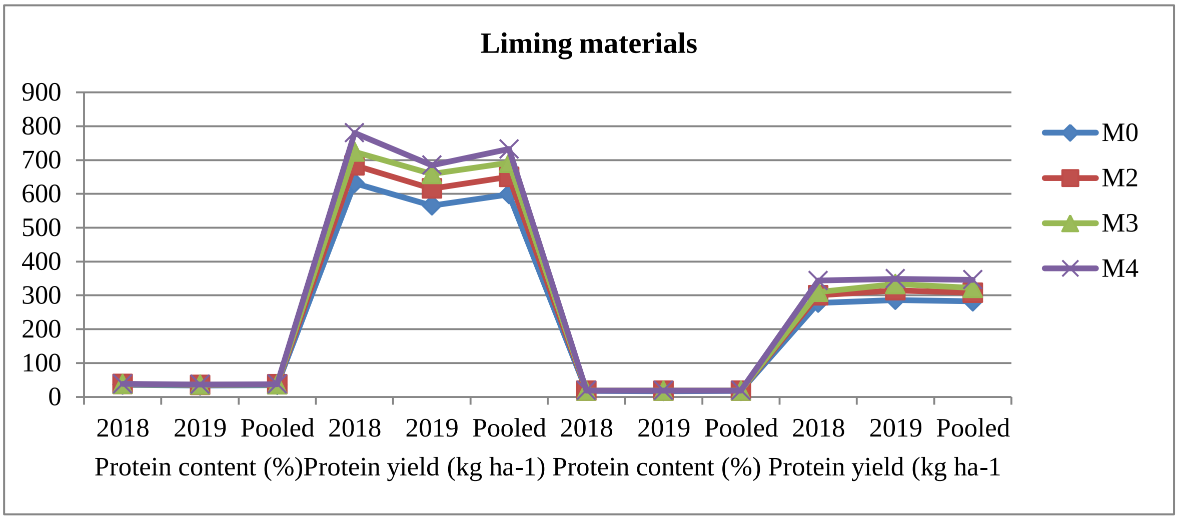
The protein yield was found to be significantly influence by combined application of liming materials with phosphorus. From the results, it was apparent that the maximum protein yield was obtain from treatment M_3P_{80} which recorded 883.97 kg ha^{-1} and 835.57 kg ha^{-1} with pooled data of 859.77 kg ha^{-1} during 2018 and 2019, respectively. The lowest was observed with

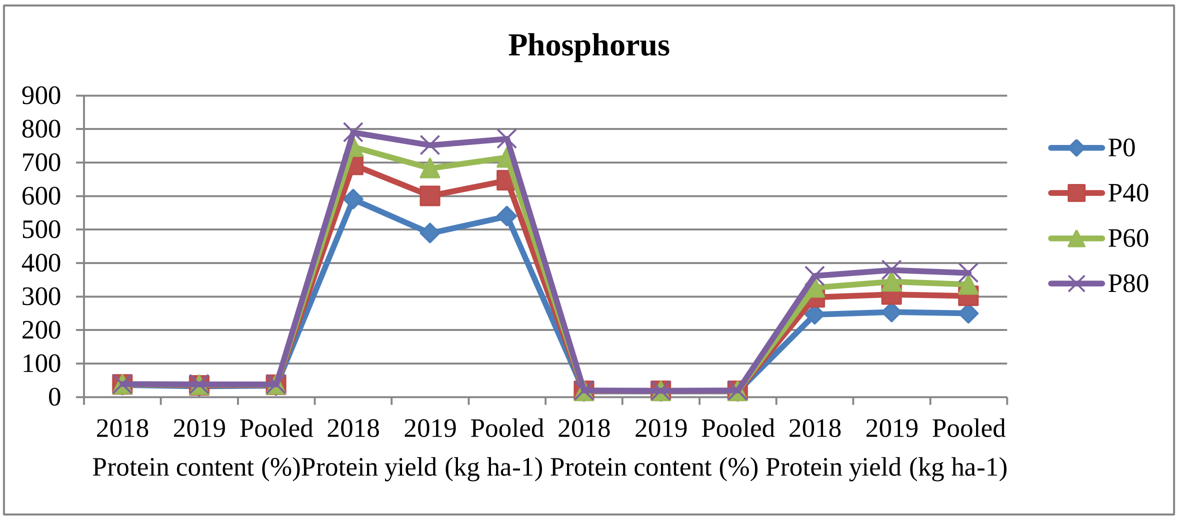
Table 4.4.1 (a) Effect of liming materials and phosphorus levels on protein content and protein yield and oil content and oil yield of soybean

Treatments	Protein content (%)			Protein yield (kg ha^{-1})			Oil content (%)			Oil yield (kg ha^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	35.77	33.52	34.64	631.90	565.67	598.78	17.76	17.05	17.41	278.01	286.49	282.25
M_1	37.74	35.44	36.59	684.17	615.73	649.95	18.50	18.11	18.30	300.17	314.96	307.56
M_2	37.83	35.81	36.82	724.32	658.83	691.57	18.12	18.13	18.12	310.16	333.40	321.78
M_3	38.42	36.61	37.52	779.95	684.58	732.27	18.84	18.67	18.75	343.57	348.88	346.23
Sem±	***0.16***	***0.47***	***0.25***	***11.43***	***11.55***	***8.13***	***0.20***	***0.26***	***0.16***	***6.98***	***6.72***	***4.85***
CD (P=0.05)	***0.55***	***1.62***	***0.76***	***39.56***	***39.97***	***25.04***	***0.68***	***0.90***	***0.50***	***24.17***	***23.26***	***14.94***
P_0	35.49	31.81	33.65	590.12	489.19	539.65	16.83	16.50	16.66	246.18	253.52	249.85
P_{40}	37.71	34.99	36.35	693.27	600.35	646.81	18.16	17.84	18.00	297.42	306.05	301.74
P_{60}	38.08	36.50	37.29	746.99	683.22	715.11	18.65	18.41	18.53	326.75	344.83	335.79
P_{80}	38.48	38.07	38.28	789.97	752.05	771.01	19.59	19.20	19.39	361.55	379.33	370.44
Sem±	***0.13***	***0.42***	***0.22***	***7.07***	***10.01***	***6.13***	***0.22***	***0.13***	***0.13***	***4.20***	***4.47***	***3.07***
CD (P=0.05)	***0.39***	***1.21***	***0.62***	***20.63***	***29.23***	***17.42***	***0.64***	***0.39***	***0.37***	***12.26***	***13.05***	***8.72***

Table 4.4.1 (b) Interaction effect of liming materials and phosphorus levels on protein content and protein yield and oil content and oil yield of soybean

Treatments	Protein content (%)			Protein yield (kg ha^{-1})			Oil content (%)			Oil yield (kg ha^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2018**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	30.04	27.19	28.61	475.05	387.78	431.41	16.41	15.48	15.95	227.88	221.30	224.59
M_0P_{40}	37.38	33.90	35.64	656.33	565.12	610.72	17.46	17.14	17.30	272.00	285.83	278.91
M_0P_{60}	37.56	35.35	36.46	689.90	625.22	657.56	18.11	17.31	17.71	296.11	306.46	301.28
M_0P_{80}	38.10	37.63	37.86	706.33	684.55	695.44	19.06	18.29	18.68	316.04	332.36	324.20
M_1P_0	37.29	32.98	35.14	608.87	516.22	562.54	16.49	16.25	16.37	236.39	254.69	245.54
M_1P_{40}	37.44	34.88	36.16	683.25	600.79	642.02	18.89	18.16	18.52	307.87	312.75	310.31
M_1P_{60}	37.92	36.27	37.09	698.03	639.21	668.62	18.96	18.68	18.82	312.48	329.29	320.88
M_1P_{80}	38.31	37.63	37.97	746.53	706.70	726.62	19.64	19.34	19.49	343.94	363.10	353.52
M_2P_0	37.23	33.13	35.18	621.38	522.68	572.03	17.03	16.89	16.96	251.78	266.69	259.23
M_2P_{40}	37.52	35.63	36.57	695.82	618.22	657.02	17.69	17.83	17.76	291.41	309.36	300.38
M_2P_{60}	38.17	36.63	37.40	757.04	713.02	735.03	18.26	18.68	18.47	322.06	363.53	342.79
M_2P_{80}	38.42	37.88	38.15	823.04	781.37	802.20	19.49	19.10	19.30	375.40	394.04	384.72
M_3P_0	37.40	33.96	35.68	655.19	530.06	592.63	17.37	17.39	17.38	268.66	271.40	270.03
M_3P_{40}	38.50	35.56	37.03	737.66	617.26	677.46	18.60	18.22	18.41	318.42	316.25	317.33
M_3P_{60}	38.69	37.75	38.22	842.98	755.44	799.21	19.26	18.99	19.12	376.37	380.04	378.21
M_3P_{80}	39.10	39.17	39.14	883.97	835.57	859.77	20.15	20.06	20.11	410.84	427.83	419.33
Sem±	***0.27***	***0.83***	***0.44***	***14.14***	***20.03***	***12.26***	***0.44***	***0.27***	***0.26***	***8.40***	***8.94***	***6.13***
CD (p=0.05)	***0.78***	***2.43***	***1.24***	***41.26***	***58.45***	***34.85***	***NS***	***NS***	***NS***	***24.51***	***26.10***	***17.44***





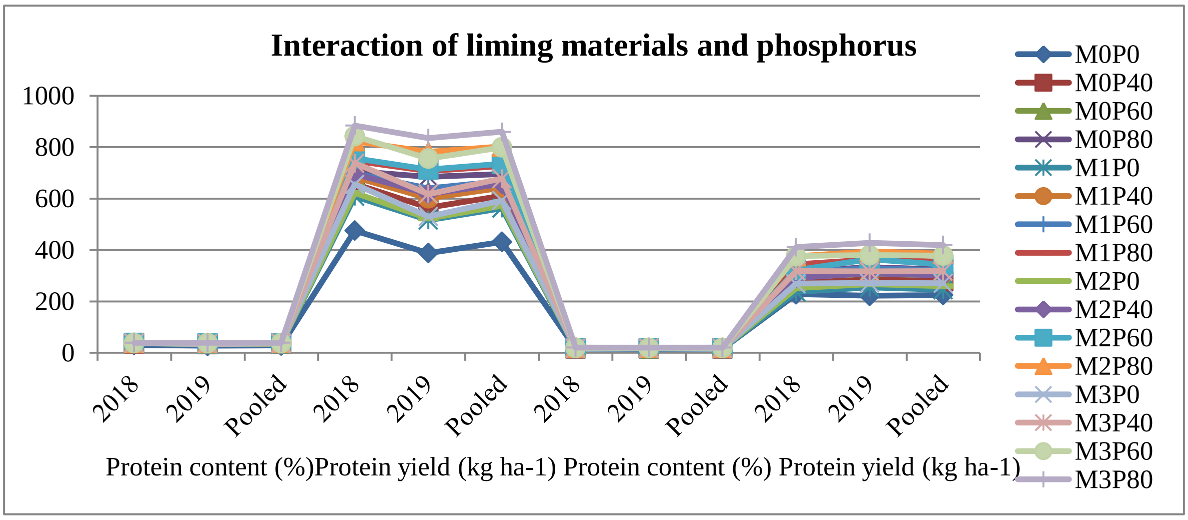


Fig. 11 Effect of liming materials, phosphorus levels and interaction on protein content and protein yield and oil content and oil yield of soybean

M_0P_0 which recorded 475.05 kg ha^{-1} and 387.78 kg ha^{-1} with pooled data of 431.41 kg ha^{-1} during 2018 and 2019, respectively. There was significant difference among the treatment, however, the protein yield obtained with M_3P_{80} was found to be significantly higher.

4.4.2. Effect on oil content and oil yield

4.4.2.1 Effect of liming materials on oil content and oil yield

Table 4.4.1 (a) and Fig. 11 presented the effect of liming materials on oil content and oil yield. From the results obtained, it was apparent that liming materials had significant influence on oil content. M_3 recorded higher oil content which recorded 18.84 % and 18.67 % as compared with M_2 (18.12 % and 18.13 %), M_1 (18.50 % and 18.11 %) and M_0 (17.76 % and 17.05 %) during 2018 and 2019, respectively. In the pooled data, M_3 had an average protein content of 18.75 % while $M_{2,}$ M_1 and M_0 had 18.12 %, 18.30 % and 17.41 % respectively.

The results indicated that CS @ 0.4 LR (M_3) recorded significantly higher protein yield which recorded 343.57 kg ha^{-1} and 348.88 kg ha^{-1} as compared to PMS @ 0.4 LR (M_2), WA @ LR (M_1) and no liming materials (M_0) which recorded 310.16 kg ha^{-1} and 333.40 kg ha^{-1}, 300.17 kg ha^{-1} and 314.96 kg ha^{-1} and 278.01 kg ha^{-1} and 286.49 kg ha^{-1} during 2018 and 2019, respectively. In the pooled data, M_3 recorded an average protein yield of 346.23 kg ha^{-1} while M_2, M_2 and M_0 were 321.78 kg ha^{-1}, 307.56 kg ha^{-1} and 282.25 kg ha^{-1} respectively. The significant increased in the oil yield could be due to increased in the seed yield with liming materials application.

The increased oil yield could be attributed to the fact that liming increased the seed yield and that the oil yield is directly related with seed yield. Similar result on oil yield with liming has been reported by Ghosh *et al*. (2006).

4.4.2.2. Effect of phosphorus on oil content and oil yield

The effect of phosphorus on oil content and yield has been presented table 4.4.1 (a) and Fig. 11. It has been observed that increasing doses of phosphorus application increased the oil content in significantly. It was evident that with increased level of phosphorus application up to 80 kg P_2O_5 ha^1 increased the oil content. The maximum oil content was observed with P_{80} (80 kg P_2O_5 ha^1) which recorded 19.59 % and 19.20 % during 2018 and 2019 respectively while in the pooled it had 19.39 %. The lowest oil content was observed with P_0 (0 kg P_2O_5 ha^1) which recorded 16.83 % and 16.50 % during 2018 and 2019 respectively while in the pooled data it was 16.66 %.

The maximum oil yield was observed with P_{80} which recorded 361.55 kg ha^{-1} and 379.33 kg ha^{-1} with pooled data as 370.44 kg ha^{-1} during the both year 2018 and 2019, respectively. The lowest oil yield was observed with P_0 which recorded 246.18 kg ha^{-1} and 253.52 kg ha^{-1} during 2018 and 2019 respectively while in the pooled data it was 249.85 kg ha^{-1}. Application of phosphorus was found to have significant effect on the oil yield. It has been observed that P_{80} was significant over $P_{60,}$ P_{40} and $P_{0.}$

The improved oil content and yield might be due to the fact that phosphorus helped in the synthesis of fatty acids and their esterification by accelerating bio-chemical reaction in glyoxalate cycle (Dwivedi and Bapat, 1998). The present findings of the study on oil content and yield are in conformity with the observation of Majumdar *et al*. (2001).

4.4.2.3 Interaction effect of liming materials phosphorus on oil content and oil yield

The interaction effect of liming materials and phosphorus on oil content and yield has been presented in table 4.4.1 (b) and Fig. 11. The result revealed that the interaction between liming materials and phosphorus have no significant effect on oil content. The maximum oil content was observed with treatment M_3P_{80} having 20.15 % and 20.06 % with pooled data as 19.12 % whereas, the lowest was observed with M_0P_0 (control) which recorded 16.41 % and 15.48 % and pooled data of 15.95 % during 2018 and 2019, respectively. The oil yield was found to be significantly influence by combined application of liming materials phosphorus. From the results, it was apparent that the maximum protein yield was obtain from treatment M_3P_{80} which recorded 410.84 kg ha^{-1} and 427.83 kg ha^{-1} with pooled data of 419.33 kg ha^{-1} during 2018 and 2019, respectively. The lowest was observed with M_0P_0 which recorded 227.88 kg ha^{-1} and 221.30 kg ha^{-1} with pooled data of 224.59 kg ha^{-1} during 2018 and 2019, respectively. There was significant difference among the treatment, however, the oil yield obtained with M_3P_{80} was found to be significantly higher.

4.5. Effect on nutrients content and uptake

The effect of liming materials, phosphorus and their interaction on the nutrient content and uptake in seed and stover are discussed below under the following headings:

4.5.1. Effect on N, P, K, S, Ca and Mg content in seed

4.5.1.1. Effect of liming material on N, P, K, S, Ca and Mg content in seed

The effect of liming materials on N, P, K, S, Ca and Mg content in seed has been shown in table 4.5.1 (a) and Fig. 12 and table 4.5.2 (a) and Fig. 13. The result revealed that liming materials significantly influence the N, P, K, S, Ca and Mg content in seed. Among the liming materials, higher N, P, K, S, Ca and Mg content in seed was observed when M_3 was applied which recorded corresponding N, P, K, S, Ca and Mg content of 6.15 % and 5.86 %, 0.41% and 0.47 %, 1.44 % and 1.49 %, 0.23 % and 0.24 %, 0.27% and 0.26% and 0.35 % and 0.34 % during the year 2018 and 2019, respectively with the pooled value

Table 4.5.1 (a) Effect of liming materials and phosphorus levels on N, P and K content in seed of soybean

Treatments	**N (%)**			**P (%)**			**K (%)**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	5.72	5.36	5.54	0.33	0.39	0.36	1.29	1.32	1.30
M_1	6.04	5.67	5.85	0.39	0.46	0.43	1.37	1.41	1.39
M_2	6.05	5.73	5.89	0.37	0.43	0.40	1.39	1.47	1.43
M_3	6.15	5.86	6.00	0.41	0.47	0.44	1.44	1.49	1.46
SEm±	***0.03***	***0.08***	***0.04***	***0.004***	***0.005***	***0.003***	***0.005***	***0.029***	***0.015***
CD (P=0.05)	***0.09***	***0.26***	***0.12***	***0.012***	***0.017***	***0.010***	***0.019***	***0.099***	***0.045***
P_0	5.68	5.09	5.38	0.25	0.29	0.27	1.20	1.13	1.16
P_{40}	6.03	5.60	5.82	0.39	0.46	0.42	1.31	1.36	1.33
P_{60}	6.09	5.84	5.97	0.42	0.48	0.45	1.46	1.54	1.50
P_{80}	6.16	6.09	6.12	0.45	0.51	0.48	1.53	1.65	1.59
SEm±	***0.02***	***0.07***	***0.03***	***0.003***	***0.003***	***0.002***	***0.015***	***0.026***	***0.015***
CD (P=0.05)	***0.06***	***0.19***	***0.10***	***0.008***	***0.008***	***0.006***	***0.043***	***0.075***	***0.042***

Table 4.5.2 (a) Effect of liming materials and phosphorus levels on S, Ca and Mg content in seed of soybean

Treatments	**S (%)**			**Ca (%)**			**Mg (%)**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	0.21	0.22	0.21	0.23	0.21	0.22	0.32	0.31	0.31
M_1	0.23	0.24	0.23	0.25	0.23	0.24	0.36	0.33	0.35
M_2	0.22	0.23	0.22	0.24	0.23	0.24	0.34	0.32	0.33
M_3	0.23	0.24	0.23	0.27	0.26	0.27	0.35	0.34	0.34
SEm±	***0.005***	***0.005***	***0.003***	***0.005***	***0.008***	***0.005***	***0.005***	***0.006***	***0.004***
CD (P=0.05)	***0.017***	***0.017***	***0.011***	***0.017***	***0.028***	***0.014***	***0.019***	***0.020***	***0.012***
P_0	0.19	0.19	0.19	0.22	0.20	0.21	0.29	0.27	0.28
P_{40}	0.22	0.22	0.22	0.24	0.23	0.23	0.35	0.32	0.33
P_{60}	0.23	0.24	0.24	0.25	0.24	0.25	0.36	0.34	0.35
P_{80}	0.25	0.26	0.25	0.27	0.27	0.27	0.37	0.37	0.37
SEm±	***0.005***	***0.005***	***0.003***	***0.004***	***0.003***	***0.003***	***0.007***	***0.006***	***0.005***
CD (P=0.05)	**NS**	**NS**	**NS**	***0.012***	***0.009***	***0.008***	***0.019***	***0.019***	***0.013***

of 6.00 %, 0.44 %, 1.46 %, 0.23 %, 0.27 % and 0.34 %, respectively. The lower N, P, K, S, Ca and Mg content in seed was observed in no liming material (M_0) which recorded corresponding value of 5.72 % and 5.36 %, 0.33 % and 0.39 %, 1.29 % and 1.32 %, 0.21 % and 0.22 %, 0.23 % and 0.21 % and 0.32 % and 0.31 % during year 2018 and 2019, respectively with pooled value of 5.54 %, 0.36 %, 1.30 %, 0.21%, 0.22 % and 0.31%.

Lynrah and Nongmaithem (2017) found the similar results that application of lime @ 1.5 t ha^{-1} gave highest values of growth and yield attributes. The N, P and K content in seed of soybean was also found to be highest under application of lime @ 1.5 t ha^{-1}.

4.5.1.2. Effect of phosphorus on N, P, K S, Ca and Mg content in seed

The effect of phosphorus on N, P, K, S, Ca and Mg content in seed has been presented in table 4.5.1 (a) and Fig. 12 and table 4.5.2 (a) and Fig. 13. The results revealed that successive increased in the levels of phosphorus application had a significant effect on the N, P, K, Ca and Mg content in seed. S content in seed of soybean had non significant effect on phosphorus application. The highest N, P, K, S, Ca and Mg content was observed when P_{80} was applied which recorded 6.16 % and 6.09 %, 0.45 % and 0.51 % 1.53 % and 1.65 %, 0.25 % and 0.26 %, 0.27 % and 0.27 % and 0.37 % and 0.37 % during year 2018 and 2019, respectively whereas, the lowest N, P, K, S, Ca and Mg content was observed with P_0 during 2018 and 2019 which recorded 5.68 % and 5.09 %, 0.25 % and 0.29 %, 1.20 % and 1.13 %, 0.19 % and 0.19 %, 0.22 % and 0.20 % and 0.29 % and 0.27 %. In the pooled mean data revealed that P_{80} recorded the highest N, P, K, S, Ca and Mg content of 6.12 %, 0.48 %, 1.59 %, 0.25 %, 0.27 % and 0.37 % while the lowest with P_0 of 5.38 %, 0.27 %, 1.16 % , 0.19 %, 0.21 % and 0.28 % during the year 2018 and 2019, respectively.

Phosphorus deficiency is a major constraint under acidic soil due to

Table 4.5.1 (b) Interaction effect of liming materials and phosphorus levels on N, P and K content in seed of soybean

Treatments	N (%)			P (%)			K (%)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	4.81	4.35	4.58	0.22	0.21	0.21	1.16	1.03	1.10
M_0P_{40}	5.98	5.42	5.70	0.31	0.43	0.37	1.19	1.25	1.22
M_0P_{60}	6.01	5.66	5.83	0.39	0.45	0.42	1.38	1.43	1.40
M_0P_{80}	6.10	6.02	6.06	0.41	0.47	0.44	1.42	1.57	1.50
M_1P_0	5.97	5.28	5.62	0.26	0.32	0.29	1.18	1.14	1.16
M_1P_{40}	5.99	5.58	5.79	0.41	0.47	0.44	1.27	1.36	1.32
M_1P_{60}	6.07	5.80	5.94	0.44	0.50	0.47	1.51	1.52	1.51
M_1P_{80}	6.13	6.02	6.08	0.47	0.53	0.50	1.53	1.61	1.57
M_2P_0	5.96	5.30	5.63	0.24	0.30	0.27	1.20	1.22	1.21
M_2P_{40}	6.00	5.70	5.85	0.39	0.45	0.42	1.38	1.40	1.39
M_2P_{60}	6.11	5.86	5.98	0.42	0.48	0.45	1.41	1.57	1.49
M_2P_{80}	6.15	6.06	6.10	0.44	0.50	0.47	1.58	1.68	1.63
M_3P_0	5.98	5.43	5.71	0.28	0.34	0.31	1.24	1.13	1.19
M_3P_{40}	6.16	5.69	5.93	0.43	0.49	0.46	1.40	1.42	1.41
M_3P_{60}	6.19	6.04	6.12	0.45	0.51	0.48	1.54	1.64	1.59
M_3P_{80}	6.26	6.27	6.26	0.47	0.54	0.50	1.57	1.76	1.67
SEm±	***0.04***	***0.13***	***0.07***	***0.005***	***0.006***	***0.004***	***0.030***	***0.051***	***0.030***
CD (P=0.05)	***0.12***	***0.39***	***0.20***	***0.016***	***0.017***	***0.011***	**NS**	**NS**	**NS**

Table 4.5.2 (b) Interaction effect of liming materials and phosphorus levels on S, Ca and Mg content in seed of soybean

Treatments	S (%)			Ca (%)			Mg (%)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	0.17	0.18	0.18	0.19	0.17	0.18	0.28	0.25	0.27
M_0P_{40}	0.20	0.21	0.21	0.22	0.20	0.21	0.31	0.29	0.30
M_0P_{60}	0.22	0.23	0.23	0.24	0.23	0.24	0.34	0.33	0.33
M_0P_{80}	0.24	0.24	0.24	0.25	0.25	0.25	0.36	0.36	0.36
M_1P_0	0.19	0.20	0.20	0.23	0.18	0.21	0.30	0.26	0.28
M_1P_{40}	0.23	0.24	0.23	0.25	0.23	0.24	0.38	0.35	0.37
M_1P_{60}	0.24	0.25	0.24	0.25	0.25	0.25	0.38	0.36	0.37
M_1P_{80}	0.26	0.26	0.26	0.26	0.27	0.27	0.39	0.37	0.38
M_2P_0	0.18	0.19	0.18	0.23	0.20	0.22	0.28	0.27	0.28
M_2P_{40}	0.21	0.22	0.21	0.23	0.23	0.23	0.34	0.32	0.33
M_2P_{60}	0.24	0.25	0.24	0.25	0.24	0.25	0.37	0.33	0.35
M_2P_{80}	0.25	0.25	0.25	0.25	0.25	0.25	0.37	0.37	0.37
M_3P_0	0.20	0.21	0.21	0.24	0.23	0.23	0.31	0.29	0.30
M_3P_{40}	0.22	0.23	0.22	0.26	0.25	0.25	0.35	0.30	0.33
M_3P_{60}	0.23	0.24	0.23	0.27	0.26	0.26	0.37	0.35	0.36
M_3P_{80}	0.26	0.27	0.27	0.32	0.31	0.32	0.38	0.40	0.39
SEm±	***0.010***	***0.010***	***0.007***	***0.008***	***0.006***	***0.005***	***0.013***	***0.013***	***0.009***
CD (P=0.05)	***NS***	***NS***	***NS***	***0.025***	***0.018***	***0.015***	***NS***	***NS***	***NS***

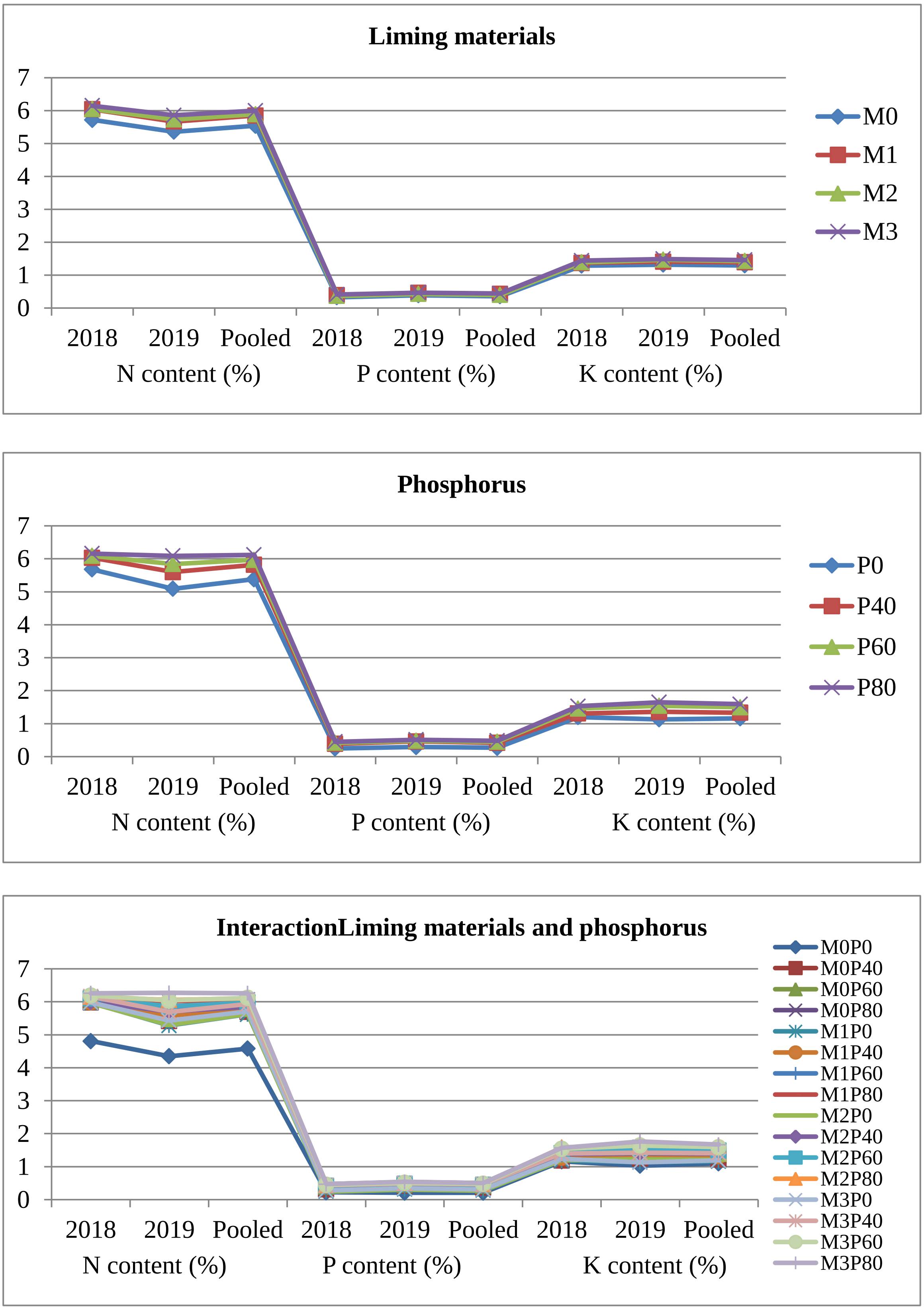


Fig. 12 Effect of liming materials, phosphorus levels and interaction on N, P and K content in seed of soybean

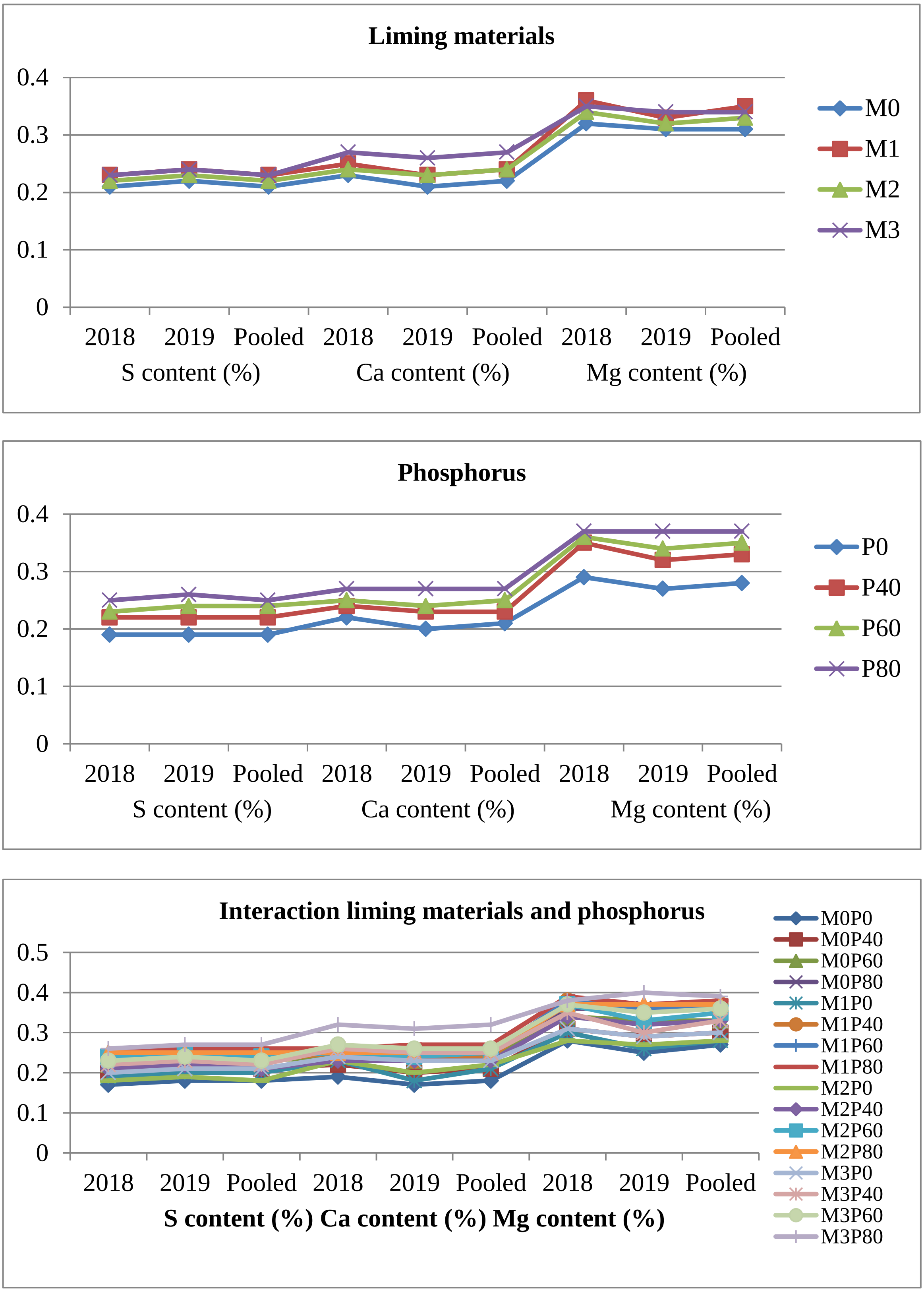


Fig.13 Effect of liming materials, phosphorus levels and interaction on S, Ca and Mg content in seed of soybean

phosphate fixation. As such application of phosphorus might have solubilises the insoluble phosphate present in the soil which increases its availability to the plants. Improve root growth and activity with enhance phosphorus availability facilitates higher uptake of nutrients from the soil and the translocation of the nutrients into different parts of the plant could have contributed to the significant increase in the N, P, K S, Ca and Mg content in soybean seeds. The results are conformity with the finding of Majumdar *et al*. (2001) who reported that the nutrient N, P and K content in soybean seeds was significantly increased with phosphorus fertilization. Naidu and Pillai (1991) reported that N, P, K S, Ca and Mg content in seed increased significantly with increasing P level upto 100 kg P_2O_5 ha^{-1}.

4.5.1.3. Interaction effect of liming material and phosphorus on N, P, K, S , Ca and Mg content in seed

The results on the interaction effect of liming material and phosphorus on N, P and K content in seed has been presented in table 4.5.1 (b) and Fig. 12 and table 4.5.2 (b) and Fig. 13. It was evident from the results obtained that the interaction between liming material and phosphorus was significant effect on N, P and Ca content in seed whereas their combined effect was not significant on K, S and Mg content in seed. The results revealed that application of treatment M_3P_{80} obtained the highest N, P, Ca content in seeds with 6.26% and 6.27 %, 0.47 % and 0.54 % and 0.32 % and 0.31 % with the pooled value of 6.26 %, 0.50 % and 0.32 % during the year 2018 and 2019, respectively. The lowest N, P, Ca content in seeds was observed in the control treatment M_0P_0 with 4.81 % and 4.35 %, 0.22 % and 0.21 % and 0.19 % and 0.17 % with the pooled value 4.58 %, 0.21 % and 0.18 % in both the year 2018 and 2019, respectively. The K, S and Mg in seeds were highest where treatment M_3P_{80} was applied which recorded 1.57 % and 1.76 % 0.26 % and 0.27 % and 0.38 % and 0.40 % during 2018 and 2019, respectively. In the pooled data, treatment

M_3P_{80} obtained the highest K, S and Mg in seeds with an average value of 1.67, 0.27 and 0.39 respectively. The lowest K, S and Mg in seeds was obtained from control treatment M_0P_0 which was 1.16 % and 1.03 %, 0.17 % and 0.18 % and 0.28 % and 0.25 % during year 2018 and 2019, respectively while in the pooled mean data with an average value of 1.10 %, 0.18 % and 0.27 %, respectively.

Fageria *et al.* (1995) reported increasing levels of applied P significantly increased nutrient uptake. Decrease in K uptake, due to high lime, is probably due to antagonistic effects of Ca and Mg.

4.5.2. Effect on N, P, K, S, Ca and Mg content in stover

4.5.2.1. Effect of liming materials on N, P, K, S, Ca and Mg content in stover

Table 4.5.3 (a) and Fig. 14 and table 4.5.4 (a) and Fig. 15 presented the effect of liming materials N, P, K, S, Ca and Mg content in stover. From the result obtained, it become evident that application liming material had a significant influence on N, P, K, Ca and Mg content in stover whereas S content in seed found non significant with application liming materials. The highest N, P, K, S, Ca and Mg content in stover was observed with M_3 (CS @ 0.4 LR) which recorded 2.33 % and 2.23 %, 0.18 % and 0.18 %, 2.22 % and 2.36 %, 0.17 % and 0.19 %, 0.70 % and 0.66 % and 0.22 % and 0.21 % while the lowest was observed M_0 (no liming material) which recorded 2.11% and 1.85 %, 0.13 % and 0.13 %, 2.10 % and 2.17 %, 0.15 % and 0.14 %, 0.64 % and 0.57 % and 0.17 % and 0.15 % with during 2018 and 2019, respectively. In the pooled data, M_3 was observed the highest an average value of 2.28 %, 0.18 %, 2.29 %, 0.18 %, 0.68 % and 0.21 % while the lowest with M_0 recorded 1.98 %, 0.13 %, 2.14 %, 0.14 %, 0.60 % and 0.16 %.

The significant increased N content in stover could be attributed to the

Table 4.5.3 (a) Effect of liming materials and phosphorus levels on N, P and K content in stover of soybean

Treatments	N (%)			P (%)			K (%)		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0	2.11	1.85	1.98	0.13	0.13	0.13	2.10	2.17	2.14
M_1	2.30	2.07	2.19	0.17	0.17	0.17	2.22	2.33	2.28
M_2	2.24	2.20	2.22	0.14	0.14	0.14	2.21	2.29	2.25
M_3	2.33	2.23	2.28	0.18	0.18	0.18	2.22	2.36	2.29
SEm±	***0.04***	***0.02***	***0.02***	***0.003***	***0.003***	***0.002***	***0.03***	***0.02***	***0.02***
CD (P=0.05)	***0.14***	***0.08***	***0.07***	***0.010***	***0.010***	***0.006***	***0.09***	***0.07***	***0.05***
P_0	1.93	1.78	1.86	0.10	0.10	0.10	2.06	2.13	2.09
P_{40}	2.16	1.89	2.02	0.16	0.16	0.16	2.18	2.24	2.21
P_{60}	2.39	2.25	2.32	0.17	0.17	0.17	2.22	2.36	2.29
P_{80}	2.48	2.44	2.46	0.19	0.19	0.19	2.31	2.43	2.37
SEm±	***0.03***	***0.03***	***0.02***	***0.001***	***0.001***	***0.001***	***0.02***	***0.02***	***0.01***
CD (P=0.05)	***0.09***	***0.07***	***0.06***	***0.004***	***0.004***	***0.003***	***0.05***	***0.05***	***0.04***

Table 4.5.4 (a) Effect of liming materials and phosphorus levels on S, Ca and Mg content in stover of soybean

Treatments	S (%)			Ca (%)			Mg (%)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	0.15	0.14	0.14	0.64	0.57	0.60	0.17	0.15	0.16
M_1	0.15	0.14	0.15	0.65	0.59	0.62	0.19	0.16	0.18
M_2	0.17	0.16	0.16	0.66	0.61	0.64	0.20	0.18	0.19
M_3	0.17	0.19	0.18	0.70	0.66	0.68	0.22	0.21	0.21
SEm±	***0.004***	***0.003***	***0.003***	***0.006***	***0.006***	***0.004***	***0.005***	***0.005***	***0.003***
CD (P=0.05)	**NS**	**NS**	**NS**	***0.021***	***0.021***	***0.013***	***0.016***	***0.016***	***0.010***
P_0	0.14	0.13	0.14	0.62	0.57	0.59	0.17	0.15	0.16
P_{40}	0.15	0.15	0.15	0.64	0.59	0.61	0.19	0.17	0.18
P_{60}	0.16	0.16	0.16	0.68	0.62	0.65	0.20	0.18	0.19
P_{80}	0.18	0.18	0.18	0.70	0.65	0.67	0.22	0.20	0.21
SEm±	***0.002***	***0.005***	***0.003***	***0.006***	***0.006***	***0.005***	***0.005***	***0.005***	***0.004***
CD (P=0.05)	***0.007***	***0.015***	***0.008***	***0.019***	***0.019***	***0.013***	***0.015***	***0.015***	***0.010***

favourable effect of liming application on root nodulation and improved N_2 fixation thereby increasing the N content in the stover (Uzoho, 2010).The results are in agreement with the findings of Majumdar *et al.*, (2007) who also observed lime application contributes to significant increase in N, P, K, Ca and Mg content in plant.

4.5.2.2. Effect of phosphorus on N, P, K, S, Ca and Mg content in stover

The effect of phosphorus on N, P, K, S, Ca and Mg content in stover has been shown in table 4.5.3 (a) and Fig.14 and 4.5.4 (a) and Fig. 15. The results revealed that phosphorus application significantly influence the N, P, K, S, Ca and Mg content in stover. Higher N content in stover was observed when P_{80} was applied which recorded N content of 2.48 % and 2.44 % in 2018 and 2019 respectively with a pooled value 2.46 % while P_0 recorded lower N content in stover with 1.93 % and 1.78 % during 2018 and 2019 respectively with pooled value of 1.86 %. The P content was observed to be higher when P_{80} was applied which recorded 0.19 % in both years and in pooled while P_0 recorded lower P content of 0.10 % in both years and in pooled data. The K content in stover with treatment P_{80} recorded 2.31 % and 2.43 % during 2018 and 2019 respectively while P_0 recorded lower K content in stover of 2.06 % and 2.13 % during 2018 and 2019, respectively. In the pooled data, maximum and lowest K content in stover was recorded with P_{80} (2.37 %) and P_0 (2.21 %), respectively. Higher S content was observed with P_{80} which recorded 0.18 % both in 2018 and 2019 and in pooled while P_0 recorded lower S content in stover with 0.14 % and 0.13 % during 2018 and 2019 respectively with pooled value of 0.14 %. The Ca content in stover was found to increase when application of phosphorus (P_{80}) which recorded 0.70 % and 0.65 during 2018 and 2019 respectively with pooled value 0.67. The Ca content in stover was found to be lower in P_0 which recorded 0.62 % and 0.57 % with a pooled value of 0.59 % during 2018 and 2019 respectively. The Mg content was observed to be higher when P_{80} was

Table 4.5.3 (b) Interaction effect of liming materials and phosphorus levels on N, P and K content in Stover of soybean

Treatments	**N (%)**			**P (%)**			**K (%)**		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0P_0	1.85	1.71	1.78	0.07	0.07	0.07	2.00	2.03	2.02
M_0P_{40}	2.15	1.70	1.92	0.13	0.13	0.13	2.08	2.09	2.09
M_0P_{60}	2.21	1.89	2.05	0.14	0.14	0.14	2.12	2.24	2.18
M_0P_{80}	2.22	2.10	2.16	0.15	0.15	0.15	2.21	2.32	2.26
M_1P_0	1.92	1.72	1.82	0.11	0.11	0.11	2.06	2.13	2.09
M_1P_{40}	2.14	1.84	1.99	0.17	0.17	0.17	2.26	2.33	2.30
M_1P_{60}	2.50	2.21	2.36	0.19	0.19	0.19	2.29	2.39	2.34
M_1P_{80}	2.62	2.52	2.57	0.21	0.21	0.21	2.28	2.48	2.38
M_2P_0	1.99	1.91	1.95	0.09	0.09	0.09	2.04	2.17	2.11
M_2P_{40}	2.20	1.97	2.09	0.15	0.15	0.15	2.19	2.22	2.21
M_2P_{60}	2.31	2.39	2.35	0.16	0.16	0.16	2.24	2.35	2.30
M_2P_{80}	2.44	2.54	2.49	0.17	0.17	0.17	2.38	2.40	2.39
M_3P_0	1.96	1.79	1.88	0.12	0.12	0.12	2.13	2.17	2.15
M_3P_{40}	2.16	2.03	2.10	0.18	0.18	0.18	2.18	2.32	2.25
M_3P_{60}	2.55	2.49	2.52	0.20	0.20	0.20	2.22	2.43	2.33
M_3P_{80}	2.63	2.62	2.62	0.21	0.21	0.21	2.37	2.51	2.44
SEm±	***0.06***	***0.05***	***0.04***	***0.003***	***0.003***	***0.002***	***0.04***	***0.03***	***0.03***
CD (P=0.05)	***0.18***	***0.15***	***0.11***	***0.009***	***0.009***	***0.006***	***NS***	***NS***	***NS***

Table 4.5.4 (b) Interaction effect of liming materials and phosphorus levels on S, Ca and Mg content in Stover of soybean

Treatments	S (%)			Ca (%)			Mg (%)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	0.13	0.12	0.12	0.60	0.53	0.56	0.15	0.13	0.14
M_0P_{40}	0.14	0.14	0.14	0.62	0.55	0.59	0.17	0.15	0.16
M_0P_{60}	0.15	0.14	0.15	0.65	0.58	0.62	0.18	0.16	0.17
M_0P_{80}	0.18	0.16	0.17	0.67	0.60	0.64	0.20	0.18	0.19
M_1P_0	0.14	0.13	0.14	0.61	0.55	0.58	0.17	0.14	0.15
M_1P_{40}	0.14	0.14	0.14	0.64	0.58	0.61	0.19	0.16	0.18
M_1P_{60}	0.16	0.14	0.15	0.66	0.60	0.63	0.20	0.17	0.19
M_1P_{80}	0.17	0.16	0.17	0.68	0.62	0.65	0.21	0.18	0.20
M_2P_0	0.14	0.14	0.14	0.62	0.57	0.60	0.17	0.15	0.16
M_2P_{40}	0.16	0.15	0.16	0.64	0.59	0.62	0.20	0.18	0.19
M_2P_{60}	0.17	0.17	0.17	0.67	0.62	0.64	0.21	0.19	0.20
M_2P_{80}	0.19	0.18	0.19	0.72	0.67	0.69	0.22	0.20	0.21
M_3P_0	0.14	0.15	0.14	0.65	0.61	0.63	0.19	0.18	0.19
M_3P_{40}	0.17	0.19	0.18	0.66	0.62	0.64	0.21	0.20	0.20
M_3P_{60}	0.17	0.19	0.18	0.73	0.69	0.71	0.22	0.21	0.22
M_3P_{80}	0.18	0.22	0.20	0.74	0.70	0.72	0.24	0.23	0.24
SEm±	***0.005***	***0.010***	***0.006***	***0.013***	***0.013***	***0.009***	***0.010***	***0.010***	***0.007***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

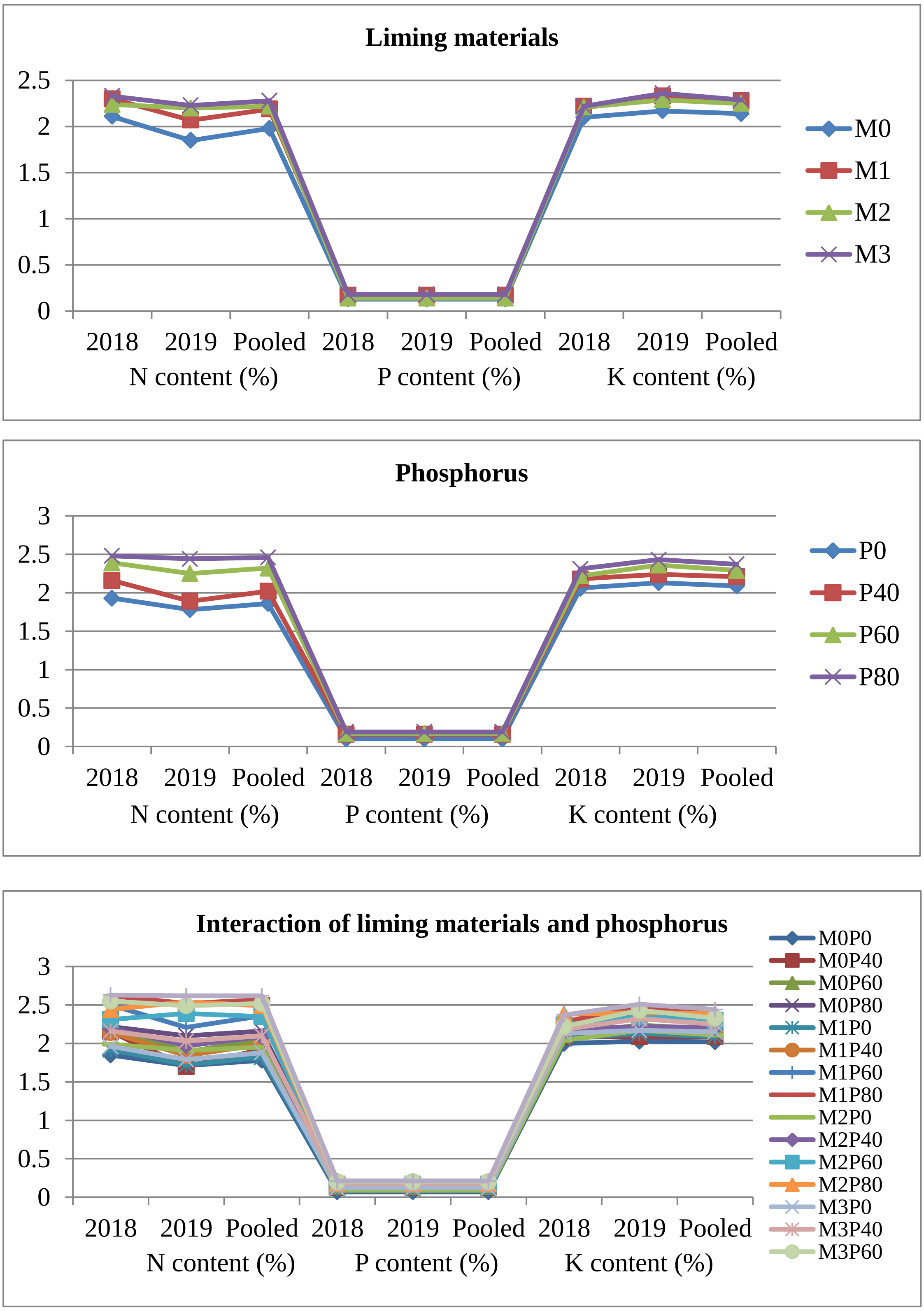
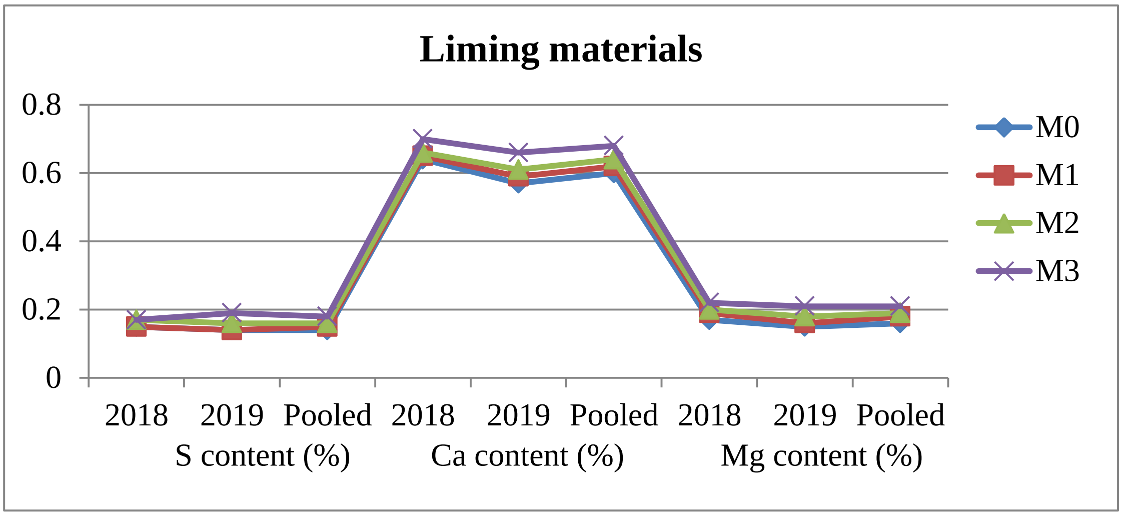
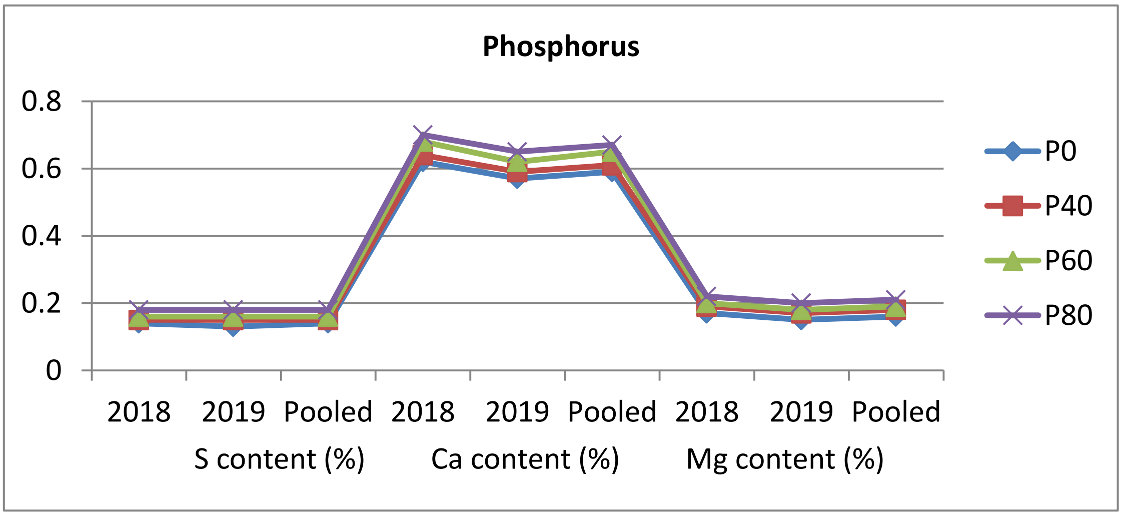


Fig. 14 Effect of liming materials, phosphorus levels and interaction on N, P and K content in stover of soybean





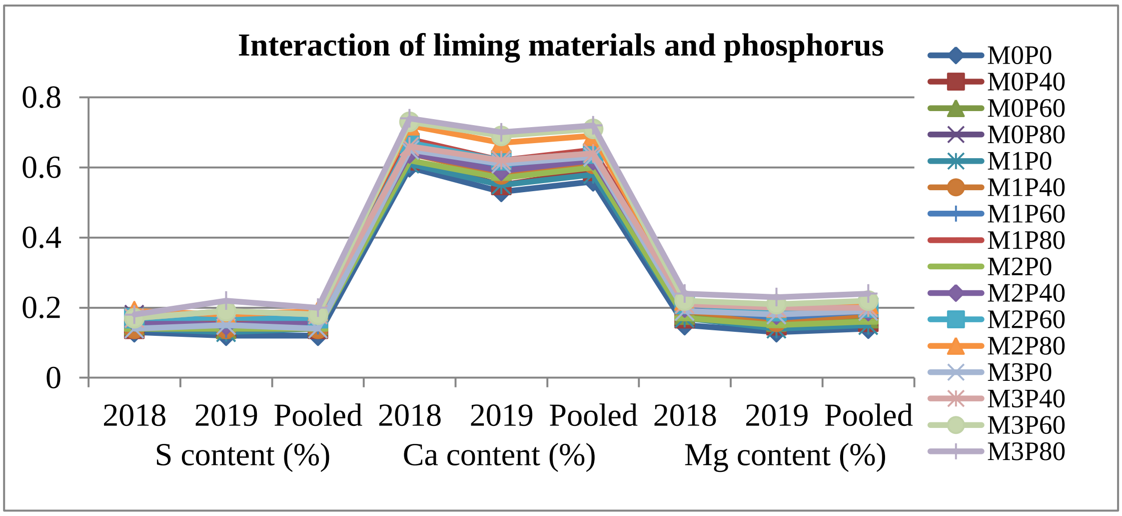


Fig. 15 Effect of liming materials, phosphorus levels and interaction on S, Ca and Mg content in stover of soybean

applied which recorded 0.22 % and 0.20 % in both years 2018 and 2019 respectively with pooled value of 0.21 while P_0 recorded lower P content of 0.17 % and 0.15 % in both years 2018 and 2019 respectively with pooled data value 0.16.

Phosphorus deficiency is a major constraint under acidic soil conditiondue to phosphate fixation. As such application of phosphorus might have increased phosphorus present in soil which increases its availability to the plants. Improved root growth and activity with enhanced phosphorus availability facilitates higher uptakes of nutrients from the soil which could have contributed to the significant increase in the N, P, K, S, Ca and Mg content in the stover. Sahoo and Panda (2001) observed higher uptake nutrients by soybean at high levels of P application.

4.5.2.3. Interaction effect of liming materials and phosphorus on N, P, K, S, Ca and Mg content in stover

The results on the interaction effect of liming materials and phosphorus on N, P, K, S, Ca and Mg content in stover has been presented in table 4.5.3 (b) and Fig.14 and table 4.5.4 (b) and Fig. 15. It was observed the interaction between liming materials and phosphorus had significant effect on N and P content in stover whereas it did not have any significant effect on K, S, Ca and Mg content in stover. The highest N content 2.63 % and 2.62 % in stover was observed with M_3P_{80} during 2018 and 2019, respectively with pooled data value of 2.62 % while M_0P_0 recorded the lowest N content of 1.85 % and 1.71 % with a pooled of 1.78 % during 2018 and 2019, respectively. The P content in stover was highest with treatment M_3P_{80} which recorded 0.21 % while M_0P_0 recorded the lowest N content of 0.07 % both years and in pooled. The highest K content in stover was observed with treatment M_2P_{80} and M_3P_{80} with value 2.38 % and 2.37 % during the year 2018 and 2019, respectively. In the pooled data treatment M_3P_{80} recorded the highest K content of 2.44 %. The lowest K content was observed in treatment M_0P_0 with the value 2.00 % and 2.03 % during 2018 and 2019, respectively. The highest S content in stover was obtained with M_3P_{80} which recorded 0.18 % and 0.22% with pooled of 0.20 % during 2018 and 2019, respectively. The lowest S content was observed in treatment M_0P_0 with the value 0.13 % and 0.12 % during 2018 and 2019, respectively with pooled data value of 0.12 %. The highest Ca content 0.74 % and 0.70 % in stover was observed with M_3P_{80} during 2018 and 2019, respectively with pooled data value of 0.72 % while M_0P_0 recorded the lowest Ca content of 0.60 % and 0.53 % with a pooled of 0.56 % during 2018 and 2019, respectively. The highest Mg content in stover was obtained with M_3P_{80} which recorded 0.24 % and 0.23 % with pooled of 0.24 % during 2018 and 2019, respectively. The lowest Mg content was observed in treatment M_0P_0 with the value 0.15 % and 0.13 % during 2018 and 2019, respectively with pooled data value of 0.14 %.

4.5.3. Effect on N, P, K, S, Ca and Mg uptake by seed

4.5.3.1. Effect of liming materials on N, P, K, S, Ca and Mg uptake by seed

Table 4.5.5 (a) and Fig. 16 and table 4.5.6 (a) and Fig. 17 presented the results on the effects of liming materials on N, P, K, S, Ca and Mg uptake by seeds. It has been observed that application of liming materials had a significant effect on uptake of N, P, K, S, Ca and Mg by seeds. Among the liming materials, the maximum uptake of N, P, K, S, Ca and Mg by seeds was observed with M_3 (CS @ 0.4 LR) which recorded 124.79 kg ha^{-1} and 109.53 kg ha^{-1}, 8.36 kg ha^{-1} and 8.90 kg ha^{-1}, 29.45 kg ha^{-1} and 28.19 kg ha^{-1}, 4.70 kg ha^{-1} and 4.42 kg ha^{-1}, 5.56 kg ha^{-1} and 5.16 kg ha^{-1} and 7.54 kg ha^{-1} and 6.31 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 117.16 kg ha^{-1}, 8.63 kg ha^{-1}, 28.82 kg ha^{-1}, 4.56 kg ha^{-1}, 5.36 kg ha^{-1} and 6.92 kg ha^{-1} respectively. The lowest uptake of N, P, K, S, Ca and Mg by seeds was observed with M_0 (no liming materials) which recorded 101.10 kg ha^{-1} and 90.51 kg ha^{-1}, 5.94 kg ha^{-1} and 6.65 kg ha^{-1}, 22.74 kg ha^{-1} and 22.32 kg ha^{-1}, 3.70 kg ha^{-1} and 3.64 kg ha^{-1}, 3.98kg ha^{-1} and 3.60 kg ha^{-1} and 5.69 kg ha^{-1} and 5.29 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 95.81 kg ha^{-1}, 6.29 kg ha^{-1}, 22.53 kg ha^{-1}, 3.67 kg ha^{-1}, 3.79 kg ha^{-1} and 5.49 kg ha^{-1} respectively. Treatment M_3 (CS @ 0.4 LR) was found to be significant over M_2 (PMS @ 0.4 LR), M_1 (WA @ 0.4 LR) and M_0 (No liming materials).

The increase in phosphorus uptake by soybean on liming might be due to the increase in the available soil phosphorus content as it breaks the aluminium and iron phosphates in the soil. Lynrah and Nongmaithem (2017) reveal that liming resulted in higher uptake of N, P and K by soybean.

4.5.3.2. Effect of phosphorus on N, P, K, S, Ca and Mg uptake by seed

The results on the effects of phosphorus on N, P, K, S, Ca and Mg uptake by seed has been presented on table 4.5.5 (a) and Fig. 16 and table 4.5.6 (a) and Fig. 17. It has been found that application of phosphorus up to 80 kg ha^{-1} had a significant influence on nutrient uptake by seeds. As evident from the results, the maximum N, P, K, S, Ca and Mg uptake by seed was observed with application of P_{80} which recorded 126.39 kg ha^{-1} and 120.33 kg ha^{-1}, 9.19 kg ha^{-1} and 10.09 kg ha^{-1}, 31.39 kg ha^{-1} and 32.69 kg ha^{-1}, 5.15 kg ha^{-1} and 5.08 kg ha^{-1}, 5.21 kg ha^{-1} and 5.55 kg ha^{-1} and 7.62 kg ha^{-1} and 7.42 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 123.36 kg ha^{-1}, 9.64 kg ha^{-1}, 32.04 kg ha^{-1}, 5.12 kg ha^{-1}, 5.38 kg ha^{-1} and 7.52 kg ha^{-1} respectively. The lowest uptake of N, P, K, S, Ca and Mg by seeds was observed with P_0 (0 kg ha^{-1}) which recorded 94.42 kg ha^{-1} and 78.27 kg ha^{-1}, 4.17 kg ha^{-1} and 4.50 kg ha^{-1}, 19.86 kg ha^{-1} and 17.33 kg ha^{-1}, 3.13 kg ha^{-1} and 2.98 kg ha^{-1}, 3.98 kg ha^{-1} and 3.29 kg ha^{-1} and 5.27 kg ha^{-1} and 4.07 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 86 .34 kg ha^{-1}, 4.34 kg ha^{-1}, 18.60 kg ha^{-1}, 3.05 kg ha^{-1}, 3.63 kg ha^{-1} and 4.67 kg

Table 4.5.5 (a) Effect of liming materials and phosphorus levels on N, P and K uptake by seed of soybean

Treatments	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0	101.10	90.51	95.81	5.94	6.65	6.29	22.74	22.32	22.53
M_1	109.47	98.52	103.99	7.24	7.98	7.61	25.00	24.53	24.76
M_2	115.89	105.41	110.65	7.28	8.05	7.67	26.84	27.17	27.00
M_3	124.79	109.53	117.16	8.36	8.90	8.63	29.45	28.19	28.82
SEm±	***1.83***	***1.85***	***1.30***	***0.10***	***0.13***	***0.08***	***0.48***	***0.54***	***0.36***
CD (P=0.05)	***6.33***	***6.39***	***4.01***	***0.34***	***0.44***	***0.25***	***1.65***	***1.87***	***1.11***
P_0	94.42	78.27	86.34	4.17	4.50	4.34	19.86	17.33	18.60
P_{40}	110.92	96.06	103.49	7.11	7.93	7.52	24.12	23.27	23.70
P_{60}	119.52	109.32	114.42	8.35	9.07	8.71	28.64	28.92	28.78
P_{80}	126.39	120.33	123.36	9.19	10.09	9.64	31.39	32.69	32.04
SEm±	***1.13***	***1.60***	***0.98***	***0.09***	***0.10***	***0.07***	***0.34***	***0.50***	***0.31***
CD (P=0.05)	***3.30***	***4.68***	***2.79***	***0.25***	***0.30***	***0.19***	***1.00***	***1.47***	***0.87***

Table 4.5.6 (a) Effect of liming materials and phosphorus levels on S, Ca and Mg uptake by seed of soybean

Treatments	S (kg ha^{-1})			Ca (kg ha^{-1})			Mg (kg ha^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	3.70	3.64	3.67	3.98	3.60	3.79	5.69	5.29	5.49
M_1	4.20	4.12	4.16	4.48	4.10	4.29	6.62	5.81	6.21
M_2	4.23	4.17	4.20	4.59	4.55	4.57	6.45	5.95	6.20
M_3	4.70	4.42	4.56	5.56	5.16	5.36	7.54	6.31	6.92
SEm±	***0.13***	***0.08***	***0.08***	***0.08***	***0.20***	***0.11***	***0.13***	***0.09***	***0.08***
CD (P=0.05)	***0.46***	***0.28***	***0.24***	***0.27***	***0.69***	***0.33***	***0.46***	***0.33***	***0.25***
P_0	3.13	2.98	3.05	3.98	3.29	3.63	5.27	4.07	4.67
P_{40}	3.97	3.81	3.89	4.38	3.92	4.15	6.35	5.44	5.89
P_{60}	4.57	4.49	4.53	5.05	4.64	4.84	7.06	6.42	6.74
P_{80}	5.15	5.08	5.12	5.21	5.55	5.38	7.62	7.42	7.52
SEm±	***0.10***	***0.10***	***0.07***	***0.15***	***0.18***	***0.12***	***0.20***	***0.11***	***0.11***
CD (P=0.05)	***0.29***	***0.28***	***0.20***	***0.44***	***0.51***	***0.33***	***0.59***	***0.32***	***0.33***

ha^{-1} respectively. Among the different levels of phosphorus, P_{80} was found to be significantly higher than P_{60}, P_{40} and P_{0}.

Sentimenla *et al*. (2012) revealed that application of different levels of phosphorus significantly increased the N, P and K uptake by soybean over control. Increased concentration might be due to soil of the experimental field is deficient in plant available P, its application increased phosphorus in soil solution, consequently greater utilization of P by the crop.

4.5.3.3. Interaction effect of liming materials and phosphorus on N, P, K, S, Ca and Mg uptake by seeds

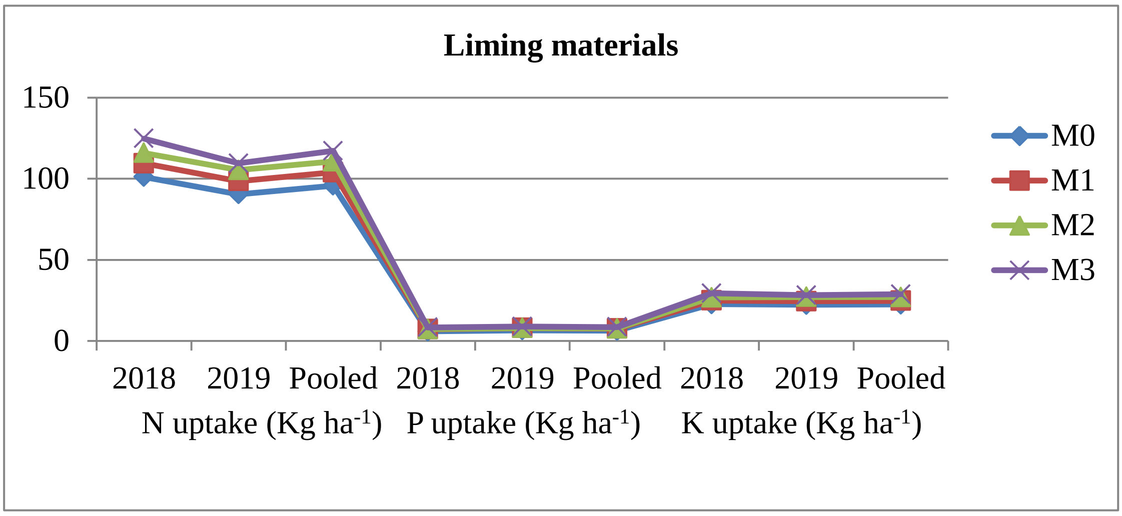
Table 4.5.5 (b) and Fig. 16 and 4.5.6 (b) and Fig. 17 presented the effect of liming materials and phosphorus interaction on N, P, K, S, Ca and Mg uptake by seeds. It was observed that application increased level of phosphorus up to 80 kg ha^{-1} along with liming materials significantly increases the nutrient uptake of N, P and K by seeds whereas S, Ca and Mg uptake by seeds did not have significant due to the effect of liming materials and phosphorus interaction. The highest N, P and K by seeds was observed with M_3P_{80} which recorded 141.43 kg ha^{-1} and 133.69 kg ha^{-1}, 10.58 kg ha^{-1} and 11.53 kg ha^{-1} and 35.52 kg ha^{-1} and 37.49 kg ha^{-1} during year 2018 and 2019, respectively while in the pooled data it was 137.56 kg ha^{-1}, 11.05 kg ha^{-1} and 36.50 kg ha^{-1}. The lowest uptake of N, P and K by seeds was observed with M_0P_0 (control) which recorded 76.01 kg ha^{-1} and 62.04 kg ha^{-1}, 3.44 kg ha^{-1} and 2.94 kg ha^{-1} and 18.38 kg ha^{-1} and 14.63 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 69.03 kg ha^{-1}, 3.19 kg ha^{-1} and 16.51 kg ha^{-1} respectively. The highest S, Ca and Mg by seeds was observed with M_3P_{80} which recorded 5.94 kg ha^{-1} and 5.75 kg ha^{-1}, 6.18 kg ha^{-1} and 6.25 kg ha^{-1} and 8.60 kg ha^{-1} and 8.53 kg ha^{-1} during year 2018 and 2019, respectively while in the pooled data it was 5.84 kg ha^{-1}, 6.21 kg ha^{-1} and 8.56 kg ha^{-1}. The lowest uptake of S, Ca and Mg by seeds was observed with M_0P_0 (control) which

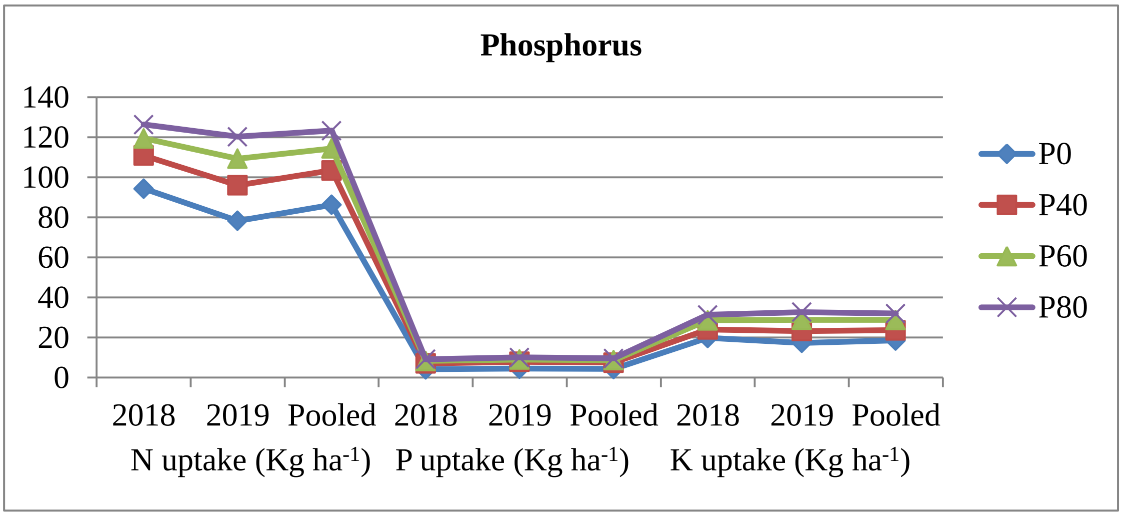
Table 4.5.5 (b) Interaction effect of liming materials and phosphorus levels on N, P and K uptake by seed of soybean

Treatments	N (kg ha-1)			P (kg ha-1)			K (kg ha-1)		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0P_0	76.01	62.04	69.03	3.44	2.94	3.19	18.38	14.63	16.51
M_0P_{40}	105.01	90.42	97.72	5.52	7.17	6.34	20.89	20.76	20.82
M_0P_{60}	110.38	100.03	105.21	7.17	7.91	7.54	25.28	25.36	25.32
M_0P_{80}	113.01	109.53	111.27	7.61	8.56	8.09	26.41	28.53	27.47
M_1P_0	97.42	82.60	90.01	4.31	5.01	4.66	19.22	17.80	18.51
M_1P_{40}	109.32	96.13	102.72	7.49	8.16	7.82	23.21	23.38	23.30
M_1P_{60}	111.68	102.27	106.98	8.05	8.82	8.43	27.74	26.79	27.26
M_1P_{80}	119.45	113.07	116.26	9.10	9.95	9.53	29.82	30.15	29.98
M_2P_0	99.42	83.63	91.52	4.02	4.73	4.38	20.05	19.21	19.63
M_2P_{40}	111.33	98.92	105.12	7.24	7.81	7.53	25.53	24.31	24.92
M_2P_{60}	121.13	114.08	117.61	8.41	9.35	8.88	27.95	30.57	29.26
M_2P_{80}	131.69	125.02	128.35	9.45	10.31	9.88	33.82	34.58	34.20
M_3P_0	104.83	84.81	94.82	4.91	5.32	5.12	21.81	17.68	19.75
M_3P_{40}	118.03	98.76	108.39	8.20	8.56	8.38	26.86	24.65	25.75
M_3P_{60}	134.88	120.87	127.87	9.75	10.20	9.98	33.61	32.94	33.27
M_3P_{80}	141.43	133.69	137.56	10.58	11.53	11.05	35.52	37.49	36.50
SEm±	***2.26***	***3.20***	***1.96***	***0.17***	***0.21***	***0.14***	***0.69***	***1.01***	***0.61***
CD (P=0.05)	***6.60***	***9.35***	***5.58***	***0.51***	***0.61***	***0.39***	***2.00***	***2.95***	***1.74***

Table 4.5.6 (b) Interaction effect of liming materials and phosphorus levels on S, Ca and Mg uptake by seed of soybean

Treatments	S (kg ha^{-1})			Ca (kg ha^{-1})			Mg (kg ha^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	2.75	2.56	2.65	2.99	2.37	2.68	4.47	3.51	3.99
M_0P_{40}	3.58	3.49	3.54	3.80	3.39	3.59	5.51	4.78	5.15
M_0P_{60}	4.09	4.07	4.08	4.64	4.08	4.36	6.18	6.14	6.16
M_0P_{80}	4.39	4.43	4.41	4.50	4.56	4.53	6.61	6.72	6.67
M_1P_0	3.16	3.14	3.15	3.76	2.87	3.32	4.96	4.02	4.49
M_1P_{40}	4.21	4.07	4.14	4.50	4.02	4.26	6.99	6.15	6.57
M_1P_{60}	4.42	4.35	4.39	4.84	4.35	4.59	7.12	6.18	6.65
M_1P_{80}	5.00	4.94	4.97	4.82	5.13	4.97	7.42	6.88	7.15
M_2P_0	3.01	2.94	2.97	3.84	3.21	3.52	4.68	4.26	4.47
M_2P_{40}	3.87	3.74	3.80	4.28	3.98	4.13	6.31	5.55	5.93
M_2P_{60}	4.75	4.80	4.78	4.90	4.74	4.82	6.96	6.42	6.69
M_2P_{80}	5.29	5.22	5.26	5.34	6.26	5.80	7.87	7.56	7.72
M_3P_0	3.60	3.28	3.44	5.33	4.70	5.02	6.97	4.50	5.73
M_3P_{40}	4.24	3.93	4.08	4.93	4.28	4.61	6.59	5.26	5.93
M_3P_{60}	5.02	4.74	4.88	5.81	5.40	5.61	8.01	6.93	7.47
M_3P_{80}	5.94	5.75	5.84	6.18	6.25	6.21	8.60	8.53	8.56
SEm±	***0.20***	***0.19***	***0.14***	***0.30***	***0.35***	***0.23***	***0.40***	***0.22***	***0.23***
CD (P=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***





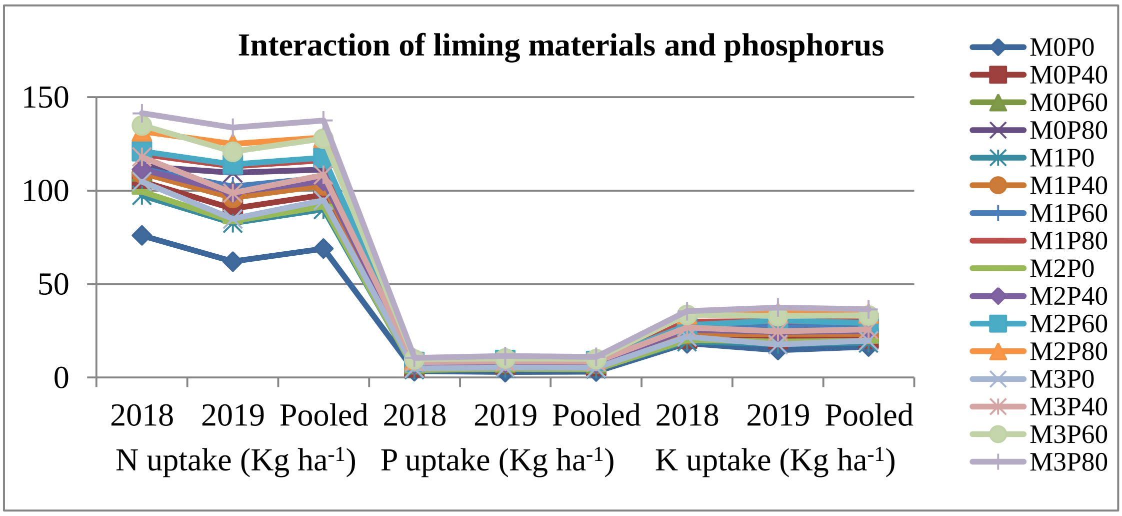
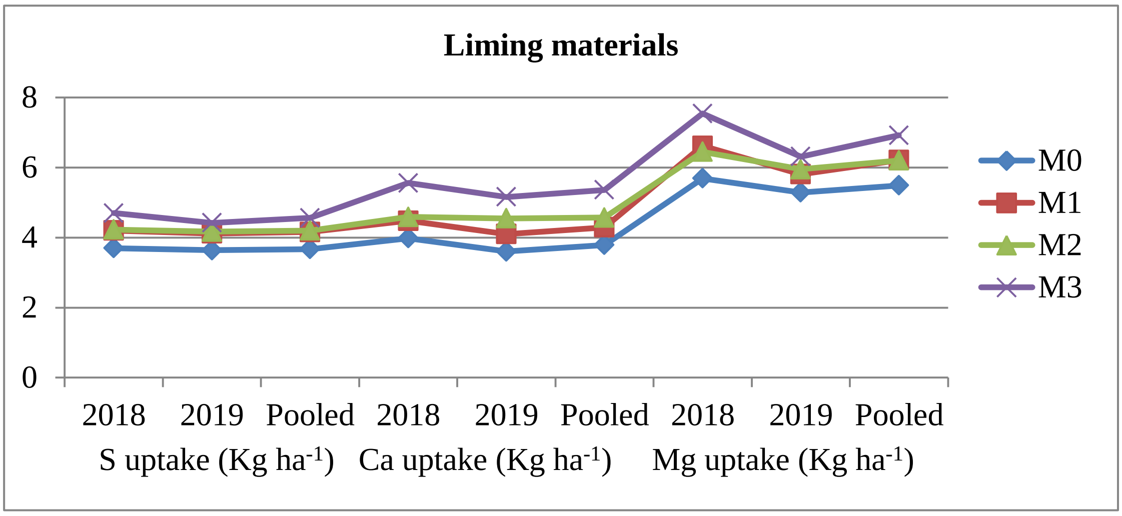
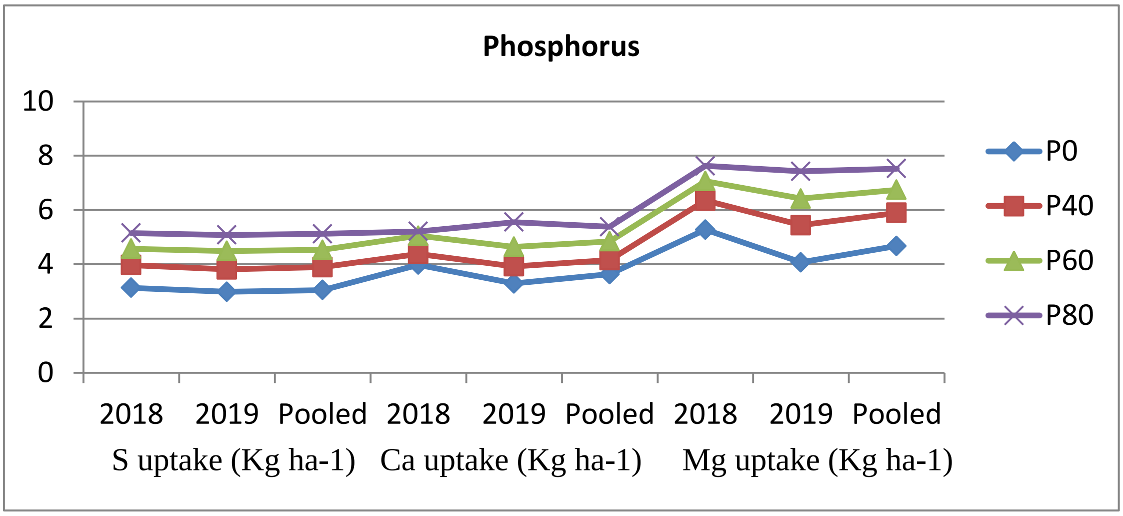


Fig. 16 Effect of liming materials, phosphorus levels and interaction on N, P and K uptake by seed of soybean





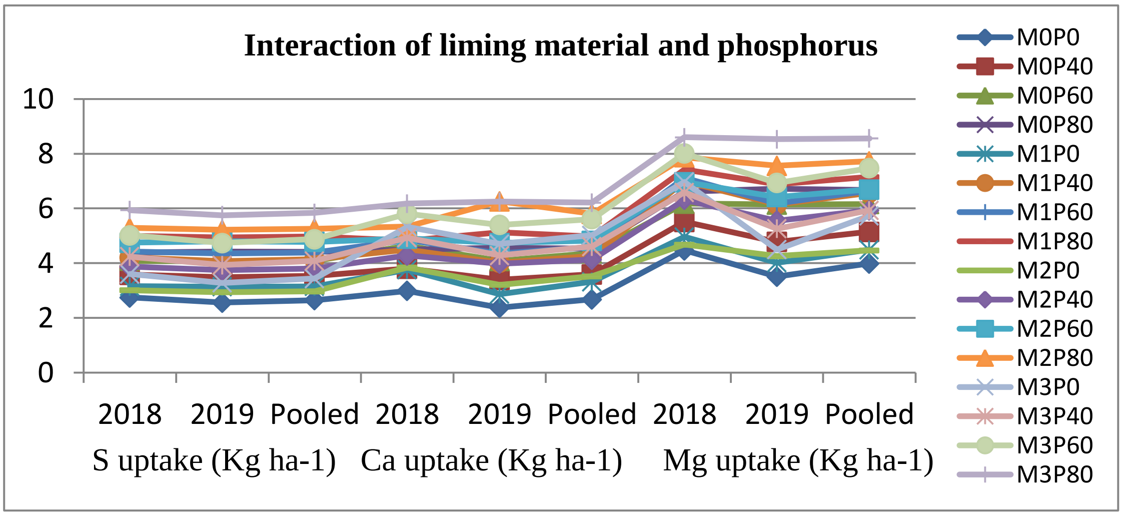


Fig.17 Effect of liming materials, phosphorus levels and interaction on S, Ca and Mg uptake by seed of soybean

recorded 2.75 kg ha^{-1} and 2.56 kg ha^{-1}, 2.99 kg ha^{-1} and 2.37 kg ha^{-1} and 4.47 kg ha^{-1} and 3.51 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 2.65 kg ha^{-1}, 2.68 kg ha^{-1} and 3.99 kg ha^{-1} respectively. There was significant difference among treatments on the uptake of N, P and K by seeds. However, treatment M_3P_{80} was observed to be significant over other treatment combinations including control.

4.5.4. Effect on N, P, K, S, Ca and Mg uptake by stover

4.5.4.1. Effect of liming materials on N, P, K, S, Ca and Mg uptake by stover

The effect of liming materials on N, P, K, S, Ca and Mg uptake by stover has shown in table 4.5.7 (a) and Fig. 18 and table 4.5.8 (a) and Fig. 19. The results revealed that application of liming materials significantly influence the N, P, K, S, Ca and Mg uptake by stover was observed when M_3 (CS @ 0.4 LR) was applied which recorded the highest N, P, K, S, Ca and Mg uptake by stover corresponding value of 60.48 kg ha^{-1} and 54.22 kg ha^{-1}, 4.66 kg ha^{-1} and 4.34 kg ha^{-1}, 57.65 kg ha^{-1} and 56.83 kg ha^{-1}, 4.32 kg ha^{-1} and 4.48 kg ha^{-1}, 17.99 kg ha^{-1} and 15.78 kg ha^{-1} and 5.58 kg ha^{-1} and 4.95 kg ha^{-1} during 2018 and 2019 respectively with corresponding value of 57.35 kg ha^{-1}, 4.50 kg ha^{-1}, 57.24 kg ha^{-1}, 4.40 kg ha^{-1}, 16.89 kg ha^{-1} and 5.27 kg ha^{-1}. Lower N, P, K, S, Ca and Mg uptake by stover was observed in M_0 (no liming materials) which recorded corresponding value of 48.88 kg ha^{-1} and 40.41 kg ha^{-1}, 2.94 kg ha^{-1} and 2.79 kg ha^{-1}, 48.63 kg ha^{-1} and 47.33 kg ha^{-1}, 3.49 kg ha^{-1} and 3.03 kg ha^{-1}, 14.74 kg ha^{-1}and 12.35 kg ha^{-1} and 4.06 kg ha^{-1} and 3.38 kg ha^{-1} during 2018 and 2019 respectively with pooled value of 44.65 kg ha^{-1} 2.88 kg ha^{-1}, 47.98 kg ha^{-1}, 3.26 kg ha^{-1}, 13.55 kg ha^{-1} and 3.72 kg ha^{-1}.

The improvement in the uptake of nutrients could be attributed to higher dry matter production, seed and haulm yield. Mohammadi (2010) revealed that application 2 % sludge remarkably increase the uptake of N, P, K, S, Ca and

Mg by soybean. Similar results was found by Behera *et al*., (2017)

4.5.4.2. Effect of phosphorus on N, P, K, S, Ca and Mg uptake by stover

Table 4.5.7 (a) and Fig. 18 and table 4.5.8 (a) and Fig. 19 presented the effect of phosphorus on N, P, K, S, Ca and Mg uptake by stover. From the result obtained, it became evident that increasing the levels of phosphorus application had a significant influence on the N, P, K, S, Ca and Mg uptake by stover. The highest N, P, K, S, Ca and Mg uptake by stover was observed with P_{80} which recorded 67.13 kg ha^{-1}, and 62.39 kg ha^{-1}, 5.05 kg ha^{-1} and 4.75 kg ha^{-1}, 62.85 kg ha^{-1} and 61.80 kg ha^{-1}, 4.94 kg ha^{-1} and 4.60 kg ha^{-1}, 18.99 kg ha^{-1} and 16.48 kg ha^{-1}and 5.92 kg ha^{-1} and 5.06 kg ha^{-1} during 2018 and 2019 respectively with pooled value of 64.76 kg ha^{-1}, 4.90 kg ha^{-1}, 62.32 kg ha^{-1}, 4.77 kg ha^{-1}, 17.74 kg ha^{-1} and 5.49 kg ha^{-1} while the lowest was observed with P_0 which recorded 41.85 kg ha^{-1} and 35.53 kg ha^{-1}, 2.15 kg ha^{-1} and 1.97 kg ha^{-1}, 44.51 kg ha^{-1} and 42.30 kg ha^{-1}, 2.98 kg ha^{-1}and 2.68 kg ha^{-1}, 13.47 kg ha^{-1} 11.28 kg ha^{-1} and 3.71 kg ha^{-1} and 3.01 during 2018 and 2019 respectively with pooled value of 38.69 kg ha^{-1}, 2.06 kg ha^{-1}, 43.40 kg ha^{-1}, 2.83 kg ha^{-1}, 12.38 kg ha^{-1} and 3.36 kg ha^{-1}, respectively.

The phosphorus deficiency is a major constraint under acidic soil condition due to phosphate fixation. Application of phosphorus increases availability of phosphorus to the plants. Improved root growth and activity with enhanced phosphorus availability facilitates higher uptake of nutrients from the soil which could have contributed to the significant increase in N, P, K, S, Ca and Mg uptake by stover. Shah et al., (2001) observed higher uptake of nutrients by soybean with application of phosphorus upto 80 kg P_2O_5 ha^{-1}.

4.5.4.3. Interaction effect of liming materials and phosphrus on N, P, K, S, Ca and Mg uptake by stover

The results of the interaction effect between liming materials and

Table 4.5.7 (a) Effect of liming materials and phosphorus levels on N, P and K uptake by stover of soybean

Treatments	**N (kg ha-1)**			**P (kg ha-1)**			**K (kg ha-1)**		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0	48.88	40.41	44.65	2.96	2.79	2.88	48.63	47.33	47.98
M_1	56.88	48.37	52.63	4.23	3.98	4.10	54.72	53.90	54.31
M_2	57.21	51.71	54.46	3.74	3.42	3.58	56.56	53.40	54.98
M_3	60.48	54.22	57.35	4.66	4.34	4.50	57.65	56.83	57.24
SEm±	***0.89***	***0.81***	***0.60***	***0.07***	***0.08***	***0.05***	***0.42***	***0.46***	***0.31***
CD (P=0.05)	***3.07***	***2.80***	***1.85***	***0.24***	***0.28***	***0.17***	***1.44***	***1.59***	***0.95***
P_0	41.85	35.53	38.69	2.15	1.97	2.06	44.51	42.30	43.40
P_{40}	52.52	42.77	47.64	3.88	3.62	3.75	52.85	50.88	51.87
P_{60}	61.95	54.03	57.99	4.51	4.18	4.35	57.35	56.48	56.91
P_{80}	67.13	62.39	64.76	5.05	4.75	4.90	62.85	61.80	62.32
SEm±	***0.94***	***0.79***	***0.61***	***0.06***	***0.05***	***0.04***	***0.48***	***0.72***	***0.43***
CD (P=0.05)	***2.74***	***2.30***	***1.74***	***0.18***	***0.14***	***0.11***	***1.40***	***2.10***	***1.23***

Table 4.5.8 (a) Effect of liming materials and phosphorus levels on S, Ca and Mg uptake by stover of soybean

Treatments	**S (kg ha-1)**			**Ca (kg ha-1)**			**Mg (kg ha-1)**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	3.49	3.03	3.26	14.74	12.35	13.55	4.06	3.38	3.72
M_1	3.79	3.34	3.56	15.88	13.50	14.69	4.76	3.78	4.27
M_2	4.23	3.79	4.01	16.88	14.30	15.59	5.17	4.26	4.72
M_3	4.32	4.48	4.40	17.99	15.78	16.89	5.58	4.95	5.27
SEm±	***0.10***	***0.09***	***0.07***	***0.15***	***0.16***	***0.11***	***0.11***	***0.10***	***0.08***
CD (P=0.05)	***0.35***	***0.30***	***0.21***	***0.52***	***0.54***	***0.34***	***0.39***	***0.35***	***0.23***
P_0	2.98	2.68	2.83	13.47	11.28	12.38	3.71	3.01	3.36
P_{40}	3.71	3.50	3.60	15.54	13.28	14.41	4.69	3.92	4.30
P_{60}	4.21	3.86	4.03	17.48	14.89	16.19	5.25	4.38	4.82
P_{80}	4.94	4.60	4.77	18.99	16.48	17.74	5.92	5.06	5.49
SEm±	***0.07***	***0.11***	***0.06***	***0.21***	***0.21***	***0.15***	***0.15***	***0.12***	***0.10***
CD (P=0.05)	***0.19***	***0.31***	***0.18***	***0.62***	***0.62***	***0.43***	***0.45***	***0.36***	***0.28***

Table 4.5.7 (b) Interaction effect of liming materials and phosphorus levels on N, P and K uptake by stover of soybean

Treatments	N (kg ha-1)			P (kg ha-1)			K (kg ha-1)		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0P_0	37.13	31.65	34.39	1.46	1.35	1.41	40.07	37.54	38.80
M_0P_{40}	49.35	37.28	43.31	3.07	2.94	3.00	47.82	45.88	46.85
M_0P_{60}	53.29	43.23	48.26	3.45	3.28	3.37	51.11	51.23	51.17
M_0P_{80}	55.76	49.50	52.63	3.86	3.61	3.73	55.54	54.66	55.10
M_1P_0	41.11	33.11	37.11	2.37	2.11	2.24	44.16	40.91	42.53
M_1P_{40}	51.45	42.40	46.93	4.01	3.84	3.92	54.32	53.56	53.94
M_1P_{60}	63.88	52.74	58.31	4.93	4.60	4.77	58.52	57.00	57.76
M_1P_{80}	71.09	65.24	68.17	5.61	5.35	5.48	61.87	64.12	63.00
M_2P_0	44.08	39.23	41.66	1.92	1.79	1.86	45.16	44.63	44.89
M_2P_{40}	54.76	44.17	49.47	3.81	3.45	3.63	54.40	50.01	52.20
M_2P_{60}	62.07	58.74	60.41	4.39	4.01	4.20	60.14	57.78	58.96
M_2P_{80}	67.90	64.71	66.31	4.82	4.42	4.62	66.53	61.17	63.85
M_3P_0	45.06	38.13	41.60	2.85	2.62	2.74	48.65	46.11	47.38
M_3P_{40}	54.51	47.22	50.86	4.63	4.28	4.45	54.88	54.07	54.47
M_3P_{60}	68.57	61.43	65.00	5.28	4.84	5.06	59.63	59.91	59.77
M_3P_{80}	73.76	70.11	71.94	5.90	5.63	5.76	67.46	67.24	67.35
SEm±	***1.88***	***1.58***	***1.23***	***0.12***	***0.10***	***0.08***	***0.96***	***1.44***	***0.87***
CD (P=0.05)	***5.48***	***4.60***	***3.49***	***0.35***	***0.29***	***0.22***	**NS**	**NS**	**NS**

Table 4.5.8 (b) Interaction effect of liming materials and phosphorus levels on S, Ca and Mg uptake by stover of soybean

Treatments	S (kg ha-1)			Ca (kg ha-1)			Mg (kg ha-1)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	2.54	2.16	2.35	11.98	9.73	10.85	3.03	2.41	2.72
M_0P_{40}	3.21	2.99	3.10	14.33	12.12	13.23	3.84	3.22	3.53
M_0P_{60}	3.61	3.19	3.40	15.72	13.32	14.52	4.25	3.57	3.91
M_0P_{80}	4.61	3.77	4.19	16.93	14.22	15.58	5.11	4.32	4.72
M_1P_0	3.01	2.57	2.79	13.08	10.58	11.83	3.58	2.63	3.10
M_1P_{40}	3.36	3.22	3.29	15.29	13.26	14.27	4.65	3.76	4.20
M_1P_{60}	4.08	3.41	3.75	16.77	14.21	15.49	5.10	4.05	4.57
M_1P_{80}	4.70	4.15	4.43	18.36	15.97	17.16	5.69	4.67	5.18
M_2P_0	3.17	2.87	3.02	13.80	11.76	12.78	3.76	3.08	3.42
M_2P_{40}	3.98	3.36	3.67	15.91	13.29	14.60	5.06	4.11	4.59
M_2P_{60}	4.48	4.26	4.37	17.91	15.13	16.52	5.74	4.74	5.24
M_2P_{80}	5.29	4.67	4.98	19.91	17.00	18.45	6.13	5.10	5.61
M_3P_0	3.21	3.12	3.17	15.03	13.06	14.04	4.45	3.91	4.18
M_3P_{40}	4.28	4.43	4.36	16.64	14.44	15.54	5.21	4.58	4.90
M_3P_{60}	4.66	4.59	4.62	19.53	16.90	18.21	5.92	5.16	5.54
M_3P_{80}	5.14	5.80	5.47	20.76	18.75	19.75	6.74	6.16	6.45
SEm±	***0.13***	***0.22***	***0.13***	***0.43***	***0.42***	***0.30***	***0.31***	***0.24***	***0.20***
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

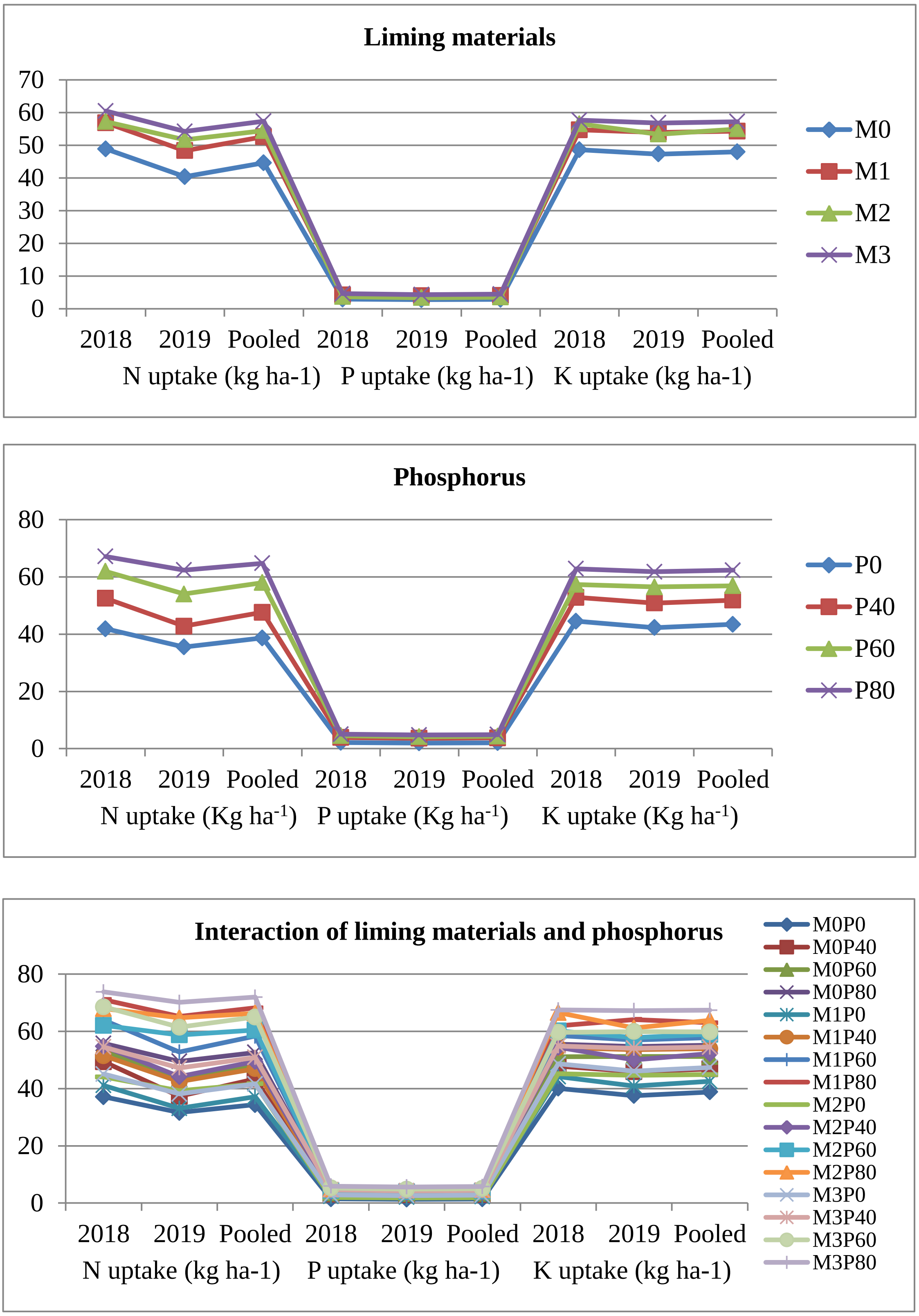


Fig. 18 Effect of liming materials, phosphorus levels and interaction on N, P and K uptake by stover of soybean

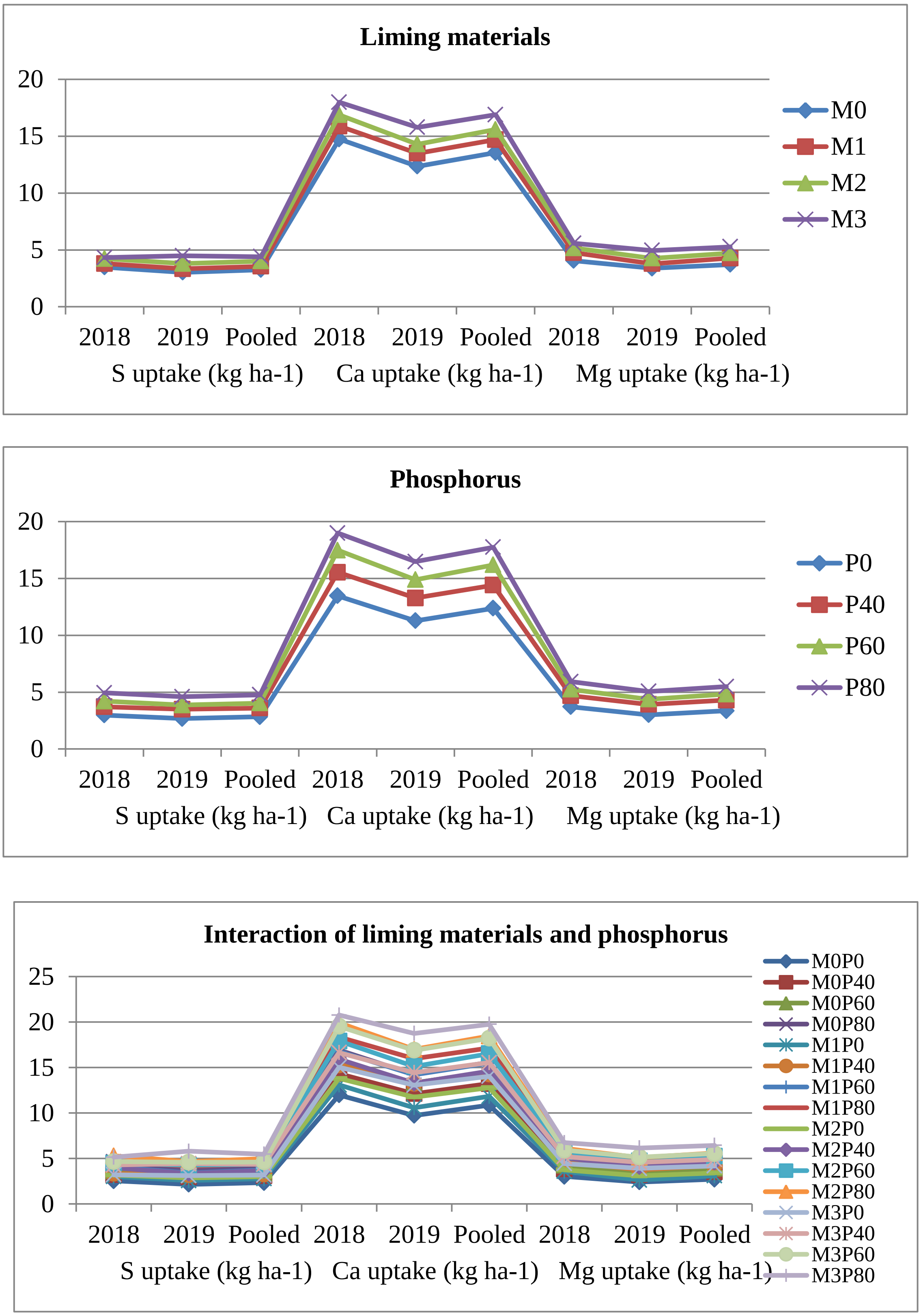


Fig. 19 Effect of liming materials, phosphorus levels and interaction on S, Ca and Mg uptake by stover of soybean

phosphorus on N, P, K, S, Ca and Mg uptake by stover has been depicted in the table 4.5.7 (b) and Fig. 18 and table 4.5.8 (b) and Fig. 19. The results obtained clearly revealed that the interaction between liming materials and phosphorus had significant effect on N and P whereas did not have any significant effect on K, S, Ca and Mg uptake by stover. The highest N, P, K, S, Ca and Mg uptake by stover was observed with treatment M_3P_{80} which recorded 73.76 kg ha^{-1} and 70.11 kg ha^{-1}, 5.90 kg ha^{-1} and 5.63 kg ha^{-1}, 67.46 kg ha^{-1} and 67.24 kg ha^{-1}, 0.13 kg ha^{-1} and 0.22 kg ha^{-1}, 0.43 kg ha^{-1} and 0.42 kg ha^{-1} and 0.31 kg ha^{-1} and 0.42 kg ha^{-1} during year 2018 and 2019 respectively with pooled value 71.94 kg ha^{-1}, 5.76 kg ha^{-1}, 67.35 kg ha^{-1}, 5.47 kg ha^{-1}, 19.75 kg ha^{-1} and 6.45 kg ha^{-1}accordingly. The lowest uptake of N, P, K, S, Ca and Mg by stover was observed with M_0P_0 (control) which recorded 37.13 kg $ha^{-1}$and 31.65 kg ha^{-1}, 1.46 kg ha^{-1} and 1.35 kg ha^{-1}, 40.07 kg ha^{-1} and 37.54 kg ha^{-1}, 2.54 kg ha^{-1} and 2.16 kg ha^{-1}, 11.98 kg ha^{-1} and 9.73 kg ha^{-1} and 3.03 kg ha^{-1} and 2.41 kg ha^{-1} during year 2018 and 2019 respectively, while in the pooled data it recorded 34.39 kg ha^{-1}, 1.41 kg ha^{-1} and 38.80 kg ha^{-1}, 2.35 kg ha^{-1}, 10.85 kg ha^{-1} and 2.72 kg ha^{-1} respectively.

4.5.5. Effect on total uptake of N, P, K, S, Ca and Mg by soybean

4.5.5.1. Effect of liming materials on total uptake of N, P, K, S, Ca and Mg by soybean

Table 4.5.9 (a) and Fig. 20 and table 4.5.9 (a) and Fig. 21 presented the effect of liming materials on total uptake of N, P, K, S, Ca and Mg by soybean. From the result obtained, it became evident that different liming materials application had a significant influence on the total uptake of N, P, K, S, Ca and Mg by soybean. The highest total uptake of N, P, K, S, Ca and Mg by soybean was observed with M_3 (CS @ 0.4 LR) which recorded 185.27 kg ha^{-1}, and 163.75 kg ha^{-1}, 13.02 kg ha^{-1} and 13.25 kg ha^{-1}, 87.02 kg ha^{-1} and 85.02 kg ha^{-1}, 9.02 kg ha^{-1} and 8.91 kg ha^{-1}, 23.55 kg ha^{-1} and 20.94 kg $ha^{-1}$and 13.12 kg ha^{-1}

and 11.26 kg ha^{-1} during 2018 and 2019 respectively with pooled value of 174.51 kg ha^{-1}, 13.13 kg ha^{-1}, 86.02 kg ha^{-1}, 8.97 kg ha^{-1}, 22.25 kg ha^{-1} and 12.19 kg ha^{-1}. The lowest total uptake of N, P, K, S, Ca and Mg by soybean was observed in M_0 (no liming materials) which recorded corresponding value of 149.98 kg ha^{-1} and 130.92 kg ha^{-1}, 8.90 kg ha^{-1} and 9.44 kg ha^{-1}, 71.37 kg ha^{-1} and 69.65 kg ha^{-1}, 7.19 kg ha^{-1}and 6.66 kg ha^{-1}, 18.72 kg ha^{-1} 15.95 kg ha^{-1} and 9.75 kg ha^{-1} and 8.67 kg ha^{-1} during 2018 and 2019 respectively with pooled value of 140.45 kg ha^{-1}, 9.17 kg ha^{-1}, 70.51 kg ha^{-1}, 6.93 kg ha^{-1}, 17.34 kg ha^{-1} and 9.21 kg ha^{-1}, respectively.

Lynrah and Nongmathem (2017) found that the total uptake of N, P and K were significantly increased with application of lime @ 1.5 t ha^{-1}. Increased total uptake of N, P, K, S, Ca and Mg by soybean has also reported by Dey and Nath (2015).

4.5.5.2. Effect of phosphorus on total uptake of N, P, K, S, Ca and Mg by soybean

The effect of phosphorus on total uptake of N, P, K, S, Ca and Mg by soybean has been presented in table 4.5.9 (a) and Fig. 20 and table 4.5.9 (a) and Fig. 21. The results revealed that successive increased in the levels of phosphorus application had a significant effect on the total uptake of N, P, K, S, Ca and Mg by soybean. The highest total uptake of N, P, K, S, Ca and Mg by soybean was observed when P_{80} was applied which recorded 193.52 kg ha^{-1} and 182.72 kg ha^{-1}, 14.23 kg ha^{-1}and 14.84 kg ha^{-1}, 93.91 kg ha^{-1} and 94.48 kg ha^{-1}, 10.09 kg ha^{-1} and 9.68 kg ha^{-1}, 24.20 kg ha^{-1} and 22.03 kg ha^{-1} and 13.54 kg ha^{-1} and 12.49 kg ha^{-1} during year 2018 and 2019, respectively whereas, the lowest total uptake of N, P, K, S, Ca and Mg by soybean was observed with P_0 during 2018 and 2019 which recorded 136.27 kg ha^{-1} and 113.80 kg ha^{-1}, 6.32 kg ha^{-1} and 6.47 kg ha^{-1}, 64.54 kg ha^{-1} and 59.63 kg ha^{-1}, 6.11 kg ha^{-1} and 5.66 kg ha^{-1}, 17.45 kg ha^{-1}and 14.57 kg ha^{-1} and 8.98 kg ha^{-1} and 7.08 kg ha^{-1}.

Table 4.5.9 (a) Effect of liming materials and phosphorus levels on total uptake of N, P and K by soybean crop

Treatments	N (kg ha-1)			P (kg ha-1)			K (kg ha-1)		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0	149.98	130.92	140.45	8.90	9.44	9.17	71.37	69.65	70.51
M_1	166.35	146.89	156.62	11.47	11.96	11.71	79.72	78.43	79.07
M_2	173.10	157.13	165.11	11.02	11.47	11.24	83.31	80.57	81.94
M_3	185.27	163.75	174.51	13.02	13.25	13.13	87.02	85.02	86.02
SEm±	***2.15***	***1.94***	***1.45***	***0.11***	***0.12***	***0.08***	***0.93***	***0.57***	***0.55***
CD (P=0.05)	***7.43***	***6.72***	***4.46***	***0.37***	***0.42***	***0.25***	***3.22***	***1.98***	***1.68***
P_0	136.27	113.80	125.03	6.32	6.47	6.40	64.54	59.63	62.08
P_{40}	163.44	138.82	151.13	10.99	11.55	11.27	76.98	74.15	75.56
P_{60}	181.47	163.35	172.41	12.86	13.25	13.05	85.99	85.40	85.69
P_{80}	193.52	182.72	188.12	14.23	14.84	14.54	93.91	94.48	94.20
SEm±	***1.18***	***1.77***	***1.06***	***0.11***	***0.12***	***0.08***	***0.69***	***0.69***	***0.49***
CD (P=0.05)	***3.44***	***5.18***	***3.03***	***0.33***	***0.34***	***0.23***	***2.01***	***2.02***	***1.39***

Table 4.5.10 (a) Effect of liming materials and phosphorus levels on total uptake S, Ca and Mg by soybean crop

Treatments	S (kg ha-1)			Ca (kg ha-1)			Mg (kg ha-1)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0	7.19	6.66	6.93	18.72	15.95	17.34	9.75	8.67	9.21
M_1	7.98	7.46	7.72	20.35	17.60	18.98	11.38	9.58	10.48
M_2	8.46	7.96	8.21	21.47	18.84	20.16	11.63	10.21	10.92
M_3	9.02	8.91	8.97	23.55	20.94	22.25	13.12	11.26	12.19
SEm±	***0.10***	***0.07***	***0.06***	***0.13***	***0.21***	***0.13***	***0.20***	***0.15***	***0.13***
CD (P=0.05)	***0.36***	***0.26***	***0.20***	***0.46***	***0.74***	***0.39***	***0.70***	***0.51***	***0.39***
P_0	6.11	5.66	5.88	17.45	14.57	16.01	8.98	7.08	8.03
P_{40}	7.68	7.31	7.49	19.92	17.20	18.56	11.04	9.35	10.20
P_{60}	8.78	8.35	8.56	22.53	19.53	21.03	12.32	10.80	11.56
P_{80}	10.09	9.68	9.89	24.20	22.03	23.12	13.54	12.49	13.01
SEm±	***0.13***	***0.14***	***0.09***	***0.24***	***0.27***	***0.18***	***0.23***	***0.16***	***0.14***
CD (P=0.05)	***0.37***	***0.39***	***0.26***	***0.71***	***0.78***	***0.51***	***0.66***	***0.48***	***0.40***

In the pooled mean data revealed that P_{80} recorded the highest total uptake of N, P, K, S, Ca and Mg by soybean of 188.12 kg ha^{-1}, 14.54 kg ha^{-1}, 94.48 kg ha^{-1}, 9.89 kg ha^{-1}, 23.12 kg ha^{-1} and 13.01 kg ha^{-1} while the lowest with P_0 of 125.03 kg ha^{-1}, 6.40 kg ha^{-1}, 62.08 kg ha^{-1}, 5.88 kg ha^{-1}, 16.01 kg ha^{-1} and 8.03 kg ha^{-1} during the year 2018 and 2019, respectively.

Soil acidity induced P deficiency were observed in the experimental plot and its increased mineralization through phosphorus application must have resulted in better root development promoting the active roots to absorbed more nutrients from the soil. Shipratewari and Pal (2005) revealed that application phosphorus increases the nutrient uptake by soybean.

4.5.5.3. Interaction effect of liming materials and phosphorus on total uptake of N, P, K, S, Ca and Mg by soybean

The results of the interaction effect between liming materials and phosphorus on total uptake of N, P, K, S, Ca and Mg by soybean has been

depicted in the table 4.5.9 (b) and Fig. 20 and table 4.5.10 (b) and Fig. 21. The results obtained clearly revealed that the interaction between liming materials and phosphorus had significant effect on total uptake of N, P, K, S, Ca and Mg by soybean. The highest total uptake of N, P, K, S, Ca and Mg by soybean was observed with treatment M_3P_{80} which recorded 215.20 kg ha^{-1} and 203.80 kg ha^{-1}, 16.48 kg ha^{-1} and 17.16 kg ha^{-1}, 101.98 kg ha^{-1} and 104.73 kg ha^{-1}, 11.09kg ha^{-1} and 11.55 kg ha^{-1}, 26.94 kg ha^{-1} and 25.00 kg ha^{-1} and 15.34 kg ha^{-1} and 14.69 kg ha^{-1} during year 2018 and 2019 respectively with pooled value 209.50 kg ha^{-1}, 16.82 kg ha^{-1}, 103.35 kg ha^{-1}, 11.32 kg ha^{-1}, 25.97 kg ha^{-1} and 15.01 kg ha^{-1} accordingly. The lowest total uptake of N, P, K, S, Ca and Mg by soybean was observed with M_0P_0 (control) which recorded 113.14 kg ha^{-1}and 93.69 kg ha^{-1}, 4.90 kg ha^{-1} and 4.30 kg ha^{-1}, 58.45 kg ha^{-1} and 52.17 kg ha^{-1}, 5.28 kg ha^{-1} and 4.72 kg ha^{-1}, 14.97 kg ha^{-1} and 12.10 kg ha^{-1} and 7.50 kg ha^{-1} and 5.92 kg ha^{-1} during year 2018 and 2019 respectively, while in the

Table 4.5.9 (b) Interaction effect of liming materials and phosphorus levels on total uptake of N, P and K by soybean crop

Treatments	**N (kg ha-1)**			**P (kg ha-1)**			**K (kg ha-1)**		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0P_0	113.14	93.69	103.41	4.90	4.30	4.60	58.45	52.17	55.31
M_0P_{40}	154.36	127.69	141.03	8.59	10.10	9.35	68.71	66.63	67.67
M_0P_{60}	163.67	143.26	153.47	10.63	11.19	10.91	76.38	76.59	76.49
M_0P_{80}	168.77	159.03	163.90	11.47	12.17	11.82	81.95	83.18	82.57
M_1P_0	138.53	115.71	127.12	6.67	7.13	6.90	63.37	58.71	61.04
M_1P_{40}	160.77	138.53	149.65	11.50	11.99	11.75	77.54	76.94	77.24
M_1P_{60}	175.57	155.01	165.29	12.98	13.42	13.20	86.26	83.79	85.03
M_1P_{80}	190.54	178.31	184.43	14.71	15.30	15.01	91.69	94.27	92.98
M_2P_0	143.50	122.86	133.18	5.94	6.52	6.23	65.21	63.84	64.53
M_2P_{40}	166.09	143.09	154.59	11.06	11.26	11.16	79.93	74.32	77.12
M_2P_{60}	183.20	172.83	178.01	12.79	13.36	13.07	88.09	88.35	88.22
M_2P_{80}	199.59	189.73	194.66	14.27	14.73	14.50	100.02	95.76	97.89
M_3P_0	149.90	122.94	136.42	7.76	7.94	7.85	71.13	63.79	67.46
M_3P_{40}	172.53	145.98	159.26	12.82	12.84	12.83	81.73	78.72	80.23
M_3P_{60}	203.45	182.30	192.87	15.03	15.05	15.04	93.24	92.85	93.04
M_3P_{80}	215.20	203.80	209.50	16.48	17.16	16.82	101.98	104.73	103.35
SEm±	***2.36***	***3.55***	***2.13***	***0.23***	***0.23***	***0.16***	***1.37***	***1.38***	***0.98***
CD (P=0.05)	***6.88***	***10.35***	***6.06***	***0.66***	***0.67***	***0.46***	***4.01***	***4.04***	***2.77***

Table 4.5.10 (b) Interaction effect of liming materials and phosphorus levels on total uptake of S, Ca and Mg by soybean crop

Treatments	S (kg ha-1)			Ca (kg ha-1)			Mg (kg ha-1)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	5.28	4.72	5.00	14.97	12.10	13.53	7.50	5.92	6.71
M_0P_{40}	6.79	6.48	6.64	18.13	15.51	16.82	9.35	8.00	8.67
M_0P_{60}	7.70	7.26	7.48	20.37	17.40	18.88	10.43	9.71	10.07
M_0P_{80}	9.00	8.20	8.60	21.43	18.78	20.11	11.72	11.05	11.39
M_1P_0	6.17	5.70	5.93	16.84	13.46	15.15	8.54	6.65	7.59
M_1P_{40}	7.57	7.29	7.43	19.79	17.28	18.54	11.64	9.91	10.77
M_1P_{60}	8.50	7.76	8.13	21.61	18.56	20.08	12.22	10.22	11.22
M_1P_{80}	9.70	9.09	9.39	23.18	21.10	22.14	13.11	11.55	12.33
M_2P_0	6.18	5.81	5.99	17.64	14.97	16.30	8.44	7.35	7.89
M_2P_{40}	7.85	7.10	7.47	20.18	17.27	18.73	11.37	9.66	10.52
M_2P_{60}	9.23	9.05	9.14	22.81	19.87	21.34	12.70	11.16	11.93
M_2P_{80}	10.58	9.89	10.23	25.24	23.26	24.25	13.99	12.66	13.33
M_3P_0	6.81	6.40	6.61	20.36	17.76	19.06	11.42	8.41	9.91
M_3P_{40}	8.52	8.36	8.44	21.57	18.72	20.15	11.80	9.85	10.83
M_3P_{60}	9.68	9.33	9.50	25.34	22.30	23.82	13.92	12.10	13.01
M_3P_{80}	11.09	11.55	11.32	26.94	25.00	25.97	15.34	14.69	15.01
SEm±	***0.25***	***0.27***	***0.18***	***0.48***	***0.53***	***0.36***	***0.45***	***0.33***	***0.28***
CD (P=0.05)	***0.73***	***0.79***	***0.53***	***1.41***	***1.56***	***1.02***	***1.32***	***0.96***	***0.80***

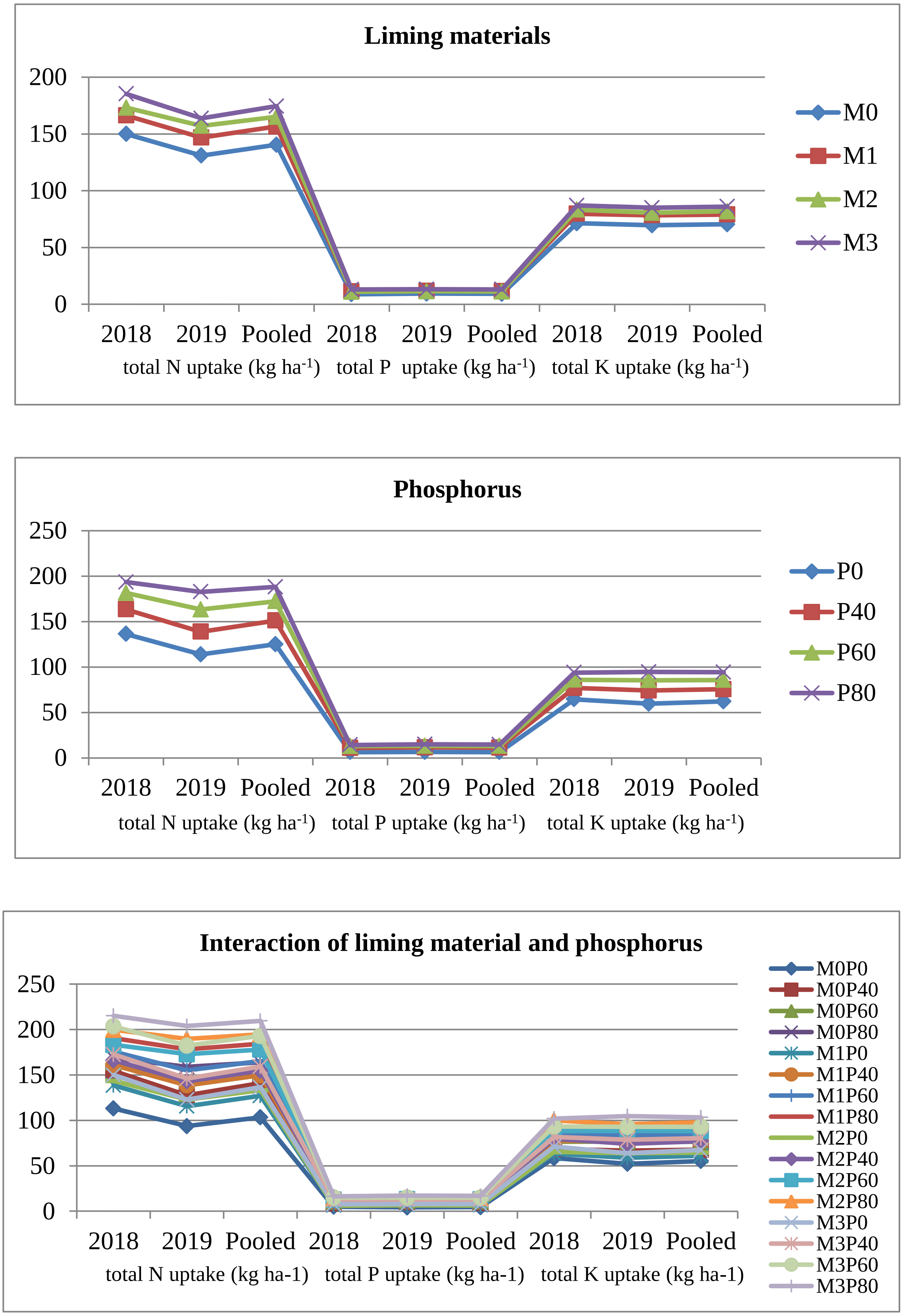
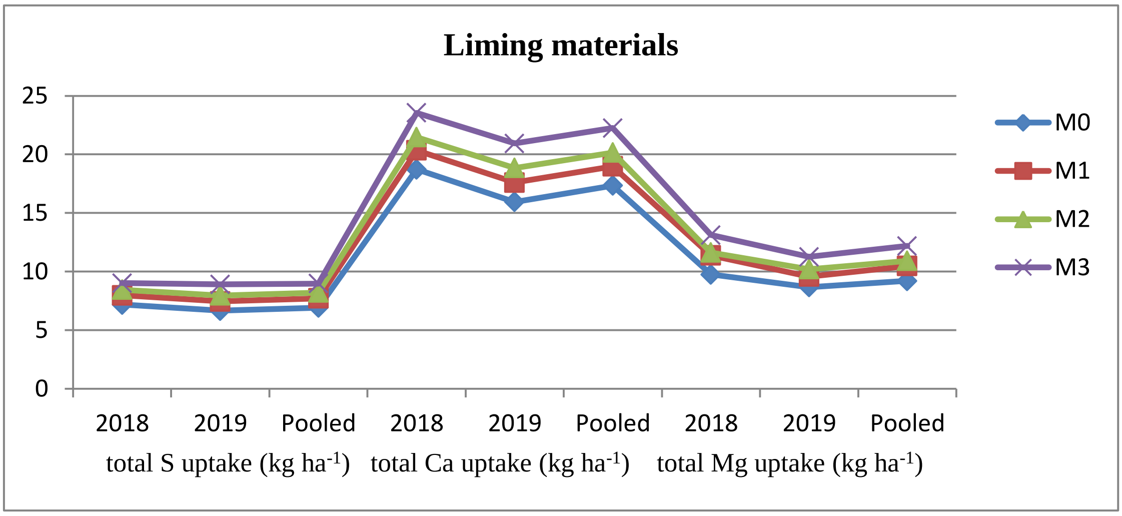
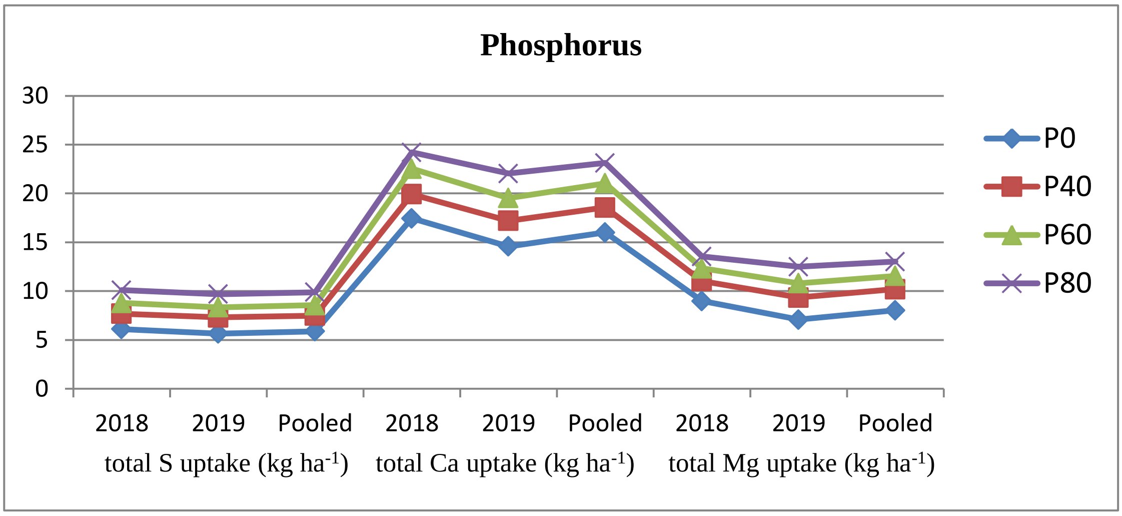


Fig. 20 Effect of liming materials, phosphorus levels and interaction on total uptake of N, P and K by soybean crop





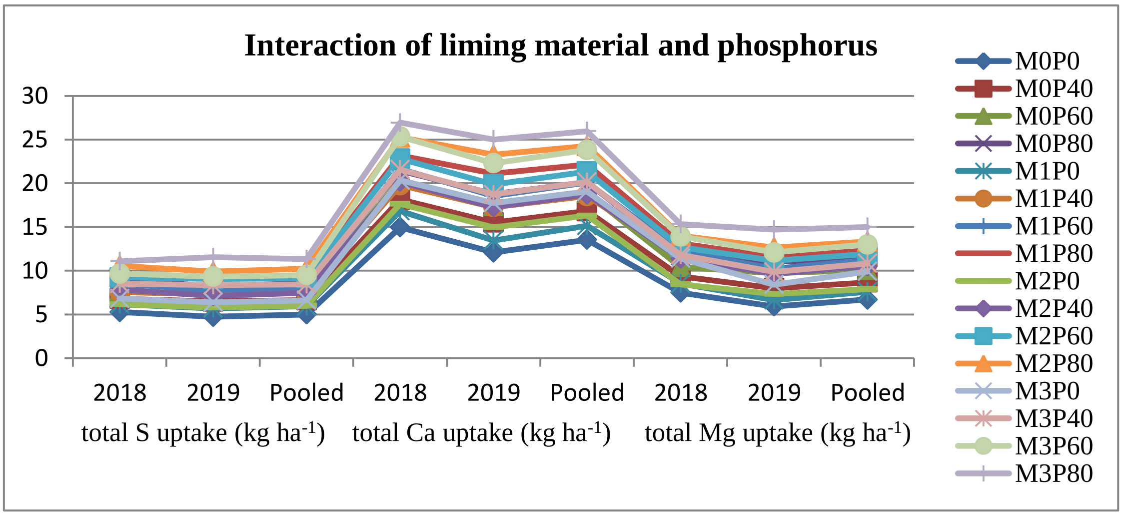


Fig. 21 Effect of liming materials, phosphorus levels and interaction on total uptake S, Ca and Mg by soybean crop

pooled data it recorded 103.41 kg ha^{-1}, 4.60 kg ha^{-1} and 55.31 kg ha^{-1}, 5.00 kg ha^{-1}, 13.53 kg ha^{-1} and 6.71 kg ha^{-1} respectively.

The increased N uptake might be due to favourable effect of liming material and phosphorus on root nodulation and higher nitrogen fixation. Ashoka *et al*., (2014) observed that lime and P increased biomass production, P concentration of shoot and root and its uptake by Indian spinach.

4.6. Effect on soil fertility after harvest

The results on the effect of liming materials and phosphorus on soil fertility after harvest are discussed below:

4.6.1. Effect on pH, organic carbon, bulk density and water holding capacity of soil after harvest

4.6.1.1. Effect of liming materials on pH, organic carbon, bulk density and water holding capacity of soil after harvest

The results on soil pH, organic carbon, bulk density and water holding capacity of soil after harvest by different treatments have been presented in table 4.6.1 (a) and Fig. 22. It was evident from the results that application of liming materials has significant effect on the soil pH. However, it was observed that with application of liming materials, there was slight increase in the soil pH. The highest soil pH was observed in the plots receiving CS @ 0.4 LR (M_3) which recorded 5.34 in both the year and pooled data while the lowest pH was observed with no liming materials (M_0) which recorded 5.16 and 5.05 with pooled data of 5.11 during 2018 and 2019, respectively.

Table 4.6.1 (a) and Fig. 22 presented the effect of liming materials on soil organic carbon. From the results obtained, it was apparent that liming materials had significant influence on soil organic carbon. The organic carbon content in soil after harvest was highest in the plots M_3 (CS @ 0.4 LR) which recorded 1.14 % and 1.20 % with pooled data of 1.17 % during 2018 and 2019, respectively.

As evident from the table 4.6.1 (a) and Fig. 22, application of liming materials did not any have significant effect on the bulk density. Bulk density of soil after harvest was highest in the plots receiving PMS @ 0.4 LR (M_2) which recorded 0.98 gcc^{-1} and 0.94 gcc^{-1} with pooled data 0.96 gcc^{-1}during 2018 and 2019, respectively.

The effect of liming materials on the water holding capacity (WHC) of soil after harvest was found to be significant. It was observed that highest soil WHC was recorded in the plots receiving CS @ 0.4 LR (M_3) which recorded 48.17 % and 49.18 % with pooled data 48.67 % during 2018 and 2019, respectively while the lowest WHC was observed with no liming materials (M_0) which recorded 46.77 % and 47.34 % with pooled data of 47.06% during 2018 and 2019, respectively.

The increase in soil pH under lime treatment was due to addition of CaO which reacts with water leading to production of OH^- ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH. Studies conducted revealed also that lime application lead to increased soil pH (Wijanarko and Taufiq 2016 and Nekesa *et al.*, 2005). In addition, Kisinyo *et al.*, (2012) attributed the soil pH increase in lime treatment as a result of H^+ and Al^{3+} ions displacement from soil adsorption sites by Ca^{2+} ions contained in lime. Liming significantly improved soil pH as reported by Anetor and Akinrinde (2006).

4.6.1.2. Effect of phosphorus on pH, organic carbon, bulk density and water holding capacity of soil after harvest

The results presented in 4.6.1 (a) and Fig. 22 revealed that application of phosphorus did not have any significant effect on soil pH. The application of phosphorus 80 kg P_2O_5 ha^{-1} recorded insignificantly higher pH values of 5.29 and 5.25 with pooled data of 5.27 during 2018 and 2019, respectively.

It was evident from the results that application of phosphorus did not have significant effect on the organic carbon content. However, it was observed that with application of phosphorus, there was slight increase in the soil organic carbon. The highest soil organic carbon was observed in the plots receiving 80 kg P_2O_5 ha^{-1} (P_{80}) which recorded 1.22 % and 1.26 % in both the year and pooled data as 1.24% while the lowest organic carbon was observed with no Phosphorus (P_0) which recorded 0.98% and 0.94 % with pooled data of 0.96 % during 2018 and 2019, respectively.

The results presented in 4.6.1 (a) and Fig. 22 revealed that application of phosphorus did not have any significant effect on bulk density. The highest soil bulk density was observed in the plots receiving 0 kg P_2O_5 ha^{-1} (P_0) which recorded 1.03 gcc^{-1} and 0.97 gcc^{-1} with pooled data 1.00 gcc^{-1} while the lowest bulk density was observed with 40 kg P_2O_5 ha^{-1} (P_2) which recorded 0.94 gcc^{-1} and 0.90 gcc^{-1} with pooled data of 0.91 gcc^{-1} during 2018 and 2019, respectively.

The effect of increase doses of phosphorus on the water holding capacity (WHC) of soil after harvest was found to be significant. It was observed that highest soil WHC was observed in the plots receiving 80 kg P_2O_5 ha^{-1} (P_{80}) which recorded 47.66 % and 48.69 % with pooled data 48.18 % during 2018 and 2019, respectively while the lowest WHC was observed with 0 kg P_2O_5 ha^{-1} (P_0) which recorded 46.83 % and 47.91 % with pooled data of 47.06 % during 2018 and 2019, respectively.

4.6.1.3. Interaction effect of liming materials and phosphorus on pH, organic carbon, bulk density and water holding capacity of soil after harvest

The result on interaction effect on soil pH, organic carbon, bulk density and water holding capacity of soil after harvest were presented in table 4.6.1 (b) and Fig. 22. It was apparent from the results that M_3P_0 recorded the highest

Table 4.6.1 (a) Effect of liming materials and phosphorus levels on pH, organic carbon, bulk density and WHC of soil after harvest

Treatments	pH			Organic carbon (%)			Bulk density (gcc^{-1})			WHC (%)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	5.16	5.05	5.11	1.06	1.08	1.07	0.95	0.88	0.92	46.77	47.34	47.06
M_1	5.32	5.32	5.32	1.11	1.11	1.11	0.97	0.93	0.95	46.58	47.68	47.13
M_2	5.32	5.20	5.26	1.02	1.12	1.07	0.98	0.94	0.96	46.67	47.75	47.21
M_3	5.34	5.34	5.34	1.14	1.20	1.17	0.99	0.89	0.94	48.17	49.18	48.67
Sem±	***0.02***	***0.02***	***0.02***	***0.02***	***0.02***	***0.02***	***0.03***	***0.03***	***0.02***	***0.10***	***0.14***	***0.08***
CD (p=0.05)	***0.09***	***0.06***	***0.05***	***0.08***	***0.08***	***0.05***	***NS***	***NS***	***NS***	***0.35***	***0.47***	***0.26***
P_0	5.30	5.25	5.27	0.98	0.94	0.96	1.03	0.97	1.00	46.41	47.02	46.71
P_{40}	5.29	5.21	5.25	1.05	1.12	1.09	0.95	0.90	0.92	46.83	47.91	47.37
P_{60}	5.26	5.20	5.23	1.09	1.19	1.14	0.94	0.87	0.91	47.30	48.34	47.82
P_{80}	5.29	5.25	5.27	1.22	1.26	1.24	0.97	0.90	0.94	47.66	48.69	48.18
Sem±	***0.03***	***0.03***	***0.02***	***0.03***	***0.02***	***0.02***	***0.02***	***0.03***	***0.02***	***0.11***	***0.18***	***0.10***
CD (p=0.05)	***NS***	***NS***	***NS***	***0.09***	***0.07***	***0.05***	***NS***	***NS***	***NS***	***0.31***	***0.51***	***0.29***

Table 4.6.1 (b) Interaction effect of liming materials and phosphorus levels on pH, organic carbon, bulk density and WHC of soil after harvest

Treatments	pH			Organic carbon (%)			Bulk density (gcc^{-1})			WHC (%)		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	5.10	4.93	5.02	0.98	0.92	0.95	1.03	0.94	0.99	46.20	45.53	45.86
M_0P_{40}	5.17	5.00	5.08	1.05	1.01	1.03	0.93	0.88	0.91	46.51	47.46	46.99
M_0P_{60}	5.18	5.10	5.14	1.07	1.18	1.13	0.90	0.85	0.88	46.84	47.92	47.38
M_0P_{80}	5.20	5.17	5.18	1.15	1.21	1.18	0.95	0.85	0.90	47.53	48.46	48.00
M_1P_0	5.33	5.40	5.37	0.96	0.91	0.93	1.01	1.03	1.02	45.74	46.73	46.24
M_1P_{40}	5.31	5.34	5.33	1.03	1.11	1.07	0.96	0.91	0.94	46.34	47.59	46.97
M_1P_{60}	5.34	5.24	5.29	1.12	1.13	1.12	0.94	0.90	0.92	46.93	47.99	47.46
M_1P_{80}	5.29	5.30	5.30	1.32	1.30	1.31	0.97	0.87	0.92	47.33	48.42	47.88
M_2P_0	5.37	5.22	5.30	0.94	0.93	0.93	1.02	0.97	1.00	46.23	47.30	46.77
M_2P_{40}	5.35	5.17	5.26	0.98	1.17	1.07	0.98	0.89	0.94	46.56	47.65	47.10
M_2P_{60}	5.22	5.19	5.20	0.99	1.19	1.09	0.93	0.85	0.89	46.45	47.55	47.00
M_2P_{80}	5.35	5.23	5.29	1.19	1.20	1.20	0.98	1.05	1.02	47.44	48.50	47.97
M_3P_0	5.39	5.44	5.41	1.04	1.01	1.03	1.04	0.95	1.00	47.49	48.50	47.99
M_3P_{40}	5.33	5.35	5.34	1.15	1.21	1.18	0.92	0.90	0.91	47.89	48.92	48.41
M_3P_{60}	5.32	5.27	5.29	1.17	1.25	1.21	1.01	0.87	0.94	48.97	49.90	49.44
M_3P_{80}	5.33	5.31	5.32	1.21	1.35	1.28	1.00	0.83	0.91	48.34	49.38	48.86
Sem±	***0.05***	***0.06***	***0.04***	***0.06***	***0.05***	***0.04***	***0.05***	***0.05***	***0.04***	***0.21***	***0.35***	***0.21***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

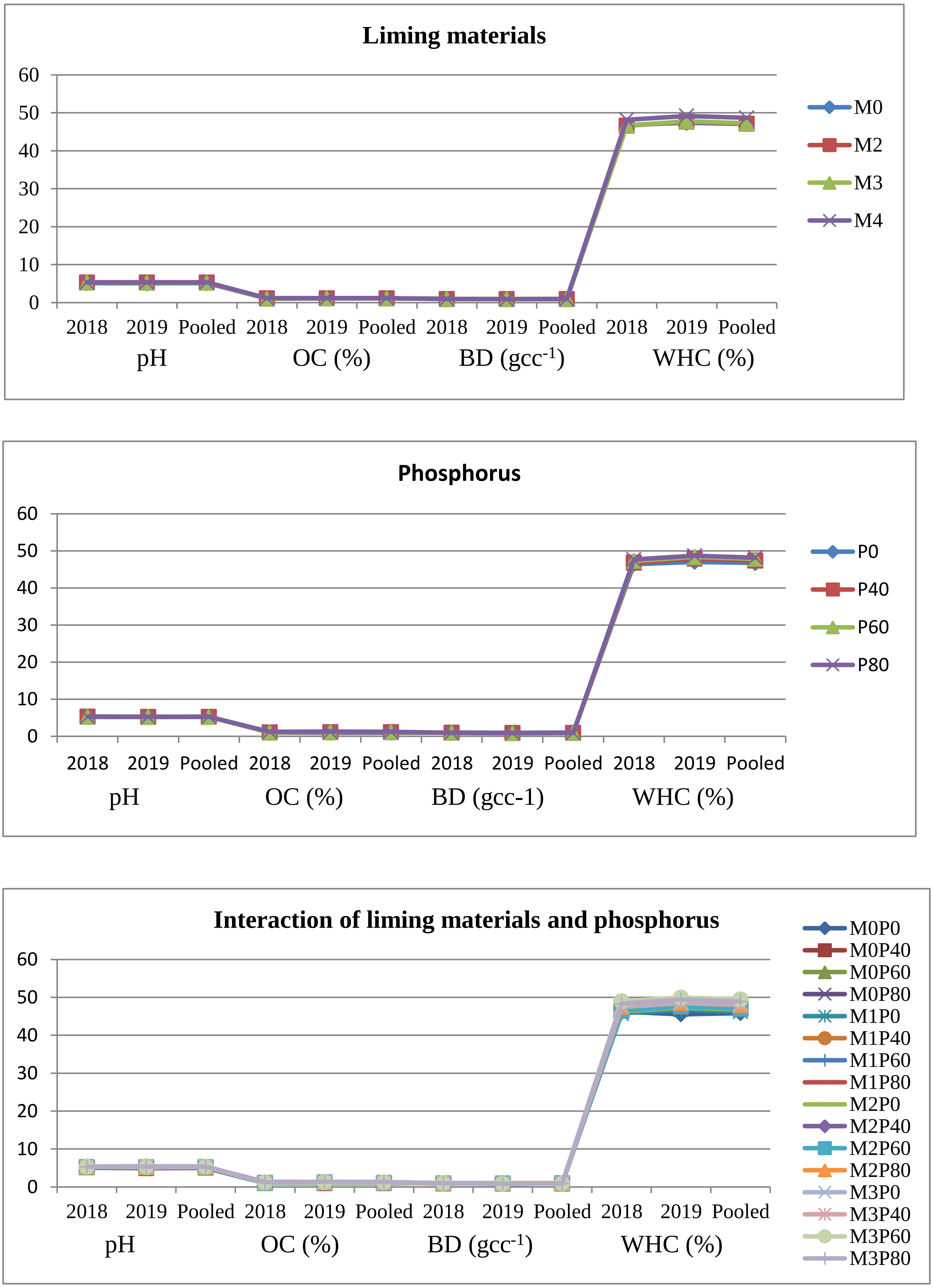


Fig. 22 Effect of liming materials, phosphorus levels and interaction levels on pH, organic carbon, bulk density and WHC of soil after harvest

pH 5.39 and 5.44 and in pooled data 5.41 during 2018 and 2019, respectively. It was observed that M_0P_0 recorded the lowest pH 5.10 and 4.93 with pooled data of 5.02 during 2018 and 2019, respectively. The results revealed that increasing levels of phosphorus fertilization along liming materials application slightly increased the pH of soil however, it was found to be non-significant.

The highest organic carbon content in soil was observed when treatment M_3P_{80} was applied which recorded 1.21 % and 1.35 % both in 2018 and 2019 and 1.24 % in the pooled while the lowest observed in the control M_0P_0 which recorded 0.92 % and 0.92 % in 2018 and 2019 respectively with pooled data of 0.95 %. The interaction between liming materials and phosphorus was found to be non-significant

The results revealed that M_1P_0 and M_2P_{80} recorded the highest bulk density of 0.98 gcc^{-1} and 1.05 gcc^{-1} in 2018 and 2019, respectively and with the pooled data of 1.02 gcc^{-1}. The treatment M_0P_{60} recorded the lowest bulk density of 0.90 gcc^{-1} and 0.85 gcc^{-1} in 2018 and 2019 and in pooled data of 0.88 gcc^{-1}.There was no significant interaction effect between liming materials and phosphorus.

As evident from the results, there was no significant interaction effect between liming materials and phosphorus on the water holding capacity (WHC) of soil after harvested. The result revealed that M_3P_{60} recorded the highest WHC 48.97 % and 49.90 % with pooled data of 49.44 % during 2018and 2019 respectively. The lowest WHC was observed with control treatment M_0P_0 which recorded 46.20 % and 45.53 % with pooled data as 45.86 during 2018 and 2019, respectively.

4.6.2. Effect on available N, P, K and S in soil after harvest

4.6.2.1. Effect of liming materials on available N, P, K and S in soil after harvest

The data presented in table 4.6.2 (a) and Fig. 23 revealed that application of liming materials had significant influenced on available N and P in soil after harvest. The results indicated that M_3 recorded maximum available N and P as 302.74 kg ha^{-1} and 311.22 kg ha^{-1} and 13.24 kg ha^{-1} and 12.86 kg ha^{-1} with pooled data as 306.98 kg ha^{-1} and 13.05 kg ha^{-1} during 2018 kg ha^{-1} and 2019 respectively. The minimum available N and P in soil after harvest were observed in M_0 as 275.89 kg ha^{-1} and 277.86 kg ha^{-1} and 11.08 kg ha^{-1} and 12.24 kg ha^{-1} during 2018 and 2019 respectively while the pooled data had 276.87 kg ha^{-1} and 11.66 kg ha^{-1}.

The maximum available K and S were recorded in M_0 as 202.93 kg ha^{-1} and 212.09 kg ha^{-1} and 1.21 kg ha^{-1} and 1.31 mg kg^{-1} and pooled data as 207.51 kg ha^{-1} and 1.26 mg kg^{-1} during 2018 and 2019 respectively. The minimum available K and S were observed in M_0 as 219.20 kg ha^{-1} and 218.46 kg ha^{-1} and 1.15 mg kg^{-1} and 1.11 mg kg^{-1} and pooled data as 218.83 kg ha^{-1} and 1.13 mg kg^{-1} during 2018 and 2019 respectively. The results revealed that application of different liming materials did not have any significant influence on the available K and S in soil after harvest.

The available N in soil after harvest increased significantly except in control plot. The build-up in available N in the soil might be due to improved nutrient availability resulting in higher root activity and nitrogen fixation. Dey and Nath (2015) observed that substantial increased available N, P, K and S of soil with application lime (10 % of actual LR was followed)

4.6.2.2. Effect of phosphorus on available N, P, K and S in soil after harvest

The results presented in 4.6.2 (a) and Fig. 23 revealed that application of phosphorus had significant influenced on available N, P and S in soil after harvest. The results indicated that P_{80} recorded maximum available N, P and S as 306.67 kg ha^{-1} and 316.48 kg ha^{-1}, 13.88 kg ha^{-1} and 15.35 kg ha^{-1} and 1.31 mg kg^{-1} and 1.34 mg kg^{-1} with pooled data as 311.58 kg ha^{-1}, 14.61 kg ha^{-1} and

1.33 mg kg^{-1} during 2018 kg ha^{-1} and 2019 respectively. The minimum available N, P and S in soil after harvest were observed in P_0 as 275.94 kg ha^{-1} and 271.45 kg ha^{-1}, 9.93 kg ha^{-1} and 9.92 kg ha^{-1} and 1.03 mg kg^{-1} and 1.00 mg kg^{-1} during 2018 and 2019 respectively while the pooled data had 273.69 kg ha^{-1}, 9.92 kg ha^{-1} and 1.01 mg kg^{-1}.

The minimum available K was recorded in P_{80} as 198.13 kg ha^{-1} and 202.37 pooled data as 200.25 kg ha^{-1} during 2018 and 2019 respectively. The maximum available K was observed in P_0 as 221.50 kg ha^{-1} and 221.63 kg ha^{-1} and pooled data as 211.57 kg ha^{-1} during 2018 and 2019 respectively. The results revealed that application of phosphorus did not have any significant influence on the available K in soil after harvest.

The increased in available N in soil could be due to improvement in nitrogen fixation through improved root activity and root nodulation. Bhakare and Sonar (1998) found that application of 100 kg P_2O_5 ha^{-1} to soybean showed increase in soil available N, P and K which could be attributed to higher P fertilization and a leguminous crop soybean having the tendency to fix the atmospheric N and defoliation, thereby increasing organic matter.

4.6.2.3. Interaction effect of liming materials and phosphorus on available N, P, K and S in soil after harvest

From the data depicted in table 4.6.2 (b) and Fig. 23, it has been observed that available N and P in soil after harvest were significantly influenced by the interaction of liming materials and phosphorus. The maximum available N and P were recorded with M_3P_{80} as 314.76 kg ha^{-1} and 330.92 kg ha^{-1} and 15.33 kg ha^{-1} and 16.80 kg ha^{-1} with pooled data as 322.84 kg ha^{-1} and 16.07 kg ha^{-1} during 2018 and 2019 respectively. The minimum available N and P were recorded with M_0P_0 as 269.70 kg ha^{-1} and 260.97 kg ha^{-1} and 8.45 kg ha^{-1} and 9.57 kg ha^{-1} with pooled data as 265.33 kg ha^{-1} and 9.01 kg ha^{-1} during 2018 and 2019 respectively.

As evident from the results, the interaction between liming materials and phosphorus did not have any significant influenced on available K and S in soil after harvest. It was observed that M_0P_0 recorded the highest available K as 226.53 kg ha^{-1} and 225.27 kg ha^{-1} during 2018 and 2019 respectively, while the pooled data had 225.90 kg ha^{-1}. It was revealed that the lowest available K recorded in M_3P_{80} as 193.47 kg ha^{-1} and 212.79 kg ha^{-1} during 2018 and 2019 respectively, while the pooled data had 203.13 kg ha^{-1}. It was revealed that the highest available S recorded in M_3P_{80} as 1.37 mg kg^{-1} and 1.47 mg kg^{-1} during 2018 and 2019 respectively, while the pooled data had 1.42 mg kg^{-}. It was observed that M_0P_0 recorded the lowest available S as^{1}1.03 mg kg^{-1} and 0.91 mg kg^{-1} during 2018 and 2019 respectively, while the pooled data had 0.97 mg kg^{-1}.

The increased in available nitrogen in soil could be due to improved nitrogen fixation through improved root activity and root nodulation. The precipitation of Al^{3+} and H^+ by lime causes the pH to increase, enhances microbial activity and nutrient availability (Onwonga *et al*., 2008). Lime improved soil available P as reported by Anetor and Akinrinde (2006), who also attributed increased soil pH with lime which in turn reduced P fixation. The results are in agreement with the findings of Bhakare and Sonar (1998).

4.6.3. Effect on available Fe, Mn and Zn in soil after harvest

4.6.3.1. Effect of liming materials on available Fe, Mn and Zn in soil after harvest

From the results presented in table 4.6.3 (a), and Fig. 24 it has observed that application liming materials did not have any significant influence on the

Table 4.6.2 (a) Effect of liming materials and phosphorus levels on available N, P K and S content in soil after harvest

Treatments	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})			S (mg kg^{-1})		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	275.89	277.86	276.87	11.08	12.24	11.66	219.20	218.46	218.83	1.15	1.11	1.13
M_1	292.03	290.42	291.23	11.82	11.50	11.66	201.57	206.24	203.90	1.19	1.20	1.19
M_2	297.11	298.61	297.86	12.59	13.06	12.83	210.51	207.24	208.87	1.21	1.22	1.22
M_3	302.74	311.22	306.98	13.24	12.86	13.05	202.93	212.09	207.51	1.21	1.31	1.26
Sem±	***2.85***	***1.63***	***1.64***	***0.31***	***0.31***	***0.22***	***4.13***	***5.38***	***3.39***	***0.03***	***0.02***	***0.02***
CD (p=0.05)	***9.87***	***5.63***	***5.06***	***1.07***	***1.08***	***0.67***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
P_0	275.94	271.45	273.69	9.93	9.92	9.92	221.50	221.63	221.57	1.03	1.00	1.01
P_{40}	288.52	288.77	288.65	11.89	11.33	11.61	210.78	215.59	213.18	1.18	1.22	1.20
P_{60}	296.65	301.40	299.02	13.04	13.06	13.05	203.80	204.44	204.12	1.24	1.28	1.26
P_{80}	306.67	316.48	311.58	13.88	15.35	14.61	198.13	202.37	200.25	1.31	1.34	1.33
Sem±	***2.14***	***1.73***	***1.38***	***0.21***	***0.30***	***0.18***	***6.68***	***6.37***	***4.61***	***0.02***	***0.03***	***0.02***
CD (p=0.05)	***6.26***	***5.06***	***3.92***	***0.61***	***0.88***	***0.52***	***NS***	***NS***	***NS***	***0.06***	***0.08***	***0.05***

Table 4.6.2 (b) Interaction effect of liming materials and phosphorus levels on available N, P and K content in soil after harvest

Treatments	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})			S (mg kg^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	269.70	260.97	265.33	8.45	9.57	9.01	226.53	225.27	225.90	1.03	0.91	0.97
M_0P_{40}	272.67	271.32	271.99	11.19	12.17	11.68	222.69	220.85	221.77	1.14	1.13	1.14
M_0P_{60}	275.00	287.46	281.23	12.27	12.78	12.53	215.78	216.88	216.33	1.18	1.17	1.17
M_0P_{80}	286.19	291.69	288.94	12.39	14.44	13.42	211.79	210.85	211.32	1.26	1.23	1.25
M_1P_0	276.51	271.85	274.18	9.68	9.71	9.69	222.12	221.86	221.99	1.02	1.06	1.04
M_1P_{40}	286.56	281.01	283.78	11.83	10.62	11.22	197.64	218.97	208.30	1.20	1.19	1.20
M_1P_{60}	291.60	294.64	293.12	12.47	12.14	12.31	195.81	194.98	195.40	1.23	1.26	1.25
M_1P_{80}	313.46	314.19	313.83	13.31	13.51	13.41	190.71	189.14	189.93	1.30	1.28	1.29
M_2P_0	278.53	270.22	274.37	10.78	10.01	10.40	223.78	223.09	223.44	1.07	1.01	1.04
M_2P_{40}	288.67	292.13	290.40	11.65	11.48	11.57	215.14	210.95	213.05	1.19	1.20	1.20
M_2P_{60}	308.98	302.93	305.96	13.46	14.10	13.78	206.57	198.19	202.38	1.27	1.29	1.28
M_2P_{80}	312.28	329.14	320.71	14.49	16.65	15.57	196.54	196.71	196.63	1.32	1.37	1.35
M_3P_0	279.04	282.76	280.90	10.79	10.37	10.58	213.58	216.30	214.94	0.99	1.01	1.00
M_3P_{40}	306.17	310.64	308.41	12.90	11.04	11.97	207.64	211.57	209.61	1.20	1.35	1.28
M_3P_{60}	311.01	320.57	315.79	13.94	13.22	13.58	197.04	207.71	202.38	1.29	1.38	1.34
M_3P_{80}	314.76	330.92	322.84	15.33	16.80	16.07	193.47	212.79	203.13	1.37	1.47	1.42
Sem±	***4.29***	***3.47***	***2.76***	***0.42***	***0.60***	***0.37***	***13.36***	***12.74***	***9.23***	***0.04***	***0.05***	***0.03***
CD (p=0.05)	***12.52***	***10.12***	***7.84***	***1.23***	***1.75***	***1.04***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

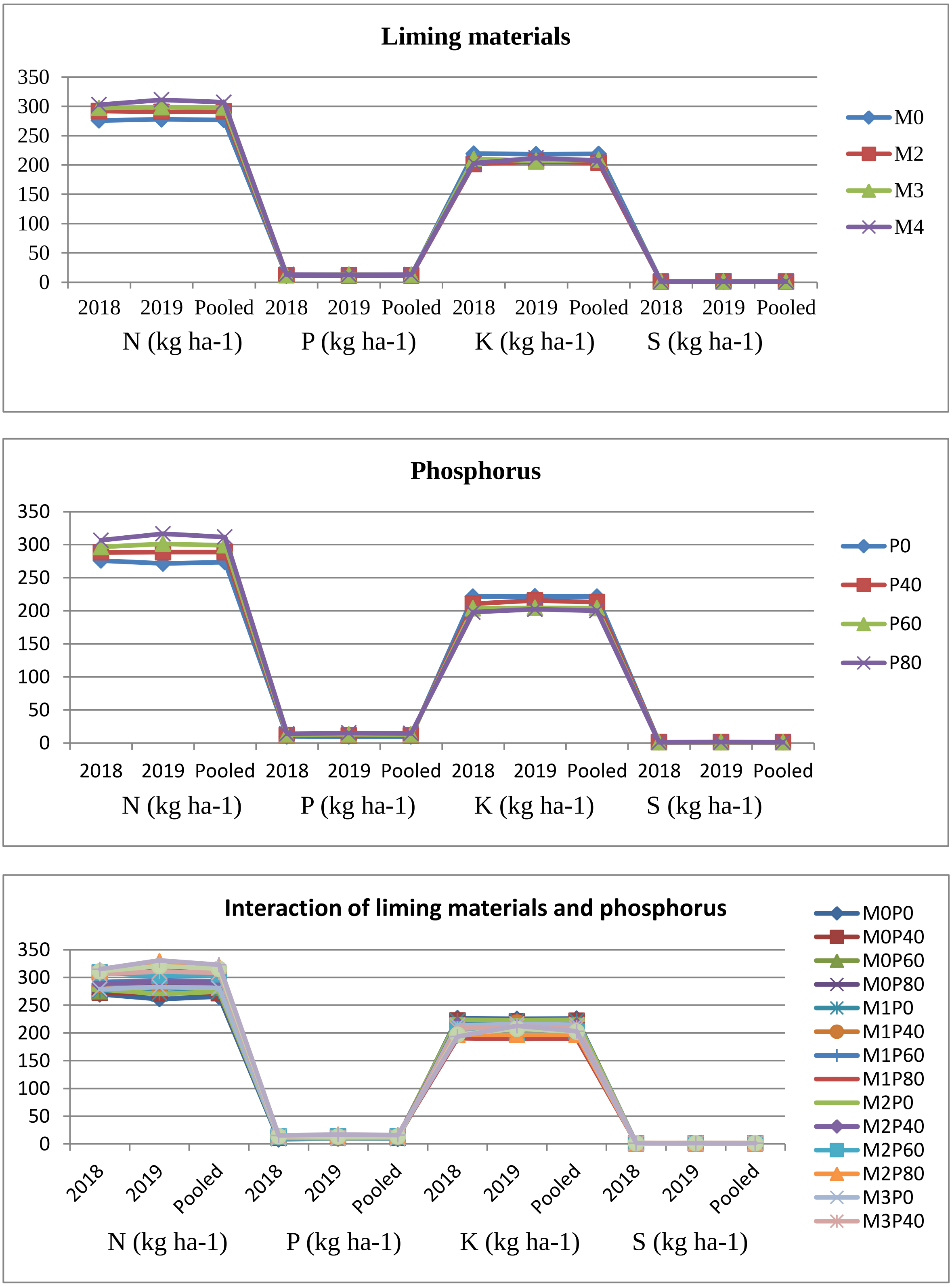


Fig. 23 Effect of liming materials, phosphorus levels and interaction on available N, P, K and S content in soil after harvest

available Fe, Mn and Zn in the soil after harvest. The highest available Fe, Mn and Zn were recorded with no liming materials (M_0) as 40.00 mg kg^{-1} and 38.90 mg kg^{-1}, 26.85 mg kg^{-1} and 24.65 mg kg^{-1} and 1.13 mg kg^{-1} and 1.10 mg kg^{-1} during 2018 and 2019, respectively, while the pooled data had 39.45 mg kg^{-1}, 25.75 mg kg^{-1} and 1.11 mg kg^{-1} respectively. The lowest available Fe, Mn and Zn were recorded with in CS @ 0.4 LR (M_3) as 37.78 mg kg^{-1} and 35.67 mg kg^{-1}, 26.51 mg kg^{-1} and 23.79 mg kg^{-1} and 1.02 mg kg^{-1} and 1.05 mg kg^{-1} during 2018 and 2019, respectively, while the pooled data had 36.73 mg kg^{-1}, 25.15 mg kg^{-1} and 1.04 mg kg^{-1} respectively.

4.6.3.2. Effect of phosphorus on available Fe, Mn and Zn in soil after harvest

From the results presented in table 4.6.3 (a), and Fig. 24 it has observed that application phosphorus did not have any significant influence on the available Fe, Mn and Zn in the soil after harvest. The highest available Fe, Mn and Zn were recorded 0 kg P_2O_5 ha^{-1} (P_0) as 39.31 mg kg^{-1} and 38.51 mg kg^{-1}, 27.60 mg kg^{-1} and 26.65 mg kg^{-1} and 1.11 mg kg^{-1} and 1.09 mg kg^{-1} during 2018 and 2019, respectively, while the pooled data had 38.91 mg kg^{-1}, 26.88 mg kg^{-1} and 1.10 mg kg^{-1} respectively. The lowest available Fe, Mn and Zn were recorded with in 80 kg P_2O_5 ha^{-1} (P_{80}) as 38.37 mg kg^{-1} and 36.42 mg kg^{-1}, 26.48 mg kg^{-1} and 23.52 mg kg^{-1} and 1.03 mg kg^{-1} and 1.00 mg kg^{-1} during 2018 and 2019, respectively, while the pooled data had 37.39 mg kg^{-1}, 25.00 mg kg^{-1} and 1.02 mg kg^{-1} respectively.

4.6.3.3. Interaction effect of liming materials and phosphorus on available Fe, Mn and Zn in soil after harvest

The interaction effect between liming materials and phosphorus on available Fe, Mn and Zn in soil after harvest has been presented on 4.6.3 (b), and Fig. 24. The results revealed that M_0P_0 gave the highest available Fe, Mn and Zn recorded 40.92 mg kg^{-1} and 40.77 mg kg^{-1}, 27.91 mg kg^{-1} and 26.80 mg

Table 4.6.3 (a) Effect of liming materials and phosphorus levels on Fe, Mn and Zn content in soil after harvest

Treatments	Fe (mg kg^{-1})			Mn (mg kg^{-1})			Zn (mg kg^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	40.00	38.90	39.45	26.69	25.29	25.99	1.13	1.10	1.11
M_1	38.80	37.37	38.09	26.80	24.69	25.74	1.02	1.05	1.04
M_2	38.22	37.18	37.70	26.51	23.79	25.15	1.11	1.03	1.07
M_3	37.78	35.67	36.73	26.85	24.65	25.75	1.05	1.05	1.05
Sem±	***0.53***	***0.67***	***0.43***	***0.44***	***0.69***	***0.41***	***0.03***	***0.04***	***0.02***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
P_0	39.31	38.51	38.91	27.60	26.15	26.88	1.11	1.09	1.10
P_{40}	38.68	37.68	38.18	26.37	24.63	25.50	1.12	1.09	1.10
P_{60}	38.44	36.51	37.47	26.39	24.12	25.25	1.05	1.04	1.04
P_{80}	38.37	36.42	37.39	26.48	23.52	25.00	1.03	1.00	1.02
Sem±	***0.61***	***0.84***	***0.52***	***0.41***	***0.66***	***0.39***	***0.03***	***0.03***	***0.02***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Table 4.6.3 (b) Interaction effect of liming materials and phosphorus levels on Fe, Mn and Zn content in soil after harvest

Treatments	Fe (mg kg^{-1})			Mn (mg kg^{-1})			Zn (mg kg^{-1})		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	40.92	40.77	40.85	27.91	26.80	27.36	1.17	1.16	1.17
M_0P_{40}	40.27	39.06	39.66	26.99	25.31	26.15	1.14	1.13	1.13
M_0P_{60}	39.62	37.40	38.51	26.62	25.45	26.04	1.11	1.09	1.10
M_0P_{80}	39.19	38.36	38.78	25.25	23.58	24.41	1.09	1.02	1.05
M_1P_0	39.53	38.89	39.21	27.00	26.31	26.66	1.05	1.07	1.06
M_1P_{40}	38.52	37.21	37.87	26.00	24.78	25.39	1.10	1.10	1.10
M_1P_{60}	38.17	36.06	37.12	26.69	24.78	25.74	0.97	1.05	1.01
M_1P_{80}	38.98	37.31	38.15	27.48	22.88	25.18	0.96	0.98	0.97
M_2P_0	38.63	37.13	37.88	27.42	25.81	26.61	1.09	1.03	1.06
M_2P_{40}	38.04	38.20	38.12	26.21	24.22	25.21	1.14	1.08	1.11
M_2P_{60}	37.99	37.13	37.56	26.16	22.84	24.50	1.09	1.01	1.05
M_2P_{80}	38.24	36.25	37.24	26.24	22.31	24.27	1.10	0.99	1.05
M_3P_0	38.17	37.26	37.72	28.08	25.69	26.89	1.13	1.11	1.12
M_3P_{40}	37.90	36.25	37.07	26.29	24.20	25.25	1.07	1.06	1.07
M_3P_{60}	37.98	35.44	36.71	26.06	23.39	24.73	1.01	1.02	1.02
M_3P_{80}	37.06	33.74	35.40	26.94	25.31	26.13	0.97	1.03	1.00
Sem±	***1.22***	***1.68***	***1.04***	***0.83***	***1.32***	***0.78***	***0.05***	***0.06***	***0.04***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

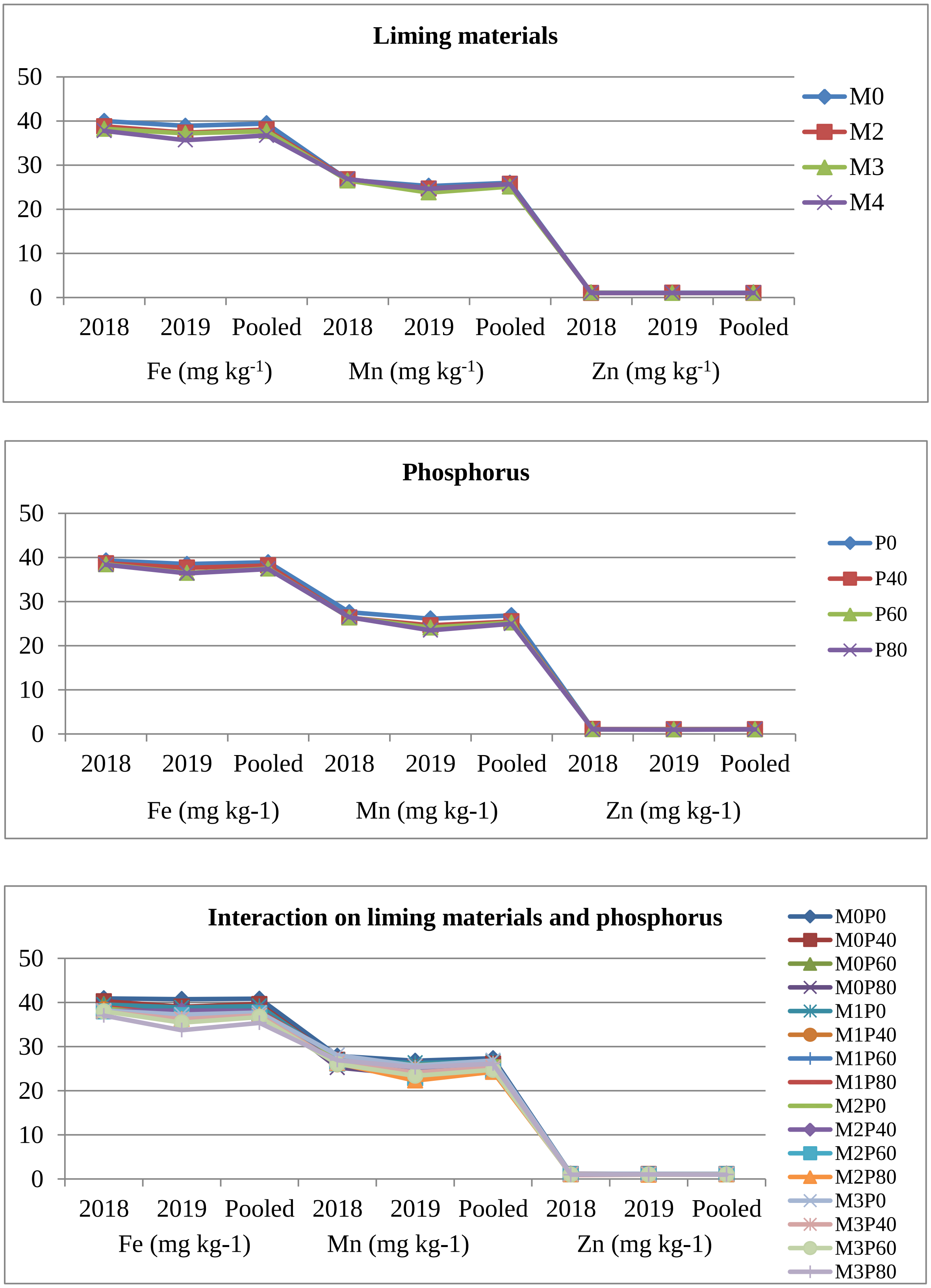


Fig. 24 Effect of liming materials, phosphorus levels and interaction on Fe, Mn and Zn content in soil after harvest

kg^{-1} and 1.17 mg kg^{-1} and 1.16 mg kg^{-1} while M_3P_{80} recorded the lowest with 37.06 mg kg^{-1} and 33.74 mg kg^{-1}, 26.94 mg kg^{-1} and 25.31 mg kg^{-1} and 0.97 mg kg^{-1} and 1.03 mg kg^{-1} during both the year 2018 and 2019, respectively. The interaction effect between liming materials and phosphorus was found to be non significant on available Fe, Mn and Zn in soil after harvest.

The highest lime and phosphorus rate resulted in a decrease in the levels of Fe, Mn and Zn in soil after harvest (Amsalu and Beyene, 2020). The similar resulted was found by Buni, 2014.

4.6.4. Effect on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest

4.6.4.1. Effect of liming materials on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest

As evident from table 4.6.4 (a) and Fig. 25, application of liming materials had significant influence on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+} and CEC of soil after harvest. The maximum exchangeable Ca^{2+}, Mg^{2+} and CEC was observed with M_3 which recorded 2.25 cmol (p^+) kg^{-1} and 2.44 cmol (p^+) kg^{-1}, 0.85 cmol (p^+) kg^{-1} and 0.99 cmol (p^+) kg^{-1} and 8.69 cmol (p^+) kg^{-1} and 9.76 cmol (p^+) kg^{-1} and pooled data of 2.34 cmol (p^+) kg^{-1}, 0.92 cmol (p^+) kg^{-1} and 9.22 cmol (p^+) kg^{-1} in 2018 and 2019, respectively. The lowest exchangeable Ca^{2+}, Mg^{2+} and CEC was observed with M_0 which recorded 1.86 cmol (p^+) kg^{-1} and 2.07 cmol (p^+) kg^{-1}, 0.73 cmol (p^+) kg^{-1} and 0.72 cmol (p^+) kg^{-1} and 7.65 cmol (p^+) kg^{-1} and 8.40 cmol (p^+) kg^{-1} and pooled data 1.96 cmol (p^+) kg^{-1}, 0.72 cmol (p^+) kg^{-1} and 8.03 cmol (p^+) kg^{-1} in 2018 and 2019, respectively.

The maximum exchangeable Al^{3+} was recorded where M_0 (No liming material) was applied which recorded 0.81 cmol (p^+) kg^{-1} and 0.79 cmol (p^+) kg^{-1} and pooled data of 0.80 cmol (p^+) kg^{-1} during 2018 and 2019, respectively.

The lowest exchangeable Al^{3+} was recorded in plots where CS @ 0.4 LR (M_3) which recorded 0.70 cmol (p^+) kg^{-1} and 0.70 cmol (p^+) kg^{-1} and pooled data of 0.70 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively.

The results obtained revealed that the effect of liming materials on exchange acidity was non significant. The maximum on exchange acidity of soil was observed with M_3 which recorded 2.04 cmol (p^+) kg^{-1} and 1.97 cmol (p^+) kg^{-1} and pooled data of 2.00 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively. The lowest exchange acidity of soil was observed with M_0 which recorded 1.67 cmol(p^+)kg^{-1} and 1.49 cmol (p^+) kg^{-1} and pooled data of 1.58 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively.

The increase in soil pH under lime treatment was due to addition of CaO which reacts with water leading to production of OH- ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH and decreasing exchangeable acidity. Studies conducted revealed also that lime application lead to increased soil pH and decreased soil exchangeable acidity (Opala, 2017 and Nekesa *et al.,* 2005). Buni (2014) revealed that application of lime showed significantly increased CEC. The lime resulted in an increased exchangeable Ca^{2+} and Mg^{2+} and a decrease in the levels of exchangeable Al^{3+} (Amsalu and Beyene, 2020)

4.6.4.2. Effect of phosphorus on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest

The results presented in table 4.6.4 (a) and Fig. 25 revealed that application of phosphorus didn't have any significant influence on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+} and CEC of soil after harvest. The maximum exchangeable Ca^{2+}, Mg^{2+} and CEC was observed with P_{80} which recorded 2.06 cmol (p^+) kg^{-1} and 2.28 cmol (p^+) kg^{-1}, 0.82 cmol (p^+) kg^{-1} and 0.90 cmol (p^+) kg^{-1} and 8.44 cmol (p^+) kg^{-1} and 9.51 cmol (p^+) kg^{-1} and pooled data of 2.17 cmol (p^+) kg^{-1}, 0.86 cmol (p^+) kg^{-1} and 8.98 cmol (p^+) kg^{-1} in 2018 and 2019, respectively. The lowest exchangeable Ca^{2+}, Mg^{2+} and CEC was observed with P_0 which recorded 2.02 cmol (p^+) kg^{-1} and 2.26 cmol (p^+) kg^{-1}, 0.80 cmol (p^+) kg^{-1} and 0.87 cmol (p^+) kg^{-1} and 8.04 cmol (p^+) kg^{-1} and 8.79 cmol (p^+) kg^{-1} and pooled data 2.14 cmol (p^+) kg^{-1}, 0.84 cmol (p^+) kg^{-1} and 8.42 cmol (p^+) kg^{-1} in 2018 and 2019, respectively.

The maximum exchangeable Al^{3+} was recorded where P_0 (0 kg P_2O_5 ha^{-1}) was applied which recorded 0.79 cmol (p^+) kg^{-1} and 0.75 cmol (p^+) kg^{-1} and pooled data of 0.77 cmol (p^+) kg^{-1} [1] during 2018 and 2019, respectively. The lowest exchangeable Al^{3+} was recorded in plots where 80 kg P_2O_5 ha^{-1} (P_{80}) which recorded 0.75 cmol (p^+) kg^{-1} and 0.75 cmol (p^+) kg^{-1} and pooled data of 0.75 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively.

The results obtained revealed that the effect of phosphorus on exchange acidity was found significant. The maximum on exchange acidity of soil was observed with P_0 which recorded 2.28 cmol (p^+) kg^{-1} and 2. cmol (p^+) kg^{-1} and pooled data of 2.24 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively. The lowest exchange acidity of soil was observed with P_{80} which recorded 1.47cmol (p^+) kg^{-1} and 0.87 cmol (p^+) kg^{-1} and pooled data of 1.17 cmol (p^+) kg^{-1} during 2018 1nd 2019 respectively.

This increase was due to improved soil conditions such as soil pH, increased soil Ca, Mg and K through mineralization and lime dissolution, reduction of exchangeable acidity which in turn increased the exchangeable sites of the soil.

4.6.4.3. Interaction effect of liming materials and phosphorus on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest

As evident from table 4.6.4 (b) and Fig. 24, the interaction between liming materials and phosphorus did not have any significant influence on the

Table 4.6.4 (a) Effect of liming materials and phosphorus levels on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, exchange acidity and CEC of soil after harvest

Treatments	**Exch. Ca^{2+} (cmol(p^+)kg^{-1})**			**Exch. Mg^{2+} (cmol(p^+)kg^{-1})**			**Exch. Al^{3+} (cmol(p^+)kg^{-1})**			**Exchange acidity (cmol(p^+)kg^{-1})**			**CEC (cmol(p^+)kg^{-1})**		
	2018	**2019**	**Pooled**	***2018***	***2019***	***Pooled***	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	1.86	2.07	1.96	0.73	0.71	0.72	0.81	0.79	0.80	1.67	1.49	1.58	7.65	8.40	8.03
M_1	2.01	2.25	2.13	0.82	0.93	0.87	0.77	0.74	0.76	1.47	1.44	1.45	8.32	9.39	8.85
M_2	2.06	2.31	2.19	0.83	0.94	0.89	0.74	0.71	0.73	1.66	1.57	1.61	8.53	9.60	9.07
M_3	2.25	2.44	2.34	0.85	0.99	0.92	0.70	0.70	0.70	2.04	1.97	2.00	8.69	9.76	9.22
Sem±	***0.05***	***0.04***	***0.03***	***0.02***	***0.03***	***0.02***	***0.021***	***0.017***	***0.013***	***0.24***	***0.27***	***0.18***	***0.09***	***0.17***	***0.10***
CD (p=0.05)	***0.17***	***0.12***	***0.09***	***0.08***	***0.11***	***0.06***	***0.073***	***0.058***	***0.041***	***NS***	***NS***	***NS***	***0.33***	***0.60***	***0.30***
P_0	2.02	2.26	2.14	0.80	0.87	0.84	0.79	0.75	0.77	2.28	2.19	2.24	8.04	8.79	8.42
P_{40}	2.05	2.25	2.15	0.81	0.90	0.85	0.74	0.73	0.74	1.40	1.76	1.58	8.27	9.34	8.80
P_{60}	2.04	2.27	2.16	0.81	0.89	0.85	0.75	0.72	0.73	1.68	1.65	1.67	8.44	9.51	8.97
P_{80}	2.06	2.28	2.17	0.82	0.90	0.86	0.75	0.75	0.75	1.47	0.87	1.17	8.44	9.51	8.98
Sem±	***0.04***	***0.05***	***0.03***	***0.02***	***0.02***	***0.01***	***0.020***	***0.024***	***0.016***	***0.20***	***0.21***	***0.15***	***0.11***	***0.20***	***0.11***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.59***	***0.63***	***0.42***	***NS***	***NS***	***NS***

Table 4.6.4 (b) Interaction effect of liming materials and phosphorus levels on Exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest

Treatments	Exch. Ca^{2+} (cmol(p^+)kg^{-1})			Exch. Mg^{2+} (cmol(p^+)kg^{-1})			Exch. Al^{3+} (cmol(p^+)kg^{-1})			Exchange acidity (cmol(p^+)kg^{-1})			CEC (cmol(p^+)kg^{-1})		
	2018	**2019**	**Pooled**	***2018***	***2019***	**Pooled**	**2018**	**2019**	***Pooled***	**2018**	**2019**	**Pooled**	***2018***	***2019***	**Pooled**
M_0P_0	1.81	2.00	1.90	0.70	0.71	0.71	0.88	0.82	0.85	2.13	1.80	1.97	7.57	7.36	7.46
M_0P_{40}	1.85	2.02	1.94	0.72	0.70	0.71	0.81	0.80	0.81	1.70	1.61	1.65	7.63	8.70	8.17
M_0P_{60}	1.88	2.16	2.02	0.77	0.73	0.75	0.77	0.75	0.76	1.73	1.63	1.68	7.80	8.87	8.34
M_0P_{80}	1.89	2.09	1.99	0.71	0.69	0.70	0.79	0.80	0.80	1.10	0.93	1.02	7.60	8.67	8.14
M_1P_0	1.92	2.23	2.08	0.82	0.94	0.88	0.81	0.78	0.80	2.00	2.37	2.18	7.81	8.88	8.35
M_1P_{40}	1.98	2.25	2.12	0.83	0.95	0.89	0.71	0.67	0.69	0.97	1.07	1.02	8.27	9.34	8.80
M_1P_{60}	2.08	2.23	2.16	0.84	0.91	0.87	0.77	0.71	0.74	1.73	1.47	1.60	8.58	9.65	9.12
M_1P_{80}	2.03	2.28	2.16	0.79	0.92	0.86	0.80	0.79	0.80	1.17	0.87	1.02	8.62	9.69	9.15
M_2P_0	2.13	2.31	2.22	0.84	0.95	0.89	0.74	0.71	0.72	2.53	2.07	2.30	8.32	9.39	8.85
M_2P_{40}	2.03	2.33	2.18	0.83	0.94	0.88	0.77	0.75	0.76	1.10	2.23	1.67	8.53	9.60	9.07
M_2P_{60}	2.01	2.26	2.13	0.82	0.92	0.87	0.71	0.70	0.71	0.93	1.07	1.00	8.62	9.69	9.16
M_2P_{80}	2.07	2.35	2.21	0.85	0.96	0.90	0.73	0.70	0.72	2.07	0.90	1.48	8.65	9.72	9.19
M_3P_0	2.27	2.46	2.36	0.85	1.00	0.93	0.72	0.69	0.71	2.47	2.53	2.50	8.47	9.54	9.00
M_3P_{40}	2.23	2.43	2.33	0.86	1.02	0.94	0.68	0.70	0.69	1.83	2.13	1.98	8.64	9.71	9.18
M_3P_{60}	2.26	2.44	2.35	0.85	1.00	0.93	0.73	0.73	0.73	2.33	2.43	2.38	8.74	9.81	9.28
M_3P_{80}	2.23	2.42	2.33	0.86	0.92	0.89	0.68	0.70	0.69	1.53	0.77	1.15	8.89	9.96	9.43
Sem±	***0.09***	***0.10***	***0.07***	***0.03***	***0.05***	***0.03***	***0.041***	***0.048***	***0.031***	***0.41***	***0.43***	***0.30***	***0.22***	***0.40***	***0.23***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

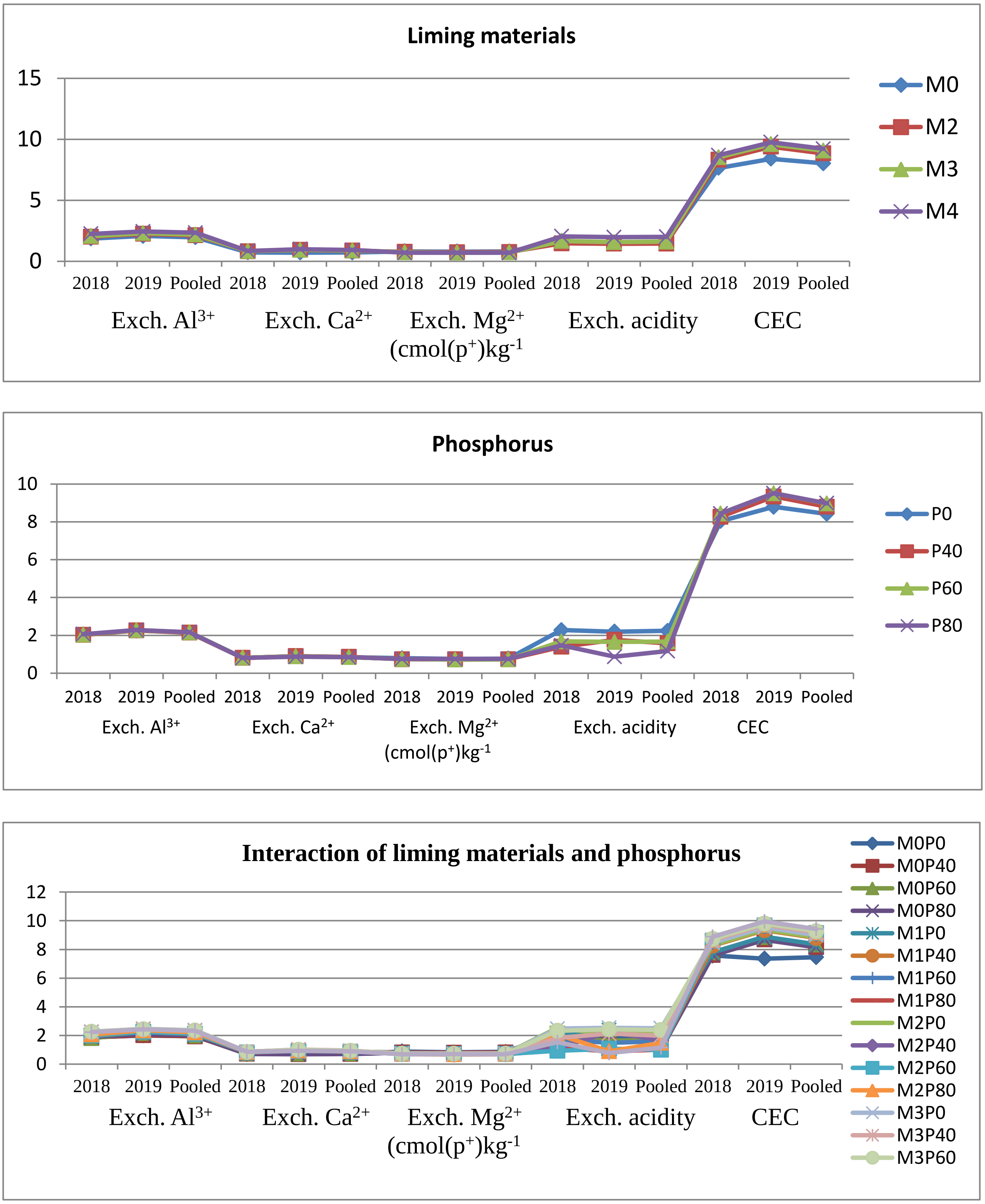


Fig. 25 Effect of liming materials, phosphorus levels and interaction on exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, exchange acidity and CEC of soil after harvest

exchangeable Al^{3+}, Ca^{2+}, Mg^{2+}, Exchange acidity and CEC of soil after harvest. The maximum exchangeable Ca^{2+} of 2.27 cmol (p^+) kg^{-1} and 2.46 cmol (p^+) kg^{-1} with pooled data of 2.36 cmol (p^+) kg^{-1} was observed with M_3P_0 (CS @ 0.4LR + 0 kg P_2O_5 ha^{-1}) while the lowest Ca^{2+} of 1.81 cmol (p^+) kg^{-1} and 2.00 cmol (p^+) kg^{-1} with pooled data of 1.90 was observed with M_0P_0 (control) during 2018 and 2019 respectively.

The maximum exchangeable Mg^{2+} of 0.86 cmol (p^+) kg^{-1} and 1.02 cmol (p^+) kg^{-1} with pooled data of 0.94 cmol (p^+) kg^{-1} was observed with M_3P_{40} (CS @ 0.4LR + 40 kg P_2O_5 ha^{-1}) while the lowest Ca^{2+} of 0.70 cmol (p^+) kg^{-1} and 0.71 cmol (p^+) kg^{-1} with pooled data of 0.71 cmol (p^+) kg^{-1} was observed with M_0P_0 (control) during 2018 and 2019 respectively.

The maximum Al^{3+} of 0.88 cmol (p^+) kg^{-1} and 0.82 cmol (p^+) kg^{-1} and pooled data of 0.85 cmol (p^+) kg^{-1} was observed with M_0P_0 (control) during 2018 and 2019 respectively where as the lowest was observed with M_3P_{80} (CS @ 0.4LR + 80 kg P_2O_5 ha^{-1}) which recorded 0.68 cmol (p^+) kg^{-1} and 0.70 cmol (p^+) kg^{-1} in 2018 and 2019 with pooled data of 0.69.

The maximum exchange acidity was recorded where M_0P_0 (control) which recorded 2.47 cmol (p^+) kg^{-1} and 2.53 cmol (p^+) kg^{-1} and pooled data of 2.50 cmol (p^+) kg^{-1} during 2018 and 2019, respectively. The lowest exchangeable exchange acidity was recorded in plots where M_1P_0 (WA@ 0.4LR + 0 kg P_2O_5 ha^{-1}) which recorded 0.97 cmol (p^+) kg^{-1} and 1.07 cmol (p^+) kg^{-1} and pooled data of 1.02 cmol (p^+) kg^{-1} during 2018 and 2019 respectively.

The highest CEC was observed with M_3P_{80} (CS @ 0.4LR + 80 kg P_2O_5 ha^{-1}) which recorded 8.89 and 9.96 with pooled data of 9.43 and M_0P_0 (control) obtained the lowest with 7.57 cmol (p^+) kg^{-1} and 7.36 cmol (p^+) kg^{-1} with pooled data of 7.46 cmol (p^+) kg^{-1} during 2018 and 2019 respectively. It was revealed that increased level of phosphorus along with application liming material increased the CEC in soil after harvest. However, the increased was observed to be non-significant.

4.6.5. Effect on soil respiration and soil microbial biomass carbon in soil after harvest

4.6.5.1. Effect of liming materials on soil respiration and soil microbial biomass carbon in soil after harvest

The results of soil respiration and soil microbial biomass carbon in soil after harvest have been presented in table 4.6.5 (a) and Fig. 26. The results revealed that application of liming material had a significant influence on soil respiration and soil microbial biomass carbon in soil after harvest. The highest soil respiration and soil microbial biomass carbon in soil after harvest were observed M_3 (CS @ 0.4 LR) as 7.37 $\mu g\,Cg^{-1}hr^{-1}$ and 7.82 $\mu g\,Cg^{-1}hr^{-1}$ and 301.32 $\mu g\,g^{-1}$ and 312.25 $\mu g\,g^{-1}$ during 2018 and 2019 respectively, while the pooled data had 7.59 $\mu g\,Cg^{-1}hr^{-1}$ and 306.78 $\mu g\,g^{-1}$. The lowest soil respiration and soil microbial biomass carbon in soil after harvest were recorded in M_0 as 7.05 $\mu g\,Cg^{-1}hr^{-1}$ and 7.33 $\mu g\,Cg^{-1}hr^{-1}$ and 277.41 $\mu g\,g^{-1}$ and 281.61 $\mu g\,g^{-1}$ during 2018 and 2019 respectively while the pooled data had 7.19 $\mu g\,Cg^{-1}hr^{-1}$ and 279.51 $\mu g\,g^{-1}$.

Similar finding on soil microbial biomass carbon reported by Gagnon *et al.*, (2001). The improve soil microbial biomass carbon might be due to improved plant nutrition which improved the soil organic matter content through higher root biomass. Fuentes *et al*. (2006) reported that application of lime at the rate of 4.4 ton ha-1 increased soil microbial biomass by 3.3 times which was attributed to increased soil pH.

4.6.5.2. Effect of phosphorus on soil respiration and soil microbial biomass carbon in soil after harvest

Table 4.6.5 (a) Effect of liming materials and phosphorus on levels soil respiration and SMBC of soil after harvest

Treatments	Soil respiration (µg C$g^{-1}$$hr^{-1}$)			SMBC (µg g^{-1})		
	2018	***2019***	***Pooled***	**2018**	**2019**	**Pooled**
M_0	7.05	7.33	7.19	277.41	281.62	279.51
M_1	7.02	7.47	7.24	286.85	294.15	290.50
M_2	7.18	7.63	7.41	296.91	305.61	301.26
M_3	7.37	7.82	7.59	301.32	312.25	306.78
Sem±	***0.03***	***0.03***	***0.02***	***1.02***	***1.16***	***0.77***
CD (p=0.05)	***0.11***	***0.11***	***0.07***	***3.51***	***4.01***	***2.37***
P_0	6.66	6.94	6.80	280.59	286.68	283.63
P_{40}	7.01	7.46	7.24	289.82	297.89	293.85
P_{60}	7.34	7.79	7.56	294.30	302.38	298.34
P_{80}	7.62	8.07	7.84	297.78	306.68	302.23
Sem±	***0.03***	***0.03***	***0.02***	***1.17***	***1.13***	***0.81***
CD (p=0.05)	***0.09***	***0.09***	***0.06***	***3.41***	***3.29***	***2.31***

Table 4.6.5 (b) Effect of liming materials and phosphorus on levels soil respiration and SMBC of soil after harvest

Treatments	**Soil respiration (µg Cg^{-1}hr^{-1})**			**SMBC (µg g^{-1})**		
	2018	**2019**	***Pooled***	**2018**	**2019**	**Pooled**
M_0P_0	6.53	6.30	6.42	275.60	273.83	274.72
M_0P_{40}	6.87	7.32	7.10	276.30	282.50	279.40
M_0P_{60}	7.26	7.71	7.49	278.00	284.20	281.10
M_0P_{80}	7.55	8.00	7.78	279.73	285.93	282.83
M_1P_0	6.64	7.09	6.86	278.13	285.43	281.78
M_1P_{40}	6.97	7.42	7.20	286.10	293.40	289.75
M_1P_{60}	7.17	7.62	7.40	290.97	298.27	294.62
M_1P_{80}	7.28	7.73	7.51	292.20	299.50	295.85
M_2P_0	6.71	7.16	6.94	280.47	289.17	284.82
M_2P_{40}	7.06	7.51	7.29	297.93	306.63	302.28
M_2P_{60}	7.40	7.85	7.62	303.13	311.83	307.48
M_2P_{80}	7.56	8.01	7.78	306.10	314.80	310.45
M_3P_0	6.75	7.20	6.98	288.17	298.27	293.22
M_3P_{40}	7.14	7.59	7.36	298.93	309.03	303.98
M_3P_{60}	7.51	7.96	7.74	305.10	315.20	310.15
M_3P_{80}	8.08	8.53	8.30	313.07	326.50	319.78
Sem±	***0.06***	***0.06***	***0.05***	***2.33***	***2.26***	***1.62***
CD (p=0.05)	***0.19***	***0.19***	***0.13***	***6.81***	***6.58***	***4.62***

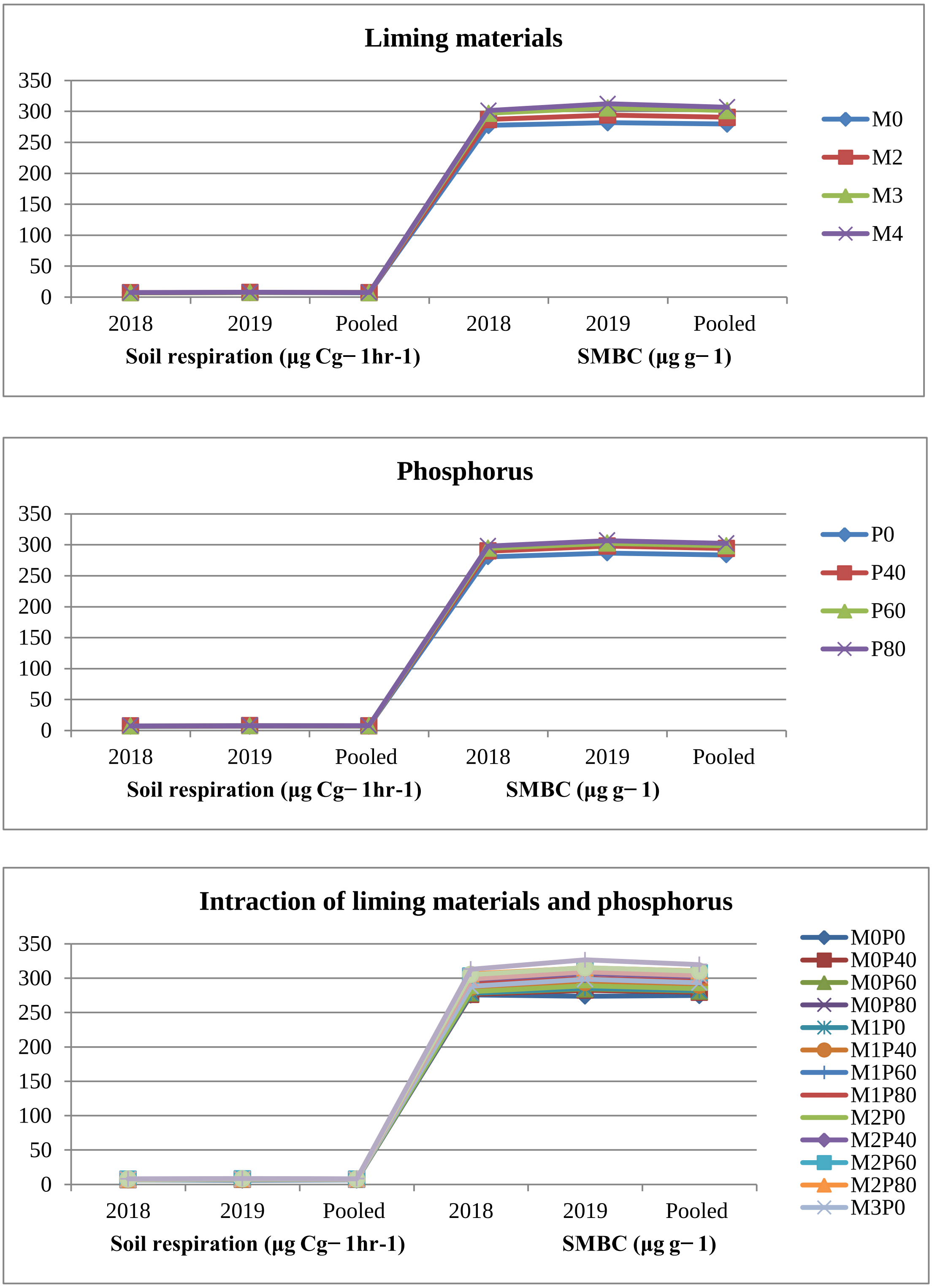


Fig. 26 Effect of liming materials, phosphorus levels and interaction soil respiration and SMBC of soil after harvest

From the data depicted in table 4.6.5 (a) and Fig. 26, it has been revealed that phosphorus fertilization upto 80 kg ha^{-1} significantly influence soil respiration and soil microbial biomass carbon in soil after harvest. The maximum soil respiration and soil microbial biomass carbon in soil after harvest were observed P_{80} (80 kg P_2O_5 ha^{-1}) which recorded 7.62 $\mu g\, C g^{-1} hr^{-1}$ and 8.07 $\mu g\, C g^{-1} hr^{-1}$ and 297.87 $\mu g\, g^{-1}$ and 306.86 $\mu g\, g^{-1}$ during 2018 and 2019 respectively while in the pooled data it was 7.84 $\mu g\, C g^{-1} hr^{-1}$ and 302.23 $\mu g\, g^{-1}$. The minimum soil respiration and soil microbial biomass carbon in soil after harvest was recorded in P_0 (0 kg P_2O_5 ha^{-1}) as 6.66 $\mu g\, C g^{-1} hr^{-1}$ and 6.94 $\mu g\, C g^{-1} hr^{-1}$ and 280.59 $\mu g\, g^{-1}$ and 286.68 $\mu g\, g^{-1}$ during 2018 and 2019 respectively, with pooled data as 6.80 $\mu g\, C g^{-1} hr^{-1}$ and 283.63 $\mu g\, g^{-1}$.

The increased soil microbial populations thus eventually increase the soil respiration and soil microbial biomass carbon.

4.6.5.3. Interaction effect of liming materials and phosphorus on soil respiration and soil microbial biomass carbon in soil after harvest

From the table 4.6.5 (b) and Fig. 26, it has become evident that the interaction between liming materials and phosphorus had significant effect on soil respiration and soil microbial biomass carbon in soil after harvest. Application of liming materials at all levels of phosphorus was found to increase the soil respiration and soil microbial biomass carbon in soil after harvest as compared to application of phosphorus alone. The maximum soil respiration and soil microbial biomass carbon has been observed with M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) which recorded 8.08 $\mu g\, C g^{-1} hr^{-1}$ and 8.53 $\mu g\, C g^{-1} hr^{-1}$ and 313.07 $\mu g\, g^{-1}$ and 326.50 $\mu g\, g^{-1}$ during 2018 and 2019 respectively with pooled data as 8.30 $\mu g\, C g^{-1} hr^{-1}$ and 319.78 $\mu g\, g^{-1}$ while minimum was observed with M_0P_0 which recorded 6.53 $\mu g\, C g^{-1} hr^{-1}$ and 6.30 $\mu g\, C g^{-1} hr^{-1}$ and 275.60 $\mu g\, g^{-1}$ and 273.83 $\mu g\, g^{-1}$ during 2018 and 2019 respectively with pooled data as 6.30 $\mu g\, C g^{-1} hr^{-1}$ and 274.72 $\mu g\, g^{-1}$.

Improved plant nutrition through lime material application along with phosphorus might have favoured as optional root rhizosphere which increased microbial populations and thereby increased the soil respiration and soil microbial biomass carbon. Gagnon *et al.*, (2001) also revealed that microbial populations in soil are enhanced with phosphorus. The increased soil microbial populations thus, eventually increased the soil microbial biomass carbon and soil respiration.

4.7. Effect on phosphorus fraction

The results on the effect of liming materials, phosphorus and their interaction on phosphorus fractions viz, saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest

4.7.1. Effect on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest

4.7.1.1. Effect of liming materials on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest

The effect of liming materials on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest has been shown in table 4.7.1 (a) and Fig. 27 and table 4.7..2 (a) and Fig. 28. The result revealed that liming materials significantly influence the saloid-P, Al-P, Fe-P, Ca-P and reductant-P content in soil after harvest. Among the liming materials, higher saloid-P content was observed when CS @ 0.4 LR (M_3) was applied which recorded saloid-P and Ca-P content of 6.42 mg kg^{-1} and 17.25 mg kg^{-1} and 7.62 mg kg^{-1} and18.17 mg kg^{-1} during the year 2018 and 2019, respectively with the pooled value of 7.02 mg kg^{-1} and 18.50 mg kg^{-1}. The lower saloid-P and Ca-P content was observed in no liming material (M_0) which recorded corresponding value of 5.79 mg kg^{-1} and 6.73 mg kg^{-1} and 14.88 mg kg^{-1} and 16.96 mg kg^{-1} during year 2018 and 2019, respectively with pooled value of 6.26 mg kg^{-1} and 15.96 mg kg^{-1}. The maximum Al-P, Fe-P and reductant-P content in soil after harvest was observed in plots receiving no liming material (M_0) which recorded Al-P, Fe-P and reductant-P of 38.25 mg kg^{-1} and 38.64 mg kg^{-1}, 48.63 mg kg^{-1} and 50.16 mg kg^{-1} and 71.88 mg kg^{-1} and 69.38 mg kg^{-1} during the year 2018 and 2019, respectively with the pooled value of 38.44 mg kg^{-1}, 49.39 mg kg^{-1} and 70.63 mg kg^{-1} respectively. The lowest Al-P, Fe-P and reductant-P content was observed in CS @ 0.4 LR (M_3) which recorded corresponding value of 30.25 mg kg^{-1} and 31.71 mg kg^{-1}, 40.54 mg kg^{-1} and 42.84 mg kg^{-1} and 67.83 mg kg^{-1} and 65.33 mg kg^{-1} during year 2018 and 2019, respectively with pooled value of 30.98 mg kg^{-1}, 41.69 mg kg^{-1} and 66.58 mg kg^{-1} respectively. occluded-P and organic–P content in soil after harvest did not have any significant influence. The maximum occluded-P and organic–P content was recorded where PMS @ 0.4 LR (M_2) was applied which recorded 48.46 mg kg^{-1} and 46.99 mg kg^{-1} and 386.25 mg kg^{-1} and 381.54 mg kg^{-1} and pooled data of 47.72 mg kg^{-1} and 383.90 mg kg^{-1} during 2018 and 2019, respectively. The lowest occluded-P was recorded in plots where CS @ 0.4 LR (M_3) which recorded 46.21 mg kg^{-1} and 44.04 mg kg^{-1} and pooled data of 45.13 mg kg^{-1} during 2018 1nd 2019 respectively. The lowest organic–P was recorded in plots where no liming material (M_0) which recorded 334.75 mg kg^{-1} and 318.93 mg kg^{-1} and pooled data of 326.84 mg kg^{-1} during 2018 1nd 2019 respectively.

The application of lime significantly affected the different P fraction. Significantly increased Saloid-P and Ca-P and deceased Al-P and Fe-P by application liming in acid soil (Kiflu *et al*.,2017)

4.7.1.2. Effect of phosphorus on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest

The effect of phosphorus application on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest has been shown in table 4.7.1 (a) and Fig. 27 and table 4.7..2 (a) and Fig. 28. The result revealed that phosphorus application significantly influence the saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest. The highest saloid-P, Al-P, Fe-P, Ca-P and organic–P content was observed when 80 kg P_2O_5 ha^{-1} (P_{80}) was applied which recorded saloid-P, Al-P, Fe-P, Ca-P and organic–P content of 7.38 mg kg^{-1} and 8.58 mg kg^{-1}, 34.13 mg kg^{-1} and 35.59 mg kg^{-1}, 44.63 m

g kg^{-1} and 46.93 mg kg^{-1}, 18.25 mg kg^{-1} and 20.58 mg kg^{-1} and 405.67 mg kg^{-1} and 401.87 mg kg^{-1} during the year 2018 and 2019, respectively with the pooled value of 7.98 mg kg^{-1}, 34.86 mg kg^{-1}, 45.78 mg kg^{-1}, 19.42 mg kg^{-1} and 403.77 mg kg^{-1} respectively. The lower saloid-P, Al-P, Fe-P, Ca-P and organic–P content was observed in 0 kg P_2O_5 ha^{-1} (P_0) which recorded corresponding value of 4.83 mg kg^{-1} and 5.78 mg kg^{-1}, 30.38 mg kg^{-1} and 30.76 mg kg^{-1}, 40.63 mg kg^{-1} and 42.16 mg kg^{-1}, 13.25 mg kg^{-1} and 15.50 mg kg^{-1} and 329.33 mg kg^{-1} and 319.10 mg kg^{-1} during year 2018 and 2019, respectively with pooled value of 5.30 mg kg^{-1}, 30.76 mg kg^{-1}, 41.39 mg kg^{-1}, 14.38 mg kg^{-1} and 324.22 mg kg^{-1} mg kg^{-1} respectively. The maximum reductant-P and occluded-P content in soil after harvest was observed in plots receiving 0 kg P_2O_5 ha^{-1} (P_0) which recorded reductant-P and occluded-P of 73.08 mg kg^{-1} and 70.58 mg kg^{-1} and 53.00 mg kg^{-1} and 51.54 mg kg^{-1} during the year 2018 and 2019, respectively with the pooled value of 71.83 mg kg^{-1} and 52.27 mg kg^{-1} respectively. The lowest reductant-P and occluded-P content was observed in 80 kg P_2O_5 ha^{-1} (P_{80}) which recorded corresponding value of 67.58 mg kg^{-1} and 65.08 mg kg^{-1} and 41.50 mg kg^{-1} and 40.13 mg kg^{-1} during year 2018 and 2019, respectively with pooled value of 66.33 mg kg^{-1} and 40.81 mg kg^{-1} respectively.

The transformation of a major portion of applied inorganic P to Al-P Fe-P in acid soil was reported by Tripathi and Minhas (1991) and Karmakar and Barthakur (1995). Increase in Fe-P and Al-P at the expense of Ca-P and reductant-P in a Vertisol was also reported by Dikshit *et al*. (1994). Decrease in reductant –P and occluded-P could be due to the release of trapped-P in these

Table 4.7.1 (a) Effect of liming materials and phosphorus levels on saloid-P, Al-P, Fe-P and Ca-P content in soil after harvest

Treatments	Saloid-P (mg kg^{-1})			Al-P (mg kg^{-1})			Fe-P (mg kg^{-1})			Ca-P (mg kg^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	5.79	6.73	6.26	38.25	38.64	38.44	48.63	50.16	49.39	14.88	16.96	15.92
M_1	6.08	7.28	6.68	31.13	32.59	31.86	41.04	43.34	42.19	15.92	18.42	17.17
M_2	6.04	7.33	6.68	30.33	31.79	31.06	40.79	43.09	41.94	15.67	18.17	16.92
M_3	6.42	7.62	7.02	30.25	31.71	30.98	40.54	42.84	41.69	17.25	19.75	18.50
Sem±	***0.08***	***0.09***	***0.06***	***0.46***	***0.60***	***0.38***	***0.73***	***0.64***	***0.49***	***0.41***	***0.47***	***0.31***
CD (p=0.05)	***0.29***	***0.32***	***0.19***	***1.59***	***2.07***	***1.16***	***2.53***	***2.22***	***1.50***	***1.42***	***1.63***	***0.96***
P_0	4.83	5.78	5.30	30.38	30.76	30.57	40.63	42.16	41.39	13.25	15.50	14.38
P_{40}	5.71	6.91	6.31	32.25	33.71	32.98	42.00	44.30	43.15	15.08	17.58	16.33
P_{60}	6.42	7.70	7.06	33.21	34.67	33.94	43.75	46.05	44.90	17.13	19.63	18.38
P_{80}	7.38	8.58	7.98	34.13	35.59	34.86	44.63	46.93	45.78	18.25	20.58	19.42
Sem±	***0.10***	***0.14***	***0.09***	***0.50***	***0.76***	***0.46***	***0.69***	***1.09***	***0.64***	***0.21***	***0.25***	***0.17***
CD (p=0.05)	***0.31***	***0.41***	***0.25***	***1.47***	***2.22***	***1.30***	***2.00***	***3.19***	***1.83***	***0.62***	***0.74***	***0.47***

Table 4.7.1 (b) Interaction effect of liming materials and phosphorus levels on saloid-P, Al-P, Fe-P and Ca-P content in soil after harvest

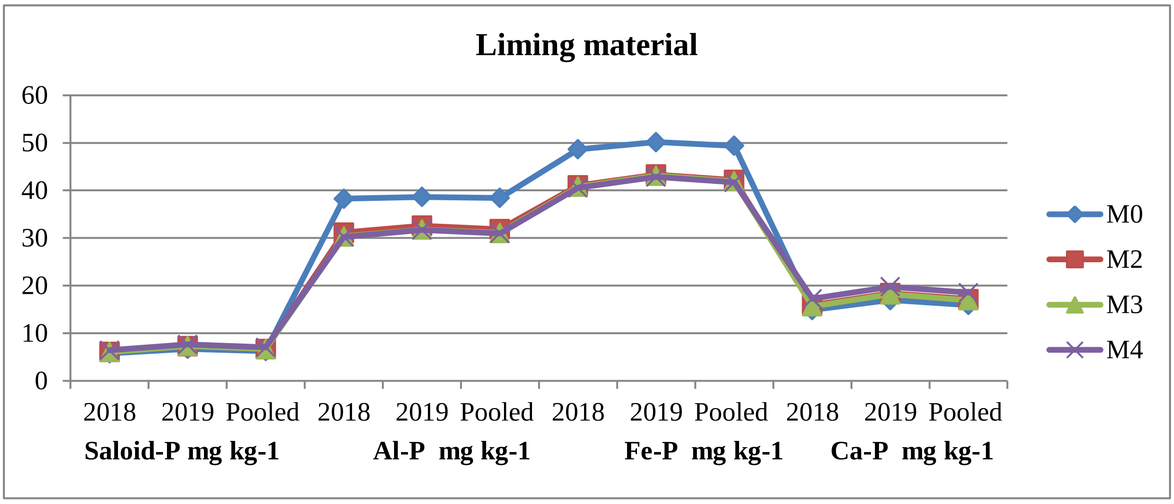
Treatments	Saloid-P (mg kg^{-1})			Al-P (mg kg^{-1})			Fe-P (mg kg^{-1})			Ca-P (mg kg^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	4.17	4.33	4.25	32.83	30.00	31.42	43.33	42.57	42.95	11.00	12.50	11.75
M_0P_{40}	5.33	6.53	5.93	38.00	39.46	38.73	45.83	48.13	46.98	13.67	16.17	14.92
M_0P_{60}	6.17	7.37	6.77	40.17	41.63	40.90	51.67	53.97	52.82	16.67	19.17	17.92
M_0P_{80}	7.50	8.70	8.10	42.00	43.46	42.73	53.67	55.97	54.82	18.17	20.00	19.08
M_1P_0	4.67	5.87	5.27	30.17	31.63	30.90	40.17	42.47	41.32	14.33	16.83	15.58
M_1P_{40}	5.83	7.03	6.43	30.83	32.29	31.56	40.83	43.13	41.98	15.17	17.67	16.42
M_1P_{60}	6.67	7.87	7.27	31.50	32.96	32.23	41.33	43.63	42.48	16.50	19.00	17.75
M_1P_{80}	7.17	8.37	7.77	32.00	33.46	32.73	41.83	44.13	42.98	17.67	20.17	18.92
M_2P_0	5.00	6.20	5.60	29.50	30.96	30.23	39.67	41.97	40.82	13.17	15.67	14.42
M_2P_{40}	6.00	7.20	6.60	30.33	31.79	31.06	40.83	43.13	41.98	14.83	17.33	16.08
M_2P_{60}	6.00	7.53	6.77	30.50	31.96	31.23	41.00	43.30	42.15	16.83	19.33	18.08
M_2P_{80}	7.17	8.37	7.77	31.00	32.46	31.73	41.67	43.97	42.82	17.83	20.33	19.08
M_3P_0	5.50	6.70	6.10	29.00	30.46	29.73	39.33	41.63	40.48	14.50	17.00	15.75
M_3P_{40}	5.67	6.87	6.27	29.83	31.29	30.56	40.50	42.80	41.65	16.67	19.17	17.92
M_3P_{60}	6.83	8.03	7.43	30.67	32.13	31.40	41.00	43.30	42.15	18.50	21.00	19.75
M_3P_{80}	7.67	8.87	8.27	31.50	32.96	32.23	41.33	43.63	42.48	19.33	21.83	20.58
Sem±	***0.21***	***0.28***	***0.17***	***1.01***	***1.52***	***0.91***	***1.37***	***2.18***	***1.29***	***0.43***	***0.51***	***0.33***
CD (p=0.05)	***0.61***	***0.82***	***0.50***	***2.93***	***4.44***	***2.59***	***NS***	***NS***	***NS***	***1.24***	***1.48***	***0.94***

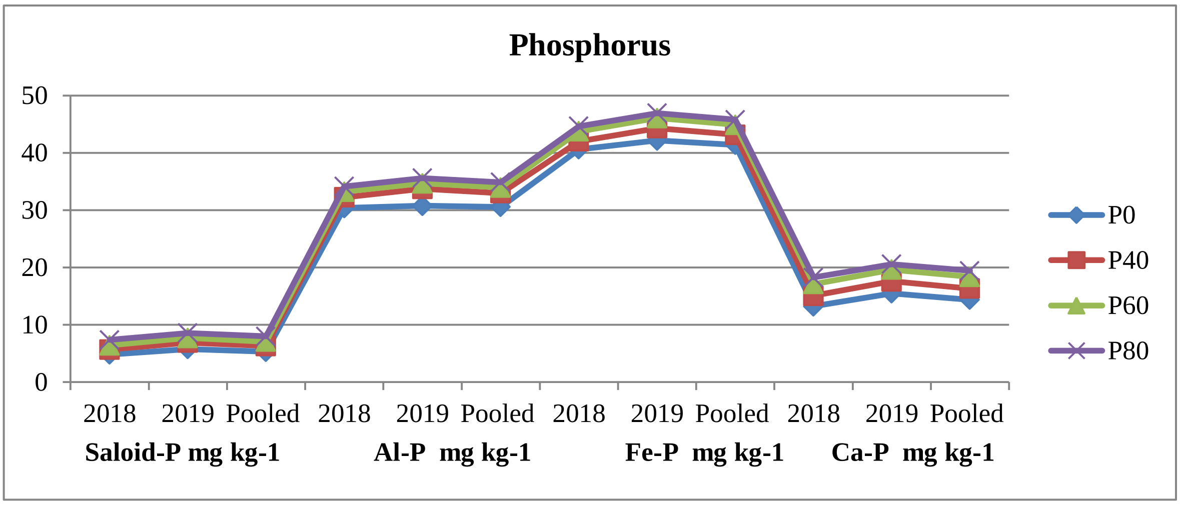
Table 4.7.2 (a) Effect of liming materials and phosphorus levels on reductant-P, occluded-P and organic–P of soil after harvest

Treatments	Reductant-P (mg kg^{-1})			Occluded-P (mg kg^{-1})			Organic–P (mg kg^{-1})		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0	71.88	69.38	70.63	46.42	45.04	45.73	334.75	318.93	326.84
M_1	71.00	68.50	69.75	47.88	46.88	47.38	359.83	349.55	354.69
M_2	69.54	67.04	68.29	48.46	46.99	47.72	386.25	381.54	383.90
M_3	67.83	65.33	66.58	46.21	44.04	45.13	384.08	380.37	382.23
Sem±	***0.79***	***0.79***	***0.56***	***0.94***	***1.76***	***1.00***	***13.58***	***13.77***	***9.67***
CD (p=0.05)	***2.73***	***2.73***	***1.72***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
P_0	73.08	70.58	71.83	53.00	51.54	52.27	329.33	319.10	324.22
P_{40}	70.63	68.13	69.38	49.17	48.08	48.62	341.50	333.38	337.44
P_{60}	68.96	66.46	67.71	45.29	43.21	44.25	388.42	376.04	382.23
P_{80}	67.58	65.08	66.33	41.50	40.13	40.81	405.67	401.87	403.77
Sem±	***0.67***	***0.67***	***0.47***	***0.70***	***1.46***	***0.81***	***7.50***	***7.38***	***5.26***
CD (p=0.05)	***1.94***	***1.94***	***1.34***	***2.05***	***4.26***	***2.30***	***21.89***	***21.55***	***14.96***

Table 4.7.2 (b) Interaction effect of liming materials and phosphorus levels on reductant-P, occluded-P and organic–P of soil after harvest

Treatments	Peductant-P (mg kg^{-1})			Occluded-P (mg kg^{-1})			Organic–P (mg kg^{-1})		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0P_0	76.17	73.67	74.92	52.33	51.33	51.83	280.17	277.27	278.72
M_0P_{40}	72.00	69.50	70.75	48.00	46.67	47.33	318.83	298.54	308.69
M_0P_{60}	70.50	68.00	69.25	44.33	42.50	43.42	362.17	325.71	343.94
M_0P_{80}	68.83	66.33	67.58	41.00	39.67	40.33	377.83	374.21	376.02
M_1P_0	74.17	71.67	72.92	53.00	52.67	52.83	308.50	278.87	293.69
M_1P_{40}	71.83	69.33	70.58	50.50	50.30	50.40	343.33	338.57	340.95
M_1P_{60}	69.50	67.00	68.25	45.17	44.00	44.58	364.33	360.54	362.44
M_1P_{80}	68.50	66.00	67.25	42.83	41.00	41.92	423.17	420.21	421.69
M_2P_0	71.17	68.67	69.92	53.67	52.33	53.00	379.50	375.87	377.69
M_2P_{40}	70.00	67.50	68.75	51.00	50.00	50.50	329.00	324.71	326.85
M_2P_{60}	69.17	66.67	67.92	47.50	43.50	45.50	434.33	429.37	431.85
M_2P_{80}	67.83	65.33	66.58	41.67	41.67	41.67	402.17	396.21	399.19
M_3P_0	70.83	68.33	69.58	53.00	49.83	51.42	349.17	344.37	346.77
M_3P_{40}	68.67	66.17	67.42	47.17	45.33	46.25	374.83	371.71	373.27
M_3P_{60}	66.67	64.17	65.42	44.17	42.83	43.50	392.83	388.54	390.69
M_3P_{80}	65.17	62.67	63.92	40.50	38.17	39.33	419.50	416.87	418.19
Sem±	***1.33***	***1.33***	***0.94***	***1.40***	***2.92***	***1.62***	***15.00***	***14.77***	***10.52***
CD (p=0.05)	***3.89***	***3.89***	***2.68***	***NS***	***NS***	***NS***	***43.77***	***43.10***	***29.92***





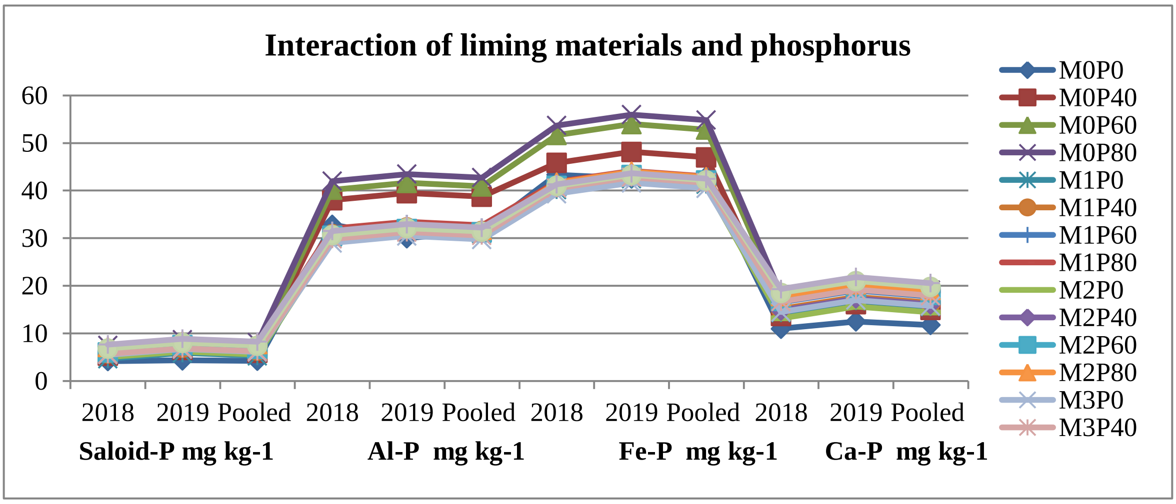


Fig. 27 Effect of liming materials, phosphorus levels and interaction on saloid-P, Al-P, Fe-P and Ca-P content in soil after harvest

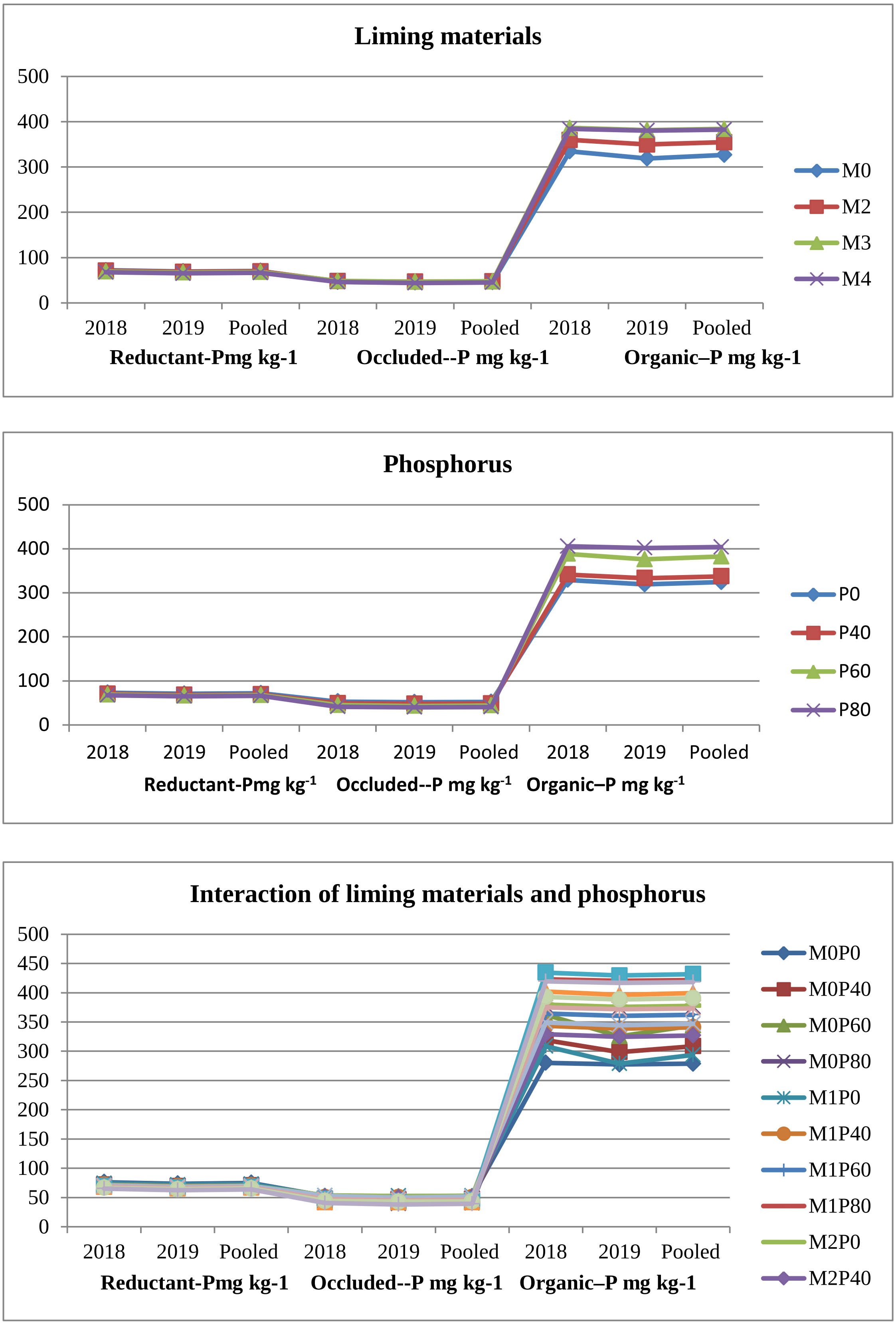


Fig.28 Effect of liming materials, phosphorus levels and interaction on reductant-P, occluded-P and organic–P of soil after harvest

two forms by higer microbial and root activities in the soil (Majumdar *et al*. 2007).

4.7.1.3. Interaction effect of liming materials and phosphorus on saloid-P, Al-P, Fe-P, Ca-P, reductant-P, occluded-P and organic–P content in soil after harvest

As evident from 4.7.1 (a) and Fig. 27 and table 4.7..2 (a) and Fig. 28, the interaction between liming materials and phosphorus had significant influence on saloid-P, Al-P, Ca-P, reductant-P and organic–P content in soil after harvest.

The maximum saloid-P and Ca-P of 7.67 mg kg^{-1} and 8.87 mg kg^{-1} and 19.33 mg kg^{-1} and 21.83 mg kg^{-1} with pooled data of 8.27 mg kg^{-1} and 20.58 mg kg^{-1} was observed with M_3P_{80} (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) while the lowest saloid-P and Ca-P of 4.17 mg kg^{-1} and 4.33 mg kg^{-1} and 11.00 mg kg^{-1} and 12.50 mg kg^{-1} with pooled data of 4.25 mg kg^{-1} and 11.75 mg kg^{-1} was observed with M_0P_0 (control) during 2018 and 2019 respectively.

The maximum Al-P of 42.00 mg kg^{-1} and 43.45 mg kg^{-1} with pooled data 42.73 was observed with M_0P_{80} (no liming material + 80 kg P_2O_5 ha^{-1}) while the lowest Al-P of 29.00 mg kg^{-1} and 30.46 mg kg^{-1} with pooled data of 29.73 mg kg^{-1} was observed with M_3P_0 (CS @ 0.4 LR + 0 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively.

The maximum reductant-P of 76.17 mg kg^{-1} and 73.67 mg kg^{-1} with pooled data 74.92 mg kg^{-1} was observed with M_0P_0 (control) while the lowest Al-P of 65.17 mg kg^{-1} and 62.67 mg kg^{-1} with pooled data of 63.92 mg kg^{-1} was observed with M_3P8_0 (CS @ 0.4 LR + 80 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively.

The maximum organic-P of 434.33 mg kg^{-1} and 429.37 mg kg^{-1} with pooled data 431.85 mg kg^{-1} was observed with M_2P_{60} (PMS @ 0.4 LR + 60 kg P_2O_5 ha^{-1}) while the lowest organic-P of 280.17 mg kg^{-1} and 277.27 mg kg^{-1}

with pooled data of 278.72 mg kg^{-1} was observed with M_0P_0 (control) during 2018 and 2019 respectively.

As evident from table 4.7.1 (b) and Fig. 27, the interaction between liming materials and phosphorus did not have any significant influence on Fe-P and occluded–P content in soil after harvest. The maximum Fe-P of 53.67 mg kg^{-1} and 55.97 mg kg^{-1} with pooled data 54.82 mg kg^{-1} was observed with M_0P_{80} (no liming material + 80 kg P_2O_5 ha^{-1}) while the lowest Fe-P of 39.33 mg kg^{-1} and 41.63 mg kg^{-1} with pooled data of 40.48 mg kg^{-1} was observed with M_3P_0 (CS @ 0.4 LR+ 0 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively. The highest occluded–P was observed with M_2P_0 (PMS @ 0.4LR + 0 kg P_2O_5 ha^{-1}) which recorded 53.67 mg kg^{-1} and 52.33 mg kg^{-1} with pooled data of 53.00 mg kg^{-1} and M_3P_{80} (CS @ 0.4LR + 80 kg P_2O_5 ha^{-1}) obtained the lowest with 40.50 mg kg^{-1} and 38.17 mg kg^{-1} with pooled data of 39.33 mg kg^{-1} during 2018 and 2019 respectively.

It was revealed that increased level of phosphorus along with application liming material had influenced the phosphorus fraction in soil after harvest (Amruth *et al*., 2017).

4.8. Effect on phosphorus efficiency

Phosphorus efficiency of soil after harvest such as agronomic efficiency of P, physiological efficiency of P, apparent recovery phosphorus and phosphorus use efficiency are discussed under the following heads:

4.8.1. Effect on agronomic efficiency of P, physiological efficiency of P, apparent recovery phosphorus and phosphorus use efficiency

4.8.1.1. Effect of liming materials on agronomic efficiency of P, physiological efficiency of P, apparent recovery P and P use efficiency

The effect of liming materials application on agronomic efficiency of P, physiological efficiency of P, apparent recovery phosphorus and phosphorus use efficiency has been shown in table 4.8.1 (a) and Fig. 29. The result revealed that liming materials application did not have any significant influence the agronomic efficiency of P, physiological efficiency of P, apparent recovery phosphorus and phosphorus use efficiency. The highest agronomic efficiency of P and physiological efficiency of P was observed when PMS @ 0.4 LR (M_2) was applied which recorded agronomic efficiency of P and physiological efficiency of P 9.40 kg kg^{-1} and 9.31 kg kg^{-1} and 100.69 kg kg^{-1} and 88.40 kg kg^{-1} with polled data of 9.35 kg kg^{-1} and 94.54 kg kg^{-1} during the year 2018 and 2019, respectively. The lower agronomic efficiency of P and physiological efficiency of P was observed in no liming material (M_0) which recorded corresponding value of 7.99 kg kg^{-1} and 8.74 kg kg^{-1} and 76.69 kg kg^{-1} and 74.75 kg kg^{-1} with pooled data of 8.36 kg kg^{-1} and 75.72 kg kg^{-1} during year 2018 and 2019, respectively.

The maximum apparent recovery phosphorus and phosphorus use efficiency was observed when CS @ 0.4 LR (M_3) was applied which recorded apparent recovery phosphorus and phosphorus use efficiency 8.99 % and 13.83 % and 9.46 % and 14.68 % with polled data of 11.41 % and 12.07 % during the year 2018 and 2019, respectively. The minimum apparent recovery phosphorus and phosphorus use efficiency was observed in no liming material (M_0) which recorded corresponding value of 6.95 % and 8.96 % and 8.49 % and 10.40 % with pooled data of 7.95 % and 9.45 % during year 2018 and 2019, respectively.

4.8.1.2. Effect of phosphorus on agronomic efficiency of P, physiological efficiency of P, apparent recovery P and phosphorus use efficiency

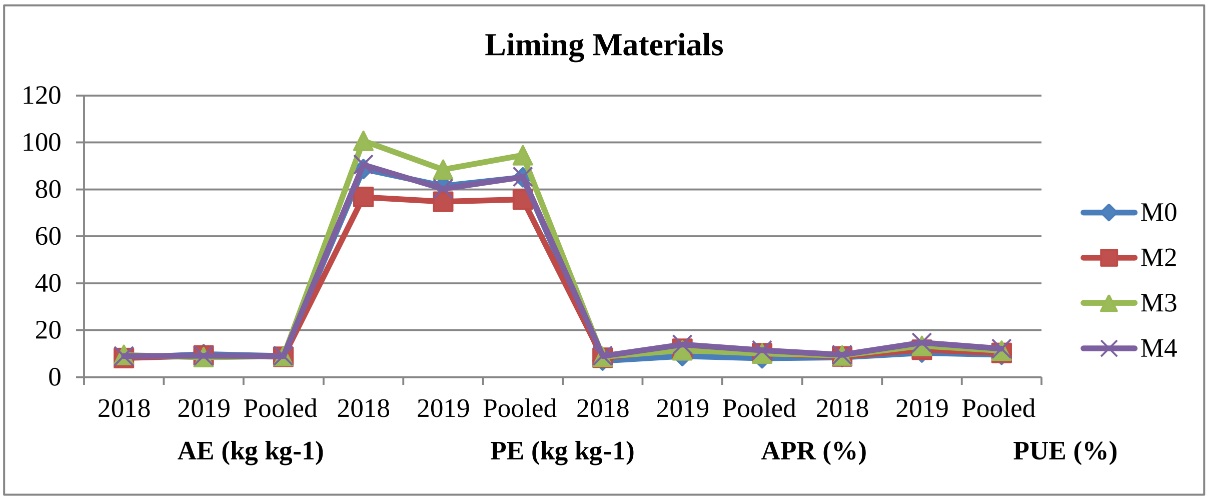
From the table 4.8.1 (a) and Fig. 29, it has become evident that the phosphorus application had significant effect on agronomic efficiency of P, physiological efficiency of P, apparent recovery P and phosphorus use

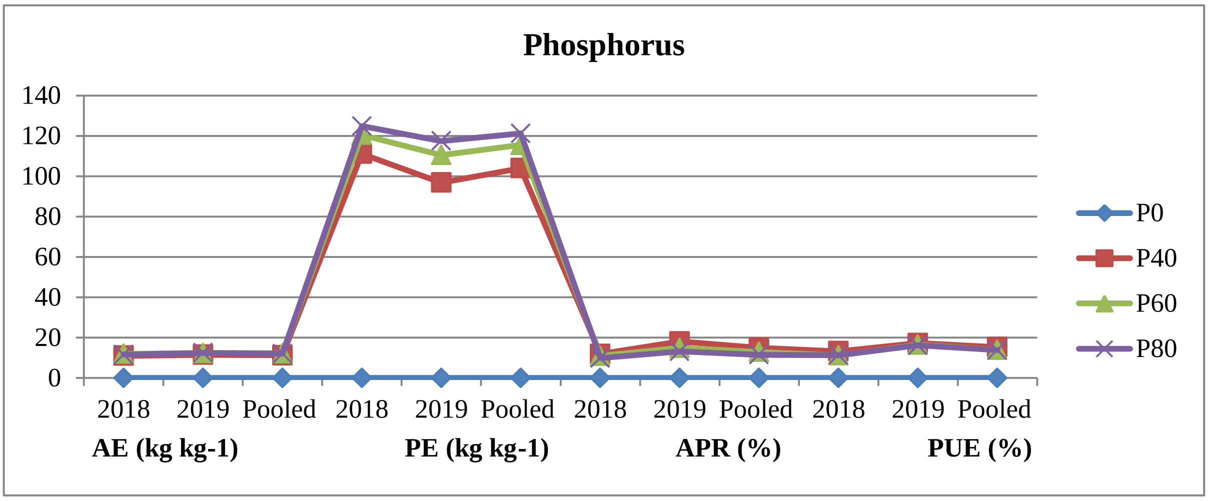
Table 4.8.1. (a) Effect of liming materials and phosphorus levels on agronomic efficiency of P, physiological efficiency of P, apparent P recovery and phosphorus use efficiency

Treatments	**Agronomic efficiency of P (kg kg^{-1})**			**Physiological efficiency of P (kg kg^{1})**			**Apparent P recovery (%)**			**Phosphorus use efficiency (%)**		
	2018	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
M_0	7.99	8.74	8.36	88.65	81.51	85.08	6.95	8.96	7.95	8.49	10.40	9.45
M_1	8.15	9.13	8.64	76.69	74.75	75.72	8.16	12.05	10.10	8.73	11.69	10.21
M_2	9.40	9.31	9.35	100.69	88.40	94.54	8.66	11.38	10.02	9.23	13.31	11.27
M_3	8.96	8.91	8.94	90.48	80.17	85.32	8.99	13.83	11.41	9.46	14.68	12.07
Sem±	***0.95***	***0.56***	***0.55***	***4.78***	***2.64***	***2.73***	***0.44***	***0.95***	***0.52***	***0.52***	***0.90***	***0.52***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
P_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P_{40}	10.86	11.36	11.11	111.16	96.82	103.99	11.89	18.12	15.01	13.27	17.35	15.31
P_{60}	12.00	12.43	12.21	120.48	110.52	115.50	10.98	14.92	12.95	11.25	16.53	13.89
P_{80}	11.64	12.29	11.97	124.87	117.49	121.18	9.89	13.18	11.53	11.39	16.20	13.80
Sem±	***0.56***	***0.69***	***0.44***	***3.76***	***3.71***	***2.64***	***0.32***	***0.62***	***0.35***	***0.43***	***0.84***	***0.47***
CD (p=0.05)	***1.63***	***2.01***	***1.26***	***10.97***	***10.84***	***7.51***	***0.93***	***1.82***	***1.00***	***1.26***	***2.46***	***1.35***

Table 4.8.1 (b) Interaction Effect of liming materials and phosphorus levels on agronomic efficiency of P, physiological efficiency of P, apparent P recovery and phosphorus use efficiency

Treatments	Agronomic efficiency of P (kg kg^{-1})			Physiological efficiency of P (kg kg^{1})			Apparent P recovery (%)			Phosphorus use efficiency (%)		
	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled	2018	2019	Pooled
M_0P_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M_0P_{40}	11.16	10.65	10.90	119.01	98.96	108.98	10.05	14.51	12.28	13.16	14.65	13.90
M_0P_{60}	11.00	13.02	12.01	116.81	112.77	114.79	9.54	11.48	10.51	11.00	13.02	12.01
M_0P_{80}	9.80	11.29	10.54	118.79	114.32	116.56	8.21	9.84	9.02	9.80	13.96	11.88
M_1P_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M_1P_{40}	11.21	13.33	12.27	95.69	96.39	96.04	12.07	19.23	15.65	13.54	17.36	15.45
M_1P_{60}	10.30	10.93	10.61	100.82	94.73	97.78	10.51	15.20	12.86	10.30	14.50	12.40
M_1P_{80}	11.07	12.24	11.66	110.26	107.89	109.07	10.05	13.75	11.90	11.07	14.92	13.00
M_2P_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M_2P_{40}	11.46	12.12	11.79	122.70	100.95	111.82	12.79	17.40	15.10	12.12	17.72	14.92
M_2P_{60}	13.13	12.84	12.99	137.52	124.42	130.97	11.42	15.09	13.26	11.79	18.80	15.30
M_2P_{80}	13.00	12.26	12.63	142.53	128.22	135.37	10.41	13.04	11.73	13.00	16.73	14.86
M_3P_0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M_3P_{40}	9.60	9.35	9.47	107.26	90.99	99.13	12.65	21.35	17.00	14.27	19.68	16.97
M_3P_{60}	13.55	12.92	13.24	126.77	110.17	118.47	12.44	17.91	15.18	11.89	19.81	15.85
M_3P_{80}	12.68	13.38	13.03	127.90	119.51	123.70	10.89	16.07	13.48	11.68	19.22	15.45
Sem±	***1.11***	***1.38***	***0.89***	***7.52***	***7.43***	***5.28***	***0.64***	***1.25***	***0.70***	***0.86***	***1.69***	***0.95***
CD (p=0.05)	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***





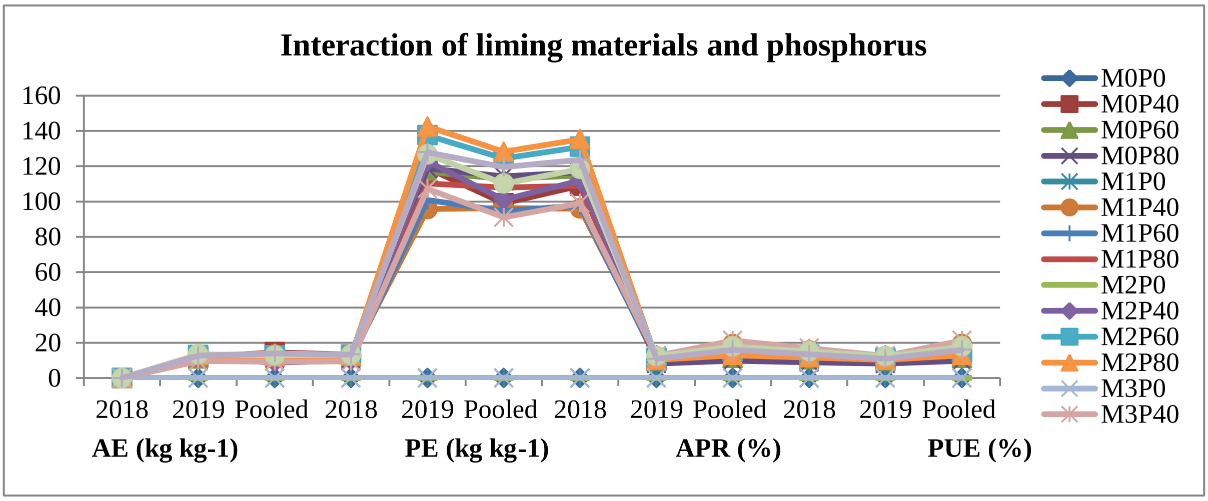


Fig. 29 Effect of liming materials, phosphorus levels and interaction on agronomic efficiency of P, physiological efficiency of P, apparent P recovery and P use efficiency of soil after harvest

efficiency. Application of phosphorus was found to increase the agronomic efficiency of P. The maximum agronomic efficiency of P has been observed with P_{60} (60 kg P_2O_5 ha^{-1}) which recorded 12.00 kg kg^{-1} and 12.43 kg kg^{-1} during 2018 and 2019 respectively with pooled data as 12.21 kg kg^{-1} while minimum was observed with P_{40} which recorded 10.86 kg kg^{-1} and 11.36 kg kg^{-1} during 2018 and 2019 respectively with pooled data as 11.18 kg kg^{-1}.

The highest physiological efficiency of P was observed when 80 kg P_2O_5 ha^{-1} (P_{80}) was applied which recorded highest physiological efficiency of P 124.87 kg kg^{-1} and 117.49 kg kg^{-1} with polled data of 121.18 kg kg^{-1} during the year 2018 and 2019, respectively. The lowest physiological efficiency of P was observed in 40 kg P_2O_5 ha^{-1} (P_{40}) which recorded corresponding value of 111.16 kg kg^{-1} and 96.82 kg kg^{-1} with pooled data of 103.99 kg kg^{-1} during year 2018 and 2019, respectively. The maximum apparent recovery phosphorus and phosphorus use efficiency was observed when 40 kg P_2O_5 ha^{-1} (P_{40}) was applied which recorded apparent recovery phosphorus and phosphorus use efficiency 11.89 % and 18.12 % and 13.27 % and 17.35 % with polled data of 15.01 % and 15.31 % during the year 2018 and 2019, respectively. The minimum apparent recovery phosphorus and phosphorus use efficiency was observed in 80 kg P_2O_5 ha^{-1} (P_{80}) which recorded corresponding value of 9.89 % and 13.18 % and 11.39 % and 16.20 % with pooled data of 11.53 % and 13.80 % during year 2018 and 2019, respectively.

Phosphorus efficiency was observed to decrease with increase in level of phosphorus application. This decrease trend is in agreement with Von Leibig's law of the Minimum which states that the most limiting factor determines the yield potentials (Gillar *et al*. 2004). Similar result was also reported by Kumar and Kushwaha (2006). The decline in phosphorus efficiency with increased doses of P might be due to the fact that plant grown in P deficient soil exhibit greater affinity for P sorption at lower doses of P

(Dubey, 2000). The results are in agreement with the study by Majumdar *et al* (2007). Significant increase phosphorus use efficiency by maize crop in acid Alfisol was reported by Venkatesh *et at.* (2002).

4.8.1.3. Interaction effect of liming materials and phosphorus on agronomic efficiency of P, physiological efficiency of P, apparent recovery P and phosphorus use efficiency

As evident from table 4.8.1 (b) and Fig. 29, the interaction between liming materials and phosphorus did not have any significant influence on the agronomic efficiency of P, physiological efficiency of P, apparent recovery P and phosphorus use efficiency. The maximum agronomic efficiency of P of 12.68 kg kg^{-1} and 14.05 kg kg^{-1} with pooled data of 13.36 kg kg^{-1} was observed with M_3P_{80} (CS @ 0.4LR + 80 kg P_2O_5 ha^{-1}) while the minimum agronomic efficiency of P of 9.60 kg kg^{-1} and 9.35 kg kg^{-1} with pooled data of 9.47 kg kg^{-1} was observed with M_3P_{40} (CS @ 0.4LR + 40 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively. The maximum physiological efficiency of P of 142.53 kg kg^{-1} and 128.22 kg kg^{-1} with pooled data of 135.37 kg kg^{-1} was observed with M_2P_{80} (PMS @ 0.4LR + 80 kg P_2O_5 ha^{-1}) while the minimum physiological efficiency of P of 95.69 kg kg^{-1} and 96.39 kg kg^{-1} with pooled data of 96.04 kg kg^{-1} was observed with M_1P_{40} (WA @ 0.4LR + 40 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively.

The highest apparent recovery P and phosphorus use efficiency of 12.65 kg kg^{-1} and 21.35 kg kg^{-1} and 14.27 kg kg^{-1} and 19,68 kg kg^{-1} with pooled data of 17.00 kg kg^{-1} and 16.97 kg kg^{-1} was observed with M_3P_{40} (CS @ 0.4LR + 40 kg P_2O_5 ha^{-1}) while the minimum apparent recovery P and phosphorus use efficiency of 8.21 kg kg^{-1} and 9.84 kg kg^{-1} and 9.80 kg kg^{-1} and 13.96 kg kg^{-1} with pooled data of 9.02 kg kg^{-1} and 11.88 kg kg^{-1} was observed with M_0P_{80} (no liming material + 80 kg P_2O_5 ha^{-1}) during 2018 and 2019 respectively.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSION

The research investigation entitled "**Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland**" was carried out during *kharif* season of 2018 and 2019 at the experimental research farm of School of Agricultural Sciences and Rural Development (SASRD), Medziphema campus, Nagaland University. The results thus obtained during the period of investigation are summarized below:

1. Application of liming materials and phosphorus alone significantly influenced the growth parameters of soybean however, when applied together further enhances the growth attributing characters in soybean. Application of liming material, CS @ 0.4 LR and phosphorus @ 80 kg P_2O_5 ha^{-1} significantly recorded the highest growth attributing parameters such as plant height, number of leave per plant, number of branches per plant, numbers of root nodules per plant, root length and root dry weight whereas the lowest was recorded with no liming materials and phosphorus @ 0 kg P_2O_5 ha^{-1}.
2. Significantly higher yield attributing parameters such as pods per plant, seeds per pod and seed test weight were obtained when liming material, CS @ 0.4 LR and phosphorus @ 80 kg P_2O_5 ha^{-1} were applied as compared to other treatment combination including control treatment. Interaction effect between liming materials and phosphorus on the yield attributing parameters of soybean was observed during the two years of research investigation.
3. Liming materials and phosphorus application individually improved the grain yield and stover yield. Significantly higher grain and stover yield were obtained when liming material, CS @ 0.4 LR and phosphorus @

80 kg P_2O_5 ha^{-1}. Synergistic interaction effect between the different treatment factors was observed.

4. The nutrient content of N, P, K, S, Ca and Mg in stover was significantly influenced by the application of liming materials and phosphorus individually. The nutrient concentration of the stover increased when the level of phosphorus application was increased. The interaction between liming materials and phosphorus was found significant influence on the N and P content in soybean stover. Combined application of CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1} showed maximum content of these nutrients in the stover.
5. Significantly higher N, P, K, S, Ca and Mg content were obtained in seeds of soybean when CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1} was applied individually. There was no significant interaction effect between liming materials and phosphorus on K, S and Mg content in seed. N,P and Ca content in seeds where synergistic interaction effect between liming materials and phosphorus combinations to significant increase in N,P and Ca content in seeds.
6. Application of liming material, CS @ 0.4 LR and phosphorus level, 80 kg P_2O_5 ha^{-1} either alone or in combination significantly increased the nutrient uptakes by stover. The increase in nutrient uptake was more pronounced when applied together indicating synergistic interaction effect between the different treatments. The highest nutrient uptake by stover was obtained from combined application of CS @ 0.4 LR along with 80 kg P_2O_5 ha^{-1} whereas the lowest was recorded in the control.
7. Plants receiving liming material, CS @ 0.4 LR and phosphorus level, 80 kg P_2O_5 ha^{-1} shows higher uptake of N, P, K, S, Ca and Mg by seeds of soybean. Synergistic interaction was found to exist between the different treatment factors.

8. The total uptake of nutrients by soybean was significantly increased with increased application of phosphorus and the highest was recorded with application of 80 kg P_2O_5 ha^{-1} and among the liming materials, CS @ 0.4 LR recorded the highest whereas the lowest was recorded in the control. The highest nutrient uptake was obtained with combined application of of CS @ 0.4 LR along with 80 kg P_2O_5 ha^{-1}.
9. Application liming materials and phosphorus had significant influence on protein content, protein yield as well as oil content and oil yield. The highest protein content and protein yield as well as oil content and oil yield was found with application CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. The highest protein content and protein yield and oil content and oil yield was obtained with combined application of of CS @ 0.4 LR along with 80 kg P_2O_5 ha^{-1} whereas lowest with control.
10. The soil fertility status was also improved with application of liming materials and phosphorus levels. It was observed that the pH of the soils tends to increase with liming materials. The highest water holding capacity, available N and P of soil after harvest was found significant with application CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. Exchangeable Ca^{+2}, Exchangeable Mg^{+2} and CEC were significantly increased with liming materials and highest value was found with CS @ 0.4 LR and lowest with control.
11. The soil microbial biomass carbon and soil respiration was recorded highest with the application of the liming material CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1} whereas the lowest was with the control.
12. The Phosphorus fractions of soil were significantly increased with the application of the liming materials and phosphorus, except reductant-P and occuluded-P and highest value was recorded with the application of the liming material CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1} whereas the lowest was recorded in the control.
13. Agronomic efficiency of P and physiological efficiency of P was found the highest in the treatment CS @ 0.4LR + 60 kg P_2O_5 ha^{-1} and PMS @

0.4LR + 60 kg P_2O_5 ha^{-1}, respectively. Apparent recovery P and P use efficiency was observed the highest with M_3P_{40} (CS @ 0.4LR + 40 kg P_2O_5 ha^{-1}) which thereafter declined with application of 60 kg P_2O_5 ha^{-1} and 80 kg P_2O_5 ha^{-1}.

Conclusion

From the observations obtained from research investigation, we can draw the conclusion that application of calcium silicate @ 0.4 LR + 80 kg P_2O_5 ha^{-1} was found to be beneficial for increasing the growth, yield attributes, yield and quality of soybean in a Dystrudept of Nagaland. The uptake of nutrients by soybean was found to be increased with increasing level of phosphorus and with different liming materials. Interaction of calcium silicate (@ 0.4 LR) and phosphorus (80 kg $P_2O_5ha^{-1}$) was found to be optimum resulting in total uptake. The soil fertility status and biological parameters were improved through liming materials and phosphorus.

The Phosphorus fractions of soil were improved through liming materials (calcium silicate @ 0.4LR) and phosphorus (80 kg P_2O_5 ha^{-1}). Agronomic efficiency of P, physiological efficiency of P, apparent recovery of P and P use efficiency was influenced by application of liming material with phosphorus. Apparent recovery P and P use efficiency was observed the highest with M_3P_{40} (calcium silicate @ 0.4LR + 40 kg P_2O_5 ha^{-1}) which thereafter declined with application of 60 kg P_2O_5 ha^{-1} and 80 kg P_2O_5 ha^{-1}.

However, this result provides some information on "Phosphorus use efficiency as influenced by liming materials in Soybean [*Glycine max* (L.) Merrill] in a Dystrudept of Nagaland". It is suggested that the experiment may repeated at different site for atleast one or two year with more specific treatment combination to get clear cut recommendation for farmers.

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Appendices

APPENDIX-1

Effect of liming materials and phosphorus levels on plant height at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	32.43	32.43	14.45	4.75
Replication	2	6.26	3.13	1.61	2	18.17	9.08	3.57	4	24.43	6.11	2.72	3.26
Factor M	3	39.85	13.28	6.84	3	40.37	13.46	5.29	6	80.22	13.37	5.96	3.00
Error I	6	11.66	1.94		6	15.27	2.55		12	26.93	2.24		
Factor P	3	121.05	40.35	31.77	3	139.61	46.54	21.63	6	260.66	43.44	25.40	2.29
MxP interaction	9	1.29	0.14	0.11	9	11.51	1.28	0.59	18	12.81	0.71	0.42	1.82
Error II	24	30.48	1.27	-	24	51.63	2.15	-	48	82.11	1.71	-	-
Total	47	210.59	-	-	47	276.56	-	-	95	519.58	-	-	-

*Significant at 5% probability level

APPENDIX-2

Effect of liming materials and phosphorus levels on plant height at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	154.03	154.03	18.54	4.75
Replication	2	65.01	32.50	3.40	2	171.17	85.58	12.13	4	236.17	59.04	7.11	3.26
Factor M	3	170.15	56.72	5.93	3	220.04	73.35	10.40	6	390.19	65.03	7.83	3.00
Error I	6	57.34	9.56		6	42.33	7.06		12	99.67	8.31		
Factor P	3	1147.32	382.44	80.27	3	626.92	208.97	37.04	6	1774.25	295.71	56.83	2.29
MxP interaction	9	13.27	1.47	0.31	9	78.69	8.74	1.55	18	91.96	5.11	0.98	1.82
Error II	24	114.35	4.76	-	24	135.41	5.64	-	48	249.75	5.20	-	-
Total	47	1567.44	-	-	47	1274.56	-	-	95	2996.02	-	-	-

*Significant at 5% probability level

APPENDIX-3

Effect of liming materials and phosphorus levels on plant height at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	17.85	17.85	1.87	4.75
Replication	2	47.03	23.52	2.04	2	98.17	49.08	6.50	4	145.20	36.30	3.81	3.26
Factor M	3	247.22	82.41	7.15	3	198.34	66.11	8.75	6	445.55	74.26	7.79	3.00
Error I	6	69.12	11.52		6	45.33	7.56		12	114.46	9.54		
Factor P	3	976.78	325.59	50.39	3	908.86	302.95	64.65	6	1885.64	314.27	56.38	2.29
MxP interaction	9	47.77	5.31	0.82	9	58.19	6.47	1.38	18	105.96	5.89	1.06	1.82
Error II	24	155.07	6.46	-	24	112.47	4.69	-	48	267.55	5.57	-	-
Total	47	1543.00	-	-	47	1421.36	-	-	95	2982.21	-	-	-

*Significant at 5% probability level

APPENDIX-4

Effect of liming materials and phosphorus levels on number of leaves per plant at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.13	0.13	0.13	4.75
Replication	2	0.51	0.26	0.36	2	29.76	14.88	10.71	4	30.27	7.57	7.18	3.26
Factor M	3	14.01	4.67	6.49	3	36.93	12.31	8.86	6	50.94	8.49	8.05	3.00
Error I	6	4.32	0.72		6	8.33	1.39		12	12.65	1.05		
Factor P	3	25.26	8.42	22.37	3	24.62	8.21	3.49	6	49.87	8.31	6.09	2.29
MxP interaction	9	0.78	0.09	0.23	9	5.69	0.63	0.27	18	6.47	0.36	0.26	1.82
Error II	24	9.03	0.38		24	56.44	2.35		48	65.47	1.36		-
Total	47	53.91			47	161.77			95	0.13	0.13	0.13	-

*Significant at 5% probability level

APPENDIX-5

Effect of liming materials and phosphorus levels on number of leaves per plant at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	113.97	113.97	20.68	4.75
Replication	2	84.33	42.17	4.49	2	24.64	12.32	7.54	4	108.97	27.24	4.94	3.26
Factor M	3	139.45	46.48	4.95	3	80.57	26.86	16.44	6	220.02	36.67	6.65	3.00
Error I	6	56.33	9.39		6	9.80	1.63		12	66.13	5.51		
Factor P	3	489.42	163.14	47.79	3	365.47	121.82	124.35	6	854.89	142.48	64.86	2.29
MxP interaction	9	21.51	2.39	0.70	9	12.29	1.37	1.39	18	33.80	1.88	0.85	1.82
Error II	24	81.93	3.41		24	23.51	0.98		48	105.44	2.20		-
Total	47	872.96			47	516.28			95	1503.21			-

*Significant at 5% probability level

APPENDIX-6

Effect of liming materials and phosphorus levels on number of leaves per plant at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	198.95	198.95	39.17	4.75
Replication	2	77.55	38.77	4.55	2	24.64	12.32	7.54	4	102.18	25.55	5.03	3.26
Factor M	3	144.12	48.04	5.64	3	80.57	26.86	16.44	6	224.68	37.45	7.37	3.00
Error I	6	51.15	8.52		6	9.80	1.63		12	60.94	5.08		
Factor P	3	481.64	160.55	45.84	3	365.47	121.82	124.35	6	847.11	141.18	63.00	2.29
MxP interaction	9	22.70	2.52	0.72	9	12.29	1.37	1.39	18	34.99	1.94	0.87	1.82
Error II	24	84.05	3.50		24	23.51	0.98		48	107.57	2.24		-
Total	47	861.20			47	516.28			95	1576.43			-

*Significant at 5% probability level

APPENDIX-7

Effect of liming materials and phosphorus levels on number of branches per plant at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	2.07	2.07	27.98	4.75
Replication	2	0.16	0.08	1.49	2	0.20	0.10	1.04	4	0.36	0.09	1.20	3.26
Factor M	3	1.15	0.38	7.19	3	2.97	0.99	10.45	6	4.12	0.69	9.28	3.00
Error I	6	0.32	0.05		6	0.57	0.09		12	0.89	0.07		
Factor P	3	6.42	2.14	37.19	3	4.01	1.34	20.53	6	10.43	1.74	28.35	2.29
MxP interaction	9	0.58	0.06	1.12	9	0.85	0.09	1.45	18	1.43	0.08	1.30	1.82
Error II	24	1.38	0.06		24	1.56	0.07		48	2.94	0.06		-
Total	47	10.01			47	10.15			95	22.24			-

*Significant at 5% probability level

APPENDIX-8

Effect of liming materials and phosphorus levels on number of branches per plant at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.77	0.77	2.60	4.75
Replication	2	0.28	0.14	0.72	2	1.45	0.72	1.83	4	1.73	0.43	1.46	3.26
Factor M	3	2.99	1.00	5.07	3	5.74	1.91	4.83	6	8.73	1.45	4.91	3.00
Error I	6	1.18	0.20		6	2.38	0.40		12	3.55	0.30		
Factor P	3	10.31	3.44	20.18	3	17.11	5.70	19.32	6	27.42	4.57	19.63	2.29
MxP interaction	9	0.45	0.05	0.30	9	0.72	0.08	0.27	18	1.17	0.07	0.28	1.82
Error II	24	4.09	0.17		24	7.09	0.30		48	11.17	0.23		-
Total	47	19.30			47	34.48			95	54.55			-

*Significant at 5% probability level

APPENDIX-9

Effect of liming materials and phosphorus levels on number of branches per plant at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	1.43	1.43	5.60	4.75
Replication	2	4.13	2.07	13.26	2	0.29	0.15	0.41	4	4.42	1.11	4.34	3.26
Factor M	3	2.80	0.93	5.99	3	7.29	2.43	6.88	6	10.10	1.68	6.61	3.00
Error I	6	0.94	0.16		6	2.12	0.35		12	3.06	0.25		
Factor P	3	7.18	2.39	10.82	3	9.16	3.05	18.54	6	16.34	2.72	14.12	2.29
MxP interaction	9	0.15	0.02	0.07	9	1.05	0.12	0.71	18	1.19	0.07	0.34	1.82
Error II	24	5.31	0.22		24	3.95	0.16		48	9.26	0.19		-
Total	47	20.50			47	23.87			95	45.79			-

*Significant at 5% probability level

APPENDIX-10

Effect of liming materials and phosphorus levels on root length at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	51.04	51.04	61.51	4.75
Replication	2	64.50	32.25	82.93	2	8.04	4.02	3.16	4	72.54	18.14	21.85	3.26
Factor M	3	320.23	106.74	274.48	3	344.56	114.85	90.38	6	664.79	110.80	133.51	3.00
Error I	6	2.33	0.39		6	7.63	1.27		12	9.96	0.83		
Factor P	3	282.06	94.02	142.52	3	312.73	104.24	105.71	6	594.79	99.13	120.46	2.29
MxP interaction	9	24.35	2.71	4.10	9	22.85	2.54	2.58	18	47.21	2.62	3.19	1.82
Error II	24	15.83	0.66		24	23.67	0.99		48	39.50	0.82		-
Total	47	709.31			47	719.48			95	1479.83			-

*Significant at 5% probability level

APPENDIX-11

Effect of liming materials and phosphorus levels on root length at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	68.34	68.34	71.32	4.75
Replication	2	6.13	3.06	3.13	2	21.38	10.69	11.40	4	27.50	6.88	7.17	3.26
Factor M	3	732.06	244.02	249.21	3	550.50	183.50	195.73	6	1282.56	213.76	223.05	3.00
Error I	6	5.88	0.98		6	5.63	0.94		12	11.50	0.96		
Factor P	3	216.73	72.24	136.88	3	148.67	49.56	87.02	6	365.40	60.90	111.01	2.29
MxP interaction	9	28.35	3.15	5.97	9	11.17	1.24	2.18	18	39.52	2.20	4.00	1.82
Error II	24	12.67	0.53		24	13.67	0.57		48	26.33	0.55		-
Total	47	1001.81			47	751.00			95	1821.16			-

*Significant at 5% probability level

APPENDIX-12

Effect of liming materials and phosphorus levels on root length at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	42.67	42.67	27.01	4.75
Replication	2	42.67	21.33	14.77	2	45.54	22.77	13.28	4	88.21	22.05	13.96	3.26
Factor M	3	2367.83	789.28	546.42	3	2367.83	789.28	460.15	6	4735.67	789.28	499.59	3.00
Error I	6	8.67	1.44		6	10.29	1.72		12	18.96	1.58		
Factor P	3	1999.50	666.50	1411.41	3	1999.50	666.50	411.91	6	3999.00	666.50	637.71	2.29
MxP interaction	9	660.67	73.41	155.45	9	660.67	73.41	45.37	18	1321.33	73.41	70.24	1.82
Error II	24	11.33	0.47		24	38.83	1.62		48	50.17	1.05		-
Total	47	5090.67			47	5122.67			95	10256.00			-

*Significant at 5% probability level

APPENDIX-13

Effect of liming materials and phosphorus levels on root volume at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.02	0.02	13.89	4.75
Replication	2	0.00	0.00	0.97	2	0.03	0.02	48.60	4	0.04	0.01	8.02	3.26
Factor M	3	0.32	0.11	54.01	3	0.30	0.10	286.60	6	0.62	0.10	88.47	3.00
Error I	6	0.01	0.00		6	0.00	0.00		12	0.01	0.00		
Factor P	3	0.31	0.10	79.39	3	0.21	0.07	54.11	6	0.51	0.09	66.75	2.29
MxP interaction	9	0.06	0.01	5.19	9	0.02	0.00	1.68	18	0.08	0.00	3.43	1.82
Error II	24	0.03	0.00		24	0.03	0.00		48	0.06	0.00		-
Total	47	0.74			47	0.59			95	1.35			-

*Significant at 5% probability level

APPENDIX-14

Effect of liming materials and phosphorus levels on root volume at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.07	0.07	29.76	4.75
Replication	2	0.01	0.01	2.58	2	0.03	0.02	7.20	4	0.05	0.01	5.01	3.26
Factor M	3	0.44	0.15	66.96	3	0.58	0.19	79.45	6	1.02	0.17	73.52	3.00
Error I	6	0.01	0.00		6	0.01	0.00		12	0.03	0.00		
Factor P	3	0.28	0.09	60.35	3	0.51	0.17	55.20	6	0.79	0.13	56.93	2.29
MxP interaction	9	0.04	0.00	2.87	9	0.03	0.00	1.06	18	0.07	0.00	1.66	1.82
Error II	24	0.04	0.00		24	0.07	0.00		48	0.11	0.00		-
Total	47	0.82			47	1.24			95	2.13			-

*Significant at 5% probability level

APPENDIX-15

Effect of liming materials and phosphorus levels on root volume at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.03	0.03	10.53	4.75
Replication	2	0.05	0.02	17.81	2	0.03	0.02	4.50	4	0.08	0.02	8.06	3.26
Factor M	3	3.93	1.31	953.97	3	3.86	1.29	341.91	6	7.78	1.30	505.53	3.00
Error I	6	0.01	0.00		6	0.02	0.00		12	0.03	0.00		
Factor P	3	1.91	0.64	386.91	3	1.98	0.66	218.83	6	3.89	0.65	278.32	2.29
MxP interaction	9	0.33	0.04	22.47	9	0.30	0.03	11.21	18	0.64	0.04	15.20	1.82
Error II	24	0.04	0.00		24	0.07	0.00		48	0.11	0.00		-
Total	47	6.27			47	6.26			95	12.56			-

*Significant at 5% probability level

APPENDIX-16

Effect of liming materials and phosphorus levels on root dry weight at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.00	0.00	0.03	4.75
Replication	2	0.16	0.08	2.34	2	0.04	0.02	2.53	4	0.20	0.05	2.38	3.26
Factor M	3	3.74	1.25	37.15	3	4.30	1.43	171.63	6	8.04	1.34	63.95	3.00
Error I	6	0.20	0.03		6	0.05	0.01		12	0.25	0.02		
Factor P	3	5.71	1.90	58.93	3	5.02	1.67	171.28	6	10.73	1.79	85.01	2.29
MxP interaction	9	1.97	0.22	6.78	9	1.62	0.18	18.44	18	3.59	0.20	9.49	1.82
Error II	24	0.78	0.03		24	0.23	0.01		48	1.01	0.02		-
Total	47	12.56			47	11.27			95	2.13			-

*Significant at 5% probability level

APPENDIX-17

Effect of liming materials and phosphorus levels on root dry weight at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.00	0.00	0.14	4.75
Replication	2	0.03	0.01	1.55	2	0.02	0.01	0.73	4	0.05	0.01	1.05	3.26
Factor M	3	5.94	1.98	208.50	3	4.29	1.43	96.80	6	10.24	1.71	140.51	3.00
Error I	6	0.06	0.01		6	0.09	0.01		12	0.15	0.01		
Factor P	3	9.93	3.31	620.87	3	8.19	2.73	246.12	6	18.12	3.02	367.73	2.29
MxP interaction	9	1.69	0.19	35.26	9	0.90	0.10	9.03	18	2.59	0.14	17.55	1.82
Error II	24	0.13	0.01		24	0.27	0.01		48	0.39	0.01		-
Total	47	17.78			47	13.77			95	31.55			-

*Significant at 5% probability level

APPENDIX-18

Effect of liming materials and phosphorus levels on root dry weight at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.95	0.95	73.55	4.75
Replication	2	0.04	0.02	1.24	2	0.01	0.01	0.64	4	0.05	0.01	1.00	3.26
Factor M	3	6.76	2.25	144.44	3	7.09	2.36	230.00	6	13.86	2.31	178.41	3.00
Error I	6	0.09	0.02		6	0.06	0.01		12	0.16	0.01		
Factor P	3	23.22	7.74	297.00	3	28.77	9.59	1136.65	6	51.99	8.66	502.36	2.29
MxP interaction	9	4.27	0.47	18.19	9	2.13	0.24	28.05	18	6.40	0.36	20.60	1.82
Error II	24	0.63	0.03		24	0.20	0.01		48	0.83	0.02		-
Total	47	35.01			47	38.27			95	74.23			-

*Significant at 5% probability level

APPENDIX-19

Effect of liming materials and phosphorus levels on number of root nodules per plant at 30 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	28.17	28.17	1.92	4.75
Replication	2	284.38	142.19	5.06	2	8.17	4.08	3.13	4	292.54	73.14	4.97	3.26
Factor M	3	2254.06	751.35	26.73	3	2112.23	704.08	539.29	6	4366.29	727.72	49.49	3.00
Error I	6	168.63	28.10		6	7.83	1.31		12	176.46	14.70		
Factor P	3	2230.56	743.52	615.33	3	1376.73	458.91	323.94	6	3607.29	601.22	458.07	2.29
MxP interaction	9	339.69	37.74	31.24	9	103.52	11.50	8.12	18	443.21	24.62	18.76	1.82
Error II	24	29.00	1.21		24	34.00	1.42		48	63.00	1.31		-
Total	47	5306.31			47	3642.48			95	8976.96			-

*Significant at 5% probability level

APPENDIX-20

Effect of liming materials and phosphorus levels on number of root nodules per plant at 60 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	565.51	565.51	481.86	4.75
Replication	2	16.54	8.27	5.07	2	72.38	36.19	50.59	4	88.92	22.23	18.94	3.26
Factor M	3	21304.83	7101.61	4351.63	3	9794.40	3264.80	4564.38	6	31099.23	5183.20	4416.46	3.00
Error I	6	9.79	1.63		6	4.29	0.72		12	14.08	1.17		
Factor P	3	18930.17	6310.06	1839.37	3	23680.90	7893.63	11840.45	6	42611.06	7101.84	3466.66	2.29
MxP interaction	9	4665.00	518.33	151.09	9	3593.35	399.26	598.89	18	8258.35	458.80	223.96	1.82
Error II	24	82.33	3.43		24	16.00	0.67		48	98.33	2.05		-
Total	47	45008.67			47	37161.31			95	82735.49			-

*Significant at 5% probability level

APPENDIX-21

Effect of liming materials and phosphorus levels on number of root nodules per plant at 90 DAS

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	541.50	541.50	241.79	4.75
Replication	2	34.13	17.06	4.12	2	86.00	43.00	129.00	4	120.13	30.03	13.41	3.26
Factor M	3	3794.75	1264.92	305.11	3	3895.75	1298.58	3895.75	6	7690.50	1281.75	572.32	3.00
Error I	6	24.88	4.15		6	2.00	0.33		12	26.88	2.24		
Factor P	3	6003.58	2001.19	832.87	3	4212.75	1404.25	4212.75	6	10216.33	1702.72	1244.63	2.29
MxP interaction	9	710.25	78.92	32.84	9	210.75	23.42	70.25	18	921.00	51.17	37.40	1.82
Error II	24	57.67	2.40		24	8.00	0.33		48	65.67	1.37		-
Total	47	10625.25			47	8415.25			95	19582.00			-

*Significant at 5% probability level

APPENDIX-22

Effect of liming materials and phosphorus levels on number of pods per plant

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	700.92	700.92	77.99	4.75
Replication	2	23.02	11.51	4.02	2	9.67	4.84	0.32	4	32.69	8.17	0.91	3.26
Factor M	3	476.55	158.85	55.48	3	531.80	177.27	11.73	6	1008.35	168.06	18.70	3.00
Error I	6	17.18	2.86		6	90.67	15.11		12	107.85	8.99		
Factor P	3	3050.96	1016.99	445.72	3	3272.74	1090.91	90.41	6	6323.70	1053.95	146.91	2.29
MxP interaction	9	30.31	3.37	1.48	9	117.42	13.05	1.08	18	147.73	8.21	1.14	1.82
Error II	24	54.76	2.28		24	289.60	12.07		48	344.36	7.17		-
Total	47	3652.78			47	4311.91			95	8665.61			-

*Significant at 5% probability level

APPENDIX-23

Effect of liming materials and phosphorus levels on number of seeds per pod

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.08	0.08	5.25	4.75
Replication	2	0.09	0.04	2.29	2	0.01	0.00	0.27	4	0.09	0.02	1.50	3.26
Factor M	3	0.15	0.05	2.63	3	0.13	0.04	3.52	6	0.28	0.05	2.98	3.00
Error I	6	0.11	0.02		6	0.07	0.01		12	0.19	0.02		
Factor P	3	0.04	0.01	0.94	3	0.08	0.03	1.62	6	0.12	0.02	1.29	2.29
MxP interaction	9	0.07	0.01	0.50	9	0.12	0.01	0.86	18	0.19	0.01	0.68	1.82
Error II	24	0.36	0.01		24	0.37	0.02		48	0.73	0.02		-
Total	47	0.82			47	0.78			95	1.68			-

*Significant at 5% probability level

APPENDIX-24

Effect of liming materials and phosphorus levels on seed test weight

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.01	0.01	1.30	4.75
Replication	2	0.02	0.01	1.80	2	0.06	0.03	4.81	4	0.07	0.02	3.49	3.26
Factor M	3	0.09	0.03	6.58	3	0.09	0.03	5.16	6	0.18	0.03	5.78	3.00
Error I	6	0.03	0.00		6	0.03	0.01		12	0.06	0.01		
Factor P	3	0.11	0.04	5.17	3	0.11	0.04	5.59	6	0.23	0.04	5.37	2.29
MxP interaction	9	0.01	0.00	0.14	9	0.00	0.00	0.04	18	0.01	0.00	0.09	1.82
Error II	24	0.18	0.01		24	0.16	0.01		48	0.34	0.01		-
Total	47	0.43			47	0.46			95	0.90			-

*Significant at 5% probability level

APPENDIX-25

Effect of liming materials and phosphorus levels on grain yield of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	260203.42	260203.42	30.56*	4.75
Replication	2.00	557470.78	278735.39	23.35*	2.00	13672.16	6836.08	1.34	4.00	571142.94	142785.74	16.77*	3.26
Factor M	3.00	514077.24	171359.08	14.35*	3.00	270873.86	90291.29	17.74*	6.00	784951.09	130825.18	15.37*	3.00
Error I	6.00	71632.09	11938.68	-	6.00	30537.64	5089.61	-	12.00	102169.73	8514.14	-	-
Factor P	3.00	1041852.66	347284.22	101.73*	3.00	1332253.03	444084.34	90.09*	6.00	2374105.68	395684.28	94.85*	2.29
MxP interaction	9.00	114589.15	12732.13	3.73*	9.00	116569.18	12952.13	2.63*	18.00	231158.33	12842.13	3.08*	1.82
Error II	24.00	81930.74	3413.78	-	24.00	118302.15	4929.26	-	48.00	200232.89	4171.52	-	-
Total	47.00	2381552.65	-	-	47.00	1882208.01	-	-	95.00	4523964.08	-	-	-

*Significant at 5% probability level

APPENDIX-26

Effect of liming materials and phosphorus levels on stover yield of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	704318.71	704318.71	122.63	4.75
Replication	2	61154.17	30577.08	4.35	2	27826.85	13913.43	3.12	4	88981.02	22245.25	3.87	3.26
Factor M	3	526272.92	175424.31	24.97	3	325042.14	108347.38	24.28	6	851315.05	141885.84	24.70	3.00
Error I	6	42145.83	7024.31		6	26775.92	4462.65		12	68921.76	5743.48		
Factor P	3	1940206.25	646735.42	82.90	3	2003020.08	667673.36	82.11	6	3943226.33	657204.39	82.49	2.29
MxP interaction	9	17885.42	1987.27	0.25	9	73968.11	8218.68	1.01	18	91853.53	5102.97	0.64	1.82
Error II	24	187233.33	7801.39		24	195164.03	8131.83		48	382397.36	7966.61		-
Total	47	2774897.92			47	2651797.13			95	6131013.76			-

*Significant at 5% probability level

APPENDIX-27

Effect of liming materials and phosphorus levels on protein content of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	105.60	105.60	71.80	4.75
Replication	2.00	0.68	0.34	1.12	2.00	17.87	8.93	3.38	4.00	18.54	4.64	3.15	3.26
Factor M	3.00	47.94	15.98	52.88	3.00	62.07	20.69	7.84	6.00	110.00	18.33	12.47	3.00
Error I	6.00	1.81	0.30		6.00	15.84	2.64		12.00	17.65	1.47		-
Factor P	3.00	64.57	21.52	100.39	3.00	256.57	85.52	41.21	6.00	321.13	53.52	46.75	2.29
MxP interaction	9.00	77.07	8.56	39.94	9.00	44.73	4.97	2.40	18.00	121.80	6.77	5.91	1.82
Error II	24.00	5.15	0.21		24.00	49.81	2.08		48.00	54.95	1.14		-
Total	47.00	197.21			47.00	446.88			95.00	749.69			-

*Significant at 5% probability level

APPENDIX-28

Effect of liming materials and phosphorus levels on protein yield of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	131019.35	131019.35	82.68	4.75
Replication	2	86429.33	43214.66	27.55	2	13481.51	6740.75	4.21	4	99910.84	24977.71	15.76	3.26
Factor M	3	141214.66	47071.55	30.01	3	97759.36	32586.45	20.36	6	238974.02	39829.00	25.13	3.00
Error I	6	9411.74	1568.62		6	9605.00	1600.83		12	19016.73	1584.73		
Factor P	3	267811.36	89270.45	148.93	3	461165.58	153721.86	127.77	6	728976.94	121496.16	134.81	2.29
MxP interaction	9	26873.81	2985.98	4.98	9	26759.41	2973.27	2.47	18	53633.22	2979.62	3.31	1.82
Error II	24	14386.36	599.43		24	28873.73	1203.07		48	43260.09	901.25		-
Total	47	546127.26			47	637644.59			95	1314791.20			-

*Significant at 5% probability level

APPENDIX-29

Effect of liming materials and phosphorus levels on oil content of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	2.41	2.41	3.80	4.75
Replication	2.00	0.22	0.11	0.24	2.00	1.19	0.60	0.74	4.00	1.41	0.35	0.56	3.26
Factor M	3.00	7.88	2.63	5.67	3.00	16.38	5.46	6.76	6.00	24.26	4.04	6.36	3.00
Error I	6.00	2.78	0.46		6.00	4.85	0.81		12.00	7.62	0.64		-
Factor P	3.00	47.69	15.90	27.47	3.00	46.52	15.51	72.15	6.00	94.21	15.70	39.57	2.29
MxP interaction	9.00	2.84	0.32	0.55	9.00	1.85	0.21	0.95	18.00	4.69	0.26	0.66	1.82
Error II	24.00	13.89	0.58		24.00	5.16	0.21		48.00	19.05	0.40		-
Total	47.00	75.30			47.00	75.94			95.00	153.65			-

*Significant at 5% probability level

APPENDIX-30

Effect of liming materials and phosphorus levels on oil yield of soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	4028.27	4028.27	7.14	4.75
Replication	2	22159.80	11079.90	18.93	2	1757.85	878.93	1.62	4	23917.65	5979.41	10.60	3.26
Factor M	3	26771.71	8923.90	15.24	3	25902.61	8634.20	15.92	6	52674.32	8779.05	15.57	3.00
Error I	6	3512.35	585.39		6	3253.89	542.32		12	6766.24	563.85		
Factor P	3	85838.55	28612.85	135.24	3	104973.64	34991.21	145.88	6	190812.18	31802.03	140.89	2.29
MxP interaction	9	5716.07	635.12	3.00	9	5421.77	602.42	2.51	18	11137.84	618.77	2.74	1.82
Error II	24	5077.72	211.57		24	5756.70	239.86		48	10834.42	225.72		-
Total	47	149076.19			47	147066.46			95	300170.92			-

*Significant at 5% probability level

APPENDIX-31

Effect of liming materials and phosphorus levels on N content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	2.70	2.70	71.80	4.75
Replication	2.00	0.02	0.01	1.12	2.00	0.46	0.23	3.38	4.00	0.47	0.12	3.15	3.26
Factor M	3.00	1.23	0.41	52.88	3.00	1.59	0.53	7.84	6.00	2.82	0.47	12.47	3.00
Error I	6.00	0.05	0.01		6.00	0.41	0.07		12.00	0.45	0.04		-
Factor P	3.00	1.65	0.55	100.39	3.00	6.57	2.19	41.21	6.00	8.22	1.37	46.75	2.29
MxP interaction	9.00	1.97	0.22	39.94	9.00	1.15	0.13	2.40	18.00	3.12	0.17	5.91	1.82
Error II	24.00	0.13	0.01		24.00	1.28	0.05		48.00	1.41	0.03		-
Total	47.00	5.05			47.00	11.44			95.00	19.19			-

*Significant at 5% probability level

APPENDIX-32

Effect of liming materials and phosphorus levels on P content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.09	0.09	385.50	4.75
Replication	2	0.01	0.01	41.14	2	0.02	0.01	33.66	4	0.03	0.01	36.20	3.26
Factor M	3	0.04	0.01	78.95	3	0.05	0.02	51.48	6	0.08	0.01	60.82	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.28	0.09	1075.52	3	0.35	0.12	1213.49	6	0.63	0.10	1148.44	2.29
MxP interaction	9	0.00	0.00	5.99	9	0.01	0.00	8.64	18	0.01	0.00	7.39	1.82
Error II	24	0.00	0.00		24	0.00	0.00		48	0.00	0.00		-
Total	47	0.34			47	0.43			95	0.85			-

*Significant at 5% probability level

APPENDIX-33

Effect of liming materials and phosphorus levels on K content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.06	0.06	10.78	4.75
Replication	2.00	0.01	0.01	19.89	2.00	0.01	0.00	0.35	4.00	0.02	0.01	1.02	3.26
Factor M	3.00	0.14	0.05	133.54	3.00	0.21	0.07	6.96	6.00	0.35	0.06	11.32	3.00
Error I	6.00	0.00	0.00		6.00	0.06	0.01		12.00	0.06	0.01		-
Factor P	3.00	0.80	0.27	101.20	3.00	1.90	0.63	80.55	6.00	2.69	0.45	85.72	2.29
MxP interaction	9.00	0.05	0.01	2.29	9.00	0.04	0.00	0.50	18.00	0.09	0.00	0.95	1.82
Error II	24.00	0.06	0.00		24.00	0.19	0.01		48.00	0.25	0.01		-
Total	47.00	1.07			47.00	2.39			95.00	3.52			-

*Significant at 5% probability level

APPENDIX-34

Effect of liming materials and phosphorus levels on S content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.00	0.00	3.47	4.75
Replication	2	0.00	0.00	2.53	2	0.00	0.00	2.82	4	0.00	0.00	2.67	3.26
Factor M	3	0.00	0.00	3.98	3	0.00	0.00	3.98	6	0.01	0.00	3.98	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.03	0.01	30.01	3	0.03	0.01	30.01	6	0.05	0.01	30.01	2.29
MxP interaction	9	0.00	0.00	0.46	9	0.00	0.00	0.46	18	0.00	0.00	0.46	1.82
Error II	24	0.01	0.00		24	0.01	0.00		48	0.01	0.00		-
Total	47	0.04			47	0.04			95	0.08			-

*Significant at 5% probability level

APPENDIX-35

Effect of liming materials and phosphorus levels on Ca content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.00	0.00	5.34	4.75
Replication	2.00	0.00	0.00	1.02	2.00	0.00	0.00	2.73	4.00	0.00	0.00	2.25	3.26
Factor M	3.00	0.01	0.00	14.54	3.00	0.01	0.00	5.99	6.00	0.03	0.00	8.37	3.00
Error I	6.00	0.00	0.00		6.00	0.00	0.00		12.00	0.01	0.00		-
Factor P	3.00	0.02	0.01	25.82	3.00	0.04	0.01	98.10	6.00	0.05	0.01	51.71	2.29
MxP interaction	9.00	0.01	0.00	2.96	9.00	0.00	0.00	2.95	18.00	0.01	0.00	2.96	1.82
Error II	24.00	0.01	0.00		24.00	0.00	0.00		48.00	0.01	0.00		-
Total	47.00	0.04			47.00	0.06			95.00	0.11			-

*Significant at 5% probability level

APPENDIX-36

Effect of liming materials and phosphorus levels on Mg content in seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.01	0.01	26.54	4.75
Replication	2	0.00	0.00	1.98	2	0.00	0.00	3.11	4	0.00	0.00	2.59	3.26
Factor M	3	0.01	0.00	10.60	3	0.01	0.00	5.39	6	0.02	0.00	7.79	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.04	0.01	28.72	3	0.07	0.02	49.50	6	0.12	0.02	39.00	2.29
MxP interaction	9	0.00	0.00	0.64	9	0.01	0.00	1.73	18	0.01	0.00	1.18	1.82
Error II	24	0.01	0.00		24	0.01	0.00		48	0.02	0.00		-
Total	47	0.07			47	0.11			95	0.19			-

*Significant at 5% probability level

APPENDIX-37

Effect of liming materials and phosphorus levels on N content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.55	0.55	41.37	4.75
Replication	2.00	0.08	0.04	2.01	2.00	0.11	0.05	7.70	4.00	0.18	0.05	3.49	3.26
Factor M	3.00	0.33	0.11	5.69	3.00	1.08	0.36	52.61	6.00	1.42	0.24	17.90	3.00
Error I	6.00	0.12	0.02		6.00	0.04	0.01		12.00	0.16	0.01		-
Factor P	3.00	2.17	0.72	63.00	3.00	3.42	1.14	150.39	6.00	5.60	0.93	97.71	2.29
MxP interaction	9.00	0.27	0.03	2.59	9.00	0.30	0.03	4.36	18.00	0.57	0.03	3.30	1.82
Error II	24.00	0.28	0.01		24.00	0.18	0.01		48.00	0.46	0.01		-
Total	47.00	3.25			47.00	5.13			95.00	8.93			-

*Significant at 5% probability level

APPENDIX-38

Effect of liming materials and phosphorus levels on P content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.00	0.00	0.00	4.75
Replication	2	0.01	0.00	26.17	2	0.01	0.00	26.17	4	0.01	0.00	26.17	3.26
Factor M	3	0.02	0.01	65.29	3	0.02	0.01	65.29	6	0.04	0.01	65.29	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.05	0.02	707.54	3	0.05	0.02	707.54	6	0.11	0.02	707.54	2.29
MxP interaction	9	0.00	0.00	2.46	9	0.00	0.00	2.46	18	0.00	0.00	2.46	1.82
Error II	24	0.00	0.00		24	0.00	0.00		48	0.00	0.00		-
Total	47	0.08			47	0.08			95	0.16			-

*Significant at 5% probability level

APPENDIX-39

Effect of liming materials and phosphorus levels on K content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.22	0.22	31.91	4.75
Replication	2.00	0.07	0.04	4.11	2.00	0.06	0.03	5.35	4.00	0.13	0.03	4.58	3.26
Factor M	3.00	0.12	0.04	4.76	3.00	0.24	0.08	15.28	6.00	0.37	0.06	8.77	3.00
Error I	6.00	0.05	0.01		6.00	0.03	0.01		12.00	0.08	0.01		-
Factor P	3.00	0.39	0.13	31.62	3.00	0.63	0.21	57.27	6.00	1.02	0.17	43.67	2.29
MxP interaction	9.00	0.06	0.01	1.55	9.00	0.03	0.00	0.92	18.00	0.09	0.00	1.26	1.82
Error II	24.00	0.10	0.00		24.00	0.09	0.00		48.00	0.19	0.00		-
Total	47.00	0.79			47.00	1.08			95.00	2.10			-

*Significant at 5% probability level

APPENDIX-40

Effect of liming materials and phosphorus levels on S content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.00	0.00	0.30	4.75
Replication	2	0.00	0.00	0.35	2	0.00	0.00	0.82	4	0.00	0.00	0.52	3.26
Factor M	3	0.00	0.00	3.88	3	0.02	0.01	42.43	6	0.02	0.00	18.05	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.01	0.00	62.82	3	0.01	0.00	13.46	6	0.03	0.00	22.15	2.29
MxP interaction	9	0.00	0.00	2.19	9	0.00	0.00	0.79	18	0.00	0.00	1.03	1.82
Error II	24	0.00	0.00		24	0.01	0.00		48	0.01	0.00		-
Total	47	0.02			47	0.04			95	0.06			-

*Significant at 5% probability level

APPENDIX-41

Effect of liming materials and phosphorus levels on Ca content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.07	0.07	165.68	4.75
Replication	2.00	0.00	0.00	3.03	2.00	0.00	0.00	3.03	4.00	0.01	0.00	3.03	3.26
Factor M	3.00	0.02	0.01	18.23	3.00	0.05	0.02	40.29	6.00	0.08	0.01	29.26	3.00
Error I	6.00	0.00	0.00		6.00	0.00	0.00		12.00	0.01	0.00		-
Factor P	3.00	0.05	0.02	32.12	3.00	0.05	0.02	32.12	6.00	0.09	0.02	32.12	2.29
MxP interaction	9.00	0.00	0.00	0.77	9.00	0.00	0.00	0.77	18.00	0.01	0.00	0.77	1.82
Error II	24.00	0.01	0.00		24.00	0.01	0.00		48.00	0.02	0.00		-
Total	47.00	0.09			47.00	0.12			95.00	0.28			-

*Significant at 5% probability level

APPENDIX-42

Effect of liming materials and phosphorus levels on Mg content in stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.01	0.01	39.27	4.75
Replication	2	0.00	0.00	2.49	2	0.00	0.00	2.49	4	0.00	0.00	2.49	3.26
Factor M	3	0.01	0.00	14.43	3	0.02	0.01	25.07	6	0.03	0.00	19.75	3.00
Error I	6	0.00	0.00		6	0.00	0.00		12	0.00	0.00		
Factor P	3	0.01	0.00	16.13	3	0.01	0.00	16.13	6	0.03	0.00	16.13	2.29
MxP interaction	9	0.00	0.00	0.30	9	0.00	0.00	0.30	18	0.00	0.00	0.30	1.82
Error II	24	0.01	0.00		24	0.01	0.00		48	0.01	0.00		-
Total	47	0.04			47	0.04			95	0.09			-

*Significant at 5% probability level

APPENDIX-43

Effect of liming materials and phosphorus levels on N uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	3354.10	3354.10	82.68	4.75
Replication	2.00	2212.59	1106.30	27.55	2.00	345.13	172.56	4.21	4.00	2557.72	639.43	15.76	3.26
Factor M	3.00	3615.10	1205.03	30.01	3.00	2502.64	834.21	20.36	6.00	6117.74	1019.62	25.13	3.00
Error I	6.00	240.94	40.16		6.00	245.89	40.98		12.00	486.83	40.57		-
Factor P	3.00	6855.97	2285.32	148.93	3.00	11805.84	3935.28	127.77	6.00	18661.81	3110.30	134.81	2.29
MxP interaction	9.00	687.97	76.44	4.98	9.00	685.04	76.12	2.47	18.00	1373.01	76.28	3.31	1.82
Error II	24.00	368.29	15.35		24.00	739.17	30.80		48.00	1107.46	23.07		-
Total	47.00	13980.86			47.00	16323.70			95.00	33658.65			-

*Significant at 5% probability level

APPENDIX-44

Effect of liming materials and phosphorus levels on P uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	11.51	11.51	74.88	4.75
Replication	2	24.63	12.32	108.32	2	9.32	4.66	24.07	4	33.95	8.49	55.23	3.26
Factor M	3	35.33	11.78	103.57	3	31.33	10.44	53.91	6	66.65	11.11	72.28	3.00
Error I	6	0.68	0.11		6	1.16	0.19		12	1.84	0.15		
Factor P	3	173.31	57.77	637.87	3	212.44	70.81	544.67	6	385.75	64.29	582.93	2.29
MxP interaction	9	3.39	0.38	4.16	9	3.79	0.42	3.24	18	7.18	0.40	3.62	1.82
Error II	24	2.17	0.09		24	3.12	0.13		48	5.29	0.11		-
Total	47	239.51			47	261.16			95	512.18			-

*Significant at 5% probability level

APPENDIX-45

Effect of liming materials and phosphorus levels on K uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	4.94	4.94	1.59	4.75
Replication	2.00	151.00	75.50	27.82	2.00	5.21	2.61	0.74	4.00	156.22	39.05	12.56	3.26
Factor M	3.00	291.06	97.02	35.74	3.00	252.77	84.26	24.04	6.00	543.83	90.64	29.15	3.00
Error I	6.00	16.29	2.71		6.00	21.03	3.51		12.00	37.32	3.11		-
Factor P	3.00	926.93	308.98	218.86	3.00	1619.57	539.86	176.61	6.00	2546.50	424.42	189.96	2.29
MxP interaction	9.00	53.25	5.92	4.19	9.00	68.01	7.56	2.47	18.00	121.26	6.74	3.02	1.82
Error II	24.00	33.88	1.41		24.00	73.36	3.06		48.00	107.25	2.23		-
Total	47.00	1472.41			47.00	2039.96			95.00	3517.31			-

*Significant at 5% probability level

APPENDIX-46

Effect of liming materials and phosphorus levels on S uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.33	0.33	2.24	4.75
Replication	2	4.36	2.18	10.11	2	0.81	0.41	5.27	4	5.17	1.29	8.84	3.26
Factor M	3	6.00	2.00	9.28	3	3.92	1.31	16.93	6	9.92	1.65	11.30	3.00
Error I	6	1.29	0.22		6	0.46	0.08		12	1.76	0.15		
Factor P	3	27.02	9.01	76.71	3	29.52	9.84	88.69	6	56.53	9.42	82.53	2.29
MxP interaction	9	1.24	0.14	1.18	9	1.34	0.15	1.34	18	2.58	0.14	1.26	1.82
Error II	24	2.82	0.12		24	2.66	0.11		48	5.48	0.11		-
Total	47	42.74			47	38.71			95	81.78			-

*Significant at 5% probability level

APPENDIX-47

Effect of liming materials and phosphorus levels on Ca uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	2.20	2.20	8.08	4.75
Replication	2.00	1.84	0.92	12.90	2.00	1.20	0.60	1.27	4.00	3.04	0.76	2.79	3.26
Factor M	3.00	15.77	5.26	73.85	3.00	15.87	5.29	11.19	6.00	31.63	5.27	19.39	3.00
Error I	6.00	0.43	0.07		6.00	2.84	0.47		12.00	3.26	0.27		-
Factor P	3.00	11.95	3.98	14.55	3.00	34.02	11.34	30.54	6.00	45.97	7.66	23.75	2.29
MxP interaction	9.00	2.17	0.24	0.88	9.00	3.87	0.43	1.16	18.00	6.04	0.34	1.04	1.82
Error II	24.00	6.57	0.27		24.00	8.91	0.37		48.00	15.48	0.32		-
Total	47.00	38.72			47.00	66.70			95.00	107.62			-

*Significant at 5% probability level

APPENDIX-48

Effect of liming materials and phosphorus levels on Mg uptake by seed

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	13.13	13.13	82.25	4.75
Replication	2	9.45	4.73	22.36	2	1.48	0.74	6.84	4	10.93	2.73	17.11	3.26
Factor M	3	20.74	6.91	32.72	3	6.42	2.14	19.83	6	27.16	4.53	28.36	3.00
Error I	6	1.27	0.21		6	0.65	0.11		12	1.92	0.16		
Factor P	3	37.17	12.39	25.49	3	73.47	24.49	164.75	6	110.65	18.44	58.11	2.29
MxP interaction	9	5.97	0.66	1.36	9	5.39	0.60	4.03	18	11.36	0.63	1.99	1.82
Error II	24	11.67	0.49		24	3.57	0.15		48	15.23	0.32		-
Total	47	86.27			47	90.98			95	190.38			-

*Significant at 5% probability level

APPENDIX-49

Effect of liming materials and phosphorus levels on N uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	1237.62	1237.62	142.82	4.75
Replication	2.00	146.78	73.39	7.76	2.00	66.57	33.29	4.23	4.00	213.35	53.34	6.15	3.26
Factor M	3.00	874.93	291.64	30.84	3.00	1300.07	433.36	55.04	6.00	2175.01	362.50	41.83	3.00
Error I	6.00	56.75	9.46		6.00	47.24	7.87		12.00	103.99	8.67		-
Factor P	3.00	4459.55	1486.52	140.41	3.00	5094.51	1698.17	227.68	6.00	9554.06	1592.34	176.48	2.29
MxP interaction	9.00	237.19	26.35	2.49	9.00	283.58	31.51	4.22	18.00	520.77	28.93	3.21	1.82
Error II	24.00	254.09	10.59		24.00	179.01	7.46		48.00	433.10	9.02		-
Total	47.00	6029.29			47.00	6970.99			95.00	14237.90			-

*Significant at 5% probability level

APPENDIX-50

Effect of liming materials and phosphorus levels on P uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	1.69	1.69	24.55	4.75
Replication	2	4.19	2.10	35.67	2	3.54	1.77	22.42	4	7.73	1.93	28.07	3.26
Factor M	3	19.21	6.40	108.92	3	16.48	5.49	69.56	6	35.69	5.95	86.36	3.00
Error I	6	0.35	0.06		6	0.47	0.08		12	0.83	0.07		
Factor P	3	57.05	19.02	434.61	3	51.83	17.28	589.51	6	108.88	18.15	496.74	2.29
MxP interaction	9	0.91	0.10	2.31	9	1.05	0.12	4.00	18	1.96	0.11	2.99	1.82
Error II	24	1.05	0.04		24	0.70	0.03		48	1.75	0.04		-
Total	47	82.76			47	74.08			95	1.69	1.69	24.55	-

*Significant at 5% probability level

APPENDIX-51

Effect of liming materials and phosphorus levels on K uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	55.99	55.99	24.40	4.75
Replication	2.00	33.63	16.81	8.11	2.00	74.62	37.31	14.82	4.00	108.25	27.06	11.79	3.26
Factor M	3.00	582.86	194.29	93.76	3.00	573.17	191.06	75.86	6.00	1156.02	192.67	83.94	3.00
Error I	6.00	12.43	2.07		6.00	15.11	2.52		12.00	27.54	2.30		-
Factor P	3.00	2164.46	721.49	261.40	3.00	2501.97	833.99	134.10	6.00	4666.42	777.74	173.23	2.29
MxP interaction	9.00	58.66	6.52	2.36	9.00	72.83	8.09	1.30	18.00	131.49	7.30	1.63	1.82
Error II	24.00	66.24	2.76		24.00	149.26	6.22		48.00	215.50	4.49		-
Total	47.00	2918.27			47.00	3386.96			95.00	6361.22			-

*Significant at 5% probability level

APPENDIX-52

Effect of liming materials and phosphorus levels on S uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	2.15	2.15	19.81	4.75
Replication	2	0.33	0.17	1.35	2	0.24	0.12	1.28	4	0.57	0.14	1.32	3.26
Factor M	3	5.43	1.81	14.56	3	14.43	4.81	52.03	6	19.86	3.31	30.54	3.00
Error I	6	0.75	0.12		6	0.55	0.09		12	1.30	0.11		
Factor P	3	24.42	8.14	155.48	3	22.85	7.62	54.82	6	47.27	7.88	82.36	2.29
MxP interaction	9	0.66	0.07	1.39	9	1.81	0.20	1.45	18	2.47	0.14	1.43	1.82
Error II	24	1.26	0.05		24	3.33	0.14		48	4.59	0.10		-
Total	47	32.83			47	43.22			95	78.20			-

*Significant at 5% probability level

APPENDIX-53

Effect of liming materials and phosphorus levels on Ca uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	136.88	136.88	479.86	4.75
Replication	2.00	8.21	4.11	14.91	2.00	4.30	2.15	7.28	4.00	12.51	3.13	10.96	3.26
Factor M	3.00	69.33	23.11	83.95	3.00	74.93	24.98	84.61	6.00	144.26	24.04	84.29	3.00
Error I	6.00	1.65	0.28		6.00	1.77	0.30		12.00	3.42	0.29		-
Factor P	3.00	206.07	68.69	125.63	3.00	178.44	59.48	111.49	6.00	384.51	64.09	118.64	2.29
MxP interaction	9.00	3.70	0.41	0.75	9.00	5.31	0.59	1.11	18.00	9.00	0.50	0.93	1.82
Error II	24.00	13.12	0.55		24.00	12.80	0.53		48.00	25.93	0.54		-
Total	47.00	302.08			47.00	277.55			95.00	716.51			-

*Significant at 5% probability level

APPENDIX-54

Effect of liming materials and phosphorus levels on Mg uptake by stover

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	15.36	15.36	112.85	4.75
Replication	2	1.81	0.90	5.93	2	1.18	0.59	4.93	4	2.99	0.75	5.49	3.26
Factor M	3	15.22	5.07	33.25	3	16.51	5.50	45.97	6	31.73	5.29	38.84	3.00
Error I	6	0.92	0.15		6	0.72	0.12		12	1.63	0.14		
Factor P	3	31.56	10.52	36.72	3	26.82	8.94	50.27	6	58.38	9.73	41.91	2.29
MxP interaction	9	0.69	0.08	0.27	9	0.67	0.07	0.42	18	1.36	0.08	0.33	1.82
Error II	24	6.88	0.29		24	4.27	0.18		48	11.14	0.23		-
Total	47	57.06			47	50.17			95	122.59			-

*Significant at 5% probability level

APPENDIX-55

Effect of liming materials and phosphorus levels on total uptake of N by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	8666.56	8666.56	172.55	4.75
Replication	2.00	3301.49	1650.74	29.87	2.00	632.65	316.32	7.00	4.00	3934.13	983.53	19.58	3.26
Factor M	3.00	7796.26	2598.75	47.02	3.00	7358.85	2452.95	54.28	6.00	15155.11	2525.85	50.29	3.00
Error I	6.00	331.59	55.26		6.00	271.12	45.19		12.00	602.71	50.23		-
Factor P	3.00	22306.71	7435.57	445.84	3.00	32204.37	10734.79	284.37	6.00	54511.08	9085.18	333.85	2.29
MxP interaction	9.00	974.80	108.31	6.49	9.00	929.43	103.27	2.74	18.00	1904.23	105.79	3.89	1.82
Error II	24.00	400.26	16.68		24.00	905.99	37.75		48.00	1306.25	27.21		-
Total	47.00	35111.10			47.00	42302.41			95.00	86080.08			-

*Significant at 5% probability level

APPENDIX-56

Effect of liming materials and phosphorus levels on total uptake of P by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	4.38	4.38	27.87	4.75
Replication	2	49.14	24.57	176.24	2	24.16	12.08	69.12	4	73.30	18.33	116.66	3.26
Factor M	3	104.23	34.74	249.19	3	90.07	30.02	171.80	6	194.29	32.38	206.14	3.00
Error I	6	0.84	0.14		6	1.05	0.17		12	1.89	0.16		
Factor P	3	429.17	143.06	933.97	3	474.05	158.02	992.86	6	903.22	150.54	963.98	2.29
MxP interaction	9	4.78	0.53	3.47	9	4.75	0.53	3.31	18	9.53	0.53	3.39	1.82
Error II	24	3.68	0.15		24	3.82	0.16		48	7.50	0.16		-
Total	47	591.83			47	597.89			95	1194.11			-

*Significant at 5% probability level

APPENDIX-57

Effect of liming materials and phosphorus levels on total uptake of K by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	90.26	90.26	12.60	4.75
Replication	2.00	209.56	104.78	10.07	2.00	101.29	50.64	12.90	4.00	310.85	77.71	10.85	3.26
Factor M	3.00	1610.93	536.98	51.63	3.00	1502.01	500.67	127.53	6.00	3112.95	518.82	72.43	3.00
Error I	6.00	62.41	10.40		6.00	23.56	3.93		12.00	85.96	7.16		-
Factor P	3.00	5725.41	1908.47	336.59	3.00	8136.33	2712.11	471.31	6.00	13861.74	2310.29	404.45	2.29
MxP interaction	9.00	135.17	15.02	2.65	9.00	163.95	18.22	3.17	18.00	299.12	16.62	2.91	1.82
Error II	24.00	136.08	5.67		24.00	138.11	5.75		48.00	274.18	5.71		-
Total	47.00	7879.56			47.00	10065.25			95.00	18035.07			-

*Significant at 5% probability level

APPENDIX-58

Effect of liming materials and phosphorus levels on total uptake of S by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	4.15	4.15	41.88	4.75
Replication	2	6.57	3.28	24.95	2	0.93	0.47	6.98	4	7.50	1.87	18.91	3.26
Factor M	3	21.60	7.20	54.71	3	31.88	10.63	159.46	6	53.48	8.91	89.92	3.00
Error I	6	0.79	0.13		6	0.40	0.07		12	1.19	0.10		
Factor P	3	102.57	34.19	180.37	3	103.86	34.62	157.58	6	206.43	34.40	168.14	2.29
MxP interaction	9	1.03	0.11	0.60	9	5.26	0.58	2.66	18	6.29	0.35	1.71	1.82
Error II	24	4.55	0.19		24	5.27	0.22		48	9.82	0.20		-
Total	47	137.10			47	147.60			95	288.85			-

*Significant at 5% probability level

APPENDIX-59

Effect of liming materials and phosphorus levels on total uptake of Ca by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	173.75	173.75	460.29	4.75
Replication	2.00	9.08	4.54	21.40	2.00	6.78	3.39	6.24	4.00	15.86	3.97	10.50	3.26
Factor M	3.00	147.99	49.33	232.42	3.00	159.65	53.22	98.06	6.00	307.64	51.27	135.83	3.00
Error I	6.00	1.27	0.21		6.00	3.26	0.54		12.00	4.53	0.38		-
Factor P	3.00	315.86	105.29	149.98	3.00	366.87	122.29	143.06	6.00	682.72	113.79	146.18	2.29
MxP interaction	9.00	7.59	0.84	1.20	9.00	13.86	1.54	1.80	18.00	21.45	1.19	1.53	1.82
Error II	24.00	16.85	0.70		24.00	20.51	0.85		48.00	37.36	0.78		-
Total	47.00	498.64			47.00	570.92			95.00	1243.31			-

*Significant at 5% probability level

APPENDIX-60

Effect of liming materials and phosphorus levels on total uptake of Mg by soybean

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	56.90	56.90	151.39	4.75
Replication	2	16.70	8.35	17.15	2	4.50	2.25	8.49	4	21.20	5.30	14.10	3.26
Factor M	3	68.62	22.87	46.99	3	42.68	14.23	53.72	6	111.31	18.55	49.36	3.00
Error I	6	2.92	0.49		6	1.59	0.26		12	4.51	0.38		
Factor P	3	137.09	45.70	74.51	3	188.89	62.96	193.41	6	325.98	54.33	115.74	2.29
MxP interaction	9	8.68	0.96	1.57	9	8.34	0.93	2.85	18	17.02	0.95	2.01	1.82
Error II	24	14.72	0.61		24	7.81	0.33		48	22.53	0.47		-
Total	47	248.73			47	253.82			95	559.45			-

*Significant at 5% probability level

APPENDIX-61

Effect of liming materials and phosphorus levels on pH of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.08	0.08	13.88	4.75
Replication	2.00	0.02	0.01	1.61	2.00	0.02	0.01	2.59	4.00	0.04	0.01	1.95	3.26
Factor M	3.00	0.25	0.08	11.52	3.00	0.64	0.21	56.26	6.00	0.90	0.15	26.90	3.00
Error I	6.00	0.04	0.01		6.00	0.02	0.00		12.00	0.07	0.01		-
Factor P	3.00	0.01	0.00	0.37	3.00	0.02	0.01	0.82	6.00	0.03	0.01	0.60	2.29
MxP interaction	9.00	0.06	0.01	0.79	9.00	0.16	0.02	1.89	18.00	0.23	0.01	1.36	1.82
Error II	24.00	0.21	0.01		24.00	0.23	0.01		48.00	0.44	0.01		-
Total	47.00	0.60			47.00	1.11			95.00	1.79			-

*Significant at 5% probability level

APPENDIX-62

Effect of liming materials and phosphorus levels on organic carbon of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.05	0.05	7.64	4.75
Replication	2	0.03	0.02	2.95	2	0.01	0.01	0.92	4	0.05	0.01	1.84	3.26
Factor M	3	0.10	0.03	5.53	3	0.10	0.03	4.76	6	0.20	0.03	5.11	3.00
Error I	6	0.04	0.01		6	0.04	0.01		12	0.08	0.01		
Factor P	3	0.36	0.12	11.59	3	0.68	0.23	33.17	6	1.04	0.17	20.18	2.29
MxP interaction	9	0.07	0.01	0.77	9	0.05	0.01	0.83	18	0.12	0.01	0.79	1.82
Error II	24	0.25	0.01		24	0.16	0.01		48	0.41	0.01		-
Total	47	0.85			47	1.05			95	1.95			-

*Significant at 5% probability level

APPENDIX-63

Effect of liming materials and phosphorus levels on bulk density of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.10	0.10	8.84	4.75
Replication	2.00	0.01	0.00	0.38	2.00	0.04	0.02	1.37	4.00	0.04	0.01	0.97	3.26
Factor M	3.00	0.01	0.00	0.32	3.00	0.03	0.01	0.78	6.00	0.04	0.01	0.59	3.00
Error I	6.00	0.05	0.01		6.00	0.08	0.01		12.00	0.13	0.01		-
Factor P	3.00	0.05	0.02	2.41	3.00	0.07	0.02	3.00	6.00	0.13	0.02	2.73	2.29
MxP interaction	9.00	0.02	0.00	0.37	9.00	0.09	0.01	1.16	18.00	0.11	0.01	0.80	1.82
Error II	24.00	0.17	0.01		24.00	0.20	0.01		48.00	0.37	0.01		-
Total	47.00	0.31			47.00	0.51			95.00	0.92			-

*Significant at 5% probability level

APPENDIX-64

Effect of liming materials and phosphorus levels on available N of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	160.02	160.02	2.47	4.75
Replication	2	152.39	76.20	0.78	2	39.67	19.83	0.62	4	192.06	48.01	0.74	3.26
Factor M	3	4814.11	1604.70	16.43	3	7080.07	2360.02	74.36	6	11894.17	1982.36	30.64	3.00
Error I	6	586.06	97.68		6	190.41	31.74		12	776.47	64.71		
Factor P	3	6082.19	2027.40	36.76	3	13142.10	4380.70	121.46	6	19224.29	3204.05	70.25	2.29
MxP interaction	9	1297.65	144.18	2.61	9	996.81	110.76	3.07	18	2294.46	127.47	2.79	1.82
Error II	24	1323.72	55.16		24	865.62	36.07		48	2189.34	45.61		-
Total	47	14256.12			47	22314.68			95	36730.82			-

*Significant at 5% probability level

APPENDIX-65

Effect of liming materials and phosphorus levels on available P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	1.28	1.28	1.11	4.75
Replication	2.00	2.64	1.32	1.16	2.00	24.30	12.15	10.46	4.00	26.93	6.73	5.85	3.26
Factor M	3.00	31.72	10.57	9.27	3.00	17.87	5.96	5.13	6.00	49.59	8.26	7.18	3.00
Error I	6.00	6.84	1.14		6.00	6.97	1.16		12.00	13.81	1.15		-
Factor P	3.00	105.43	35.14	66.32	3.00	197.44	65.81	60.81	6.00	302.87	50.48	62.63	2.29
MxP interaction	9.00	4.85	0.54	1.02	9.00	17.29	1.92	1.78	18.00	22.14	1.23	1.53	1.82
Error II	24.00	12.72	0.53		24.00	25.97	1.08		48.00	38.69	0.81		-
Total	47.00	164.19			47.00	289.84			95.00	455.32			-

*Significant at 5% probability level

APPENDIX-66

Effect of liming materials and phosphorus levels on available K of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	144.72	144.72	0.52	4.75
Replication	2	960.29	480.15	2.35	2	1268.26	634.13	1.83	4	2228.56	557.14	2.02	3.26
Factor M	3	2369.06	789.69	3.87	3	1124.64	374.88	1.08	6	3493.70	582.28	2.11	3.00
Error I	6	1225.88	204.31		6	2082.32	347.05		12	3308.21	275.68		
Factor P	3	3645.94	1215.31	2.27	3	3018.35	1006.12	2.07	6	6664.29	1110.72	2.17	2.29
MxP interaction	9	521.30	57.92	0.11	9	1281.78	142.42	0.29	18	1803.07	100.17	0.20	1.82
Error II	24	12853.48	535.56		24	11679.57	486.65		48	24533.05	511.11		-
Total	47	21575.95			47	20454.92			95	42175.60			-

*Significant at 5% probability level

APPENDIX-67

Effect of liming materials and phosphorus levels on available S of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.01	0.01	1.26	4.75
Replication	2.00	0.02	0.01	1.16	2.00	0.02	0.01	3.04	4.00	0.04	0.01	1.70	3.26
Factor M	3.00	0.03	0.01	1.23	3.00	0.24	0.08	24.43	6.00	0.26	0.04	7.96	3.00
Error I	6.00	0.05	0.01		6.00	0.02	0.00		12.00	0.07	0.01		-
Factor P	3.00	0.53	0.18	32.87	3.00	0.79	0.26	31.88	6.00	1.32	0.22	32.27	2.29
MxP interaction	9.00	0.03	0.00	0.58	9.00	0.06	0.01	0.78	18.00	0.09	0.00	0.70	1.82
Error II	24.00	0.13	0.01		24.00	0.20	0.01		48.00	0.33	0.01		-
Total	47.00	0.78			47.00	1.32			95.00	2.11			-

*Significant at 5% probability level

APPENDIX-68

Effect of liming materials and phosphorus levels on Fe of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	48.48	48.48	11.15	4.75
Replication	2	1.33	0.66	0.20	2	16.55	8.27	1.56	4	17.87	4.47	1.03	3.26
Factor M	3	33.31	11.10	3.28	3	62.66	20.89	3.93	6	95.97	16.00	3.68	3.00
Error I	6	20.34	3.39		6	31.85	5.31		12	52.19	4.35		
Factor P	3	6.66	2.22	0.50	3	36.28	12.09	1.42	6	42.94	7.16	1.11	2.29
MxP interaction	9	4.53	0.50	0.11	9	19.77	2.20	0.26	18	24.30	1.35	0.21	1.82
Error II	24	106.35	4.43		24	204.08	8.50		48	310.44	6.47		-
Total	47	172.51			47	371.19			95	592.19			-

*Significant at 5% probability level

APPENDIX-69

Effect of liming materials and phosphorus levels on Mn of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	106.41	106.41	26.50	4.75
Replication	2.00	21.00	10.50	4.55	2.00	3.07	1.54	0.27	4.00	24.08	6.02	1.50	3.26
Factor M	3.00	0.81	0.27	0.12	3.00	13.55	4.52	0.79	6.00	14.36	2.39	0.60	3.00
Error I	6.00	13.84	2.31		6.00	34.35	5.73		12.00	48.19	4.02		-
Factor P	3.00	12.85	4.28	2.09	3.00	45.77	15.26	2.93	6.00	58.62	9.77	2.69	2.29
MxP interaction	9.00	12.28	1.36	0.67	9.00	19.68	2.19	0.42	18.00	31.95	1.78	0.49	1.82
Error II	24.00	49.13	2.05		24.00	125.11	5.21		48.00	174.24	3.63		-
Total	47.00	109.91			47.00	241.53			95.00	457.85			-

*Significant at 5% probability level

APPENDIX-70

Effect of liming materials and phosphorus levels on Zn of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.01	0.01	0.53	4.75
Replication	2	0.06	0.03	3.52	2	0.29	0.15	6.86	4	0.35	0.09	5.92	3.26
Factor M	3	0.09	0.03	3.48	3	0.03	0.01	0.49	6	0.12	0.02	1.33	3.00
Error I	6	0.05	0.01		6	0.13	0.02		12	0.18	0.01		
Factor P	3	0.07	0.02	2.95	3	0.07	0.02	2.35	6	0.13	0.02	2.62	2.29
MxP interaction	9	0.03	0.00	0.49	9	0.02	0.00	0.23	18	0.05	0.00	0.35	1.82
Error II	24	0.18	0.01		24	0.22	0.01		48	0.41	0.01		-
Total	47	0.48			47	0.76			95	1.25			-

*Significant at 5% probability level

APPENDIX-71

Effect of liming materials and phosphorus levels on Exch. Ca^{2+} of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	1.21	1.21	54.78	4.75
Replication	2.00	0.01	0.01	0.26	2.00	0.02	0.01	0.57	4.00	0.03	0.01	0.37	3.26
Factor M	3.00	0.93	0.31	10.87	3.00	0.85	0.28	18.26	6.00	1.78	0.30	13.47	3.00
Error I	6.00	0.17	0.03		6.00	0.09	0.02		12.00	0.26	0.02		-
Factor P	3.00	0.01	0.00	0.09	3.00	0.01	0.00	0.08	6.00	0.01	0.00	0.09	2.29
MxP interaction	9.00	0.08	0.01	0.35	9.00	0.06	0.01	0.24	18.00	0.14	0.01	0.29	1.82
Error II	24.00	0.58	0.02		24.00	0.68	0.03		48.00	1.26	0.03		-
Total	47.00	1.78			47.00	1.71			95.00	4.70			-

*Significant at 5% probability level

APPENDIX-72

Effect of liming materials and phosphorus levels on Exch. Mg^{2+} of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.17	0.17	18.39	4.75
Replication	2	0.01	0.00	0.46	2	0.06	0.03	2.62	4	0.06	0.02	1.79	3.26
Factor M	3	0.11	0.04	5.54	3	0.55	0.18	16.50	6	0.66	0.11	12.31	3.00
Error I	6	0.04	0.01		6	0.07	0.01		12	0.11	0.01		
Factor P	3	0.00	0.00	0.18	3	0.01	0.00	0.35	6	0.01	0.00	0.30	2.29
MxP interaction	9	0.01	0.00	0.42	9	0.02	0.00	0.32	18	0.03	0.00	0.35	1.82
Error II	24	0.07	0.00		24	0.17	0.01		48	0.23	0.00		-
Total	47	0.24			47	0.87			95	1.28			-

*Significant at 5% probability level

APPENDIX-73

Effect of liming materials and phosphorus levels on Exch. Al^{3+} of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	0.01	0.01	2.04	4.75
Replication	2.00	0.02	0.01	1.47	2.00	0.02	0.01	2.43	4.00	0.03	0.01	1.84	3.26
Factor M	3.00	0.08	0.03	4.93	3.00	0.06	0.02	5.69	6.00	0.14	0.02	5.23	3.00
Error I	6.00	0.03	0.01		6.00	0.02	0.00		12.00	0.05	0.00		-
Factor P	3.00	0.01	0.00	0.95	3.00	0.01	0.00	0.32	6.00	0.02	0.00	0.58	2.29
MxP interaction	9.00	0.04	0.00	0.80	9.00	0.04	0.00	0.58	18.00	0.07	0.00	0.67	1.82
Error II	24.00	0.12	0.00		24.00	0.17	0.01		48.00	0.28	0.01		-
Total	47.00	0.29			47.00	0.30			95.00	0.61			-

*Significant at 5% probability level

APPENDIX-74

Effect of liming materials and phosphorus levels on Exchange acidity of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	0.20	0.20	0.26	4.75
Replication	2	1.62	0.81	1.19	2	3.96	1.98	2.28	4	5.58	1.39	1.80	3.26
Factor M	3	2.09	0.70	1.02	3	2.05	0.68	0.79	6	4.14	0.69	0.89	3.00
Error I	6	4.09	0.68		6	5.21	0.87		12	9.29	0.77		
Factor P	3	5.82	1.94	3.93	3	10.98	3.66	6.61	6	16.79	2.80	5.35	2.29
MxP interaction	9	4.91	0.55	1.11	9	4.51	0.50	0.91	18	9.43	0.52	1.00	1.82
Error II	24	11.84	0.49		24	13.29	0.55		48	25.13	0.52		-
Total	47	30.36			47	40.00			95	70.55			-

*Significant at 5% probability level

APPENDIX-75

Effect of liming materials and phosphorus levels on CEC of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	23.52	23.52	100.83	4.75
Replication	2.00	0.17	0.09	0.82	2.00	0.85	0.43	1.19	4.00	1.03	0.26	1.10	3.26
Factor M	3.00	7.50	2.50	23.43	3.00	13.38	4.46	12.39	6.00	20.88	3.48	14.91	3.00
Error I	6.00	0.64	0.11		6.00	2.16	0.36		12.00	2.80	0.23		-
Factor P	3.00	1.28	0.43	2.97	3.00	4.17	1.39	2.97	6.00	5.45	0.91	2.97	2.29
MxP interaction	9.00	0.56	0.06	0.44	9.00	2.00	0.22	0.47	18.00	2.56	0.14	0.47	1.82
Error II	24.00	3.45	0.14		24.00	11.25	0.47		48.00	14.70	0.31		-
Total	47.00	13.60			47.00	33.82			95.00	70.94			-

*Significant at 5% probability level

APPENDIX-76

Effect of liming materials and phosphorus levels on WHC of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	21.10	21.10	121.82	4.75
Replication	2	0.19	0.10	0.79	2	0.57	0.28	1.27	4	0.76	0.19	1.10	3.26
Factor M	3	20.38	6.79	55.64	3	23.75	7.92	35.29	6	44.13	7.36	42.46	3.00
Error I	6	0.73	0.12		6	1.35	0.22		12	2.08	0.17		
Factor P	3	10.67	3.56	26.32	3	18.83	6.28	16.90	6	29.50	4.92	19.41	2.29
MxP interaction	9	2.79	0.31	2.30	9	6.18	0.69	1.85	18	8.97	0.50	1.97	1.82
Error II	24	3.24	0.14		24	8.91	0.37		48	12.15	0.25		-
Total	47	38.01			47	59.58			95	118.70			-

*Significant at 5% probability level

APPENDIX-77

Effect of liming materials and phosphorus levels on Soil respiration of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	3.99	3.99	318.39	4.75
Replication	2.00	0.19	0.09	7.41	2.00	0.19	0.09	7.41	4.00	0.37	0.09	7.41	3.26
Factor M	3.00	0.91	0.30	24.19	3.00	1.58	0.53	42.16	6.00	2.49	0.42	33.17	3.00
Error I	6.00	0.08	0.01		6.00	0.08	0.01		12.00	0.15	0.01		-
Factor P	3.00	6.19	2.06	165.07	3.00	8.48	2.83	226.28	6.00	14.66	2.44	195.68	2.29
MxP interaction	9.00	0.48	0.05	4.31	9.00	1.37	0.15	12.16	18.00	1.85	0.10	8.24	1.82
Error II	24.00	0.30	0.01		24.00	0.30	0.01		48.00	0.60	0.01		-
Total	47.00	8.14			47.00	11.99			95.00	24.11			-

*Significant at 5% probability level

APPENDIX-78

Effect of liming materials and phosphorus levels on SMBC of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	1454.71	1454.71	102.17	4.75
Replication	2	194.27	97.14	7.85	2	141.73	70.86	4.40	4	336.00	84.00	5.90	3.26
Factor M	3	4112.67	1370.89	110.79	3	6522.30	2174.10	135.01	6	10634.98	1772.50	124.48	3.00
Error I	6	74.24	12.37		6	96.62	16.10		12	170.86	14.24		
Factor P	3	1991.39	663.80	40.62	3	2665.78	888.59	58.20	6	4657.17	776.19	49.11	2.29
MxP interaction	9	582.49	64.72	3.96	9	397.35	44.15	2.89	18	979.84	54.44	3.44	1.82
Error II	24	392.25	16.34		24	366.41	15.27		48	758.66	15.81		-
Total	47	7347.32			47	10190.19			95	18992.21			-

*Significant at 5% probability level

APPENDIX-79

Effect of liming materials and phosphorus levels on Saloid-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	32.09	32.09	345.45	4.75
Replication	2.00	1.17	0.58	7.00	2.00	3.26	1.63	15.92	4.00	4.43	1.11	11.92	3.26
Factor M	3.00	2.38	0.79	9.50	3.00	4.89	1.63	15.92	6.00	7.27	1.21	13.04	3.00
Error I	6.00	0.50	0.08		6.00	0.61	0.10		12.00	1.11	0.09		-
Factor P	3.00	41.79	13.93	105.58	3.00	51.00	17.00	72.53	6.00	92.79	15.47	84.44	2.29
MxP interaction	9.00	3.17	0.35	2.67	9.00	6.60	0.73	3.13	18.00	9.77	0.54	2.96	1.82
Error II	24.00	3.17	0.13		24.00	5.62	0.23		48.00	8.79	0.18		-
Total	47.00	52.17			47.00	71.99			95.00	156.25			-

*Significant at 5% probability level

APPENDIX-80

Effect of liming materials and phosphorus levels on Al-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	420.01	420.01	198.54	4.75
Replication	2	20.82	10.41	4.60	2	2.79	1.40	0.71	4	23.61	5.90	2.79	3.26
Factor M	3	8.50	2.83	1.25	3	74.35	24.78	12.61	6	82.85	13.81	6.53	3.00
Error I	6	13.59	**2.27**		6	11.79	**1.97**		12	25.39	**2.12**		
Factor P	3	47.99	16.00	2.10	3	40.72	13.57	4.22	6	88.72	14.79	2.72	2.29
MxP interaction	9	5.11	0.57	0.07	9	8.09	0.90	0.28	18	13.20	0.73	0.14	1.82
Error II	24	183.25	**7.64**		24	77.25	**3.22**		48	260.50	**5.43**		-
Total	47	**279.28**			47	**214.99**			95	**914.28**			-

*Significant at 5% probability level

APPENDIX-81

Effect of liming materials and phosphorus levels on Fe-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	92.43	92.43	20.35	4.75
Replication	2.00	4.26	2.13	0.45	2.00	3.57	1.79	0.41	4.00	7.83	1.96	0.43	3.26
Factor M	3.00	82.50	27.50	5.83	3.00	26.10	8.70	1.99	6.00	108.60	18.10	3.99	3.00
Error I	6.00	28.28	4.71		6.00	26.22	4.37		12.00	54.50	4.54		-
Factor P	3.00	48.79	16.26	9.65	3.00	101.44	33.81	20.70	6.00	150.24	25.04	15.09	2.29
MxP interaction	9.00	15.13	1.68	1.00	9.00	11.63	1.29	0.79	18.00	26.76	1.49	0.90	1.82
Error II	24.00	40.46	1.69		24.00	39.21	1.63		48.00	79.67	1.66		-
Total	47.00	219.42			47.00	208.18			95.00	520.03			-

*Significant at 5% probability level

APPENDIX-82

Effect of liming materials and phosphorus levels on Ca-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	137.76	137.76	58.91	4.75
Replication	2	2.32	1.16	0.57	2	8.45	4.22	1.59	4	10.77	2.69	1.15	3.26
Factor M	3	35.10	11.70	5.78	3	47.18	15.73	5.92	6	82.28	13.71	5.86	3.00
Error I	6	12.14	2.02		6	15.93	2.65		12	28.06	2.34		
Factor P	3	176.52	58.84	108.28	3	183.85	61.28	79.68	6	360.36	60.06	91.52	2.29
MxP interaction	9	14.88	1.65	3.04	9	19.88	2.21	2.87	18	34.76	1.93	2.94	1.82
Error II	24	13.04	0.54		24	18.46	0.77		48	31.50	0.66		-
Total	47	253.99			47	293.74			95	685.50			-

*Significant at 5% probability level

APPENDIX-83

Effect of liming materials and phosphorus levels on Reductant-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1.00	150.00	150.00	20.09	4.75
Replication	2.00	46.91	23.45	3.14	2.00	46.91	23.45	3.14	4.00	93.81	23.45	3.14	3.26
Factor M	3.00	112.85	37.62	5.04	3.00	112.85	37.62	5.04	6.00	225.71	37.62	5.04	3.00
Error I	6.00	44.80	7.47		6.00	44.80	7.47		12.00	89.60	7.47		-
Factor P	3.00	201.69	67.23	12.64	3.00	201.69	67.23	12.64	6.00	403.38	67.23	12.64	2.29
MxP interaction	9.00	16.94	1.88	0.35	9.00	16.94	1.88	0.35	18.00	33.88	1.88	0.35	1.82
Error II	24.00	127.63	5.32		24.00	127.63	5.32		48.00	255.25	5.32		-
Total	47.00	550.81			47.00	550.81			95.00	1251.63			-

*Significant at 5% probability level

APPENDIX-84

Effect of liming materials and phosphorus levels on Occluded-P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	54.15	54.15	2.26	4.75
Replication	2	19.20	9.60	0.91	2	216.13	108.06	2.90	4	235.32	58.83	2.46	3.26
Factor M	3	43.56	14.52	1.37	3	74.72	24.91	0.67	6	118.28	19.71	0.82	3.00
Error I	6	63.55	10.59		6	223.50	37.25		12	287.05	23.92		
Factor P	3	883.60	294.53	49.93	3	924.59	308.20	12.06	6	1808.19	301.36	19.16	2.29
MxP interaction	9	21.01	2.33	0.40	9	19.93	2.21	0.09	18	40.94	2.27	0.14	1.82
Error II	24	141.58	5.90		24	613.54	25.56		48	755.12	15.73		-
Total	47	1172.49			47	2072.41			95	3299.06			-

*Significant at 5% probability level

APPENDIX-85

Effect of liming materials and phosphorus levels on Organic–P of soil after harvest

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	3161.36	3161.36	1.56	4.75
Replication	2	4337.09	2168.55	1.05	2	1952.57	976.29	0.49	4	6289.67	1572.42	0.77	3.26
Factor M	3	9342.62	3114.21	1.51	3	17357.03	5785.68	2.90	6	26699.65	4449.94	2.19	3.00
Error I	6	12411.66	2068.61		6	11956.59	1992.77		12	24368.25	2030.69		
Factor P	3	51140.89	17046.96	25.49	3	56138.06	18712.69	31.30	6	107278.95	17879.82	28.23	2.29
MxP interaction	9	17067.25	1896.36	2.84	9	21075.24	2341.69	3.92	18	38142.49	2119.03	3.35	1.82
Error II	24	16049.08	668.71		24	14348.00	597.83		48	30397.08	633.27		-
Total	47	110348.59			47	122827.49			95	236337.45			-

*Significant at 5% probability level

APPENDIX-86

Effect of liming materials and phosphorus levels on Apparent P recovery

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	271.84	271.84	41.53	4.75
Replication	2	10.28	5.14	2.22	2	90.73	45.36	4.21	4	101.01	25.25	3.86	3.26
Factor M	3	28.88	9.63	4.16	3	146.67	48.89	4.54	6	175.55	29.26	4.47	3.00
Error I	6	13.89	2.32		6	64.64	10.77		12	78.54	6.54		
Factor P	3	1097.23	365.74	299.71	3	2287.69	762.56	163.13	6	3384.92	564.15	191.41	2.29
MxP interaction	9	11.83	1.31	1.08	9	51.49	5.72	1.22	18	63.32	3.52	1.19	1.82
Error II	24	29.29	1.22		24	112.19	4.67		48	141.48	2.95		-
Total	47	1191.39			47	2753.41			95	4216.65			-

*Significant at 5% probability level

APPENDIX-87

Effect of liming materials and phosphorus levels on agronomic efficiency of P

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	4.65	4.65	0.45	4.75
Replication	2	3.26	1.63	0.14	2	3.18	1.59	0.18	4	6.44	1.61	0.15	3.26
Factor M	3	13.76	4.59	0.38	3	9.60	3.20	0.36	6	23.36	3.89	0.37	3.00
Error I	6	71.81	11.97		6	53.49	8.91		12	125.30	10.44		
Factor P	3	1206.84	402.28	107.82	3	1332.94	444.31	88.05	6	2539.78	423.30	96.46	2.29
MxP interaction	9	37.55	4.17	1.12	9	87.10	9.68	1.92	18	124.65	6.92	1.58	1.82
Error II	24	89.54	3.73		24	121.10	5.05		48	210.65	4.39		-
Total	47	1422.76			47	1607.41			95	3034.82			-

*Significant at 5% probability level

APPENDIX-88

Effect of liming materials and phosphorus levels on physiological efficiency of P

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	1505.76	1505.76	8.42	4.75
Replication	2	3864.46	1932.23	7.05	2	1191.17	595.59	7.13	4	5055.64	1263.91	7.07	3.26
Factor M	3	3483.44	1161.15	4.23	3	1134.47	378.16	4.53	6	4617.91	769.65	4.30	3.00
Error I	6	1645.30	274.22		6	500.94	83.49		12	2146.24	178.85		
Factor P	3	128276.18	42758.73	252.15	3	108166.56	36055.52	217.76	6	236442.74	39407.12	235.16	2.29
MxP interaction	9	1767.64	196.40	1.16	9	1040.68	115.63	0.70	18	2808.32	156.02	0.93	1.82
Error II	24	4069.86	169.58		24	3973.81	165.58		48	8043.67	167.58		-
Total	47	143106.88			47	116007.64			95	260620.27			-

*Significant at 5% probability level

APPENDIX-89

Effect of liming materials and phosphorus levels on Phosphorus use efficiency

(ANNOVA TABLE)

Source of variation	2018				2019				Pooled				F Tab. At 5%
	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	DF	SS	MSS	Fcal	
Year	-	-	-	-	-	-	-	-	1	301.64	301.64	46.64	4.75
Replication	2	2.90	1.45	0.45	2	98.74	49.37	5.10	4	101.65	25.41	3.93	3.26
Factor M	3	7.11	2.37	0.73	3	125.29	41.76	4.32	6	132.40	22.07	3.41	3.00
Error I	6	19.54	3.26		6	58.06	9.68		12	77.61	6.47		
Factor P	3	1320.06	440.02	197.59	3	2517.07	839.02	98.22	6	3837.13	639.52	118.77	2.29
MxP interaction	9	20.97	2.33	1.05	9	58.72	6.52	0.76	18	79.70	4.43	0.82	1.82
Error II	24	53.45	2.23		24	205.01	8.54		48	258.46	5.38		-
Total	47	1424.04			47	3062.90			95	4788.58			-

*Significant at 5% probability level