FEASIBILITY OF PHOSPHOGYPSUM AS AN AMELIORANT FOR SOIL ACIDITY IN LATERITE SOIL

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Thesis submitted in partial fulfilment of the requirement
for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2003

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DECLARATION

I hereby declare that this thesis entitled **"Feasibility of phosphogypsum as an ameliorant for soil acidity in laterite soil"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that this thesis entitled "**Feasibility of phosphogypsum as an ameliorant for soil acidity in laterite soil**" is a record of research work done independently by Ms. Jeena Mathew (2001-11-27) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ACKNOWLEDGEMENT

I bow my head before God Almighty, for all the blessings showered upon me which enabled me to complete this venture.

I am deeply indebted to Dr. K.C. Manorama Thampatti, Assistant Professor, Department of Soil Science and Agricultural Chemistry, Chairman of the Advisory Committee for her invaluable guidance, inspiring support, encouragement, constructive criticism and suggestions during the course of investigation.

I acknowledge the critical comments and valuable suggestion of Dr. V.K. Venugopal, Professor and Head, Department of Soil Science and Agricultural Chemistry. Dr. Suman Susan Varghese, Associate Professor, Soil Science and Agricultural Chemistry, Dr. Sunny K. Oommen, Associate Professor, Department of Plant Breeding and Genetics – the members of advisory Committee which enabled me in bringing the thesis in the final form.

I express my gratitude towards Dr. C.R. Sudharmaidevi, Associate Professor, Dr. Thomas George, Assistant Professor of the Soil Science and Agricultural Chemistry for their timely help and suggestions during the chemical analysis. I am grateful to Dr. Suman George, Associate Professor, Dr. P.B. Usha, Associate Professor, Dr. Usha Mathew, Assistant Professor, Dr. Ushakumari, Associate Professor, Dr. Subramanya Iyyer, for the utmost help and encouragement rendered during the study period.

I am thankful to Sri. C.E. Ajithkumar, Computer Programmer, for his timely help in statistical anlysis.

I am grateful to my friends Anu, Simi, Sreeja, Pammu, Bijily, Sherin, Priya, Deepthi, Lekha, Ninitha, Beena, Ancy and all my colleagues who encouraged me in this venture.

I am also thankful to Sheeba, Devichechi, Indu and Neenu for the help rendered during the study period.

I acknowledge all the non-teaching staff of the Department of Soil Science and Agricultural Chemistry and the casual labourer Sivarajan for the help rendered during my research work.

I am deeply indebted the prayers and co-operation of my parents and Vivek. I am also thankful to Reena, Swetha, Rohit, Leena, Aaron and Bejoy.

I am thankful to Biju and Sindhu for completing the DTP work in time.

Finally, I thank all those who had directly and indirectly help me in this venture.

Jeena Mathew

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LIST OF ABBREVIATIONS

%	Per cent
μ S	Micro Siemens
^{0}C	Degree Celsius
CD	Critical difference
cmol	Centimole
EC	Electrical Conductivity
et al.	And others
FACT	The Fertilizers and Chemicals Travancore Limited
Fig.	Figure
FYM	Farmyard manure
g	Gram
ha^{-1}	Per hectare
KAU	Kerala Agricultural University
kg	Kilogram
LR	Lime Requirement
PG	Phosphogypsum
POP	Package of Practices
spp.	Species
viz.	Namely

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Dedicated to My Parents

INTRODUCTION

1. INTRODUCTION

Laterite soils are the most extensive soils of Kerala occupying the mid land and mid-upland region of the state covering an area of 22370 sq.km. Due to aberrant weather, soil related constraints and poor management crop production in these soils has remained low and unsustainable. It has been proved beyond doubt by several workers that under proper management, the laterite soils hold a great promise especially for export oriented plantation crops.

The foremost and major reason for the low productivity of the laterite soil is the inherent acidity coupled with low base status and associated with toxic factors. The dominance of low activity clays *viz.*, kaolinite and hydrous oxides has been responsible for the very high P fixing capacity. Liming, an essential component in the management of these soils is very seldom practiced by farmers due to high cost and scarcity of the material. The common practice of surface incorporation of lime neutralises acidity and toxic factors only in the surface soil while sub soil acidity, low base status and toxicity continue to exist as a problem below the normal plough depth. Sumner (1970) has reported that gypsum could act as an ameliorant for subsoil acidity prevalent in laterite soil. Considering the cost factor and the mobility of calcium to the subsoil layers, phosphogypsum is a suitable ameliorant. In Kerala it is available from the FACT divisions at Cochin and Udyogamandal.

Several industrial byproducts such as fly ash, cellulose factory effluent, tannery sludge etc as well as organic wastes such as mushroom spent compost, wood ash and cattle manure have been proved as an amendment for reducing the hazards of acidity. But in the present situation of Kerala, these alternatives do not offer a practical solution, since availability of the same cannot be ensured. Hence a cheap and easily available industrial by product such as phosphogypsum could be considered. Phosphogypsum, the by product from phosphoric acid plant is basically hydrated $CaSO_4$ with small proportions of P, Si, Al, Na, K, Mg, F and several minor elements. The annual production of phosphogypsum in India is about 2.8 million tonnes, of which only 64 to 76 per cent is presently utilized. In Kerala, about one lakh tonne of phosphogypsum is generated annually by the divisions of FACT at Cochin and Udyogamandal. A major portion of this remains unutilized and are dumped at the factory premises causing serious disposal problems. Though phosphogypsum has long been used for the reclamation of sodic soils from years back, its use for improvement of acid soils is very recent. Phosphogypsum is highly suitable for the correction of acidity especially subsoil acidity, aluminium toxicity and surface crusting in soils dominated by active Al and Fe. It also serves as a source for Ca and S (Alcordo and Recheigl, 1993).

Jacob (1992) reported that the combination treatment with $MgCO_3$ + 75 per cent $CaSO_4$. $2H_2O$ could neutralize surface and subsoil acidity in laterite soils of Kerala. As phosphogypsum is very similar to mined gypsum in its chemical properties and composition, it could also serve as a suitable ameliorant for correcting acidity. At the same time it ensures a novel methodology for utilization of waste product from P fertilizer plants.

In the light of the recent findings on the effect of phosphogypsum in the correction of soil acidity and to improve the over all productivity, the present investigation with the following objectives was undertaken at College of Agriculture, Vellayani.

(1) To evaluate the suitability of phosphogypsum for the correction of soil acidity in laterite soil.

(2) To understand the dissolution and nutrient release pattern of phosphogypsum in soil.

(3) To study the effect of phosphogypsum on crop production and soil characteristics.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Kerala state is dominated by laterite soils with a pH range of 4.5 to 5.5. Nutrient management strategies are of prominent importance for optimum productivity and sustainability. Among the different parameters that limit crop production in these soils, severe soil acidity and its consequent effects on nutrient availability and Al toxicity of the subsoil are of importance. Hence adequate management strategies are to be planned for improving the productivity of these soils.

Currently liming is the only practice that the farmers are following for the correction of acidity. Because of the high price of lime, farmers will often try to skip this practice. Hence it is high time to identify other cheaper materials which can act as a supplement or even substitute to lime. Phosphogypsum, the byproduct of phosphoric acid plant is one such material. It is very similar to mined gypsum in almost all the properties and has been widely used for the reclamation of sodic soils.

During 1970's the ability of phosphogypsum to correct soil acidity in laterite soil rich in Fe and Al was revealed by Sumner (1970). Afterwards lot of research has been undertaken on the ability of phosphogypsum for the control of soil acidity in iron and aluminium rich soils. The literature on different aspects of acidity and its management with special reference to feasibility of phosphogypsum for correcting soil acidity are reviewed here.

2.1 NATURE OF SOIL ACIDITY IN LATERITE SOIL

In Kerala, more than sixty per cent of soils are laterite with a pH less than 5.5. Soil acidity and associated problems are the major chemical constraints for crop production in laterite soils (Sarkar *et al.*, 1989; Jose *et al.*, 1998).

In red soils of Trivandrum, the exchangeable acidity contributes 6 per cent and pH dependent acidity contributes 60 per cent of total acidity. Among the components of exchangeable acidity, exchangeable aluminum contributes more than 90 per cent of it and is considered as the major source of exchangeable acidity in these soils (Sharma *et al.*, 1990).

According to Nambiar and Meelu (1996) soil acidity in laterite soil is increasing over the years due to long-term fertilizer use. Varghese and Usha (1997) reported that the wet lands of red and laterite soils of Vellayani have an active acidity of 4.46 cmol kg^{-1}, exchangeable acidity of 0.5 cmol kg^{-1}, non exchangeable acidity of 13.2 cmol kg^{-1} and potential acidity of 13.78 cmol kg^{-1}.

Chand and Mandal (2000) found that the values of total potential acidity, total acidity, pH dependent acidity, hydrolytic and exchangeable acidity ranged from 1.5 to 11.25, 0.93 to 4.75, 1.41 to 10.35, 0.89 to 3.85 and 0.04 to 1.03 cmol kg^{-1} respectively in red and laterite soil of West Bengal. Dolui and Sarkar (2001) noticed that in the red soil profiles of Orissa, exchangeable acidity contributed to 9 to19 per cent of total acidity whereas pH dependent acidity constituted 81 per cent of total potential acidity. In the red soils of West Bengal the mean values of exchangeable and pH dependent acidity were 12.4 and 87.6 per cent of total potential acidity (Rahman and Karak, 2001).

2.2 IMPACT OF SOIL ACIDITY ON THE GROWTH OF LEGUMES

Aluminium toxicity and calcium deficiency are the important limitations for the crop growth in acid soil. Poor root penetration and proliferation are commonly observed in acid soils (Pearson, 1966). Haynes (1984), Farina and Channon (1988), Noble *et al.* (1988), Shainberg *et al.* (1989), Alva and Sumner (1990), Vizcayno *et al.* (2001) and Sharma and Singh (2002) also reported the poor root growth in the acid soils due to Al toxicity and Ca deficiency.

Ota (1968) reported that the bronzing of paddy in poorly drained soil is due to aluminum toxicity along with calcium deficiency. Black (1973) noted that poor crop growth in acid soils was directly related with aluminium saturation of soils and that pH had no direct effect on plant growth, except below 4.2

Trivalent aluminium reduced growth of main root axis and inhibited lateral root formation and there by making them less efficient in absorbing water and nutrients (Foy, 1974). Trivalent aluminium inhibited the root growth by binding to the phosphate portion of DNA in the root cell nuclei, thereby reducing the template activity and cell division (Matsumoto *et al.*, 1976; Matsumoto and Morimura, 1980; Horst *et al.*, 1983).

Abraham (1984) reported that aluminium concentration in the range 20 to 40 ppm in the nutrient solution decreased root elongation and caused reduction in the number of productive tillers, yield of grains and straw as well as shortening and branching of roots with a resultant reduction in the uptake of nutrients. Higher concentration of aluminium in the nutrient solution led to a higher uptake of iron in rice. The site of aluminium toxicity is root apex and aluminium injured roots have been found to be stubby and brown (Narayanan and Syamala, 1989; Ryan *et al.*, 1993).

In legumes, the growth of root hairs and nodule initiation were impaired by trivalent aluminium (Munns and Franco, 1982; Carvalho *et al.*, 1982). Narayanan and Syamala (1989) noticed that the dry weight of leaves, stem and roots of soyabean declined at higher aluminium concentration greater than 10 ppm. Reduction in the root length of soyabean is correlated with monomeric aluminium species (Blamey *et al.*, 1983; Alva *et al.*, 1986; Noble *et al.*, 1988; Cakmak and Horst, 1991).

Aluminium toxicity also affected the shoot growth of non leguminous plants like rice (Fageria, 1982) and Gleditsia (Thornton *et al.*, 1986). Reduction in the length of coffee roots (Pavan *et al.*, 1982; Scott *et al.*, 1991) and fresh weight of wheat (Scott *et al.*, 1991) were also reported. Neogy *et al.* (2002)

observed that, the toxic concentration of aluminium sulphate in solution cultures caused shoot nutrient deficiency, poor crop yield, reduced leaf area and dry weight of mungbean.

2.3 RECLAMATION OF SOIL ACIDITY IN LATERITE SOIL.

Liming is one of the most important management options in laterite soil where soil acidity poses the major challenge for successful crop production.

Varghese and Money (1965) showed that, the acidic pH of red and laterite soils of Vellayani, could be raised by calcium and magnesium compounds. Liming though a relatively costly remedial treatment, it is the most effective solution for correcting the problem of soil acidity (Ukrainetz, 1984; Malhi *et al.*, 1995). Enright (1984) reported that the application of lime @ 2 t ha^{-1} in laterite soil increased the soil pH by two units by decreasing exchangeable aluminium content.

Abraham (1984) reported that lime @ 1200 kg ha^{-1} in Kari soil raised the pH from 3.8 to 5.7. Several workers have reported that application of lime decreased aluminium saturation and increased pH and exchangeable calcium content of soil (Lin *et al.*, 1988; Broadbent *et al.*, 1989).

Lime amended soil had 0.5 to 1.1 units pH higher than unlimed soil from a single application @ 4.5 to 6.5 t ha^{-1} in acid soils of Canada (Beckie and Ukrainetz, 1996). The increase in the pH of acid soil by the application of 800 kg ha^{-1} of Ca in the form of lime was reported by Oyanagi *et al.* (2001). Repsiene (2002) reported that hydrolytic and exchangeable acidity decreased as much as 64 per cent by liming in podzolic soils.

Mora *et al.* (2002) reported that combined application of limestone, dolomite and gypsum raised pH and decreased aluminium saturation from 20 per cent to less than 1 per cent in acid soil. The positive influence of lime in soil pH after liming was also reported by Staley (2002), Caires *et al.* (2002a), Whalen *et* *al.* (2002), Nkana and Tonye (2003) and Tang *et al.* (2003). Concurrent application of lime into planting furrows and surface application raised soil pH and decreased exchangeable aluminium in acid soil (Pires *et al.*, 2003).

2.4 ALTERNATE SOURCES OF LIMING

Several industrial by products and wastes as well as organic wastes like mushroom spent compost and wood ash have found to be acting as ameliorants for soil acidity.

Subramoney (1956) suggested the use of magnesium silicate in acid sulphate soils of Kerala to control soil acidity as well as to prevent the production of hydrogen sulphide. Marykutty (1986) reported that lime application raised the pH of lateritic alluvial soils of Kerala.

The ameliorating effect of flyash have been suggested by Dunn and Stevens (2000), Mc Callister *et al.* (2002) and Marx (2002).

Several workers have reported that industrial by products like phosphogypsum and cellulose factory effluents (Kimjo *et al.*, 1992), pulverised fuel ash (Perkin, 1996), flue gas desulphurization byproduct (Wendell and Ritchey, 1996), cement flue dust (Ogyntoyenbo *et al.*, 1996), tannery sludge (Castilhos *et al.*, 2002), sewage sludge (Hue, 1992, Oliveira *et al.*, 2002), and boiler ash (Dee *et al.*, 2003) could act as ameliorants in acidic soil.

The ameliorating effect of sugar factory waste was reported by Mesi (2001) and Dee *et al.* (2003).

The ameliorating effect on acid soil by the application of organic waste products like chicken manure (Hue, 1992), spent mushroom substrate (Ahalwat and sagar, 2001) fresh cattle manure (Whalen *et al.*, 2002) and wood ash (Nkana and Tonye, 2003) have also been reported.

2.5 PHOSPHOGYPSUM AS AN AMELIORANT FOR SOIL ACIDITY

Amelioration of acid soils by conventional liming materials such as calcium oxide, calcium carbonate, calcium hydroxide etc. are limited to the depth of incorporation only because of their low mobility and solubility (Brown and Munsell, 1938; Pearson *et al.*, 1973; Recheigl *et al.*, 1985; Sumner *et al.*, 1986; Farina and Channon, 1988).

The sub soil acidity which is also a major problem in tropical soils requires deeper incorporation of these liming materials. Mechanical incorporation of lime into deeper soil horizon is costly and heavy application of lime is toxic. Hence alternate liming materials with better mobility were attempted for the correction of soil acidity. Phosphogypsum was found to be one such effective material for the correction of subsoil acidity (Sumner, 1970; Reeve and Sumner, 1972). Later several scientists such as Shainberg *et al.* (1989), Sumner (1990) and Alcordo and Recheigl (1993) also reported the same.

Ameliorative effect of mined gypsum and phosphogypsum in acid subsoil was also suggested by Caldwell *et al.* (1990), Mc Cray *et al.* (1991), Oliveira and Pavan (1996), Carvalho and Raij (1997), Recheigl and Mislevy (1997), Moody *et al.* (1998) and Hoveland (2000).

An increase in the soil pH to the extent of 0.8 units in dark red latosol after gypsum application was reported by Ritchey *et al.* (1980). Similar results of pH increase was also reported by Keng and Uehara (1974), Hue *et al.* (1985), Chaves *et al.* (1988a) and Bolan *et al.*(1992).

Jacob (1992) suggested that soil pH increased by 0.05 units by the application of lime and gypsum @ 3 times exchangeable aluminium in red and laterite soil of Kerala.

Contrary to the above reports, a decrease in pH after gypsum application was noticed by Black and Cameroon (1984). Soil pH decreased to the extent of

0.5 to 0.9 units after gypsum application in non allophanic Andosol (Toma and Saigusa, 1997). In highly weathered Palexerult soils also the decrease in pH was noticed by Arias and Fernandez (2001) whereas no change in pH due to phosphogypsum application was reported by Hammel *et al.* (1985), Oates and Caldwell (1985) and Sumner *et al.* (1986).

The detoxification of subsoil aluminium by the flouride content of phosphogypsum was reported by Alva *et al.* (1988) and Alva and Sumner (1988).

Gypsum increased subsoil base status and reduced subsoil exchangeable and soluble aluminium (Rhue and Kamprath, 1973; Sumner *et al.*, 1988). Alva and Sumner (1989) found that application of phosphogypsum alleviated aluminium toxicity and increased soyabean root growth in nutrient solutions. Both phosphogypsum and mined gypsum can ameliorate aluminium toxicity in the subsoil horizon of highly weathered soil belonging to soil orders such as Ultisol and Oxisol (Martin *et al.* (1988) and also in soils such as non allophanic Andosol (Saigusa *et al.*, 1996; Toma and Saigusa, 1997). In Dystric Luvisol, aluminium toxicity was alleviated by phosphogypsum @ 12.5 to 25 t ha^{-1} (Mesi, 2001; Borisov, 2001)

Alva and Sumner (1990) suggested that the ameliorating effect of mined gypsum or phosphogypsum is due to the supply of calcium. This was also reported by Sumner (1993) and Jacob and Venugopal (1993) and also due to the enhanced mobility of gypsum (Alcordo and Recheigl, 1993; Sumner, 1993).

According to Jacob (1992) the combination treatment of 75 per cent gypsum and 25 per cent magnesium carbonate can be suggested as an ameliorant for surface acidity and subsoil acidity in red and laterite soils of Kerala. The effectiveness of combination treatment in Plinthic Palexerult was suggested by Vizcayno *et al.* (2001). Mora *et al.* (2002) suggested that the combined application of limestone, gypsum and dolomite raised soil pH and decreased aluminium saturation from 20 per cent to less than 1 per cent in acidic Andosol.

Successive equilibration of soils with phosphogypsum decreased exchangeable aluminium (Alva *et al.*, 1990) and increased cation exchange capacity of soil (Alva *et al.*, 1991b). According to Liu and Hue (2001) gypsum treatment decreased exchangeable aluminium through out the profile as a result of exchange reaction between calcium and aluminium in highly weathered acidic Ultisol (Rhodic Kandiudult).

2.5.1 Mechanisms Involved in the Amelioration of Soil Acidity by Phosphogypsum

Phosphogypsum could act as ameliorant for soil acidity in soils rich in Fe and Al. This is made possible through several mechanisms such as

1) Self liming effect which involves a ligand exchange of hydroxyl by sulphate on the sesquioxide surface (Reeve and Sumner, 1972; Sumner *et al.*, 1986; Farina and Channon, 1988; Shainberg *et al.*, 1989; Alva *et al.*, 1990)

2) Precipitation of solid phases in the form of basic aluminium sulphates such as jurbanite (Hue *et al.*, 1985; Alva *et al.*, 1991a)

3) Cosorption of SO_4^{2-} and Al^{3+} which involves a preferential salt adsorption of Al^{3+} over the Ca^{2+} on negative charges formed by specific adsorption of SO_4^{2-} (Sumner *et al.*, 1986; Sumner, 1993).

4) Ion pair formation (Chaves *et al.*, 1991b) which involves formation of ion pairs such as $AlSO_4^+$ (Cameron *et al.*, 1986; Mc lay and Ritchie, 1993; Pavan *et al.*, 1982) and AlF^{2+} in the case of phosphogypsum, (Cameron *et al.*, 1986).

5) Increasing ionic strength of solution, which reduces activity of Al^{3+} in solution (Pavan and Bingham, 1982).

2.6 EFFECT OF PHOSPHOGYPSUM AND MINED GYPSUM ON PLANT GROWTH

2.6.1 Biometric Characters

Application of phosphogypsum as well as mined gypsum significantly influenced the biometric characters of leguminous plants .

Balasubramanian and Ramamoorthi (1995) found that gypsum application @ 40 kg S ha^{-1} increased the plant height in green gram. Beena (2000) also reported that gypsum application @ 30 kg S ha^{-1} recorded maximum height in cowpea var. Kanakamoni grown in laterite soils of Vellayani. This was also reported by Beena and Usha (2002).

Sarmah and Debnath (1999) noticed positive correlation between gypsum application and number of primary branches per plant in toria. Gypsum application @ 45 kg S ha^{-1} increased the number of primary branches in groundnut grown in sandy loam soils in Uttar Pradesh (Chaubey *et al.*, 2000). Application of gypsum @ 40 kg S ha^{-1} increased the number of branches and plant height in mustard (Kumar *et al.*, 2001).

2.6.2 Root Characteristics

Since the application of mined gypsum alleviates aluminium toxicity in acid soils root growth is promoted considerably. Alva and Sumner (1990) reported that root weight of soyabean was significantly increased by treatment with phosphogypsum. Jacob (1992) found that, the root length and number of nodules per plant in soyabean grown on laterite soil of Kerala were increased by liming @ 1.5 times exchangeable aluminium. Several reports have been published which shows that gypsum application improved the root length of several crops grown in acid soils such as beans (Oliveira *et al.*, 1986; Souza and Ritchey, 1986), alfalfa (Sumner and Carter, 1988; Sumner, 1993), barley (Toma and Saigusa, 1997) and maize (Carvalho and Raij, 1997). The rooting pattern of forage crops were also improved by gypsum application such as sudan grass (Wendall and Ritchey, 1996) and star grass (Recheigl and Mislevy, 1997).

Beena (2000) reported that application of gypsum @ 30 kg S ha^{-1} resulted in maximum number of root nodules per plant in cowpea grown in laterite soil of Vellayani. It also decreased the days to reach maximum flowering stage and maturity. Srinivasan *et al.* (2000) reported that gypsum application @ 40 kg S ha^{-1} increase the number of effective nodules per plant and nodule dry weight in black gram grown in an acidic Alfisol of Tamil Nadu.

2.6.3 Yield Attributes

Gypsum application @ 500 kg ha^{-1} increased shelling percentage and hundred kernel weight in groundnut (Bhaskar and Shankar, 1993). The yield attributes of groundnut like pod weight per plant, number of pods per plant and weight of kernel were increased with gypsum application @ 500 kg ha^{-1}(Rao and Moorthy, 1994). Geethalakshmi and Lourdraj (1998) reported that increased number of pods were obtained by gypsum application in mustard. Chaubey *et al.* (2000) noticed that gypsum application @ 45 kg S ha^{-1} enhanced the yield attributes of groundnut. Similar results were published by Bandopadhyay and Samui (2000). Its application @ 250 kg ha^{-1} increased number of pods per plant, percentage of sound mature kernel in sandy clay loam soils of Rajasthan (Rao and Shaktawat, 2002).

Gypsum application @ 40 kg S ha^{-1} produced higher number of pods per plant and grains per pod in green gram (Balasubramanian and Ramamoorthy, 1995; Ramamoorthy *et al.*, 1997; Srinivasan *et al.*, 2000). Beena (2000) reported that number of pods per plant, bhusa yield, harvest index and total dry matter production gave the highest values in cowpea var. Kanakamoni with gypsum @ 30 kg S ha^{-1} in red and laterite soil of Vellayani, Kerala.

Application of gypsum @ 20 kg S ha^{-1} gave largest number of siliqua $plant^{-1}$ and seeds $siliqua^{-1}$ in rapeseed (Mahopatra and Jee, 1992). The yield attributes of mustard like length of siliqua, seeds siliqua^{-1}, 1000 seed weight etc. were increased by gypsum application @ 60 kg S ha^{-1} (Tripathi and Sharma, 1994) and at 50 kg S ha^{-1} (Geethalakshmi and Lourdraj 1998; Sarmah and Debnath, 1999). Gypsum application @ 40 kg S ha^{-1} also increased the yield attributes of mustard (Kumar *et al.*, 2001; Bohra and Srivastava, 2002).

In sunflower yield attributes like seed and stalk yield, head diameter, hundred seed weight and kernel husk ratio were increased by gypsum application (Sreemannarayana and Raju, 1993). Krishnamurthi and Gnanamurthy (2002) reported that yield attributes of sunflower like 100 seed weight and head diameter were increased by application of gypsum @ 60 kg S ha^{-1}. Reddi *et al.* (2002) observed that application 500 kg gypsum ha^{-1} along with 125 per cent of recommended dose of fertilizer recorded highest leaf stalk yield, dry matter accumulation and highest seed yield in sunflower.

The harvest index of mustard was increased due to the application of gypsum @ 40 kg S ha^{-1} (Kachroo and Kumar, 1997). The harvest index of groundnut was highest with gypsum @ 400 kg ha^{-1} applied at the pegging stage (Geethalakshmi and Lourdraj, 1998). Beena (2000) also reported that the harvest index of cowpea was increased by application of gypsum @ 30 kg S ha^{-1} in laterite soils of Vellayani.

2.6.4 Crop Yield

Application of phosphogypsum or mined gypsum in soils rich in iron and aluminium had favourably influenced the yield of many crops. The review of literature on response of legumes to sulphur application have indicated that, their yield was favourably influenced by the application of sulphur either as mined gypsum or as phosphogypsum.

Gypsum application increased the pod yield of groundnut (Sridhar *et al.*, 1985; Rao *et al.*, 1990; Devi and Reddi, 1991). Application of 40 kg S ha^{-1} as gypsum increased yield of groundnut in sandy loam soils of Orissa (Misra *et al.*, 1990; Singh *et al.*, 1993) and as phosphogypsum in black gram @ 40 kg S ha^{-1} (Singh *et al.*, 1998a).

Twenty one per cent increase in the yield of groundnut over control, with gypsum @ 40 kg S ha^{-1} was noticed by Bhattacharya and Manisha de (1997). Geethalakshmi and Lourdraj (1998) also noticed an increase of 14 per cent in pod yield of groundnut by the application of gypsum. Application of phosphogypsum @ 300 kg ha^{-1} increased pod yield of groundnut grown in Gangetic alluvial soils (Singh and Sarkar, 1999). Positive correlation between application of phosphogypsum and yield of groundnut in laterite soil was reported by Sahu *et al.* (2001).

Increase in the yield of groundnut by gypsum application was also reported by Alva and Gascho (1991), Sharma *et al.* (1992), Sahu and Das (1997), Devakumar and Giri (1998), Singh and Sarkar (1999), Bandopadhyay and Samui (2000), Chaubey *et al.* (2000) and Chandrasekaran (2001).

Split application of gypsum was also found to be beneficial to enhance the yield of groundnut (Chitkaladevi and Reddi, 1991; Bhaskar and Shankar, 1993; Rao and Moorthy, 1994). Application of gypsum @ 250 kg ha^{-1} in groundnut either in full or split dose could increase the pod yield by 9.1 per cent over control (Rao and Shaktawat, 2002).

The superiority of gypsum over other sulphur sources was reported by Aulakh and Parischa (1986) and Ramamoorthy *et al.* (1997). Application of gypsum @ 40 kg S ha^{-1} increased the yield of chickpea (Ram and Dwivedi, 1992). Beneficial effects of sulphur applied as gypsum on yield of crops like lentil - mung, chickpea - mung, groundnut - wheat in rotation have been reported by Aulakh and Chibba (1992). Bora (1997) found that gypsum application in brassica varieties increased the seed yield significantly. Twenty five per cent increase in yield of blackgram over pyrites and elemental sulphur in red soil of Tamil Nadu was reported by Srinivasan *et al.* (2000). Application of gypsum @

30 kg S ha^{-1} in cowpea var. Kanakamoni grown in red and laterite soils of Vellayani, showed 42 per cent yield increase over treatment with N, P and K alone (Beena, 2000). It also increased the number of pods per plant and seeds per pod.

Vitti *et al.* (1986) found that by applying phosphogypsum @ 0.1 t ha^{-1} resulted in 37 to 43 per cent yield increase in soyabean grown on Oxisols and Ultisols. Significant yield increase due to surface application of gypsum was recorded by Hammel *et al.* (1985) and Sumner *et al.* (1988). Application of phosphogypsum could significantly increase the yield of soyabean (Oliveira and Pavan, 1996).

Application of gypsum @ 30 to 40 kg S ha^{-1} had significantly increased the yield of mustard (Singh and Saran, 1987; Jain and Saxena, 1991; Dubey and Khan, 1993).

The superiority of phosphogypsum over pyrites and elemental sulphur in increasing yield of mustard was noticed by Sarmah and Debnath (1997) and Kumar *et al.* (2001). Sulphur application through gypsum @ 40 to 60 kg S ha^{-1} increased the yield attributes of mustard (Venkatesh *et al.*, 2002; Prakash and Singh, 2002).

The increase in seed yield of sunflower by gypsum application was reported by Krishnamurthi and Gnanamurthy (2002) and Mandal and Giri (2002).

The yield increase by gypsum application have been published by several workers in non leguminous crops such as Maize (Hammel, 1985; Sumner, 1992; Marcano *et al.*, 1997; Raij *et al.*, 1998), wheat (Sakal *et al.*, 1999; Sivran *et al.*, 2000; Kundu *et al.*, 2000; Caires *et al.*, 2002b), citrus (Lin *et al.*, 1988), millets (Okorkov and Abdrakhmanov, 1996; Singarvel, 2002; Aloudat *et al.*, 1998; Jat *et al.*, 2002), pasture (Recheigl and Mislevy, 1997; Ritchey and Snuffer, 2002; Clark and Baligar, 2003), rice (Sakal *et al.*, 1999) and onion (Paula *et al.*, 2002).

al., 2002), pasture (Recheigl and Mislevy, 1997; Ritchey and Snuffer, 2002; Clark and Baligar, 2003), rice (Sakal *et al.*, 1999) and onion (Paula *et al.*, 2002).

Contrary to the above reports, reduction in yield due to gypsum application was also reported. Gypsum application reduced the yield of lupins (Mc lay *et al.*, 1992; Ellington *et al.*, 1992).

2.6.5 Crop Quality

Mined gypsum and phosphogypsum contain about 16 and 18.9 per cent sulphur respectively. Sulphur application not only enhances the grain yield, but also improves the quality of pulses and legumes due to its association with certain aminoacids (Sumner, 1993).

Several workers have reported that application of gypsum increases the grain protein and aminoacids such as methionine and tryptophan content of legumes (Dwivedi and Singh, 1982; Chander *et al.*, 1984). Ram and Dwivedi (1992) found that gypsum application @ 40 kg S ha^{-1} recorded maximum protein content (22.6 per cent), methionine (1.17 per cent) and tryptophan (0.83 per cent) in chickpea grown on sandy loam soils of Uttar Pradesh.

Misra *et al.* (1990) reported that lime application along with gypsum @ 30 to 40 kg S ha^{-1} increased pod yield and shelling percentage of kharif groundnut grown in acidic soils of Orissa.

Gypsum application @ 40 kg S ha^{-1} increased the oil yield of mustard (Dubey and Khan, 1993; Tripathi and Sharma, 1994). Singh *et al.* (1998b) noticed that application of phosphogypsum @ 60 to 80 kg S ha^{-1} increased protein and oil yield of mustard and black gram. Jaggi *et al.* (2000) observed that the oil yield of raya was higher with gypsum application compared to elemental sulphur and ammonium sulphate. Prakash and Singh (2002) reported that application of gypsum increased the protein and oil content of mustard.

Panda *et al.* (1997) observed that phosphogypsum @ 30 kg S ha^{-1} recorded the highest oil content in groundnut. Application of gypsum @ 40 kg S ha^{-1} increased the oil yield of groundnut grown in Gangetic alluvial soils (Bhattacharya and Manisha de, 1997) and sandy loam soils (Bandopadhyay and Samui, 2000).

Application of gypsum @ 40 kg S ha^{-1} increased the protein content of blackgram grown in an Alfisol (Srinivasan *et al.*, 2000). Beena (2000) reported that protein content in cowpea was maximum with 30 kg S ha^{-1} as gypsum, grown in laterite soil of Vellayani. The oil and protein content of soyabean was significantly improved by applying 30 kg S ha^{-1} as gypsum in a clay loam soil (Singh *et al.*, 2001).

Sonune *et al.* (2001) reported that application 40 kg S ha^{-1} as gypsum increased protein content in soyabean. Protein and oil content of sunflower showed a positive correlation with rate of gypsum as sulphur source (Venkatesh *et al.*, 2002). The same relation was noticed in the oil yield of sesamum by Allam (2002).

Sakal *et al.* (1999) noticed positive correlation between the rate of application of phosphogypsum and protein content in rice and wheat. The grain protein content of pearl millet was increased by 20 kg S ha^{-1} as gypsum (Jat *et al.*, 2002). Germanovich (1997) found that phosphogypsum @ 60 to 90 kg S ha^{-1} had a significant influence on the synthesis of aminoacids in barley.

2.6.6 Dry Matter Production

Application of both mined gypsum and phosphogypsum could increase the dry matter production in leguminous crops.

Jacob (1992) reported that the total dry weight of soyabean was highest with application of gypsum and lime @ 3 times exchangeable aluminium. Sreemannarayana and Raju (1993) found that the total dry matter yield of sunflower grown in acidic Alfisol was increased by gypsum application. In black gram an increase in plant dry weight due to gypsum application was noticed under rainfed condition (Ramamoorthy *et al.*, 1997). Beena (2000) reported that the total dry matter production of cowpea was maximum with gypsum @ 30 kg S ha^{-1} in red and laterite soils of Vellayani.

2.7 INFLUENCE OF GYPSUM ON NUTRIENT COMPOSITION OF LEGUMINOUS CROPS

Application of phosphogypsum had significant effect on the concentration of nutrients in leguminous crops. Rosen *et al.* (1987) reported that by the application of phosphogypsum, leaf Ca and S contents were elevated while leaf Mg content was decreased. This was also reported by Farina and Channon (1988), Sumner and Carter (1988), Shainberg *et al.* (1989) and Carvalho and Raij (1997). Application of gypsum @ 250 kg ha^{-1} in single or split dose increased the accumulation of N, P, K, Ca, Mg and S in groundnut (Rao and Shaktawat, 2002).

Alva and Sumner (1990) found that the concentration of Ca was significantly higher after the application of phosphogypsum in alfalfa plants grown on an acid soil Typic Hapludult. Deng *et al.* (1990) found that phosphogypsum increased the S content in rice.

Jacob (1992) reported that P and Fe contents of soyabean shoot were increased with the treatment combination of gypsum and lime @ 3 times exchangeable Al in laterite soils of Kerala. However, the K, Ca, Mg, Mn and Zn content in shoot and pod of soyabean was not significantly influenced by liming.

Increased levels of application of sulphur @ 20 to 60 kg ha^{-1} through gypsum increased the concentration of N, P, Ca and S in cowpea grown in an alluvial soil (Hazra, 1997). Application of phosphogypsum @ 60 kg S ha^{-1} increased the concentration of N, P, S and Ca in wheat and rice grown in sandy soils of Bihar (Sakal *et al.*, 1999).

Gypsum application @ 50 kg S ha^{-1} increased the S content in sugarcane (Bokhtiar *et al.*, 2001). The Ca and S contents of wheat leaves were increased by gypsum application (Caires *et al.*, 2002 b).

Ritchey and Snuffer (2002) reported that forage plants treated with byproduct gypsum @ 32 t ha^{-1} had higher concentration of K and P but low concentration of Mg in a Typic Hapludult soil.

2.8 NUTRIENT UPTAKE

Application of gypsum either as mined or phosphogypsum have a significant effect on the uptake of nutrients as revealed by review of literature pertaining to this aspect.

Souza and Ritchey (1986) found that the total uptake of N by maize increased from 91 kg ha^{-1} to 135 kg ha^{-1} with 6 t ha^{-1} of gypsum. The beneficial effect of gypsum in promoting the uptake of N, P, K, Ca, S, Cu and Mn in Oxisols was reported by Souza *et al.* (1992). Tripathi and Sharma (1994) reported that the uptake of N in mustard increased with the application of gypsum @ 40 kg S ha^{-1} and @ 60 kg S ha^{-1} in wheat.

Increased uptake of N over the control with gypsum application was noticed in maize (Carvalho and Raij, 1997) and wheat (Sakal *et al.*, 1999; Kundu *et al.*, 2000).

Nitrogen uptake in cowpea grown in red and laterite soils of Vellayani was increased by the application of gypsum @ 30 kg S ha^{-1} (Beena, 2000). Shankaralingappa *et al.* (2000) found that N uptake in pigeon pea increased with 20 kg S ha^{-1} as gypsum. Nitrogen uptake by groundnut grown in sandy clay loam soil was also increased by the application of gypsum @ 20 kg S ha^{-1} (Rao and Shaktawat, 2002).

Jacob (1992) found that by the application of gypsum and lime @ 3 times exchangeable aluminium improved P uptake in soyabean grown in laterite soil. Increased uptake of P with gypsum application @ 40 kg S ha^{-1} in mustard was reported by (Tripathi and Sharma, 1994). Sakal *et al.* (1999) reported that application of gypsum @ 60 kg S ha^{-1} improved the P uptake in wheat. The uptake of P was improved with 20 kg S ha^{-1} in pigeon pea (Shankaralingappa *et al.*, 2000). Beena (2000) observed that the uptake of P in cowpea was improved by the application of gypsum @ 30 kg S ha^{-1} in red and laterite soil of Vellayani. Positive correlation between gypsum application and P uptake was also reported by Rao and Shaktawat (2002) in groundnut.

Jacob (1992) reported that maximum uptake of K in soyabean was noticed with lime and gypsum @ 3 times exchangeable aluminium in laterite soils of Kerala. The increased K uptake with gypsum @ 40 kg S ha^{-1} in mustard was reported by Tripathi and Sharma (1994). Carvalho and Raij (1997) found that by the application of phosphogypsum, uptake of K increased in maize grown in latosols. The uptake of K was maximum with 60 kg S ha^{-1} applied through gypsum in wheat (Sakal *et al.*, 1999). Beena (2000) found that gypsum @ 15 kg S ha^{-1} recorded maximum uptake of K in cowpea, whereas for pigeon pea the requirement was of about 20 kg S ha^{-1} as gypsum for maximum K uptake (Shankaralingappa *et al.*, 2000).

Misra *et al.* (1990) found that gypsum application @ 30 kg S ha^{-1} increased Ca and S uptake in groundnut. Jacob (1992) noticed that maximum Ca uptake in soybean was obtained with lime and gypsum @ 3 times exchangeable aluminium. Tripathi and Sharma (1994) reported that uptake of S and Fe by mustard increased with gypsum application @ 40 kg S ha^{-1} in sandy loam soil.

Uptake of S in rapeseed increased with gypsum application @ 25 kg S ha^{-1} (Mahopatra, and Jee, 1992) whereas an increase was noticed with 40 to 60 kg S ha^{-1} in mustard and wheat (Singh *et al.*, 1998b; Sakal *et al.*, 1999; Kumar *et al.*, 2001). Beena (2000) reported that the uptake of Ca, Mg and S in cowpea grown in red and laterite soil of Vellayani, was increased with the application of gypsum @ 30 kg S ha^{-1}. Caires *et al.* (2001) noticed the enhanced Ca and S uptake with gypsum @ 4 to12 t ha^{-1}. Krishnamurthi and Gnanamurthy (2002) reported that uptake of S in sunflower was maximum with 60 kg S ha^{-1} as gypsum. Beena and Usha (2002) reported that the uptake of N, P, K, Ca, Mg and S in cowpea was improved by the application of gypsum @ 15 to 30 kg ha^{-1}

2.9 EFFECT OF GYPSUM APPLICATION ON SOIL PROPERTIES

2.9.1 Chemical Properties

Application of mined gypsum or phosphogypsum have marked effects on the chemical properties of acid soil profiles.

Leaching studies conducted with disturbed or undisturbed soil columns have shown a general pattern of decrease in exchangeable aluminium and increase in exchangeable calcium. Reeve and Sumner (1972) in a leaching study found that gypsum application decreased subsoil exchangeable Al and increased base saturation. An increase in exchangeable Ca content of soil due to gypsum application was reported by Sumner *et al.* (1988) and Shainberg *et al.* (1989). Alva *et al.* (1991b) suggested that repeated equilibration of phosphogypsum in a cultivated woodland soil resulted in decrease in exchangeable Al, and increase in exchangeable Ca and a net increase in cation exchange capacity of the soil.

Caldwell *et al.* (1990) suggested that in phosphogypsum treated plots exchangeable Ca increased from 30 cm to 60 cm depth from first year to third year in an acidic silty loam soil. Liming with conventional liming materials could neutralize the acidity in the plough layer only and is not effective in reducing subsoil acidity (Alcordo and Recheigl, 1993; Sumner, 1993; Carvalho and Raij, 1997).

The calcium content in maize treated with calcium carbonate were less due to their lower calcium content in soil solution than those treated with phosphogypsum and calcium sulphate. It promoted greater root length and increased calcium uptake (Carvalho and Raij, 1997).

Toma and Saigusa, (1997) noticed that in lime treated non allophanic Andosol, the exchange acidity in the top soil disappeared, whereas for phosphogypsum treatment, slight decrease in exchange acidity through out the soil profile was noticed.

Smith *et al.* (1995) also noticed that movement of Ca from phosphogypsum was greater compared to that from calcium citrate. Similar results were published earlier by Ritchey *et al.* (1980), Hammel *et al.* (1985) and Sumner *et al.* (1986). Liu and Hue (2001) reported that only 7.6 per cent of Ca from lime moved to next 10 cm of the applied layer while 93.4 per cent of it remained in the applied layer itself whereas, for phosphogypsum 60 per cent of Ca moved throughout the profile and only 40 per cent of it was retained in the applied layer. A constant concentration of Ca throughout the profile was noticed in control plots.

Toma and Saigusa (1997) observed that about 54 to 60 per cent of Ca applied as phosphogypsum moved into subsoil in a non allophanic Andosol, whereas in the lime treated soil only 4 to 6 per cent of calcium moved into subsoil. Ninety two per cent of applied Ca through liming in Ultisol remained in topsoil and no Ca leached beyond 35 cm, whereas, for gypsum about, 60 per cent moved past the applied layer and 6.4 percent moved beyond 45 cm (Liu and Hue, 2001).

Reduction in mechanical impedance due to gypsum application and associated increase in root penetration due to increased Ca supply by gypsum was reported by Radcliffe *et al.* (1986). The yield increase in crops associated with gypsum application is due to the improvement in soil Ca level (Sumner, 1993; Carvalho and Raij, 1997; Raij *et al.*, 1998).

The downward movement of Mg and K after gypsum application was reported by Reeve and Sumner (1972), Kotze and Deist (1975) and

Quaggio *et al.* (1982). Severe loss of Mg and K from upper 60 cm of red loam soil was reported by Chaves *et al.* (1988a) and Vitti *et al.* (1992). The exchangeable Mg and K in lime treated plots remained constant, whereas it decreased in gypsum treated plots (Liu and Hue, 2001).

Potassium and nitrogen were equally depleted from plots treated with gypsum and lime in latosol (Carvalho and Raij, 1997).

According to Vizcayno *et al.* (2001), addition of lime and gypsum in a Plinthic Palexerult increased the loss of Mg, Na and K than treatment with gypsum alone.

Broadbent *et al.* (1989) found high levels of soil phosphate after treatment with phosphogypsum. The decrease in P adsorption by the combined application of limestone, dolomite, and gypsum was suggested by Arias and Fernandez (2001). Palliyal and Verma (2002) found that gypsum application @ 2.7 to 5.4 t ha^{-1} decreased P adsorption, while lime application @ 1.5 to 3 t ha^{-1} increased P adsorption. Sarmento *et al.* (2002) reported that P fixation was decreased by the application of gypsum and rock phosphate.

Contrary to the above reports Sistani and Morril (1992) reported that application of gypsum resulted in tying up of P as calcium phosphate and caused P deficiency in peanuts.

Severe loss of exchangeable Mg and K from surface horizon was reported to be due to the high solubility of gypsum (Shainberg *et al.*, 1989; Alva and Gascho, 1991; Liu and Hue, 2001).

Gypsum application checked the volatilization loss of ammonia and improved nitrogen use efficiency (Tripathi *et al.*, 1997). Increased recovery of nitrate from subsoil horizon was reported as an additional benefit of phosphogypsum application by Sousa and Ritchey (1986) and Raij *et al.* (1988).

Mobilisation of silicon by gypsum application was suggested by Sumner *et al.* (1985).

Beena (2000) reported that by the application of gypsum @ 30 kg S ha^{-1} the exchangeable calcium, magnesium and available sulphur were increased in red and laterite soil of Vellayani.

Misra (1995) suggested that application of phosphogypsum could correct S deficiency in red and laterite soil, black soil and alluvial soil. Mora *et al.* (2002) reported that combined application of limestone, dolomite and gypsum increased concentration of plant available P, K, Ca, Mg and S in soil. Paula *et al.* (2002) noticed that phosphogypsum increased soil sulphur content.

2.9.2 Effect of Phosphogypsum on Soil Physical Properties

In addition to the correction of chemical constraints, both mined gypsum and phosphogypsum could improve the internal and surface physical properties of acid soils.

Phosphogypsum @ 2 t ha^{-1} could improve the cotton seedling emergence by preventing soil crusting (Miller, 1988; Mamedov and Levy, 2001). Phosphogypsum is suitable for the alleviation of surface crusting caused by the impact of raindrops in Oxisol and Ultisol (Shainberg *et al.*, 1989; Norton, 1991; Sumner, 1992).

Gypsum alleviated the problem of hard setting of sandy loam soils by promoting aggregate stability and macro porosity (Chartres *et al.*, 1985; Taylor and Olsson, 1987). This is made possible by reduction in exchangeable Na and by its beneficial effect on clay dispersion, crusting and hydraulic conductivity (Greene and Ford, 1985; Taylor and Olsson, 1987; White and Robson, 1989).

In highly weathered Oxisol and Ultisol, root penetration into subsoil is restricted by subsurface hard layers. Both mined gypsum and phosphogypsum could reduce the cone index value which is a measure of the resistance of the soil to root penetration (Radcliffe *et al.*, 1986; Sumner *et al.*, 1990 and Mc Cray *et al.*, 1991).

Chiang *et al.* (1987) and Bolan *et al.* (1992) found that application of phosphogypsum improved bulk density, total porosity, number of pores greater than 30 mm, and hydraulic conductivity. This was also reported by Marcano *et al.* (1997).

2.9.3 Effect of Phosphogypsum on Soil Biological Property

Gould *et al.* (1988) reported that application of amendments such as phosphogypsum and calcitic limestone increased the population of fluorescent *Pseudomonas* in the rhizosphere of citrus. Chaudhary *et al.* (2001) reported that by increasing the level of gypsum an increase in the level of disease control was noticed in the case of root rot of apple. Oyanagi *et al.* (2001) found that lime application resulted in an increase in the number of heterotrophic and nitrate bacteria in the soil.

2.10 Environmental Considerations in the Use of Phosphogypsum

2.10.1 Effect on Soils

Mays and Mortvedt (1986) reported that incorporation of phosphogypsum into a coarse silty loam soil of Albama increased ^{226}Ra level from 34.8 to 73.3 Bq kg^{-1} at 0 to 15 cm depth, but had no effect at lower depth. Shainberg *et al.* (1989) reported that use of phosphogypsum up to 10 t ha^{-1} for agriculture purposes created no environmental problems. Recheigl *et al.* (1992) found that application of phosphogypsum up to 4 t ha^{-1} in a grass pasture had no effect on soil radionucleides.

2.10.2 Effect on Crop Tissues

Gupta (1969) reported a reduction in Mo content in brussels sprouts treated with phosphogypsum. Mays and Mortvedt (1986) showed that phosphogypsum at 22 and 112 t ha^{-1} has no effect on ^{226}Ra and Cd content in corn, wheat and soyabean grain.

2.10.3 Effect on Surficial and Ground Water

Phosphogypsum contains certain amount of heavy metals like As, Ba, Cd, Cr, Hg and Se at concentrations which are below the environmental protection agency consideration limits. Hence the contamination of drinking water by these metals is not expected to be a hazard (Alcordo and Recheigl, 1993).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An investigation was carried out at College of Agriculture, Vellayani, to study the feasibility of using phosphogypsum, a waste product from phosphorus fertilizer plants as an ameliorant for correcting soil acidity in laterite soil along with its influence on crop performance and soil quality with cowpea as the test crop.

The experiment was carried out in two steps.

1) Incubation study

2) Microplot Field Experiment: This include a regular crop and a residue crop.

The experiment details with special reference to the materials used and methods adopted are discussed in this chapter.

3.1 INCUBATION STUDY

The incubation study was conducted during July to August, 2002 to understand the kinetics of dissolution of phosphogypsm and the nutrient release pattern. Its behaviour during the incubation was compared with that of lime.

3.1.1 Soil

The soil samples for incubation study were collected from Instructional Farm, Vellayani. Soil belongs to the Vellayani Series (Typic Kandiudult). The collected samples were thoroughly mixed, air dried under shade and sieved through a 2 mm sieve.

Two kg of these soils were incubated at field capacity for sixty days after application of treatments at room temperature. The field capacity was maintained throughout the study period by replenishing the moisture lost by evaporation. This loss on account of evaporation was calculated by noting the weight difference. Lime and phosphogypsum were applied to the soil as per the treatments scheduled. The details of the experiment are presented below.

Design: CRD

Number of replications : 3

Number of treatments : 7

T_1 : Absolute control

T_2 : Lime @ full LR*

T_3 : Phosphogypsum @ full LR

T_4 : Lime @ ½ LR

T_5 : Phosphogypsum @ ½ LR

T_6: Lime @ ½ LR + Phosphogypsum @ ½ LR

T_7 : Lime @ POP (250 kg ha^{-1})

LR* = Lime requirement @ 1.5 times of Exchangeable Al (t ha^{-1})

Soil samples were taken at 12 days interval for the estimation of pH, EC, exchangeable Al^{3+}, H^+, K, Ca, Mg and Na, available P and S and DTPA extractable Fe, Mn, Cu and Zn

The chemical composition of amendments used is presented in the Table 1.

3.2 MICROPLOT FIELD EXPERIMENT

This includes a regular crop taken during September to November, 2002 followed by a residue crop during November, 2002 to January, 2003.

Table 1. Typical analysis of amendments used for the experiment

Sl. No.	Parameters	Content	
		Phosphogypsum	Lime
1	Total nitrogen	0.56 %	0.00
2	Total phosphorus	0.67 %	0.00
3	Total potassium	0.00	Traces
4	Total sodium	0.28 %	Traces
5	Total sulphur	14.42 %	0.00
6	Total calcium	24.16 %	38.00 %
7	Total magnesium	4.752 %	2.00
8	Total iron	Traces	398 ppm
9	Total copper	Traces	Traces
10	Total Manganese	546 ppm	608 ppm
11	Total zinc	314 ppm	Traces

3.2.1 Experimental Site

The field experiment was laid out in Instructional Farm, Vellayani, with cowpea var. Kanakamoni as the test crop.

3.2.2 Soil

The soil belongs to Vellayani series (Typic Kandiudult). Important physico-chemical properties of the soil are analysed as per the standard procedures given in Table 2.

3.2.3 Season

The regular crop was grown from September 1st to November 15th, 2002 and the residue crop from November 19th 2002 to January 31st, 2003. Weather conditions during entire cropping season were recorded from Meteorological Observatory attached to Department of Agronomy, College of Agriculture, Vellayani, and presented as weekly average in Appendix I.

3.2.4 Variety

The variety chosen for the study was Kanakamoni (Ptb.1). It is a dual purpose variety obtained through pureline selection from "Kunnamkulam Local" and was released from Regional Agricultural Research Station, Pattambi. The duration of this variety is 65-75 days.

3.2.5 Planting Material

Seeds of Kanakamoni were purchased from Instructional Farm Vellayani.

3.2.6 Manures and Fertilizers

Urea (46% N), rock phosphate (20% P_2O_5), and muriate of potash (56% K_2O) were used as the source of N, P and K respectively. They were applied as per the soil test data in accordance with the treatments scheduled. FYM as per POP of KAU (KAU, 1996) was applied in all the plots except at absolute control.

Table 2. Physico-chemical properties of the soil at the experiment site

Sl. No.	Parameter	Content
A.	**Mechanical composition**	
1	Coarse sand	14.2 %
2	Fine sand	33.1 %
3	Silt	27.5 %
4	Clay	24.6 %
5	Texture	Sandy loam
B.	**Physical properties**	
1	Particle density	2.86 Mg m^{-3}
2	Bulk density	1.4 Mg m^{-3}
3	Water holding capacity	29.00 %
4	Hydraulic conductivity	0.8 cm hr^{-1}
C	**Chemical properties**	
1	pH	4.10
2	EC	<0.02 dSm^{-1}
3	CEC	3.2 cmol kg^{-1}
4	Organic carbon	0.745 %
5	Available phosphorus	80.64 kg ha^{-1}
6	Available potassium	134.38 kg ha^{-1}
7	Exchangeable aluminium	0.7 cmol kg^{-1}
8	Exchangeable acidity	1.2 cmol kg^{-1}
9	Exchangeable Calcium	0.79 cmol kg^{-1}
10	Exchangeable Magnesium	0.95 cmol kg^{-1}
11	Available sulphur	14.20 kg ha^{-1}
	DTPA exchangeable micronutrients	
12	Iron	20 ppm
13	Manganese	3.04 ppm
14	Copper	Traces
15	Zinc	Traces

3.2.7 Amendments

Lime and phosphogypsum were applied as per the lime requirement of the soil at the experiment site. Phosphogypsum for the experiment had been obtained from FACT division at Udyogamandal and lime was purchased locally.

Design and layout of experiment

The layout of the experimental field is presented in Fig. 1.

Design :	RBD
Number of replications:	3
Number of Treatments:	8
Plot size:	2 m x 1.5 m
Number of plants per plot:	48
Spacing:	25 cm x 15 cm
Total number of plots:	24

Treatment

T_1 : POP recommendation (N, P_2O_5, K_2O @ 20:30:10 kg ha^{-1} + lime @ 250 kg ha^{-1})

T_2 : N : P_2O_5 : K_2O as per soil test data + lime @ full LR*

T_3 : N : P_2O_5 : K_2O as per soil test data + phosphogypsum @ full LR

T_4 : N : P_2O_5 : K_2O as per soil test data + lime @ half LR.

T_5 : N : P_2O_5 : K_2O as per soil test data + phosphogypsum @ half LR

T_6 : N : P_2O_5 : K_2O as per soil test data + lime @ half LR and phosphogypsum @ half LR

T_7 : N : P_2O_5 : K_2O as per soil test data + lime @ ¼th LR + phosphogypsum @ ¼th LR

T_8 : Absolute control

LR* = Lime requirement @ 1.5 times of exchangeable Al in tonnes ha^{-1}

Details of Cultivation

3.2.8 Sowing

The land was ploughed thoroughly for about two times and weeds and stubbles were removed. Channels of 30 cm breadth and 15 cm depth were taken. Seeds were sown in channels with 2 seeds per hole at a spacing of 25 cm x 15 cm.

3.2.9 Application of Fertilizers and Amendments

Lime and phosphogypsum were applied and thoroughly mixed with soil as per the treatments scheduled, about 2 weeks before sowing. Half the quantity of nitrogen, whole of phosphorus and potassium were applied at the time of final ploughing. Remaining nitrogen was applied at 15 days after sowing.

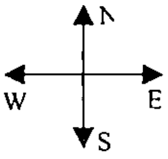
3.2.10 After Cultivation

A light hoeing was given at the time of application of second dose of nitrogen. Weeding was also done before second dose of fertilizer application.

3.2.11 Irrigation

After the cessation of monsoon the crop was irrigated once in three days.

Fig. 1 Layout of the experimental field



Replication I	Replication II	Replication III
T_1	T_5	T_6
T_4	T_8	T_3
T_6	T_2	T_4
T_7	T_1	T_8
T_2	T_3	T_1
T_5	T_7	T_2
T_3	T_4	T_7
T_8	T_6	T_5

3.2.12 Chemical Analysis

3.2.12.1 Soil Analysis

Soil samples for chemical analysis were taken at three stages - before sowing, at fifty per cent flowering and at the time of harvest.

The soil samples were air dried and passed through 2 mm sieve. After that, samples were used for the analysis of organic carbon, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, pH and EC using standard procedures as given in Table 3.

3.2.12.2 Plant Analysis

Plant samples were collected at fifty per cent flowering and at harvest. The samples were oven dried at 70°C and powdered and used for the estimation of N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn. Standard procedures adopted are given in Table 4.

3.2.12.3 Grain analysis

Seeds from the sample plants were extracted, dried and powdered. Chemical analysis were carried out for estimation of N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn. Procedures adopted were same as that for plant analysis.

3.2.13 Seed Protein Content

Seed protein content was worked out by multiplying seed nitrogen value by 6.25 (Simpson *et al.*, 1965).

3.2.14 Uptake of Nutrients

Uptake of nutrients by grain and bhusa were calculated by multiplying the nutrient concentration with corresponding dry weight. Total nutrient uptake was calculated by adding the uptake of grain and bhusa.

Table 3. Analytical methods followed in soil analysis

Sl. No.	Parameter	Method	Reference
1	Mechanical composition	International Pipette Method	Piper (1967)
2	Particle density	Pycnometer method	Black *et al.* (1965)
3	Bulk density	Undisturbed core sample	Black *et al.* (1965)
4	Water holding capacity	Undisturbed core sample	Black *et al.* (1965)
5	Hydraulic conductivity	Undisturbed core sample	Black *et al.* (1965)
6	pH	pH meter	Jackson, 1973
7	Electrical Conductivity	Conductivity meter	Jackson, 1973
8	Cation Exchange Capacity	Ammonium saturation using neutral normal ammonium acetate	Jackson, 1973
9	Organic carbon	Walkley and Black chromic acid wet digestion method	Walkley and Black (1934)
10	Available P	Bray extraction and photo electric colorimetry	Jackson (1973)
11	Available K	Flame photometry	Pratt (1965)
12	Available sulphur	Turbidimetry	Chesnin and Yien (1950)
13	Exchangeable acidity	Extraction using KCl	Yuan (1959)
14	Exchangeable Ca and Mg	Neutral normal ammonium acetate extraction and titration with EDTA (Versenate titration)	Hesse (1971)
15	Fe, Mn, Cu, Zn	Extraction using DTPA and read in Atomic Absorption Spectrophotometer	Lindsay and Norvell (1975)

Table 4. Analytical methods followed in plant analysis

Sl. No.	Element	Method	Reference
1	Nitrogen	Microkjeldhal digestion in sulphuric acid and distillation	Jackson (1973)
2	Phosphorus	Nitric-perchloric acid digestion (9 : 3) and colorimetery making use of vanado molybdo phosphoric yellow colour method	Jackson (1973)
3	Potassium	Nitric – perchloric acid (9 : 3) digestion and flame photometry	Jackson (1973)
4	Calcium	Nitric – perchloric acid (9 :3) digestion and versenate titration with standard EDTA	Tandon (1993)
5	Magnesium	Nitric – perchloric acid (9 : 3) digestion and versenate titration with standard EDTA	Tandon (1993)
6	Sulphur	Nitric – perchloric acid (9 : 3) digestion and turbidemetry	Tabatabai and Bremner (1970)
7	Fe, Mn, Cu, Zn	Nitric – perchloric acid (9 : 3) digestion and Atomic Absorption spectrophotometry	Lindsay and Norvell (1978)

3.2.15 Observations Recorded

The important biometric observations like height of the plant and number of branches at fifty per cent flowering were recorded. The root characteristics like root weight and number of nodules were recorded at fifty per cent flowering and at harvest. Other observations recorded include days to fifty per cent flowering, days to maturity and last picking date. The important yield components recorded include grain yield per plant, grain yield per plot, bhusa yield per plot and per plant, pod length and number of pods per plant.

3.2.15.1 Biometric Observation

Five representative plants were marked in each plot for taking biometric observations and their average was calculated for each parameter.

3.2.15.1.1 Height and Number of Branches per Plant

Height of the plant was measured from the scar of the first cotyledonous leaf of the plant to the tip of the growing point at fifty percent flowering stage. The number of branches per plant were also recorded at the same stage.

3.2.15.2 Days to fifty per cent Flowering and Maturity

Number of days to reach fifty per cent flowering and maturity stage were noted from observation plants and average was calculated

3.2.15.3 Last Picking Date

The date at which last picking was done were noted for observation plants as well as for other plants.

3.2.15.4 Root Characteristics

To study the root characteristics, another set of five observation plants were uprooted and the average were taken for each parameter.

3.2.15.4.1 Root Weight

Selected plants were uprooted. Roots were separated and washed free of adhering soil and length of roots was taken. Weight of roots were taken after oven drying.

3.2.15.4.2 Number of Nodules per Plant

The root portion of observation plants after uprooting were washed free of soil. The nodules were separated and counted.

3.2.15.5 Yield and Yield Attributes

3.2.15.5.1 Total Grain Yield

After each picking the pods were dried, seeds were extracted and weighed. Weight of seeds from different pickings were added to get the total grain yield.

3.2.15.5.2 Bhusa Yield

Plants were uprooted after the harvest of pods, and after oven drying the weight was recorded.

3.2.15.5.3 Grain Yield per Plant

The pods collected from five numbers of observation plants were separated and dried. Seeds were extracted and weighed and expressed in gram $plant^{-1}$.

3.2.15.5.3 Number of Pods per Plant, Seeds per Pod and Pod Length

Number of pods obtained from observation plants were taken first and the number of seeds per each pod were counted and the average was calculated. The length of pods from the above plants was measured and the average was presented.

3.2.15.6 Total Dry Matter Production

The total of dry weight of pods and bhusa were added to get the total dry matter production.

3.2.15.7 Statistical Analysis

The data was analysed using RBD and CRD described by Cochran and Cox (1963) and significance was tested by F test (Snedecor and Cochran, 1967).

3.2.15.8 Benefit : Cost Ratio

The benefit : cost ratio of the main crop and residue crop were calculated by taking the ratio between the total cost of out put and the total cost of input.

3.3 RESIDUE CROP

A residue crop with cowpea var. Kanakamoni was taken to understand the residual effects of treatments after the harvest of the main crop on the same plots without the addition of lime and phosphogypsum during November, 2002 to January, 2003. All the cultivation operations practiced for main crop was repeated here. The same observations on yield and yield attributes recorded for the main crop were also noticed for the residue crop.

RESULTS

4. RESULTS

An investigation was carried out at College of Agriculture, Vellayani with phosphogypsum to study its suitability as an amendment for correcting soil acidity in laterite soil with cowpea as the test crop. The investigation consists of an incubation study as well as a microplot field experiment. The results of the study are presented in this section.

4.1. INCUBATION STUDY

The data on various parameters during the period of incubation are presented in Tables 5 to19.

4.1.1 Available Phosphorus (Table 5)

A perusal of the data indicated a gradual increase in available P concentration up to the 24^{th} day of incubation, followed by a decrease. At twelveth day of incubation, the maximum content was recorded by T_2 (Lime @ full LR) followed by T_5 (PG @ half LR). The values ranged from 34 to 38 ppm. The lowest value was recorded by T_3 (PG at full LR).

At twenty fourth day of incubation the trend was slightly changed with T_5 recording the highest value of 46 ppm followed by T_6 (44 ppm) which received PG and lime each at half LR.

Both at 36^{th} and 48^{th} day of incubation, the highest values were shown by T_6, which was 40 ppm and 39 ppm respectively. At 60^{th} day of incubation, the highest value of 36 ppm was shown by T_3. Except at 12^{th} day of incubation, the lowest value was observed in the absolute control, throughout the period of incubation.

Table 5. Available P content of the soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
	ppm				
T_1	36	37	31	32	30
T_2	38	41	34	36	34
T_3	34	40	38	39	36
T_4	35	37	35	34	32
T_5	37	46	36	37	33
T_6	36	44	40	39	33
T_7	35	42	34	33	33
$F_{(24,56)}$	4.46**				
CD (0.05)	2.844				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.2 Available K (Table 6)

All the treatments showed the maximum values for available K at 12th DOI followed by a gradual decrease during the course of incubation. At 12th DOI, the highest value of 122 ppm was recorded by T_4 (Lime at half LR) followed by T_6 (Lime and PG each at half LR), T_5 (PG at half LR) and T_2 ((Lime at full LR), which were on par with each other. The lowest value (106 ppm) was recorded by absolute control.

At 24th DOI, T_5 recorded the highest value (106 ppm) and was on par with T_4, T_3 and T_6. All the treatments showed a decrease in available K content compared to 12th DOI. Here also the lowest value was shown by absolute control.

From 36th DOI onwards the maximum available K content was shown by T_3 and this trend continued till the end of incubation. The treatment that recorded the second highest available K content did not show a steady pattern. At 36th DOI, it was T_5, while at 48th and 60th DOI, T_6 was the second best treatment. Throughout the incubation period, the absolute control recorded the lowest value.

Table 6. Available K (ppm) of soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	96	78	72	70	69
T_2	113	94	93	90	89
T_3	107	103	108	106	105
T_4	122	105	77	72	73
T_5	113	106	102	90	98
T_6	118	97	98	98	110
T_7	106	82	91	95	92
$F_{(24,56)}$	5.35**				
CD (0.05)	11.24				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.3 Exchangeable Calcium (Table 7)

Statistical analysis of the data revealed that the exchangeable calcium content was highest throughout the incubation period for T_3 which was significantly superior to all other treatments except at 36th DOI and the lowest value was recorded by the absolute control.

Towards 24th DOI, there was an increase in exchangeable calcium content for all the treatments, which further decreased gradually to record the lowest values at 60th DOI.

4.1.4 Exchangeable Magnesium (Table 8)

Exchangeable Mg did not show a uniform pattern of variation during the period of incubation. However there was no significant effect for various treatments through out the incubation period.

Table 7. Exchangeable calcium content (cmol kg^{-1}) of the soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	0.98	0.98	0.84	0.887	0.860
T_2	1.86	1.86	1.30	1.08	0.893
T_3	2.30	2.56	1.98	1.88	1.76
T_4	1.24	1.58	1.08	0.93	0.91
T_5	1.50	1.60	1.40	1.02	0.97
T_6	1.84	2.18	1.96	1.45	1.07
T_7	1.35	1.48	1.05	1.04	0.98
$F_{(24,56)}$	2.06*				
CD (0.05)	0.377				

DOI – Day of incubation, *Significant at 5 per cent level

Table 8. Exchangeable magnesium content (cmol kg^{-1}) of soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	0.417	0.360	0.273	0.250	0.203
T_2	0.417	0.443	0.773	0.593	0.353
T_3	0.317	0.197	0.390	0.183	0.117
T_4	0.193	0.162	0.530	0.290	0.213
T_5	0.398	0.273	0.390	0.327	0.233
T_6	0.277	0.233	0.537	0.260	0.290
T_7	0.200	0.152	0.330	0.260	0.237
$F_{(24,56)}$	1.62^{NS}				
CD (0.05)					

DOI – Day of incubation, NS – Non Significant

4.1.5 Exchangeable Aluminium (Table 9)

A perusal of the data indicated that absolute control recorded the highest value of exchangeable aluminium at all stages of sampling. It showed an increasing trend up to 48th DOI, followed by a slight decrease.

At 12th DOI, the treatment that received lime @ full LR (T_2) showed the minimum content followed by the treatment that received lime and PG each at half LR (T_6). The POP recommendation also recorded comparatively lower values for exchangeable aluminium at 12th DOI. But the 24th, 36th, 48th and 60th day samples showed a different trend with PG at full LR (T_3) recording the lowest values. All the treatments that received lime either alone or in combination with PG showed an increasing trend for exchangeable aluminium throughout the period of incubation. The treatment that received PG alone showed a reverse trend.

Table 9. Exchangeable Aluminium content of the soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
	cmol kg^{-1}				
T_1	0.767	0.800	0.867	0.800	0.733
T_2	0.267	0.467	0.467	0.467	0.600
T_3	0.467	0.423	0.300	0.333	0.300
T_4	0.500	0.500	0.633	0.633	0.667
T_5	0.633	0.600	0.500	0.400	0.400
T_6	0.300	0.467	0.567	0.567	0.567
T_7	0.367	0.433	0.533	0.600	0.667
$F_{(24,56)}$	2.920**				
CD (0.05)	0.171				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.6 Exchangeable Hydrogen (Table 10)

Statistical analysis of the data revealed that the influence of treatments and period of incubation was not significant. However the treatment that received lime @ full LR (T_2) recorded the lowest value throughout the period of incubation. Almost all the treatments except absolute control and PG @ full LR showed a decrease in exchangeable H^+ content during the period of incubation. Application of PG @ full LR increased the exchangeable H^+ content up to 48th DOI followed by decrease. For absolute control (T_1), an increase was generally observed except at 36th DOI.

Table 10. Exchangeable hydrogen (cmol kg^{-1}) in soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	0.193	0.130	0.093	0.120	0.160
T_2	0.123	0.073	0.047	0.038	0.020
T_3	0.133	0.137	0.150	0.141	0.095
T_4	0.160	0.090	0.087	0.067	0.067
T_5	0.177	0.140	0.130	0.130	0.091
T_6	0.140	0.124	0.098	0.098	0.095
T_7	0.143	0.140	0.107	0.075	0.051
$F_{(24,56)}$	1.02^{NS}				
CD (0.05)					

DOI – Day of incubation, NS – Non Significant

4.1.7 Exchangeable Acidity (Table 11)

Statistical analysis of the data on exchangeable acidity showed a trend almost similar to that for exchangeable aluminium which is the major component of exchangeable acidity. In general, the treatments that received lime either alone or with phosphogypsum showed lower values at 12th DOI. Afterwards, the exchangeable acidity of these treatments were found to increase during the course of incubation. But the treatments that received phosphogypsum alone, either @ full LR or half LR showed a reverse trend for exchangeable acidity. The highest value was shown by absolute control (T_1) throughout the incubation period.

Table 11. Exchangeable acidity (cmol kg^{-1}) in soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	0.96	0.93	0.96	0.92	0.893
T_2	0.39	0.54	0.514	0.505	0.620
T_3	0.60	0.56	0.45	0.474	0.395
T_4	0.66	0.59	0.72	0.70	0.734
T_5	0.81	0.74	0.63	0.53	0.491
T_6	0.44	0.591	0.665	0.665	0.662
T_7	0.51	0.573	0.64	0.675	0.718
$F_{(24,56)}$	3.9**				
CD (0.05)	0.151				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.8 Exchangeable Sodium (Table 12)

A perusal of the data revealed that for all the treatments except absolute control (T_1) the values gradually increased up to 48th DOI, followed by a decrease towards the end of incubation. For T_1 the values gradually increased up to 60th day of incubation. The highest value through out the incubation period except at 12th DOI was recorded by T_3 (PG @ full LR). Towards the end of incubation all the treatments except T_4 (Lime @ half LR) and T_7 (POP) were on par with each other.

Table 12. Exchangeable sodium (ppm) in soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	39	39	41	43	44
T_2	39	40	46	50	48
T_3	38	52	56	64	49
T_4	36	39	43	43	39
T_5	34	45	46	49	44
T_6	31	45	48	58	46
T_7	33	44	47	50	38
$F_{(24,56)}$	2.87**				
CD (0.05)	7.453				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.9 Available Sulphur (Table 13)

Statistical analysis of the data on available sulphur content of soil have shown that phosphogypsum had a significant effect on the available soil sulphur content. For all the treatments the values gradually increased up to 36th day of incubation and thereafter it showed a sharp decrease.

T_3 (PG at full LR) maintained the highest value throughout the incubation period and was on par with T_5 (PG at half LR). The combination of lime and phosphogypsum recorded higher values compared to treatments which received lime alone.

At all sampling time the lowest value was recorded by the treatment which received lime @ full LR (T_2) and was on par with absolute control (T_1).

Table 13. Available sulphur (ppm) at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	13	21	23	13	11
T_2	10	20	22	12	11
T_3	29	76	62	32	23
T_4	17	28	30	15	15
T_5	26	61	56	24	21
T_6	27	65	53	26	22
T_7	15	28	29	16	11
$F_{(24,56)}$	7.86**				
CD (0.05)	8.16				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.10 Soil pH (Table 14)

Perusal of the data on soil pH revealed that it was significantly influenced by the application of treatments.

The lowest value for soil pH throughout the period was recorded by T_1 (absolute control) and highest value by T_2. The treatment with lime showed a decreasing trend for pH while that with phosphogypsum showed an increasing trend. T_3 (PG @ full LR) recorded maximum value on 60th DOI and T_5 (PG @ half LR) showed maximum value at 48th DOI.

Table 14. pH of soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	4.16	4.18	4.27	4.28	4.36
T_2	5.26	5.20	4.91	4.85	4.72
T_3	4.30	4.35	4.36	4.37	4.40
T_4	4.59	4.67	4.71	4.72	4.49
T_5	4.35	4.36	4.41	4.42	4.38
T_6	4.75	4.89	4.87	4.73	4.73
T_7	4.69	4.69	4.69	4.67	4.57
$F_{(24,56)}$	5.05**				
CD (0.05)	0.193				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.11 Electrical Conductivity (Table 15)

Statistical analysis of the data revealed that application of phosphogypsum significantly influenced the electrical conductivity during the incubation period. A perusal of the data revealed that the electrical conductivity for all the treatments was maximum at 24th DOI. Afterwards the EC decreased gradually recording the lowest value at 60th DOI. Treatment T_3 (PG @ full LR) recorded highest value followed by T_5 throughout the period of incubation. The lowest value was shown by T_7 (Lime as per POP)

4.1.12 DTPA Extractable Micronutrients (Table 16-19)

4.1.12.1 Iron

The iron content of the soil was not significantly influenced by the treatments. However, the lowest concentration was always observed for T_3 that received phosphogypsum @ full LR. In general the highest concentration was observed at 36th DOI for most of the treatments. But the pattern of variation with days of incubation was erratic.

Table 15. Electrical conductivity (μS m^{-1}) of soil at different periods of incubation

Treatments	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	143	147	134	121	107
T_2	159	169	150	146	93
T_3	349	476	278	270	167
T_4	159	166	126	118	89
T_5	272	249	199	169	113
T_6	216	238	176	156	98
T_7	184	122	105	105	105
$F_{(24,56)}$	11.59**				
CD (0.05)	39.317				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.12.2 Manganese (Table 17)

The Mn content in the soil was significantly influenced by the treatments. Here also the pattern of variation with days on incubation was erratic for most of the treatments. However lime @ full LR maintained the lowest concentration of available Mn at all periods of sampling except at the 60th DOI. For this treatment a general increasing trend was observed. Lime @ half LR also showed the same trend, but the values were greater than that of phosphogypsum @ full LR and half LR.

4.1.12.3 Copper (Table 18)

For copper, the treatment effect was significant. The copper content gradually decreased from the 12th DOI recording non detectable levels at 60th DOI. Copper content was highest for T_5 at 12th and 24th DOI and at later periods absolute control recorded the highest values.

Table 16. DTPA Extractable iron (ppm) at different periods of incubation

Treatment	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	4.25	7.05	8.85	5.25	4.71
T_2	4.57	4.75	9.75	5.79	7.13
T_3	3.71	4.09	8.21	4.50	4.08
T_4	5.87	7.34	9.49	6.7	4.69
T_5	6.02	6.47	10.6	4.86	9.62
T_6	6.24	5.71	9.3	6.11	5.31
T_7	8.32	5.24	3.17	5.75	8.53
$F_{(24,56)}$	1.43^{NS}				
CD (0.05)					

DOI – Day of incubation

Table 17. DTPA Extractable Mn (ppm) at different periods of incubation

Treatment	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	4.59	6.33	5.78	4.71	7.34
T_2	4.02	4.20	4.20	4.33	7.52
T_3	4.70	5.34	6.18	5.26	9.29
T_4	5.30	5.63	6.48	6.63	7.19
T_5	4.84	5.61	4.53	4.82	7.13
T_6	4.36	4.52	6.57	5.60	6.46
T_7	5.67	4.44	4.32	5.26	6.93
F	52.43**				
CD (0.05)	0.298				

DOI – Day of incubation, **Significant at 1 per cent level

Table 18. DTPA Extractable Cu (ppm) at different periods of incubation

Treatment	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	2.61	1.05	0.743	0.657	0.00
T_2	2.42	1.18	0.553	0.010	0.00
T_3	2.21	1.22	0.087	0.087	0.00
T_4	2.30	1.26	0.707	0.013	0.00
T_5	2.76	1.45	0.087	0.087	0.00
T_6	2.04	1.15	0.700	0.403	0.00
T_7	2.04	1.08	0.087	0.087	0.00
$F_{(24,56)}$	120.42**				
CD (0.05)	0.161				

DOI – Day of incubation, **Significant at 1 per cent level

4.1.12.4 ***Zinc*** (Table 19)

Available zinc did not show any trend in variation with days of incubation. But by 60th DOI, it was reduced to very low levels.

Table 19. DTPA Extractable Zn (ppm) at different periods of incubation

Treatment	12th DOI	24th DOI	36th DOI	48th DOI	60th DOI
T_1	1.13	1.26	1.43	1.34	0.21
T_2	1.35	1.11	1.34	1.45	0.24
T_3	1.51	1.45	1.30	1.58	0.34
T_4	1.50	1.65	1.47	1.58	0.52
T_5	1.49	1.68	1.49	1.23	0.26
T_6	1.43	1.58	1.22	1.67	0.38
T_7	1.60	1.20	1.39	1.83	0.56
$F_{(24,56)}$	3.13**				
CD (0.05)	0.252				

DOI – Day of incubation, **Significant at 1 per cent level

4.2 MICROPLOT FIELD EXPERIMENT

4.2.1 Main crop

4.2.1.1 Soil

The data on soil available nutrients as well as electrochemical properties during different stages of crop growth are presented in this section.

4.2.1.1.1 Organic Carbon (Table 20)

Statistical analysis revealed that the influence of phosphogypsum on organic carbon content of the soil was significant.

At fifty per cent flowering, the values ranged from 0.94 to 1.4 %. The highest value was recorded by treatment T_6 (PG and lime @ half LR each) followed by T_3 and T_7 which were statistically on par with it. The lowest value was for T_8 (absolute control) which was on par with T_2, T_4 (lime @ full LR and half LR respectively) and T_1 (POP).

At the time of harvest, the highest value of 1.04 per cent was recorded by T_5 (PG @ half LR) and was on par with T_3, T_4 and T_7. The lowest value was showed by T_8. The organic carbon content of T_5 was 22.35 per cent more than that of absolute control.

***4.2.1.1.2 Available P** (Table 20)*

Application of phosphogypsum significantly influenced the available phosphorus content of soil at fifty per cent flowering stage. The highest content of soil available phosphorus was observed in treatment T_5 (PG at half LR) followed by T_3 (PG @ full LR). Absolute control recorded the lowest value of 75.87 kg ha^{-1} and was on par with T_1 (POP).

Statistical analysis of the data at harvest showed that there was no significant difference due to the application of different treatments.

However, the highest value was recorded by T_5 and lowest by T_8. The values ranged from 87.00 to 121.17 kg ha^{-1}.

Table 20- Organic carbon, available P and K of soil at different growth stages

Treatments	Organic carbon (%)		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	1.11	0.907	87.44	96.06	99.49	89.71
T_2	1.03	0.907	114.10	107.72	137.2	105.27
T_3	1.33	0.994	124.53	120.35	88.04	77.46
T_4	1.07	0.993	119.47	115.10	142.8	90.88
T_5	1.19	1.04	126.03	121.17	144.35	106.82
T_6	1.40	0.917	100	109.48	135.52	115.73
T_7	1.29	0.973	109.83	119.68	117.08	112.94
T_8	0.94	0.85	75.87	87.00	91.17	77.85
$F_{(7,14)}$	9.91**	3.76*	8.059**	1.51^{NS}	8.93**	3.53*
CD (0.05)	0.154	0.096	19.303	-	26.147	24.465

FPF – Fifty per cent flowering, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.1.1.3 Available K (Table 20)

Statistical analysis of the data at fifty per cent flowering showed that all the treatments showed significantly higher values for available K compared to T_3 (PG at full LR). The highest value of 144.35 kg ha^{-1} was recorded by T_5 (PG at half LR) and was on par with T_4, T_2 and T_6, which received lime at half LR, full LR and lime and PG each at half LR respectively.

At the time of harvest also, the lowest value was noticed for T_3 which was on par with T_8, T_1 and T_4. The highest value was observed for treatment T_6 which is 49.4 per cent more than that of T_3. This was also on par with T_7, T_5 and T_2.

4.2.1.1.4 ***Exchangeable Calcium*** (Table 21)

The exchangeable calcium content of soil at fifty per cent flowering ranged from 0.87 to 1.54 cmol kg^{-1}. The highest value was recorded by T_6 followed by T_3 which were on par with each other. Soil exchangeable Ca was lowest for T_8.

Table 21. Exchangeable Ca and Mg, available S and electrochemical properties of soil at different growth stages

Treatments	Exch. Ca (cmol kg^{-1})		Exch. Mg (cmol kg^{-1})		Available S (kg ha^{-1})		pH		EC (µS m^{-1})	
	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	1.22	1.08	0.467	0.700	55.35	31.77	5.17	5.19	57.85	55.74
T_2	1.35	1.24	0.907	0.410	60.09	33.52	5.13	5.06	64.57	55.15
T_3	1.52	1.48	0.513	0.253	81.20	49.12	4.91	4.92	113.77	62.82
T_4	1.20	1.56	0.480	0.400	62.09	34.48	5.16	5.31	79.97	45.33
T_5	1.28	1.14	0.500	0.367	67.57	43.71	4.76	4.92	102.18	54.77
T_6	1.54	1.22	0.697	0.320	64.87	40.96	5.25	5.13	101.56	57.36
T_7	1.08	1.50	0.40	0.220	64.96	38.64	4.88	4.85	76.57	68.23
T_8	0.87	0.67	0.313	0.260	30.43	19.08	4.75	4.81	57.53	42.19
$F_{(7,14)}$	8.28**	6.41**	5.56**	3.54**	8.89**	13.58**	23.02**	10.0**	7.50**	1.98^{NS}
CD (0.05)	0.234	0.349	0.239	0.245	14.64	7.46	0.127	0.169	24.12	-

FPF – Fifty per cent flowering, **Significant at 1 per cent level, NS – Non Significant

At the harvest stage the soil exchangeable Ca content was highest for treatment T_4 followed by T_7 and T_3. All other treatments were significantly superior to that of absolute control.

4.2.1.1.5 ***Exchangeable Mg*** (Table 21)

At fifty per cent flowering, the values ranged from 0.313 to 0.907 cmol kg^{-1} and the highest value was recorded by T_2 (Lime @ full LR) followed by T_6 and were on par. The lowest value was shown by the absolute control.

At the time of harvest highest content of exchangeable Mg in soil was observed in T_1 and this was significantly superior to others, followed by T_2 and T_4. The lowest value was recorded by T_7.

4.2.1.1.6 ***Available Sulphur*** (Table 21)

A perusal of data showed that the available sulphur in the soil was significantly influenced by the application of phosphogypsum through out the crop period. At fifty per cent flowering the highest value of 81.20 kg ha^{-1} was recorded by T_3 (PG at full LR), followed by T_5 (PG at half LR) and the lowest value of 30.43 kg ha^{-1} was recorded by the absolute control. The same trend was noticed at the time of harvest also, with the values ranging from 19.08 to 49.12 kg ha^{-1}.

4.2.1.1.7 ***pH*** (Table 21)

At fifty percent flowering, absolute control recorded the lowest soil pH of 4.75 and the highest value was recorded by T_6 (5.25) which received lime and PG each at half LR and was on par with T_1 (POP) and T_4 (Lime at half LR). The pH values at the harvest stage ranged from 4.81 to 5.31 with the highest being recorded by T_4 (Lime at half LR) followed by T_1 (POP) and the lowest value was recorded by T_8. An increase in pH was noted for all the treatments during the crop growth period.

4.2.1.1.8 ***EC*** (Table 21)

Statistical analysis of the values at fifty per cent flowering revealed that phosphogypsum application significantly increased the EC values with the highest value recorded by T_3 (113.77 $\mu S\ m^{-1}$) followed by T_5. The lowest value of 57.53 $\mu S\ m^{-1}$was observed in T_8 and was on par with T_1, T_2, T_7 and T_4. At harvest there was no significant difference in EC due to the various treatments.

4.2.1.1.9 DTPA Extractable Micronutrients (Table 22)

The available iron, manganese, copper and zinc content in the soil were significantly influenced by the treatments. The highest value for available Fe was recorded by T_2 which was significantly superior to others and the lowest by absolute control. For Mn, the highest value (5.57 ppm) was shown by T_6 followed by T_3 and the lowest by T_2 (Lime at full LR). At fifty per cent flowering the highest value for Cu was shown by T_5 (PG @ half LR) and lowest by T_3 (PG @ full LR) with the value 5.80 ppm. In the case of Zn the highest value of 2.54 ppm was shown by T_5 and the lowest value was recorded by T_4 (lime @ half LR).

At harvest also the micronutrient cations were significantly influenced by the application of different treatments. The highest value for Fe was shown by T_7 (Lime and PG each @ ¼ LR) and lowest by T_2 (Lime @ full LR). In the case of Mn, the values ranged from 0.71 ppm to 8.54 ppm recorded by T_4 and T_8 respectively. The copper content was maximum for T_6 and the lowest value was shown by T_3. With regard to Zn the values ranged from 0.68 to 1.74 ppm recorded by T_1 and T_5 respectively.

Table 22. Effect of treatments on DTPA extractable micronutrients at different growth stages

Treatments	Fe (ppm)		Mn (ppm)		Cu (ppm)		Zn (ppm)	
	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	6.54	11.49	3.44	1.24	8.17	5.85	1.73	0.68
T_2	11.27	9.91	2.79	2.60	8.64	7.35	1.14	1.34
T_3	9.81	10.08	4.36	2.81	5.80	5.24	1.34	1.36
T_4	5.68	12.80	3.73	0.71	8.10	6.65	1.22	1.05
T_5	6.99	11.48	2.92	1.82	15.60	6.79	2.54	1.74
T_6	7.39	12.39	5.57	1.32	5.14	9.65	2.28	1.54
T_7	5.41	13.35	3.21	4.52	8.52	6.76	1.61	1.14
T_8	2.48	9.61	2.83	8.54	8.25	8.21	1.54	0.89
$F_{(7,14)}$	28.02**	22.03**	25.24**	23.89**	62.94**	12.91**	37.25**	22.69**
CD (0.05)	0.546	0.855	0.171	0.475	1.244	1.08	0.233	0.206

FPF – Fifty per cent flowering, **Significant at 1 per cent level

4.2.1.2 Effect of Treatments on Growth Characteristics

4.2.1.2.1 Height of the Plant (Table 23)

Statistical analysis of the data revealed that, the maximum height at both stages was recorded by T_6 (PG and lime each at half LR) followed by T_3 (PG @ full LR) and they were on par with each other. In both stages absolute control (T_8) recorded the lowest value and all other treatments were significantly superior to the absolute control. All the treatments which received fertilizer and amendments either as per POP or on the basis of soil test data recorded significantly higher values through out the cropping period.

4.2.1.2.2 Number of branches per plant (Table 23)

Statistical analysis of the data showed that at fifty per cent flowering, maximum number of branches were recorded by T_6 followed by T_3 and were on par with each other. The lowest number of branches were recorded by the absolute control. The number of branches showed the same trend as that of plant height during fifty per cent flowering and at harvest.

4.2.1.2.3 Root Characteristics

4.2.1.2.3.1 Root Weight (Table 24)

Statistical analysis of the data revealed that there was no significant difference between the treatments on the root weight at fifty per cent flowering stage and at harvest. However, the highest root weight was recorded by treatment T_5 and T_7 followed by T_3 and T_6. The lowest value was observed for absolute control.

At the time of harvest, the maximum root dry weight was produced by T_3 followed by T_5. As in the case of fifty per cent flowering, the lowest weight was recorded by T_8 (absolute control).

4.2.1.2.3.2 Number of Nodules per Plant^{-1} (Table 24)

Statistical analysis of the data revealed that the number of nodules per plant at fifty per cent flowering was significantly influenced by treatments. The maximum number of root nodules per plant was produced by T_3 which received PG @ full LR and was on par with T_1 (POP) and T_6 (Lime and PG each at @ ½ LR). The lowest number of root nodules per plant was produced by T_8 (absolute control) and was on par with T_2 and T_4 which received lime @ full LR and half LR respectively.

Table 23. Growth characters of cowpea at different growth stages

Treatment	Height		Number of branches plant^{-1}	
	FPF	Harvest	FPF	Harvest
T_1	77.33	79.33	5.00	5.67
T_2	74.00	77.00	4.00	4.67
T_3	89.00	93.00	9.67	10.33
T_4	80.33	86.00	6.33	7.67
T_5	82.67	86.00	7.00	8.00
T_6	91.33	93.67	10.00	10.33
T_7	73.67	59.82	7.33	8.33
T_8	46.33	59.00	3.33	4.33
$F_{(7, 14)}$	12.88**	25.59**	13.12**	11.91**
CD (0.05)	11.013	61.93	1.916	1.929

FPF – Fifty per cent flowering, **Significant at 1 per cent level

Table 24. Root characteristics as influenced by different treatments

Treatment	Root weight (g)		Number of nodules $plant^{-1}$	
	FPF	Harvest	FPF	Harvest
T_1	0.53	0.75	6.33	0.33
T_2	0.47	0.78	2.00	0.33
T_3	0.83	1.30	7.67	1.73
T_4	0.70	0.85	2.00	1.17
T_5	0.93	1.00	4.67	2.90
T_6	0.83	0.87	5.67	3.27
T_7	0.93	0.93	7.33	2.33
T_8	0.40	0.47	0.67	0.33
$F_{(7, 14)}$	1.62^{NS}	2.44^{NS}	13.84**	2.37^{NS}
CD (0.05)			2.179	

FPF – Fifty per cent flowering, **Significant at 1 per cent level, NS – Non significant

At harvest, there was no significant difference between the treatments on the number of root nodules per plant. However the maximum number of nodules was produced by T_6 followed by T_5 and T_7. The treatments T_8 and T_2 produced the lowest values.

4.2.1.2.4 Days to Fifty per cent Flowering and Maturity (Table 25)

No significant difference was observed on the days to fifty per cent flowering, maturity and the last picking date due to the application of various treatments. However, phosphogypsum treated plants flowered earlier.

Table 25. Effect of treatments on days to fifty per cent flowering and maturity

Treatments	Days to FPF	Days to maturity	Last picking date
T_1	28	73	12/11/2002
T_2	28	72	12/11/2002
T_3	25	70	12/11/2002
T_4	28	74	12/11/2002
T_5	26	71	12/11/2002
T_6	26	72	12/11/2002
T_7	27	72	12/11/2002
T_8	39	80	12/11/2002

FPF – Fifty per cent flowering

4.2.1.3 Yield and Yield attributes

4.2.1.3.1 Grain Yield (Table 26)

Statistical analysis of the data revealed that phosphogypsum significantly influenced the grain yield. The highest grain yield (2311 kg ha^{-1}) was shown by treatment T_3 (PG @ full LR) followed by T_7 (PG and lime each at ¼ LR) and were on par with each other. The lowest value of 1339 kg ha^{-1} was recorded by absolute control (T_8). The grain yield per plant also followed the same trend.

The pod yield per plot also followed the same trend as that of grain yield. The highest value of 739 g was shown by T_3 (PG @ full LR) followed by T_7 (711 g). The lowest value was that of T_8 (470 g).

4.2.1.3.2 Bhusa Yield (Table 26)

The bhusa yield per plant at fifty per cent flowering had a significant influence of various treatments. The values ranged from 3.23 to 25.07 g. The highest value was that of T_3 (PG @ full LR) and the lowest value was that of T_8 (absolute control).

At harvest stage also there was significant difference between the various treatments applied. The highest bhusa yield was recorded by T_3 (20.61 g) which was on par with T_7 (19.25 g) and the lowest value was that of T_8 (7.67 g). Bhusa yield per plot also showed the same trend.

4.2.1.3.3 Yield Attributes (Table 26)

The highest number of pods was produced by treatment T_3 (PG @ full LR) followed by T_5 (PG @ half LR) and they were on par. The lowest number of pods was produced by absolute control.

Statistical analysis of the data revealed that there was no significant difference between the treatments on the number of seeds pod^{-1}. The values ranged from 11.67 to 16.33. The highest value was shown by T_5 and lowest by T_8.

Perusal of the data (Table 27) revealed that pod length was significantly influenced by the application of various treatments. The highest value was shown by T_3 (PG @ full LR) followed by T_6 (PG and lime each at half LR) and they were on par with each other. The lowest value was shown by T_1 (POP).

4.2.1.3.4 Benefit : Cost Ratio (Table 26)

Application of phosphogypsum had a significant impact on the B: C ratio as revealed by the data in Table 27. The highest value was shown by T_3 which received phosphogypsum at full LR and was on par with T_7. The lowest value was shown by absolute control.

4.2.1.3.5 Total Dry Matter Production (Table 27)

The data indicated on Table 27 showed that the different treatments applied have a significant effect on the total dry matter production. The treatment T_5 which received PG @ half LR recorded the highest value of 1671 g, followed by T_3 and they were statistically on par. The lowest value was that of T_8 (absolute control) which was significantly inferior to other treatments.

Table 26. Effect of treatments on yield and yield attributes at harvest

Treatments	Bhusa yield plot^{-1} (g)	Bhusa yield plant^{-1} (g)	Grain yield plot^{-1} (kg ha^{-1})	Grain yield plant^{-1}	Number of pods plant^{-1}	Number of seeds pod^{-1}	B:C Ratio
T_1	496	10.34	1875	11.72	4.27	13.67	2.10
T_2	680	14.17	1900	11.88	5.53	12.67	2.14
T_3	884	20.61	2311	14.44	8.93	15.67	2.84
T_4	770	17.06	2086	13.04	3.56	14.33	2.45
T_5	685	16.61	2084	13.03	7.73	16.33	2.56
T_6	636	13.16	1724	10.78	5.63	14.00	2.03
T_7	828	19.25	2201	13.76	5.27	14.67	2.64
T_8	376	7.67	1339	8.37	2.23	11.67	1.81
$F_{(7, 14)}$	1.34^{NS}	7.89**	15.94**	2.92*	14.45**	1.12^{NS}	14.64**
CD (0.05)	-	4.601	233.58	3.256	1.725	-	0.262

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

Table 27. Effect of treatments on yield attributes and dry matter production

Treatment	Pod length (cm)	Pod yield plot^{-1} (g)	Total dry matter production plot (g plot^{-1})	Bhusa yield plant^{-1} (g) FPF
T_1	11.67	623	1119	11.27
T_2	15.90	640	1320	8.73
T_3	18.00	739	1623	25.07
T_4	14.25	682	1453	16.27
T_5	16.33	682	1671	21.43
T_6	17.83	582	1218	18.77
T_7	15.00	711	1539	19.43
T_8	13.72	471	847	3.23
$F_{(7, 14)}$	3.12*	9.87**	10.22**	9.03**
CD (0.05)	3.673	82.142	266.503	7.315

FPF – Fifty per cent flowering, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.1.4 Nutrient Concentration in Plant Parts

4.2.1.4.1 Bhusa

4.2.1.4.1.1 N, P and K (Table 28)

Statistical analysis of data revealed that phosphogypsum application increased the N content both at fifty per cent flowering and at harvest. The values at fifty per cent flowering ranged from 1.44 to 3.68 per cent, the highest being recorded by T_3 (PG at full LR), which was significantly superior to others, followed by T_5 (PG at half LR). The lowest value was recorded by absolute control. All the treatments showed significantly higher values compared to T_8.

The highest value at harvest was also showed by T_3 followed by T_6 (PG and Lime at half LR each) and the lowest by absolute control. The trend was same as in the case of at fifty per cent flowering stage.

The data presented in Table 28 showed that the phosphorus content of bhusa at fifty per cent flowering and at harvest was significantly influenced by the application of phosphogypsum. The values at fifty per cent flowering ranged from 0.183 to 0.291 per cent. Phosphogypsum applied @ half LR (T_5) recorded the highest P content and was significantly superior to all others followed by T_6 (PG and lime each at half LR). The lowest value was shown by T_8 (absolute control).

The highest content of phosphorus at harvest stage was observed in T_6 followed by T_5 (PG at half LR) and was 35 per cent higher than that of T_8, that recorded the lowest value.

The potassium content at both stages was significantly influenced by the application of different treatments. The values at fifty per cent flowering, ranged from 1.23 to 1.66, the highest value being recorded by T_2 (Lime at full LR) followed by T_5 (PG at half LR). They were on par with T_3, T_4, T_7

and T_6. The lowest content of K was showed by absolute control. At harvest, the highest content was recorded by T_6 and the lowest value by T_8.

4.2.1.4.1.2 Ca, Mg and S (Table 28 and 29)

Application of phosphogypsum significantly increased the calcium content in bhusa at fifty per cent flowering. The highest value of 2.87 per cent was produced by T_3, which received PG at full LR and was on par with T_5 (PG @ half LR) and T_2 (Lime at full LR). Here also T_8 recorded the lowest calcium content (1.20%). The Ca content in bhusa at harvest ranged from 1.13 to 2.40 per cent with the highest value being recorded by T_6 and the lowest by T_8.

Magnesium content in bhusa was significantly influenced by the application of treatments. At fifty per cent flowering, both T_1 (POP) and T_5 (PG at half LR) recorded the highest Mg content and were significantly superior the others. The lowest value was recorded by T_3 (0.47 per cent) preceded by T_8 (0.51 per cent) and they were on par with each other.

At the time of harvest also the same trend was followed with the lowest value by T_8 and T_3. The highest magnesium content of 2.29 per cent was recorded by T_4 followed by T_1 (2.04 per cent), both of which were superior to other treatments.

The sulphur content in bhusa at fifty per cent flowering and at the time of harvest were significantly influenced by application of phosphogypsum. T_3 (PG at full LR) recorded the highest value, both at fifty per cent flowering and at the time of harvest. The values at fifty per cent flowering ranged from 0.083 per cent to 0.185 per cent. The lowest value was shown by T_8.

At the time of harvest S content ranged from 0.088 to 0.187 per cent. The highest value was observed in T_3 and the lowest in T_8. T_3 was on par with T_6 (PG and Lime at half LR each), T_5 (PG at half LR) and T_2 (Lime at half LR) with values 0.178, 0.163 and 0.155 respectively.

Table 28. Effect of treatments on concentration of N, P, K and Ca in bhusa

Treatments	N(%)		P(%)		K(%)		Ca (%)	
	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	2.56	2.22	0.218	0.329	1.24	1.46	2.46	1.64
T_2	2.37	2.18	0.197	0.358	1.66	2.12	2.71	2.20
T_3	3.68	3.03	0.242	0.367	1.54	2.05	2.87	2.32
T_4	2.31	2.18	0.238	0.34	1.49	1.64	2.48	2.17
T_5	2.93	2.31	0.291	0.433	1.62	1.76	2.77	1.43
T_6	2.76	2.59	0.262	0.444	1.47	2.22	1.50	2.40
T_7	2.08	2.23	0.203	0.35	1.47	1.66	2.48	2.24
T_8	1.44	1.21	0.183	0.35	1.23	1.25	1.20	1.13
$F_{(7,14)}$	61.42**	30.58**	15.82**	33.85**	2.78*	23.797**	23.198**	12.03**
CD (0.05)	0.254	0.279	0.0276	0.039	0.286	0.209	0.387	0.413

FPF – Fifty per cent flowering, **Significant at 1 per cent level, *Significant at 5 per cent level

Table 29. Effect of treatments on concentration of Mg and S in bhusa

Treatment	Mg(%)		S(%)	
	FPF	Harvest	FPF	Harvest
T_1	1.99	2.04	0.123	0.133
T_2	1.45	1.44	0.135	0.155
T_3	0.47	0.41	0.185	0.187
T_4	1.56	2.29	0.130	0.137
T_5	1.99	1.45	0.153	0.163
T_6	1.44	0.61	0.121	0.178
T_7	1.14	1.62	0.150	0.136
T_8	0.51	0.16	0.083	0.088
$F_{(7,14)}$	112.52**	34.39**	10.89**	4.93**
CD (0.05)	0.167	0.402	0.025	0.0427

FPF – Fifty per cent flowering, **Significant at 1 per cent level

4.2.1.4.1.3 Micronutrients (Table 30)

Perusal of the data revealed that application of amendments had a significant effect on the concentration of micronutrient cations.

In the case of Fe, at fifty per cent flowering the highest value was shown by T_6 which received phosphgypsum and lime each @ half LR and was followed by T_3 (PG @ full LR). The lowest value was shown by absolute control (T_8). At harvest, the highest value was shown by T_5 and the lowest by T_8.

For Mn, application of phosphogypsum significantly influenced its concentration. The highest value at fifty per cent flowering and at harvest were recorded by T_5 and T_3 respectively and the lowest by T_6 in both cases.

The Cu concentration also showed a significant effect due to the application of various amendments. The highest value at two stages were shown by T_4 (Lime @ half LR) and T_1 (POP) respectively, whereas the lowest values were registered by T_7 and T_8 respectively.

The treatment T_3 recorded the highest value for Zn at fifty per cent flowering. At harvest T_1 (POP) showed the highest value. The lowest values at two stages were recorded by T_7 and T_8 respectively.

Table 30. Concentration of micronutrients in bhusa at fifty per cent flowering and at harvest

Treatment	Fe (ppm)		Mn (ppm)		Cu (ppm)		Zn (ppm)	
	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	1242	850	761	716	61	43	62	73
T_2	1357	872	839	651	63	27	72	68
T_3	1399	782	809	775	68	31	90	51
T_4	1039	845	729	622	91	32	88	49
T_5	869	981	859	628	76	28	86	54
T_6	1648	929	711	617	90	33	76	52
T_7	1317	866	725	641	58	35	61	45
T_8	298	420	731	737	38	23	78	43
$F_{(7,14)}$	11.86**	12.80**	36.66**	50.6**	28.45**	10.76**	5.29**	6.3**
CD (0.05)	35.39	13.621	26.145	24.2	9.326	5.262	13.82	12.06

FPF – Fifty per cent flowering, **Significant at 1 per cent level

4.2.1.4.2 **Grain**

4.2.1.4.2.1 N, P and K (Table 31)

The values ranged from 1.06 to 3.60 per cent. The maximum N content in grain was recorded by T_3 (PG at full LR) followed by T_2 (Lime @ full LR). The minimum content was shown by T_8 (absolute control), which was on par with T_4 (Lime @ half LR).

As in the case of N, the P content in grain was maximum in T_3 followed by T_2. The minimum value was shown by absolute control (T_8). The values ranged from 0.298 to 0.529 per cent.

The highest value for potassium content in grain also followed the same trend as N and P and the values ranged from 0.49 to 1.21 per cent.

4.2.1.4.2.2 Ca, Mg and S (Table 31)

Statistical analysis of data on calcium content in grain showed that it was significantly influenced by various treatments. The values ranged from 0.79 to 2.32 per cent with T_5 (PG @ half LR) recording the highest value and absolute control (T_8) showing the lowest value. All other treatments were significantly superior to T_8.

In the case of Mg the values ranged from 0.229 to 1.071 per cent, with the highest being T_4 (lime @ ½ LR) and the lowest value recorded by T_3 (PG @ full LR) which was on par with T_8 (absolute control) and T_5 (PG at half LR).

The sulphur content of grain was significantly influenced by application of phosphogypsum. The highest value of 0.064 per cent was recorded by T_5 followed by T_3 (PG at half LR and full LR respectively) and were on par with each other. The lowest value was recorded by T_8, which was on par with T_1 and T_4.

Table 31. Effect of treatments on concentration of nutrients in grain (%)

Treatment	N	P	K	Ca	Mg	S	Protein
T_1	2.74	0.479	1.00	1.44	0.501	0.013	16.98
T_2	3.43	0.521	1.16	1.32	0.342	0.033	21.83
T_3	3.60	0.529	1.21	1.73	0.229	0.063	22.50
T_4	1.29	0.473	1.01	1.82	1.071	0.023	8.00
T_5	3.07	0.440	1.04	2.32	0.282	0.064	19.18
T_6	2.82	0.470	0.97	1.19	0.862	0.059	18.24
T_7	1.57	0.464	0.58	1.89	0.757	0.037	9.75
T_8	1.06	0.298	0.49	0.79	0.233	0.013	6.65
$F_{(7.14)}$	59.36**	40.180**	36.36**	53.45**	87.18**	32.09**	67.16**
CD (0.05)	0.392	0.0342	0.13	0.197	0.105	0.0115	2.340

**Significant at 1 per cent level

4.2.1.4.2.3 Micronutrients (Table 32)

The perusal of the data revealed that only Mn and Zn was translocated to the grain. For Mn, the highest value was shown by T_1 (POP) and lowest by T_3 (PG @ full LR), whereas for Zn the highest value was shown by T_8 and lowest by T_6 (Lime and PG each @ half LR).

Table 32. Concentration of micronutrients in grain (ppm)

Treatment	Mn	Zn
T_1	584.00	24.60
T_2	528.00	23.20
T_3	525.00	25.10
T_4	537.00	25.00
T_5	550.00	22.60
T_6	537.00	22.33
T_7	545.00	27.17
T_8	542.00	27.20
$F_{(7,14)}$	1.76^{NS}	4.02*
CD (0.05)	-	2.664

NS – Non significant, *Significant at 5 per cent level

4.2.1.4.2.4 Grain protein (Table 31)

The grain protein content was significantly influenced by the application of phosphogypsum. The highest value (22.50 %) was recorded by T_3 followed by T_2 and they were on par with each other. The lowest value was shown by absolute control

4.2.1.5 Uptake of Nutrients

4.2.1.5.1 Uptake of Nutrients by Bhusa

4.2.1.5.1.1 N, P and K (Table 33)

Statistical analysis of the values revealed that the uptake of nitrogen was significantly influenced by application of phosphogypsum both at fifty per cent flowering and at the time of harvest, with the highest value being recorded by T_3 (PG at full LR) followed by T_5 in both stages. The lowest value for nitrogen uptake in both stages was observed in absolute control (T_8).

Data on phosphorus uptake indicated that phosphogypsum application significantly increased the uptake of phosphorus both at fifty per cent flowering and at the time of harvest. The highest uptake at fifty per cent flowering was recorded by T_5 (PG at half LR) followed by T_3 and T_6 and they were on par with each other. The uptake was lowest in absolute control. At harvest, the highest uptake was recorded by T_5 and was significantly superior to others. All the treatments which received fertilizers and amendments were significantly superior to that of absolute control (T_8).

The maximum uptake of potassium at fifty per cent flowering was showed by T_3 (PG at full LR) followed by T_5 which were on par with T_7.

At the harvest stage also the trend was same, with values ranging from 15.5 to 60.4 kg ha^{-1}. In both stages, the lowest uptake was showed by T_8.

Table 33. Uptake of N, P and K by bhusa (kg ha^{-1})

Treatments	N		P		K	
	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	45.7	36.9	3.9	5.48	22.38	23.64
T_2	33.3	49.3	2.8	8.2	23.4	49.9
T_3	147.2	89.7	9.7	10.8	61.8	60.4
T_4	60.1	55.7	6.2	8.7	38.9	36.2
T_5	98.8	74.5	10.0	14.3	55.1	57.9
T_6	83.0	54.2	7.7	7.3	42.8	46.6
T_7	63.8	61.9	6.9	9.7	47.2	46.5
T_8	7.4	15.1	0.94	2.5	6.3	15.5
$F_{(7,14)}$	16.29**	12.85**	11.23**	14.57**	9.93**	11.53**
CD (0.05)	32.244	19.163	2.938	2.786	17.91	14.196

**Significant at 1 per cent level

4.2.1.5.1.2 Ca, Mg and S (Table 34)

Statistical analysis of the data revealed that calcium uptake by bhusa was significantly increased by the application of phosphogypsum at fifty per cent flowering and at harvest. The maximum value for calcium uptake at fifty per cent flowering was recorded by T_3 (112.9 kg ha^{-1}) which received PG @ full LR followed by T_5. Absolute control was significantly inferior to all other treatments. At harvest also, the highest value (68.3 kg ha^{-1}) was recorded by T_3, followed by T_7, T_4 and T_6 and were on par with each other and the lowest value by T_8.

The maximum uptake of Mg at fifty per cent flowering was recorded by T_4 (Lime @ half LR). The uptake was lowest for T_8 (absolute control), which was on par with T_3 (PG at full LR) and T_6 (PG and Lime at half LR each). The trend on Mg uptake at harvest was similar to that at fifty per cent flowering.

Statistical analysis of the data revealed that sulphur uptake was significantly influenced by the application of phosphogypsum. The maximum uptake of sulphur was recorded by T_3 followed by T_5, both at fifty per cent flowering and at harvest stage, whereas the uptake was lowest for T_8 at both stages.

Table 34. Uptake Ca, Mg and S (kg ha^{-1}) by bhusa

Treatments	Ca		Mg		S	
	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	43.4	27.7	35.9	33.6	2.3	2.2
T_2	37.6	49.9	20.4	33.8	1.9	3.50
T_3	112.9	68.3	19.1	12.2	7.4	5.5
T_4	64.4	55.7	40.5	60.3	3.4	3.5
T_5	93.30	47.2	67.4	47.7	5.3	5.40
T_6	45.50	50.8	43.3	12.8	3.6	3.8
T_7	76.4	61.94	34.85	45.24	4.49	3.78
T_8	6.2	14.12	2.67	1.99	0.437	1.12
$F_{(7,14)}$	14.55**	8.75**	14.28**	10.34**	12.23**	7.4**
CD (0.05)	26.999	18.285	15.55	19.138	1.757	1.634

FPF – Fifty per cent flowering, **Significant at 1 per cent level

4.2.1.5.1.3 Micronutrients

The data on the uptake of micronutrients at fifty per cent flowering and at harvest are presented in Table 35. The highest value for uptake of iron was shown by T_3 followed by T_6 and the lowest value by T_8. For Mn the values ranged from 2.40 to 20.21 mg plant^{-1} recorded by T_8 and T_3 respectively. The values for copper ranged between 0.123 and 1.720 mg plant^{-1} registered by T_8 and T_3. The same trend was noticed for zinc also with the values ranging from 0.252 to 2.280 mg plant^{-1}.

Perusal of the data on uptake of micronutrients at harvest revealed that the treatment effect was significant. In the case of Fe the values ranged from 3.26 to 20.24 mg plant^{-1} recorded by T_8 and T_3 respectively. The same trend was noticed in the case of Mn also. The values for copper ranged between 0.174 to 0.597 mg plant^{-1} recorded by T_8 and T_7 respectively. The highest value for zinc was recorded by T_5 and the lowest by T_8.

Table 35. Uptake of micronutrients by bhusa (mg plant^{-1})

Treatment	Fe		Mn		Cu		Zn	
	FPF	Harvest	FPF	Harvest	FPF	Harvest	FPF	Harvest
T_1	13.99	8.80	8.58	7.80	0.683	0.442	0.691	0.763
T_2	11.80	12.30	7.34	9.20	0.549	0.387	0.621	0.961
T_3	34.90	14.10	20.21	14.30	1.720	0.580	2.280	0.938
T_4	16.90	13.57	11.90	9.99	1.470	0.511	1.440	0.792
T_5	18.60	20.24	17.20	12.90	1.630	0.576	1.860	1.125
T_6	30.90	14.47	13.40	8.10	1.710	0.437	1.450	0.712
T_7	25.60	13.40	14.10	11.00	1.130	0.597	1.190	0.789
T_8	9.70	3.26	2.40	5.69	0.123	0.174	0.252	0.337
$F_{(7,14)}$	8.56**	8.85**	11.14**	8.19**	9.23**	5.06**	8.47**	3.92*
CD (0.05)	2.52	4.982	5.169	3.038	0.609	0.189	0.706	0.353

FPF – Fifty per cent flowering, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.1.5.2 Uptake of Nutrients by Grain

4.2.1.5.2.1 N, P and K (Table 36)

As in the case of concentration of N, the uptake was also highest in T_3 (PG at full LR) followed by T_2 (Lime at full LR). The lowest value of uptake was recorded by T_8, which was significantly inferior to other treatments.

The highest uptake of 12.2 kg ha^{-1} was registered by T_3 (PG at full LR) followed by T_7 (PG and lime each at ¼ LR each). No other treatment was on par with T_3. The lowest uptake was recorded by absolute control and all other treatments were significantly superior to that.

Perusal of the data revealed significant difference among the treatments on the K uptake by grain. Treatment which received PG at full LR (T_3) recorded the highest K uptake followed by T_2 (Lime @ full LR). The lowest uptake of K as in the case of other nutrients was registered by T_8. No other treatments were on par with that treatment.

4.2.1.5.2.2 Ca, Mg and S (Table 36)

The uptake of Ca by grains was significantly influenced by various treatments. The treatment T_5 (PG @ half LR) recorded the highest Ca uptake of 48.3 kg ha^{-1}, followed by T_7, which received PG and lime each at ¼ LR. The uptake was lowest for T_8 with a value of 10.5 kg ha^{-1}.

The maximum uptake of 22.3 kg ha^{-1} was registered by T_4 (Lime at half LR), which was significantly superior to all other treatments. This was followed by T_7 (PG and lime each at ¼ LR). T_8 showed the lowest uptake of 3.1 kg ha^{-1}.

The sulphur uptake by grains was profoundly influenced by application of phosphogypsum, which is evident from Table 36. The treatment T_3 gave the highest value of 1.5 kg ha^{-1} followed by T_5, which gave a value of 1.35 kg ha^{-1} and they were on par with each other. The lowest value of sulphur uptake was recorded by T_8 (0.17 kg ha^{-1}) and was on par with T_1 (0.24 kg ha^{-1}).

Table 36. Effect of treatments on nutrient uptake by grain

Treatment	N	P	K	Ca	Mg	S	Mn	Zn
	kg ha^{-1}						mg plant^{-1}	
T_1	51.6	8.99	18.8	27.04	9.4	0.24	6.86	0.288
T_2	66.5	9.9	22.0	25.1	6.5	0.62	6.28	0.276
T_3	83.3	12.2	28.1	40.0	5.2	1.50	7.58	0.362
T_4	26.9	9.9	21.2	37.4	22.3	0.483	6.99	0.326
T_5	64.1	9.2	21.5	48.3	5.9	1.35	7.19	0.294
T_6	48.6	8.1	16.4	20.8	15.0	1.03	5.77	0.240
T_7	34.5	10.2	12.9	41.7	16.7	0.80	7.49	0.374
T_8	14.3	3.99	6.5	10.5	3.1	0.17	4.52	0.228
$F_{(7,14)}$	33.596**	25.33**	34.37**	52.8**	53.27**	27.15**	15.71**	18.97**
CD (0.05)	11.142	1.339	3.168	4.923	2.627	0.262	0.789	0.0367

**Significant at 1 per cent level

4.2.1.5.2.3 Micronutrients (Table 36)

The highest value for the uptake of Mn was shown by T_3 and the lowest by T_8. In the case of zinc the highest and lowest values were recorded by T_7 and T_8 respectively.

4.2.1.6 *Total Uptake of Nutrients*

4.2.1.6.1 *N, P and K* (Table 37)

The treatment T_3 (PG @ full LR) recorded the highest value for the uptake of N (173 kg ha^{-1}) followed by T_5 (PG at half LR). No other treatments were on par with T_3, which indicated that it was the superior treatment. The lowest value of 29.4 kg ha^{-1} was recorded by T_8 (absolute control) and all the treatments were significantly superior to that.

Application of phosphogypsum significantly influenced the uptake of phosphorus. The treatments, which received phosphogypsum at full LR and half LR, (T_3 and T_5) respectively recorded the highest uptake of phosphorus which were on par with each other. The lowest value was shown by T_8, which received no fertilizers and amendments.

Perusal of the data showed that phosphogypsum had a significant impact on the uptake of potassium. This also followed the same trend as in the case of phosphorus, with values ranging from 22.0 to 88.5 kg ha^{-1}.

4.2.1.6.2 *Ca, Mg and S* (Table 37)

The treatment T_3 (PG at full LR) recorded the highest uptake of calcium (108.2 kg ha^{-1}) followed by T_7 (103.6 kg ha^{-1}) and T_5 (95.50 kg ha^{-1}), which received PG and lime each at ¼ LR and PG at half LR respectively. The lowest value was shown by absolute control and was significantly inferior to others.

The different treatments scheduled had a significant effect on the uptake of Mg. The highest uptake of magnesium was recorded by T_4 (Lime at half LR) and was significantly superior to other treatments. The lowest uptake was shown by T_8 which was on par with T_3 (PG @ full LR) with values 5.1 kg ha^{-1} and 17.5 kg ha^{-1} respectively.

Table 37. Effect of treatments on total uptake of nutrients

Treatments	N	P	K	Ca	Mg	S	Mn	Zn (mg plant^{-1})
	kg ha^{-1}						mg plant^{-1}	
T_1	88.5	14.5	42.5	54.7	42.9	2.4	14.2	1.1
T_2	115.8	18.1	71.9	75.0	40.3	4.1	15.5	1.2
T_3	173.0	23.0	88.5	108.2	17.5	6.9	21.9	1.3
T_4	82.6	18.5	57.3	93.1	82.6	4.0	16.9	1.1
T_5	138.5	23.5	79.4	95.5	53.6	6.8	20.1	1.4
T_6	102.8	17.4	63.4	71.5	27.9	4.9	13.9	0.9
T_7	96.4	19.9	59.4	103.6	61.9	4.6	18.5	1.2
T_8	29.4	6.6	22.0	24.7	5.1	1.3	10.2	0.5
$F_{(7,14)}$	24.99**	24.17**	19.25**	18.28**	13.35**	11.05**	11.88**	4.96**
CD (0.05)	23.949	3.094	13.63	18.71	19.38	1.651	3.307	0.359

**Significant at 1 per cent level

Statistical analysis revealed that application of phosphogypsum significantly influenced the uptake of sulphur. The values ranged from 1.3 kg ha^{-1} to 6.9 kg ha^{-1}. The highest value was shown by T_3 followed by T_5, which received PG at full LR and half LR respectively. The lowest value of uptake was registered by T_8 (absolute control) which was on par with the treatment scheduled as per POP (T_1).

4.2.1.6.3 Micronutrients

Perusal of the data presented in Table 37 revealed that the treatments effects were significant in the total uptake of Mn and Zn. The values for Mn ranged between 10.2 and 21.9 mg plant^{-1} recorded by T_8 and T_3. For Zn the highest value was shown by T_5 and the lowest by T_8. Since there was no translocation of Fe and Cu to the grain the total uptake was same as that of bhusa.

4.2.2 Residue Crop

4.2.2.1 Soil Analysis (Table 38)

4.2.2.1.1 Organic Carbon

The values ranged from 0.58 to 0.94 per cent. The highest value was recorded by T_5 (PG @ half LR) followed by T_3 (PG @ full LR). They were on par with T_6 (PG and lime at half LR each), T_4 (Lime @ half LR) and T_7 (PG and lime each at ¼ LR). The lowest value was shown by T_8 (absolute control).

4.2.2.1.2 Available P

Statistical analysis of the data revealed that the phosphorus content of soil was significantly influenced by the application of various treatments. The highest value of 141.4 kg ha^{-1} was shown by T_3 (PG @ full LR) followed by T_1 (POP) and T_5 (PG @ half LR). The lowest value of 73.1 kg ha^{-1} was registered by T_8 (absolute control).

4.2.2.1.3 Available Potassium

The values ranged between 70.6 kg ha^{-1} and 162.0 kg ha^{-1} with the highest being T_2 and lowest with T_8. T_8 was significantly inferior to other treatments.

4.2.2.1.4 Exchangeable Calcium and Magnesium

The exchangeable Ca content of the soil was significantly influenced by the various treatments applied. The maximum value of 1.7 cmol kg^{-1} was registered by T_6 and T_1. The lowest value of 0.67 cmol kg^{-1} was shown by absolute control which was significantly inferior to other treatments.

Perusal of the data revealed that the exchangeable Mg content during the residue crop was significantly influenced by the various treatments. The treatment which received PG at full LR (T_3) registered the lowest value of 0.143 cmol kg^{-1} and the highest value was shown by T_4 (0.823 cmol kg^{-1}) followed by T_2 (0.515 cmol kg^{-1}) which received lime at half LR and full LR respectively.

4.2.2.1.5 Available Sulphur

The sulphur status of the soil was significantly influenced by the application of phosphogypsum. The treatment T_3 (PG @ full LR) registered the maximum sulphur content of 48.1 kg ha^{-1} followed by T_6. The lowest value (14.9 kg ha^{-1}) was shown by absolute control and was significantly inferior to other treatments.

4.2.2.1.6 Soil pH and EC

The soil pH was significantly influenced by the various treatments. The highest value was shown by T_1 (POP) followed by T_4 (Lime at half LR) and T_2 (Lime at full LR) with values 5.7, 5.5 and 5.4 respectively. The treatments T_2, T_5 and T_6 were on par. Lowest value was shown by T_8

The values for EC ranged between 110.5 and 51.3 μS m^{-1}. The highest value was shown by T_1 (POP) followed by T_3 and the lowest value was showed by T_8.

Table 38. Chemical properties of soil as influenced by treatments

Treatment	Organic carbon (%)	P (kg ha^{-1})	K (kg ha^{-1})	Ca (cmol kg ha^{-1})	Mg (cmol kg ha^{-1})	S (kg ha^{-1})	pH	EC (μS m^{-1})
T_1	0.777	135.2	86.9	1.7	0.423	29. 6	5.7	110.5
T_2	0.817	128.7	162.0	1.6	0.515	31.2	5.4	87.6
T_3	0.930	141.4	116.5	1.6	0.143	48.1	5.2	105.1
T_4	0.890	108.0	146.4	1.6	0.823	26.7	5.5	97.7
T_5	0.940	135.1	138.9	1.5	0.273	42.3	5.3	89.9
T_6	0.923	121.3	139.6	1.7	0.220	47.7	5.3	95.2
T_7	0.843	132.1	103.0	1.6	0.213	36.8	5.1	82.3
T_8	0.583	73.1	70.6	0.67	0.223	14.9	4.8	51.3
$F_{(7,14)}$	6.63**	12.81**	54.59**	13.52**	48.44**	10.94**	29.09**	19.15**
CD (0.05)	0.139	18.88	13.013	0.278	0.098	10.425	0.153	12.51

**Significant at 1 per cent level

4.2.2.1.7 Micronutrients

The data on the micronutrient content of the soil during the residue crop are presented in the Table 39. Perusal of the data revealed that the treatment effects were significant in the availability of micronutrients. The highest value for Fe was shown by T_7 and the lowest by T_2. The trend was same as in the case of main crop. For Mn the highest value was shown by T_2 followed by T_7 and the lowest value was recorded by T_8. In the case of copper also the highest value was shown by T_2 and the lowest content was shown by T_6 (Lime and PG each @ half LR) and for Zn, the highest value was shown by T_7 and the lowest value by T_1 (POP) as in the case of main crop.

Table 39. Effect of treatments on micronutrient status of soil

Treatment	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
T_1	11.5	5.1	6.5	1.4
T_2	9.9	7.7	12.9	2.1
T_3	10.1	7.4	6.6	2.1
T_4	12.8	7.1	8.2	2.2
T_5	11.5	6.7	9.3	1.9
T_6	12.4	5.4	6.2	1.7
T_7	13.4	7.5	7.0	2.3
T_8	9.6	5.1	6.4	2.32
$F_{(7,14)}$	22.04**	14.04**	19.27**	6.09**
CD (0.05)	0.855	0.268	0.464	0.365

**Significant at 1 per cent level

4.2.2.2 Growth Characteristics

4.2.2.2.1 Root Characteristics (Table 40)

4.2.2.2.1.1 Root Weight and number of nodules plant^{-1}

Perusal of the data on root weight at harvest revealed that, there was no significant difference between various treatments. However the highest value was recorded by T_3 and the lowest value by T_8.

As in the case of root weight, there was no significant difference between the treatments for number of nodules per plant.

Table 40. Effect of treatments on root characteristics of residue crop

Treatment	Root weight (g)	Number of nodules plant^{-1}
T_1	1.77	3.33
T_2	1.53	2.33
T_3	2.63	2.33
T_4	1.33	2.33
T_5	1.88	2.33
T_6	1.33	2.67
T_7	0.93	3.00
T_8	1.25	0.67
$F_{(7, 14)}$	1.23^{NS}	1.18^{NS}
CD (0.05)	-	-

NS – Non significant

4.2.2.3 Yield and Yield attributes

4.2.2.3.1 Yield

4.2.2.3.1.1 Grain Yield

The data on grain yield per plot of the residue crop are presented in Táble 41. Perusal of the data revealed that the grain weight per plot was significantly influenced by the various treatments. The highest value of 1104 kg ha^{-1} was shown by T_3 (PG @ full LR) followed T_5 (1086 kg ha^{-1}) which received PG @ half LR. The lowest value of 577 kg ha^{-1} was recorded by T_8 (absolute control). The treatment T_3 was on par with T_5 and T_6 (PG and lime each @ half LR).

4.2.2.3.2 Yield Attributes (Table 41)

Statistical analysis of the data revealed that phosphogypsum had a significant effect on the number of pods $plant^{-1}$. The treatment which received PG @ full LR (T_3) was significantly superior to others and registered a value of 9.5 and was followed by T_5 (PG @ half LR) and T_6 (PG and lime each at half LR). The lowest value (3.0) was recorded by T_8 (absolute control) which was on par with T_4 and T_2.

Analysis of the data revealed that there was no significant difference between treatments applied on the number of seeds pod^{-1}. The highest value was recorded by T_5 (15.7) followed by T_6 (13.7) and the lowest value was shown by T_8 and T_1.

The data on pod length showed that the different treatments tried had a significant impact on the length of pods of residue crop. The longest pod was produced by T_2 (Lime @ full LR) followed by T_4 (Lime @ half LR) and T_6 (Lime and PG each @ half LR). Pod length was lowest for T_1.

Statistical analysis of the data (Table 42) revealed that the various treatments applied did not produce any significant effect on the pod yield plot^{-1}. However the values ranged from 316 gram to 581 g. The highest value was shown by T_3, followed by T_5 and the lowest value was recorded by T_8.

4.2.2.3.2.1 Bhusa Yield

Statistical analysis of the data presented in Table 41 revealed that there was no significant difference on the bhusa yield per plot of the residue crop due to the application of various treatments. The highest value was that of T_4 followed by T_3 and the lowest was for T_8. The bhusa yield plant^{-1} of residue crop also (Table 42) was not significantly influenced by various treatments.

Table 41. Grain and bhusa yield of cow pea and its yield attributes

Treatment	Grain yield plot^{-1} (kg ha^{-1})	Bhusa yield plot^{-1} (g)	Grain yield plant^{-1}	Number of pods plant^{-1}	Number of seeds pod^{-1}	Pod length
T_1	722	633	4.52	5.8	12.0	11.20
T_2	721	879	4.51	4. 7	12.3	16.60
T_3	1104	882	6.90	9.5	13.3	16.20
T_4	700	938	4.37	4.5	13.3	16.40
T_5	1086	422	6.80	6.4	15. 7	14.40
T_6	1030	857	6.40	6.1	13.7	16.20
T_7	845	670	5.30	5.5	13.3	14.00
T_8	577	425	3.03	3.0	12.0	14.00
$F_{(7, 14)}$	13.53**	2.19^{NS}	1.54 ^{NS}	7.54**	1.68^{NS}	2.96*
CD (0.05)	175.876	-	-	2.094	-	3.054

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.3.2.2 Total Dry Matter Production (Table 42)

The treatment effects were significant on the total dry matter production of the residue crop. The highest value was shown by T_3 followed by T_4 and the lowest value by T_8.

Table 42. Pod yield and total dry matter production by residue crop

Treatment	Pod yield plot^{-1} (g)	Total dry matter production (g)	Bhusa yield plant^{-1} (g)	B:C Ratio
T_1	458	1092	13.2	1.04
T_2	456	1335	18.31	1.00
T_3	581	1463	18.38	1.54
T_4	501	1439	19.54	0.98
T_5	553	975	8.79	1.51
T_6	459	1317	17.86	1.44
T_7	470	1140	13.96	1.18
T_8	316	741	8.87	0.734
$F_{(7, 14)}$	2.47^{NS}	3.36*	2.19^{NS}	13.69**
CD (0.05)	-	411.785	-	0.224

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.4 Concentration of Nutrients in bhusa

4.2.2.4.1 N, P and K (Table 43)

The data on N, P and K content of bhusa revealed that the treatment influence was significant. The nitrogen content was maximum in T_2 with a value of 3.10 per cent, followed by T_5 and T_3, which were on par with T_2. The lowest content of N_2 of 1.34 per cent was recorded by T_8 (absolute control).

The values ranged from 0.183 to 0.350 per cent, with T_3 registered the highest value followed by T_6 and were on par with T_1. The lowest content was recorded by T_8.

The maximum content of potassium was registered by T_7 (PG and lime each at ¼ LR) followed by T_3 (PG @ full LR). The lowest value was shown by T_8 (absolute control), which was on par with T_4 (Lime @ half LR) and T_5 (PG @ half LR).

4.2.2.4.2 Ca, Mg and S (Table 43)

The calcium, magnesium and sulphur contents of the crop were significantly influenced by the application of various treatments. The values ranged from 1.75 to 2.68 per cent. The highest content of Ca was shown by T_1 (POP) followed by T_6 (Lime and PG each at half LR). The lowest content was for T_8 (absolute control).

The highest content of Mg was registered by T_4 (Lime at half LR), which was significantly superior to all other treatments. This was followed by T_2 (Lime at full LR) and T_1 (POP). The lowest content of Mg was registered by T_8 (absolute control), which was on par with T_7 and T_3.

The highest S content was registered by T_3 (PG at full LR) followed by T_6 (PG and lime each at half LR) and was 65 and 47 per cent more than that of T_8 respectively. The values ranged from 0.089 to 0.147 per cent.

Table 43. Concentration of nutrients in bhusa - residue crop

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn
	%						ppm		
T_1	2.12	0.278	1.15	2.68	0.933	0.107	434	644	21.07
T_2	3.10	0.198	1.33	2.47	1.11	0.122	485	623	25.07
T_3	2.82	0.350	1.36	2.32	0.38	0.147	563	686	20.73
T_4	2.23	0.243	1.09	2.48	1.92	0.105	364	636	21.33
T_5	3.06	0.243	1.13	2.51	0.636	0.124	518	687	22.57
T_6	2.39	0.29	1.23	2.64	0.497	0.131	374	679	21.73
T_7	2.18	0.208	1.41	2.46	0.294	0.121	545	655	22.50
T_8	1.34	0.183	0.827	1.75	0.282	0.089	224	604	23.50
$F_{(7,14)}$	11.30**	4.37**	3.20*	4.96**	92.87**	8.78**	73.88**	3.51*	5.075**
CD (0.05)	0.525	0.080	0.318	0.397	0.176	0.018	37.72	46.67	1.812

**Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.4.3 Micronutrients (Table 43)

The content of Fe, Mn, and Zn in bhusa were significantly influenced by the various treatments. However the copper content was undetectable. In the case of Fe the highest content was shown by T_3 (PG @ full LR) and lowest by T_8 (absolute control). For Mn also the trend was same. The highest and lowest values for Zn were recorded by T_2 and T_3 respectively.

4.2.2.5 **Concentration of nutrients in grain**

4.2.2.5.1 N, P and K (Table 44)

The treatment effect N content of grain was significant and the values ranged from 0.88 to 3.24 per cent. The highest value was registered by T_2 followed by T_3 and they were on par with T_7 and T_1. The lowest value was recorded by T_8.

The treatment effect for P content in the grain was significant and T_1 (POP) registered the highest value of 0.467 per cent and was on par with T_7, T_2 and T_4, whereas the lowest value of 0.296 per cent was shown by T_8. All other treatments were significantly superior to absolute control.

The values for K ranged from 0.54 to 1.16 per cent. The treatment T_6 registered the highest value followed by T_3 and were on par with T_5. The lowest value was shown by T_8 and was on par with T_7.

4.2.2.5.2 Ca, Mg and S (Table 44)

Calcium content was highest (1.45%) in T_7 followed by T_5. The lowest value was shown by T_8. All the treatments were significantly superior to the absolute control.

The values of Mg ranged from 0.246 per cent to 0.425 per cent and the highest value was shown by T_4 and was on par with T_7, T_2 and T_1. The treatments T_3 and T_5 recorded significantly lower values compared to others.

Sulphur content in the grains was significantly influenced by the application of phosphogypsum. The treatment T_3 registered the highest value of 0.073 per cent. This was followed by T_5. The lowest value was shown by T_8 (0.011 per cent).

Table 44. Concentration of nutrients in grain – residue crop

Treatment	N	P	K	Ca	Mg	S	Mn	Zn	Protein
	%						ppm		%
T_1	1.82	0.467	1.07	1.26	0.387	0.023	588	24.60	9.11
T_2	3.24	0.462	0.94	1.23	0.394	0.019	573	23.20	15.06
T_3	2.74	0.441	1.11	1.34	0.246	0.073	568	25.10	17.74
T_4	1.47	0.462	1.01	0.845	0.425	0.036	545	25.00	9.18
T_5	1.25	0.420	1.09	1.38	0.246	0.049	560	22.60	7.78
T_6	1.34	0.390	1.16	1.29	0.299	0.048	539	22.33	8.35
T_7	2.73	0.465	0.62	1.45	0.394	0.037	569	27.17	8.40
T_8	0.88	0.296	0.54	0.623	0.288	0.011	530	27.20	5.48
$F_{(7,14)}$	3.08*	9.01**	47.64**	17.82**	8.37**	8.88**	2.378^{NS}	4.02*	18.87**
CD (0.05)	1.483	0.059	0.103	0.207	0.076	0.020	-	2.664	2.861

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.5.3 Micronutrients (Table 44)

The content of Fe and Cu in the grain were found in traces as in the case of main crop. In the case of Mn, the highest concentration was recorded by T_7 and the lowest by T_8 and for Zn also the highest concentration was shown by T_7 while the lowest value was shown by T_2.

4.2.2.5.4 Grain Protein (Table 44)

Statistical analysis of the data in Table 44 showed that the protein content was significantly influenced by application of treatments. The highest value was shown by T_3 followed by T_2 and were significantly superior to the rest and the lowest value was shown by T_8.

4.2.2.6 Nutrient Uptake by Bhusa

4.2.2.6.1 N, P and K

The data on the uptake of N are furnished in Table 45. The uptake of nitrogen was highest for T_2 (91.9 kg ha^{-1}) followed by T_3 (85.6 kg ha^{-1}) and were on par with each other. The lowest value of 18.9 kg ha^{-1} was recorded by T_8. The performance of T_5, T_7 and T_1 were statistically on par with T_8.

Phosphorus uptake was significantly influenced by the application of phosphogypsum (Table 45). The treatment T_3 recorded the highest value of 10.5 kg ha^{-1}, followed by T_6 (7.9 kg ha^{-1}) and were on par with each other. The lowest value of 2.6 kg ha^{-1} was shown by absolute control and was on par with T_5 and T_2.

The K uptake was highest for T_3 (40.4 kg ha^{-1}) followed by T_2 and T_6. The lowest value (11.8 kg ha^{-1}) was shown by absolute control.

4.2.2.6.2 Ca, Mg and S (Table 45)

Eventhough there was no significant difference in uptake of calcium by the residue crop due to application of various treatments, the highest value was observed in T_4 and the lowest value for T_8.

Magnesium uptake was highest in T_4 and no other treatments were on par with it. The lowest value (4.1 kg ha^{-1}) was shown by T_8. The Mg uptake of T_3 was also very low (11.3 kg ha^{-1}).

Phosphogypsum application significantly improved the sulphur uptake, with the highest value of 4.3 kg ha^{-1} registered by T_3 followed by T_6 (3.8 kg ha^{-1}). The lowest value of 1.3 kg ha^{-1} was shown by T_8.

Table 45. Effect of treatments on nutrient uptake by bhusa – residue crop

Treatment	N	P	K	Ca	Mg	S	Fe	Mn	Zn
	kg ha^{-1}						mg $plant^{-1}$		
T_1	44.5	5.9	24.2	57.0	19.6	2.2	5.8	8.5	0.280
T_2	91.9	5.80	38.5	71.5	32.6	3.6	8.9	11.4	0.462
T_3	85.6	10.5	40.4	68.1	11.3	4.3	10.4	12.6	0.381
T_4	69.0	7.4	34.3	76.0	60.3	3.3	7.1	12.5	0.422
T_5	39.6	3.4	15.9	35.1	9.2	1.7	4.6	6.0	0.197
T_6	68.4	7.9	35.5	74.8	14.7	3.8	6.5	12.3	0.394
T_7	49.1	4.7	26.7	57.1	6.9	2.7	7.6	9.1	0.313
T_8	18.9	2.6	11.8	24.4	4.1	1.3	2.0	5.34	0.208
$F_{(7,14)}$	3.80*	3.92*	2.81*	2.35^{NS}	10.63**	3.20*	4.46**	2.26^{NS}	1.97^{NS}
CD (0.05)	38.50	3.92	19.14	-	17.33	1.79	3.698	-	-

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.6.3 Micronutrient (Table 45)

Statistical analysis of the data revealed that the treatment effects were significant in the uptake of micronutrients by bhusa. The uptake of iron showed the same trend as in the case of concentration with values ranging from 2 mg plant^{-1} to 10.4 mg plant^{-1} recorded by T_8 and T_3 respectively. For Mn also the same trend was observed. In the case of Zn the highest and lowest values were recorded by T_2 and T_8 as in the case of concentration.

4.2.2.7 Nutrient Uptake of Grain

4.2.2.7.1 N, P and K

The data presented in Table 46 indicated that phosphogypsum had a significant effect on N. P and K uptake by grain of residue crop. The maximum uptake of nitrogen (30.11 kg ha^{-1}) was shown by treatment T_3 followed by T_2 and were on par with T_5 and T_6. The lowest value was recorded by the absolute control

As in the case of main crop, the highest uptake of phosphorus (4.9 kg ha^{-1}) was registered by T_3 followed by T_5 and were on par with T_6 and T_7. The lowest value was registered by T_8.

In the case of K, T_3 registered a highest uptake of 12.40 kg ha^{-1} followed by T_6 and were on par with T_5.

4.2.2.7.2 Ca, Mg and S (Table 46)

The highest uptake of Ca (14.70 kg ha^{-1}) was showed by T_3 followed by T_6 and were on par with T_5 and T_7. The lowest uptake was showed by T_8 (3.20) and was on par with T_4.

There was no significant difference in the uptake of Mg due to various treatments applied. The values ranged from 1.50 to 3.33 kg ha^{-1} with the highest value by T_7 and the lowest by T_8.

The treatment T_3, which received PG at full LR was significantly superior to others in sulphur uptake and recorded value of 0.813 kg ha^{-1} followed by T_5 (PG at half LR). The lowest value as in the case of other nutrients was recorded by T_8.

Table 46. Effect of treatments on nutrient uptake by grain - residue crop

Treatments	N	P	K	Ca	Mg	S	Mn	Zn
	(kg ha^{-1})						mg plant^{-1}	
T_1	10.44	3.36	7.75	9.06	2.78	0.173	2.65	0.114
T_2	17.35	3.32	6.78	8.94	2.85	0.137	2.60	0.116
T_3	30.11	4.90	12.40	14.70	2.74	0.813	3.92	0.169
T_4	10.16	3.21	7.03	5.95	2.98	0.247	2.36	0.107
T_5	13.61	4.57	11.88	12.86	2.68	0.537	3.80	0.173
T_6	13.99	4.02	12.03	13.31	3.12	0.490	3.47	0.134
T_7	11.50	3.93	6.55	12.27	3.33	0.290	3.01	0.134
T_8	4.51	1.53	3.05	3.20	1.50	0.057	1.61	0.064
$F_{(7,14)}$	22.98**	8.32**	14.41**	9.79**	2.13^{NS}	9.250**	11.05**	12.02**
CD (0.05)	4.44	1.024	2.505	3.62	-	0.236	0.715	0.0306

NS – Non significant, **Significant at 1 per cent level

4.2.2.7.3 Micronutrient (Table 46)

The uptake of Mn was highest for T_3, while the lowest value was shown by T_8. In the case of Zn the highest value was shown by T_5 and lowest value by T_8.

4.2.2.8 Total Uptake of Nutrients

4.2.2.8.1 N, P and K (Table 47)

The total uptake of nitrogen was significantly influenced by the treatments. The treatment T_3 recorded the highest value followed by T_2 and T_6. The lowest value of 23.3 kg ha^{-1} was shown by T_8.

The highest value for phosphorus uptake (15.4 kg ha^{-1}) was shown by T_3, followed by T_6 and the lowest value, as in the case of other nutrients was recorded by absolute control, which received no fertilizers and amendments.

As in the case of phosphorus uptake, the maximum value for the uptake of K (52.8 kg ha^{-1}) was registered with T_3 followed by T_6 and the lowest uptake of 14.9 kg ha^{-1} by T_8 (absolute control), which was on par with T_5, T_1 and T_7.

4.2.2.8.2 Ca, Mg and S (Table 47)

Statistical analysis of the data showed that there was no significant difference due to various treatments applied in the uptake of calcium. However the values ranged between 27.60 and 88.20 kg ha^{-1} recorded by T_8 and T_6 respectively.

Perusal of data revealed that there was significant difference in the uptake of magnesium due to various treatments applied. The highest uptake (63.30 kg ha^{-1}) was registered by T_4 followed by T_2 and the lowest value was shown by T_8 which was on par with T_7, T_5 and T_3.

The values for sulphur uptake ranged from 1.32 to 5.12 kg ha^{-1} with the maximum being recorded by T_3 followed by T_6 which were on par, and the minimum value was shown by absolute control.

Table 47. Effect of treatments on total nutrient uptake - residue crop

Treatments	N	P	K	Ca	Mg	S	Mn	Zn
	kg ha^{-1}						mg $plant^{-1}$	
T_1	54.9	9.3	31.9	66.07	24.44	2.41	11.13	0.394
T_2	109.5	9.1	45.2	80.41	35.47	3.73	14.03	0.608
T_3	115.6	15.4	52.8	82.84	14.04	5.12	16.51	0.550
T_4	79.5	10.7	41.3	81.99	63.30	3.52	14.83	0.529
T_5	53.2	8.0	27.8	47.95	11.88	2.28	9.85	0.370
T_6	82.4	11.9	47.6	88.20	17.84	4.25	15.74	0.527
T_7	60.6	8.7	33.2	69.32	10.28	2.94	12.15	0.447
T_8	23.3	4.1	14.9	27.60	5.54	1.32	6.95	0.272
$F_{(7,14)}$	5.56**	6.65**	3.40*	2.74^{NS}	10.22*	4.17**	2.59^{NS}	2.19^{NS}
CD (0.05)	37.082	3.589	18.976	-	16.722	1.682	-	-

NS – Non significant, **Significant at 1 per cent level, *Significant at 5 per cent level

4.2.2.8.3 Micronutrients (Table 47)

The highest value for the uptake of Mn was shown by T_3 and the lowest by T_1 whereas for Zn the highest value was shown by T_2 and lowest by T_1. Fe and Cu were not translocated to the grain. Hence their total uptake was same as that of bhusa.

DISCUSSION

5. DISCUSSION

Results of an investigation carried out at College of Agriculture, Vellayani to test the feasibility of phosphogypsum as an ameliorant for correcting soil acidity in laterite soil are discussed here. This investigation comprises an incubation study to find out the nature of dissolution and kinetics of phosphogypsum when applied to soil and a micro plot field experiment to evaluate its influence on crop growth and yield with cowpea as the test crop.

5.1 INCUBATION STUDY

51.1 Dissolution and Kinetics of Phosphogypsum

Perusal of the data on status of different nutrients (Fig. 6-9) in the soil and the electrical conductivity (Fig. 5) of the same showed a higher level of nutrients in phosphogypsum treated plots. The highest value for EC throughout the incubation was recorded by T_3 (PG @ full LR). This is mainly due to the better mobility of phosphogypsum compared to lime. The EC was maximum on 24th DOI followed by a decrease. Hence it can be assumed that by 24th DOI, most of the nutrients are in readily available form and later it might have been adsorbed to non-exchange sites. Considering the individual nutrients, P, Ca and S showed the maximum values on 24th DOI, while for K, it was on 12th DOI. The main influence might be due to Ca and S present in phosphogypsum and increased values of EC is mainly due to easy release of Ca and S from phosphogypsum. Small quantities of P is also released to soil from phosphogypsum.

The initial increase up to 24th DOI was the result of solubilisation of nutrients from phosphogypsum and lime. During the later stages, K might have been adsorbed in the non exchange sites from which it may not be easily extractable. The initial increase followed by a decrease is due to its adsorption on non exchange sites during the period on incubation.

The solubility of gypsum is higher than lime and the solubility of phosphogypsum is still higher than mined gypsum (Bolan *et al.*, 1992). The solubility of phosphogypsum is 2.5 g l^{-1} and this varies with particle size (Frenkel and Fey, 1989).

The results of the incubation study clearly indicated the higher solubility of phosphogypsum compared to lime.

5.1.2 Effect of Phosphogypsum on Ameliorating soil Acidity in Laterite Soil

Liming is the most important management option for the control of soil acidity. The high cost of lime and its unavailability often restricts its use by farmers. Hence alternate sources were attempted for the correction of soil acidity. Phosphogypsum, a waste product from phosphoric acid plant was found to be effective in correcting soil acidity in laterite soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and Sumner, 1972). Since phosphogypsum is highly mobile it can correct subsoil acidity also (Alcordo and Recheigl, 1993).

In the present experiment also a reduction in exchangeable acidity, especially exchangeable aluminium (Fig.2, 3) was observed due to phosphogypsum application, but the effect was more evident during the second half of incubation. The ameliorating effect of phosphogypsum is more lasting compared to lime. The application of lime was highly effective in reducing exchangeable acidity up to 24th DOI and lime @ full LR was the most effective treatment. But during later stages the performance of phosphogypsum was much better than lime. By 60th DOI, the treatment with PG at full LR recorded almost the same value as that of

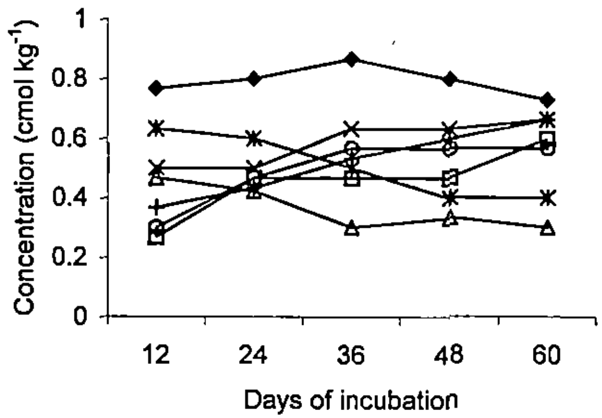


Fig. 2 Exchangeable aluminium

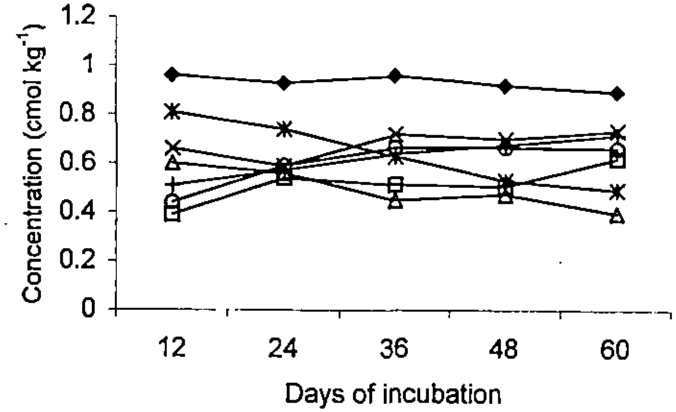


Fig. 3 Exchangeable acidity

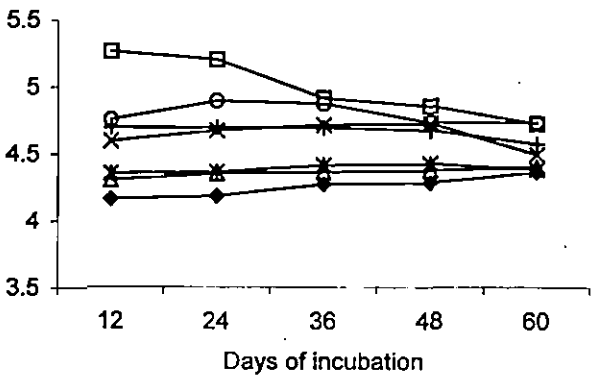


Fig. 4 Soil pH

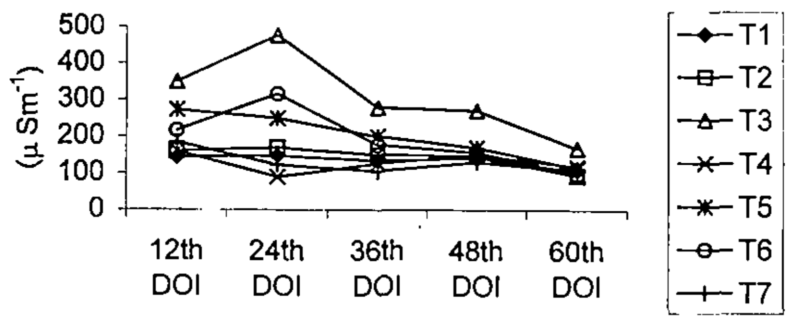


Fig. 5 Electrical conductivity

lime @ full LR on 12th DOI. All the treatments that received phosphogypsum either alone or in combination with lime showed an increasing trend in exchangeable acidity during the period of incubation. The exchangeable aluminium which being the major component of exchangeable acidity followed the same trend.

Application of any of the amendments either lime or phosphogypsum reduced the exchangeable aluminium significantly (Table 9, Fig. 2) as evidenced by the highest value for T_1 throughout the course of incubation. Data indicated that during the early sampling stages, lime was much efficient in reducing the exchangeable aluminium content and for phosphogypsum during the initial stages, value was much higher, followed by a decrease towards the end of incubation. At the 60th DOI, the exchangeable aluminium content was minimum for T_3. This clearly indicates the ability of phosphogypsum to reduce exchangeable aluminium content.

The ability of phosphogypsum to reduce or detoxify the aluminium present in the soil was reported by Sumner (1970), Alva *et al.* (1988) and Alva and Sumner (1988). They also suggested that the ameliorating effect of phosphogypsum is mainly due to the supply of calcium. The various mechanism include ligand exchange of hydroxyl by sulphate (Reeve and Sumner, 1972; Sumner *et al.*, 1986), precipitation as basic aluminium sulphates (Hue *et al.*, 1985), co-sorption of sulphate and aluminium (Sumner *et al.*, 1986) and ion pair formation (Cameroon *et al.*, 1986). What ever be the mechanism, the ability of phosphogypsum for reducing the exchangeable aluminium content is clearly evident from the study and is in conformity with the results published by Liu and Hue (2001).

Data on the exchangeable H^+ (Table 10) content indicated that lime is most effective in reducing exchangeable H^+ content of the soil, though the treatment effects were not significant. Treatments with phosphogypsum showed comparatively higher values for exchangeable H^+. Hence the ameliorating effect of phosphogypsum is entirely due to the reduction in exchangeable Al content and this had no effect on neutralizing the exchangeable H^+. Information on the effect of phosphogypsum on exchangeable H^+ was much meagre and hence it can be concluded that the remediation of soil acidity by phosphogypsum in entirely due to reduction in exchangeable Al and increase in exchangeable Ca content (Fig.8)

The behaviour of soil pH (Fig.4) was very much similar to that of exchangeable H^+, since pH is actually the measure of exchangeable H^+. Comparing lime and phosphogypsum, lime is more effective in increasing the pH. However, treatment with phosphogypsum showed an increasing trend in pH which is mainly due to reduction in exchangeable aluminium and we can accept a better pH during the course of time. But for lime, it showed a decreasing trend. This data has further confirmed that beneficial effect of phosphogypsum is entirely due to reduction or detoxificaiton of exchangeable Al in soil and increase in base saturation. Compared to lime, phosphogypsum is not efficient in improving soil pH within a period of 60 days. Similar results were published by Hammel *et al.* (1985) and Sumner *et al.* (1986).

5.1.3 Influence of Phosphogypsum on Available Nutrient Content

Application of phosphogypsum had significantly influenced the available nutrient content of soil. Its influence on individual nutrients vary much throughout the period of incubation.

5.1.3.1 Phosphorus

Analysis of data (Fig.6) revealed that application of amendments either as lime or as phosphogypsum have a marked effect on the release of soil phosphorus. The highest value of available phosphorus during the second half of incubation was shown by treatment which received PG @

full LR, followed by those treatments which received PG @ half LR, and also that in combination with lime This is mainly because phosphogypsum decreased P adsorption because of its high solubility (Frenkel and Fey, 1989). Lime in the initial stages increased P availability, but later it enhanced the adsorption of phosphorus and decreased its availability. Palliyal and Verma (2002) reported that application of gypsum @ 2.7 to 5.4 t ha^{-1} decreased the adsorption of P, and lime @ 1.5 to 3.0 t ha^{-1} increased its adsorption.

On comparing phosphogypsum with lime, it was observed that application of phosphogypsum maintained slightly higher levels of P in the soil that ensures enhanced availability. From the view point of crop growth, the behaviour of phosphogypsum seems to be very beneficial, since we apply these amendments at least three weeks before sowing. The application of phosphogypsum can thus ensure better supply of P to crops at planting or sowing time, as evidenced by higher phosphorus content at the 36th DOI.

5.1.3.2 Potassium

The application of lime or phosphogypsum had definitely increased the available K content (Fig.7) due to the release of K^+ from the exchange sites by Ca^{2+}. At the first sampling stage, treatment with lime showed higher values compared to phosphogypsum. But on second sampling onwards phosphogypsum @ full LR maintained the highest values except at the 60th DOI. Thus the displacing effect of calcium in phosphogypsum is very high compared to that of calcium in lime, which may be because of its better mobility. As the quantity of lime decreased, better K status was maintained. For phosphogypsum also a similar trend was noticed in the initial sampling stages. However, the combined application showed exceptionally high values at the 60th DOI.

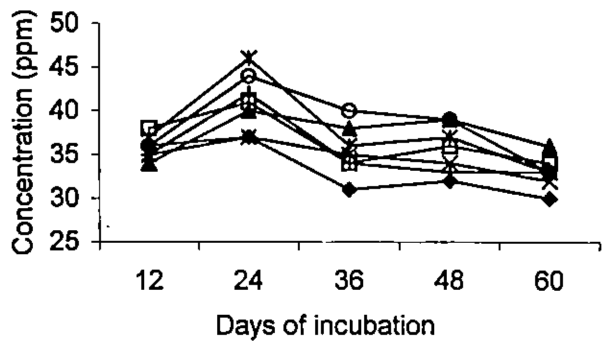


Fig. 6 Available phosphorus

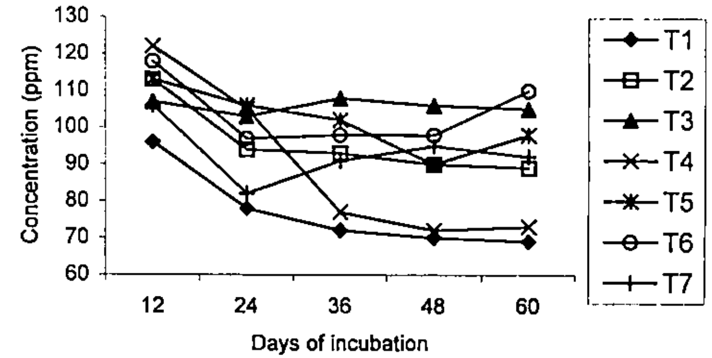


Fig. 7 Available potassium

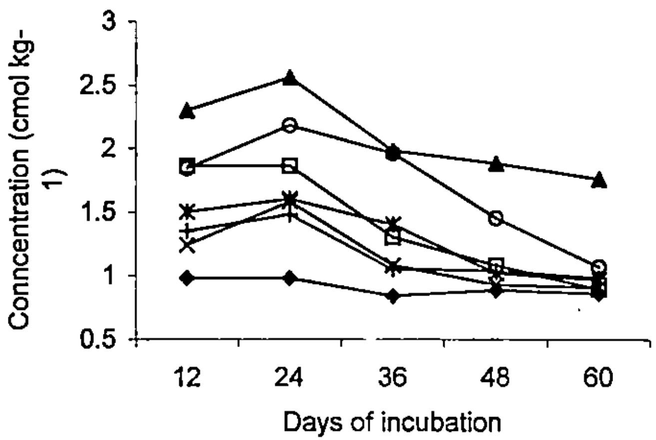


Fig. 8 Exchangeable calcium

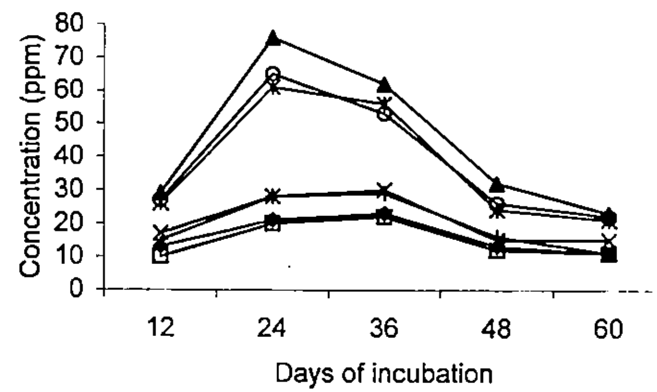


Fig. 9 Available sulphur

Because of the greater mobility and solubility of phosphogypsum, the release of fixed K from the non-exchange site is favoured and hence in the later stages of incubation, increased K availability was noticed.

Application of phosphogypsum in soil encourages downward movement of K since calcium in phosphogypsum easily displaces K and this often result in K deficiency in phosphogypsum amended soils (Pavan *et al.*, 1982).

5.1.3.3 Calcium, Magnesium and Sulphur

Perusal of the data on exchangeable calcium (Fig.8) showed that application of phosphogypsum @ full LR had significantly increased the exchangeable calcium content. Application of calcium either as lime or as phosphogypsum had resulted in an increase in exchangeable calcium content and which is proportional to the quantity of amendment applied. The higher values for exchangeable calcium in phosphogypsum treated plots are due to the better solubility and mobility of phosphogypsum. The movement of calcium from phosphogypsum was greater compared to lime. Better solubility and mobility of phosphogypsum ensures higher calcium content in soil. These results were in conformity with that of Jacob (1992) and Liu and Hue (2001)).

The exchangeable Mg content was not significantly influenced by the application of lime or phosphogypsum or by the periods of incubation. The treatment with phosphogypsum @ full LR showed comparatively lower values for exchangeable Mg. But earlier reports showed that application of phosphogypsum resulted in movement and loss of Mg from soil at rates greater than 10 t ha^{-1} (Omar and Sumner, 1991; Liu and Hue, 2001). In the present study the rate applied being very low (1.2 t ha^{-1}) might not be sufficient to displace Mg from the non-exchange sites and thereby reduce the availability. The downward leaching of Mg after the application of gypsum was also reported by Jacob (1992). Much research has not been undertaken on the status and movement of Mg at lower rates of phosphogypsum application in acid soils

Phosphogypsum significantly influenced the available soil sulphur content, which is evident from the data (Fig.9) that the highest value throughout the incubation was recorded by T_3 followed by either T_5 or T_6, all of which received phosphogypsum @ full LR, half LR and combination of lime and PG each at half LR respectively. The increase is due to sulphur content in phosphogypsum, which is readily soluble. However, the sulphur content showed a gradual decrease for all treatments. Phosphogypsum increased the available sulphur status of the soil. The gradual decrease in the course of incubation is due to the adsorption of S as SO_4 in the exchange sites.

Misra (1995) suggested that application of phosphogypsum could correct S deficiency in red and laterite soil. Beena (2000) reported that gypsum @ 30 kg S ha^{-1} increased available sulphur content in red and laterite soils of Vellayani. Thus the application of phosphogypsum had a beneficial effect on increasing S availability. This will be very much useful in the management of laterite soil, where S deficiency is also a major problem.

5.1.3.4 Sodium

The exchangeable sodium content of these soils is very low. However application of lime and phosphogypsum had significantly influenced it, but its behaviour did not show a definite trend. Though gypsum is widely used for the reclamation of sodic soils, through the removal of sodium, no such effect was observed here. At earlier stages of incubation, treatment with phosphogypsum showed lower values since the amount of sodium being low and acidic pH does not encourage the reaction that takes place in sodic soils. Again the large quantities of Fe and Al, compared to sodium might have discouraged its reaction with sulphate radicle.

5.1.3.5 Micronutrients

The lowest concentration of available Fe (Table 16) as result of phosphogypsum application at full LR may be due to the ligand exchange of iron or other mechanisms involved in the amelioration of Al toxicity. Similar to Al, the availability of Fe may also be reduced by the action of phosphogypsum (Sumner, 1993; Shainberg *et al.*, 1989).

Lime at full LR was found to reduce the available Mn content significantly. The effect of phosphogypsum was not so evident as in the case of lime. For phosphogypsum the reaction is mainly with Fe and Al and this is evident from the higher Mn content of treatment with phosphogypsum.

The general decrease of copper (Table 18) in the incubation period may be due to entrapment of Cu in the non available sites or its reaction with soil organic matter. The addition of amendments may have facilitated the microbial activity of soil and temporary locking up of copper by microorganisms may be one of the reasons for its general decrease. A decrease in the available Zn content was noticed by the 60^{th} DOI which might be due its adsorption on the non-exchange sites or its utilization by microorganisms.

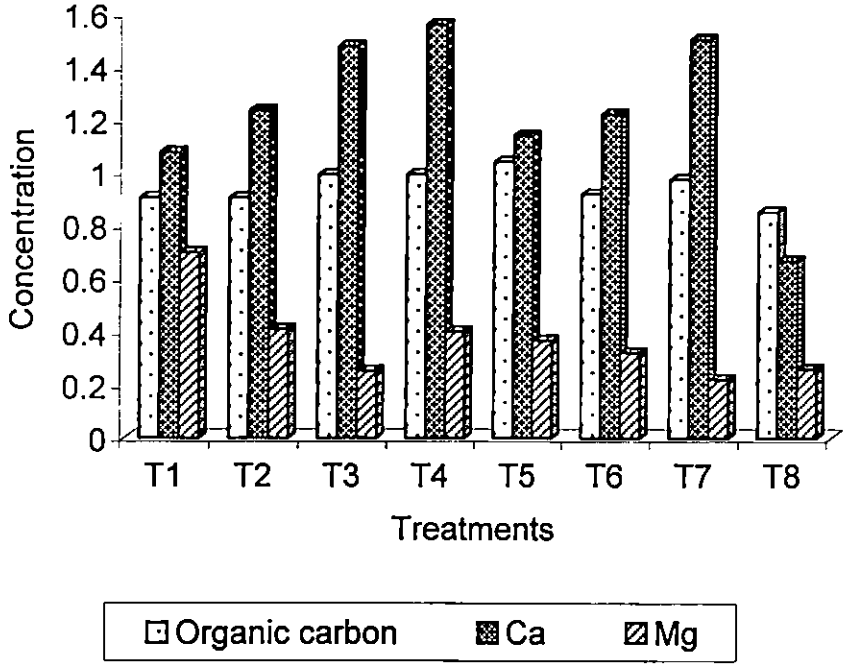
5.2 MICROPLOT FIELD EXPERIMENT

The results of microplot field experiment which consists of a main crop to study the effect of application of phosphogypsum on crop growth and soil characters as well as a residue crop to find out the extent of residual effect of amendments and how this influence the succeeding crop growth and yield.

5.2.1 Effect of Phosphogypsum on Nutrient Availability

Availability of nutrients estimated at fifty per cent flowering and at harvest stages for various treatments (Table 20, Fig.10) were evaluated. For all the major nutrients and secondary nutrients, the treatment effects were significant. In general, a higher nutrient status was observed at fifty per cent flowering, evidently due to the crop removal. The organic carbon content at fifty per cent flowering was highest for treatment that received lime and PG @ half LR each (T_6) followed by PG @ full LR and PG and lime @ ¼ LR each. Thus the application of phosphogypsum either alone or with lime had a favourable influence on organic carbon content. Application of phosphogypsum have promoted plant growth and thus the biological activity of the soil was enhanced. Hence the organic carbon content was more for the treatments containing phosphogypsum. Gould *et al.* (1988) reported that application of amendments such as phosphogypsum increased the population of microbes in the rhizosphere of citrus. At harvest stage though the effect was significant most of the treatments were on par.

The available phosphorus content of the soil was significantly influenced by the application of phosphogypsum at fifty per cent flowering stage only. The highest value was noticed for the treatment which received PG @ half LR followed by T_3 which received PG at full LR. The treatment which received phosphogypsum alone showed higher values compared to those which received lime alone or in combination. This in turn shows the significant influence of phosphogypsum in the release of adsorbed soil P. At the harvest stage also, though there was no significant difference due to various treatments, the highest value was shown by T_5. These results were in conformity with the findings of Palliyal and Verma (2002).



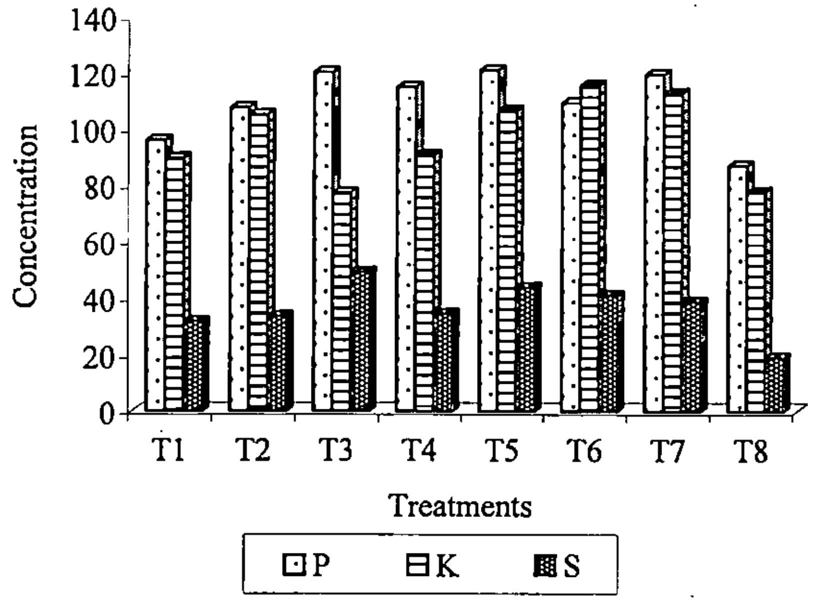


Fig. 10 Chemical analysis of soil - main crop

Regarding the available K content, the lowest value was noticed in treatment with PG @ full LR and this might be due to the downward movement of K as a result of application of phosphogypsum. The enhanced displacement of K by Ca and its downward movement through soil profile or its loss in leaching water had been reported earlier (Shainberg *et al.*, 1989; Liu and Hue, 2001). However when the rate of application of phosphogypsum is reduced, the trend was different indicating that the displacement effect of Ca may be very much less and have facilitated the retention of K in the surface soil itself. In the initial stages of incubation study also similar trend was noticed.

The available Ca content of the soil at fifty per cent flowering and at harvest did not show a particular trend and this might be due to the difference in crop uptake. However phosphogypsum increased soil available calcium content than treatments with lime alone, at fifty per cent flowering. By the time of harvest, the treatment that received phosphogypsum showed lower Ca content that with lime. One of the reason for this may be better downward movement of Ca from phosphogypsum. Jacob (1992) observed the downward movement of Ca to depth of 60 cm in laterite soils from gypsum applied to soil columns. Liu and Hue (2001) found that about 60 per cent of calcium from phosphogypsum moved to deeper layer compared to that from lime. The variation in crop uptake (Fig.) may also contributed to the above phenomenon.

Phosphogypsum have a significant influence on the exchangeable Mg content of the soil. Because of the high rate of dissolution of phosphogypsum, as in the case of potassium, Mg may also be leached to lower layers as evidenced by the lower values for the plots treated with phosphogypsum. It is more pronounced at the harvest stage. At fifty per cent flowering, the lowest value was shown by absolute control and T_3 followed it. The treatments which received lime alone recorded higher values. Lime is less mobile than phosphogypsum. Hence there won't be much displacement of Mg. The leaching of exchangeable Mg to deeper layers was also reported by Shainberg *et al.* (1989), Jacob (1992) and Liu and Hue (2001).

The availability of sulphur was increased by the application of phosphogypsum at both stages, evidently due to high S content of phosphogypsum. Both at harvest and at fifty per cent flowering, the maximum value was shown by treatments which received phosphogypsum, than those with lime alone or in combination. Thus application of phosphogypsum is very much beneficial to crops grown in laterite soil, where there is wide spread deficiency of sulphur.

Regarding the micronutrients application of amendments either lime or phosphogypsum increased the availability of micronutrient cations throughout the crop growth period. Cation exchange reaction within the soil might have favourably influenced its release to the soil.

In general application of phosphogypsum had favourably influenced the available nutrient status when they are applied at a rate less than or equal to 1.5 times exchangeable aluminium. However, for K and Mg, the continuous use of phosphogypsum may result in deficiency of the same. The values of electrical conductivity (Table 21) is in confirmity with the about observation.

5.2.2 Effect on Soil pH

Perusal of the data in pH (Table 21) indicated that lime is the most effective material for increasing soil pH and that too, lime @ half LR seems to be the best treatment. Lime @ ½ LR was found to be most effective in increasing soil pH of acid soil. The treatment with phosphogypsum did not increase soil pH considerably. In the incubation study also the same trend was observed, where exchangeable Al content alone was reduced. The lower pH of phosphogypsum itself is one of the

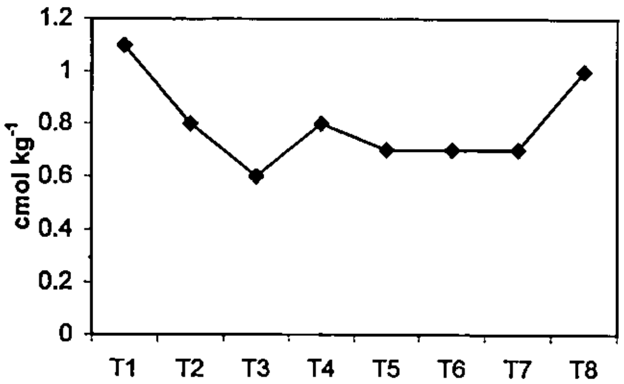


Fig. 11 Exchangeable acidity at 50 per cent flowering

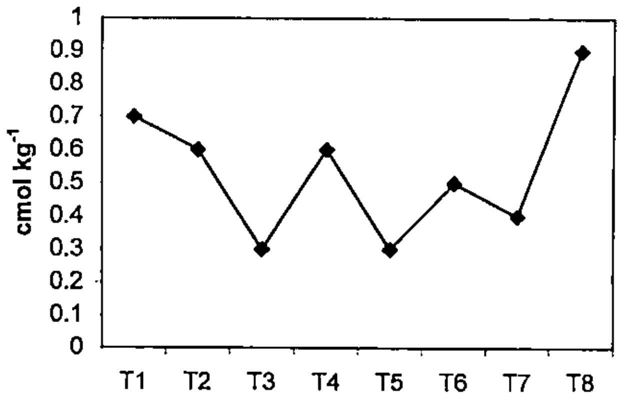


Fig. 12 Exchangeable aluminium at 50 per cent flowering

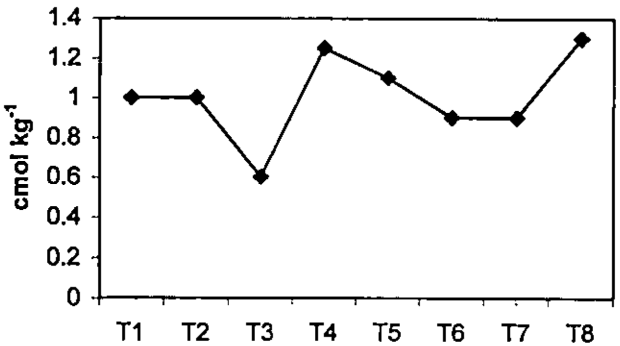


Fig. 13 Exchangeable acidity at harvest

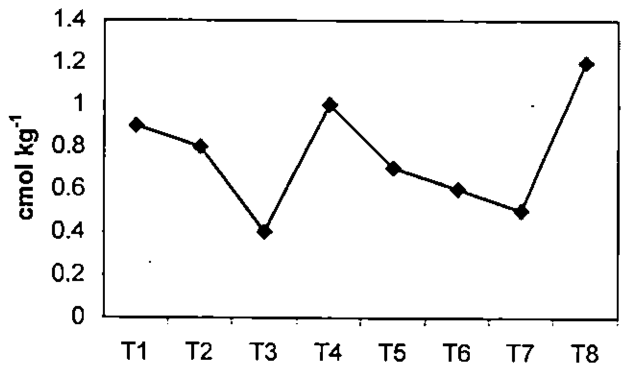


Fig. 14 Exchangeable aluminium at harvest

main reason for the lower pH values. Jacob (1992) confirmed the pH increase by the combined application of lime and gypsum in red and laterite soil. Decrease in pH due to application of phosphogypsum was reported by Arias and Fernandez (2001).

5.2.3 Influence of Phosphogypsum on Growth Characters

5.2.3.1 Height and Number of Branches Plant^{-1}

The growth characters like height and number of branches plant^{-1} were significantly influenced by the application of phosphogypsum. The maximum height and number of branches plant^{-1} at both stages were recorded by the combination treatment, T_6. Application of phosphogypsum together with lime might have influenced the metabolism of growing plants and increased the photosynthetic rate and hence increased the growth characteristics. The positive influence of gypsum on increasing the height and number of branches plant^{-1} was reported earlier by Balasubramanian and Ramamoorthy (1995). Beena (2000) found that gypsum application @ 30 kg S ha^{-1} recorded maximum height in cowpea var. Kanakamoni grown in laterite soils of Vellayani.

5.2.3.2 Root Characteristics

Root weight and number of nodules plant^{-1} were not significantly influenced by the treatments. However the number of nodules per plant was highest for treatments with phosphogypsum (Plate 3) and its influence was significant at fifty per cent flowering. Application of phosphogypsum resulted in the production of medium sized, pinkish nodules. This may be due to the increased nitrogen accumulation, due to N fixation as a result of phosphogypsum application. Similar result was published by Beena (2000) with gypsum @ 30 kg S ha^{-1} in red and laterite soils of Vellayani. Most of the effective nodules degenerated after the 50 per cent flowering stage and hence a non-significant result was obtained at the harvest stage.

Plate 1 Effect of treatments on growth Characters of cowpea

Plate 2

Effect of treatments on growth Characters of cowpea

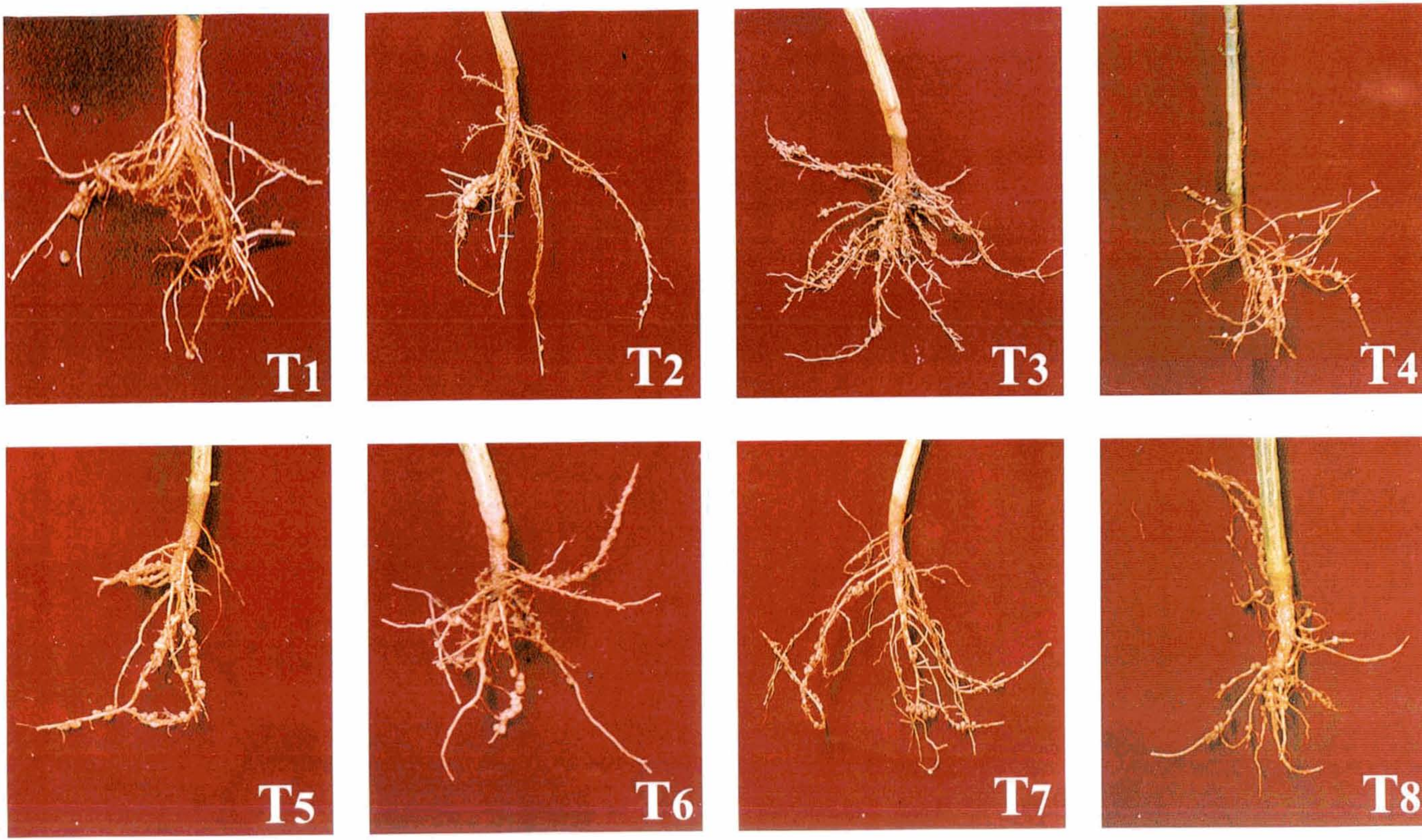


Plate 3 **Effect of treatments on root characters of cowpea**

5.2.4 Influence of Phosphogypsum on Yield and Yield Attributes

Phosphogypsum application have significantly enhanced the yield and all the yield attributing characters (Fig.15 and Table 26). The grain yield plot^{-1} was maximum for treatment receiving phosphogypsum at full LR and was on par with the combination treatment receiving lime and phosphogypsum at ¼ LR. As the rate of application of phosphogypsum was reduced to half LR, corresponding yield reduction was also noticed. The increase in yield might be due to the readily available calcium and sulphur through phosphogypsum which in turn resulted in well filled and bold grains. Moreover, it resulted in the better partitioning of photosynthates and finally enhance the grain yield per plant and hence the grain yield per plot. The total number of pods plant^{-1} was also maximum in the treatment receiving phosphogypsum at full LR and was followed by phosphogypsum at half LR. The pod yield per plot also followed the same trend. The other treatments receiving lime alone or in combination recorded almost similar yields. The length of individual pods was also high with phosphogypsum at full LR. It is observed that, as the rate of amendments decreased, the pod length also decreased correspondingly. Application of phosphogypsum enabled the plants to have better uptake of nutrients thus leading to increase in yield and yield attributes. Similar results were published earlier by Balasubramanian and Ramamoorthy (1995).

5.2.5 Influence of Phosphogypsum on Dry Matter Production

Total dry matter production was profoundly influenced by the application of phosphogypsum. The grain yield and bhusa yield were significantly increased by the application of phosphogypsum. The better uptake of nutrients facilitated by phosphogypsum, increased the vegetative growth and thus resulted in increased dry matter production also. Beena

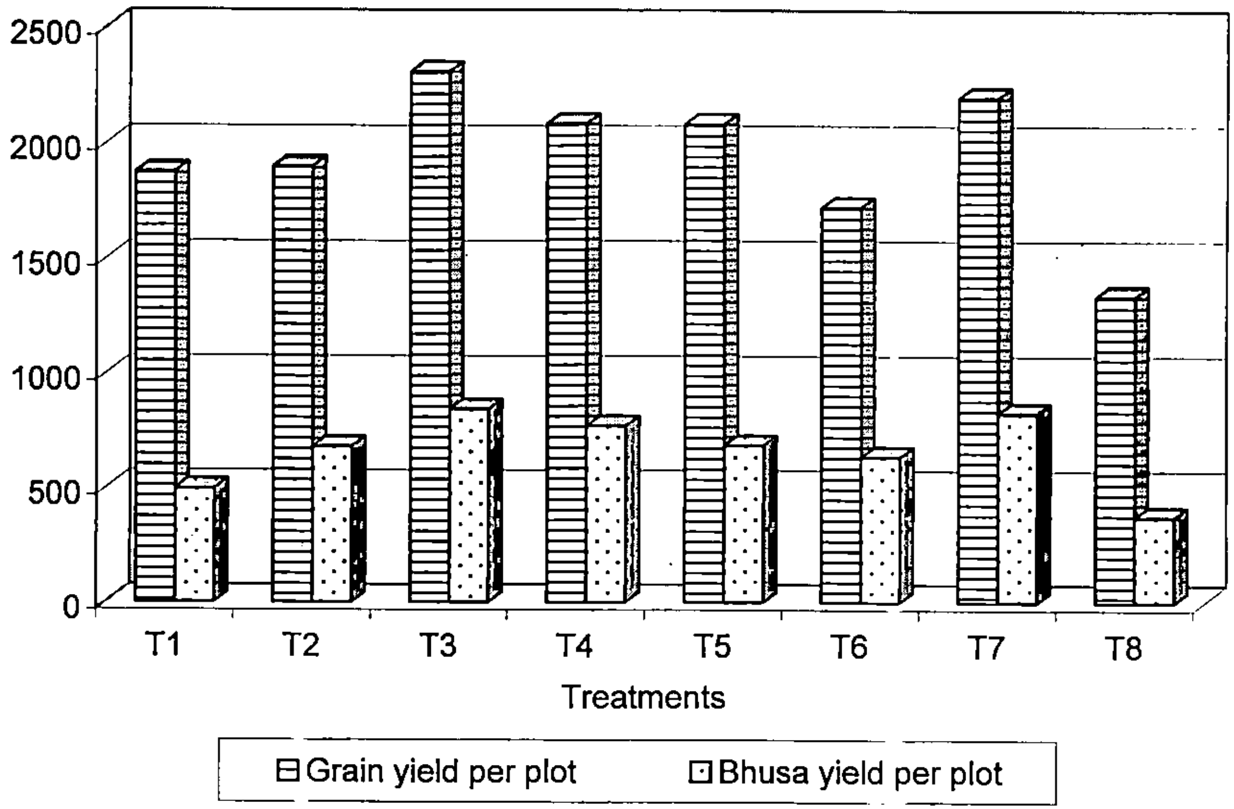


Fig. 15 Grain yield and bhusa yield - main crop

(2000) also reported the favourable effect of gypsum on dry matter production.

5.2.6 Influence of Phosphogypsum on Nutrient Content and Uptake

The phosphogypsum increased the content of plant available nutrients in soil. Hence the concentration of nutrients in bhusa and grain were also favourably influenced throughout the crop growth.

The highest N content in both bhusa and grain was recorded by the treatment with phosphogypsum at full LR was significantly (Fig 16, Table 30) superior to others. The better nodulation (Plate 3) facilitated by phosphogypsum might have promoted the accumulation of nitrogen and hence increased the nitrogen content. The high concentration and dry matter production naturally increased the uptake also. The amino acid production also might have been increased by phosphogypsum. All these contributed to the higher content of nitrogen compared to treatments with lime. The combination treatments also showed higher values for N in bhusa compared to the treatments with lime alone. All these favourably influenced the protein content also. Grain protein content was maximum for treatment with phosphogypsum at full LR due to the better assimilation of nitrogen.

Hazra (1997) observed that gypsum application @ 20 to 60 kg ha^{-1} increased the N content in cowpea. Ram and Dwivedi (1992) found that gypsum application increased the protein content in chickpea.

Treatments that received phosphogypsum at half LR showed highest concentration of P in bhusa, while PG @ full LR, showed the highest value in grain. Total uptake of P was also highest for T_5 (PG @ half LR). Thus phosphogypsum favourably influenced the P concentration and uptake. This may be due to the increase in available P content of soil due to release of fixed P. Jacob (1992) reported that by the application of

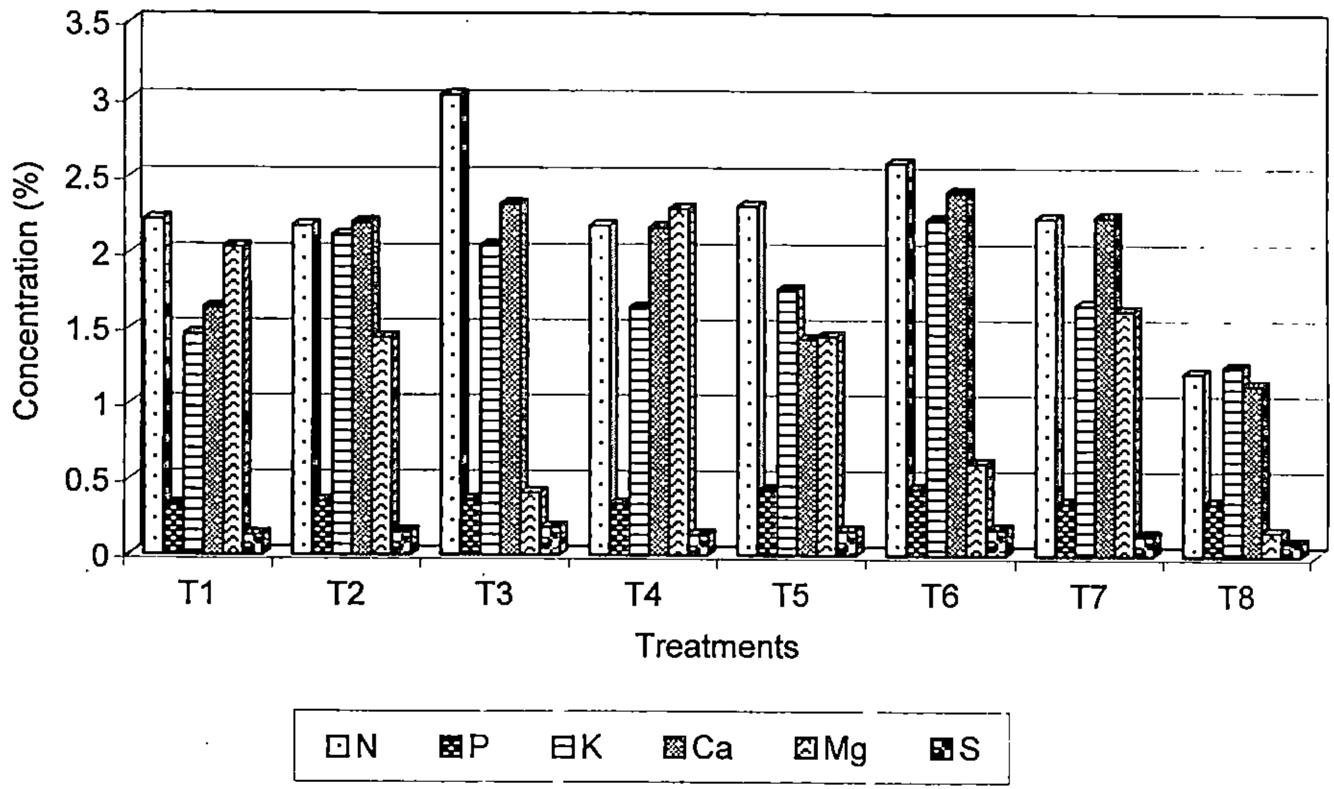


Fig. 16 Concentration of nutrients in bhusa - main crop

gypsum and lime @ three times exchangeable Al, improved the uptake and concentration of P in soyabean grown in laterite soil. Beena (2000) also reported the positive relation between gypsum application and P uptake.

The K content of bhusa at both stages was significantly influenced by phosphogypsum. The K content in grains was also highest for treatments which received phosphogypsum either alone or in combination. The Ca from phosphogypsum might have displaced the K from non-exchange sites and facilitated the uptake of K. Hence their concentration was higher in plants treated with phosphogypsum. This is evidenced by the higher values of total uptake of potassium (Fig.17, Table 37) in plots treated with phosphogypsum at full LR. The high dry matter production of phosphogypsum treated plots also might have contributed to the highest total uptake of K. Similar results were reported by Rao and Shaktawat (2002).

Regarding the concentration and total uptake of calcium, the better mobility of Ca in phosphogypsum have played its role. The calcium concentration in bhusa at both stages was highest for treatments containing phosphogypsum, either alone or in combination with lime at half LR each. The grain calcium concentration (Table 31) was also highest for T_3. Ca from phosphogypsum may be readily available for crop uptake because of its better solubility. These results were in confirmity with those of Hazra (1997). The grain yield and bhusa yield was highest for plots treated with phosphogypsum and this may also account for the highest uptake of Ca.

The highly soluble phosphogypsum with the mobile calcium displaced the Mg to lower layers. Hence its concentration in grain and bhusa was very much reduced in treatment with phosphogypsum @ full LR and compared to that at half LR and those treatments containing lime.

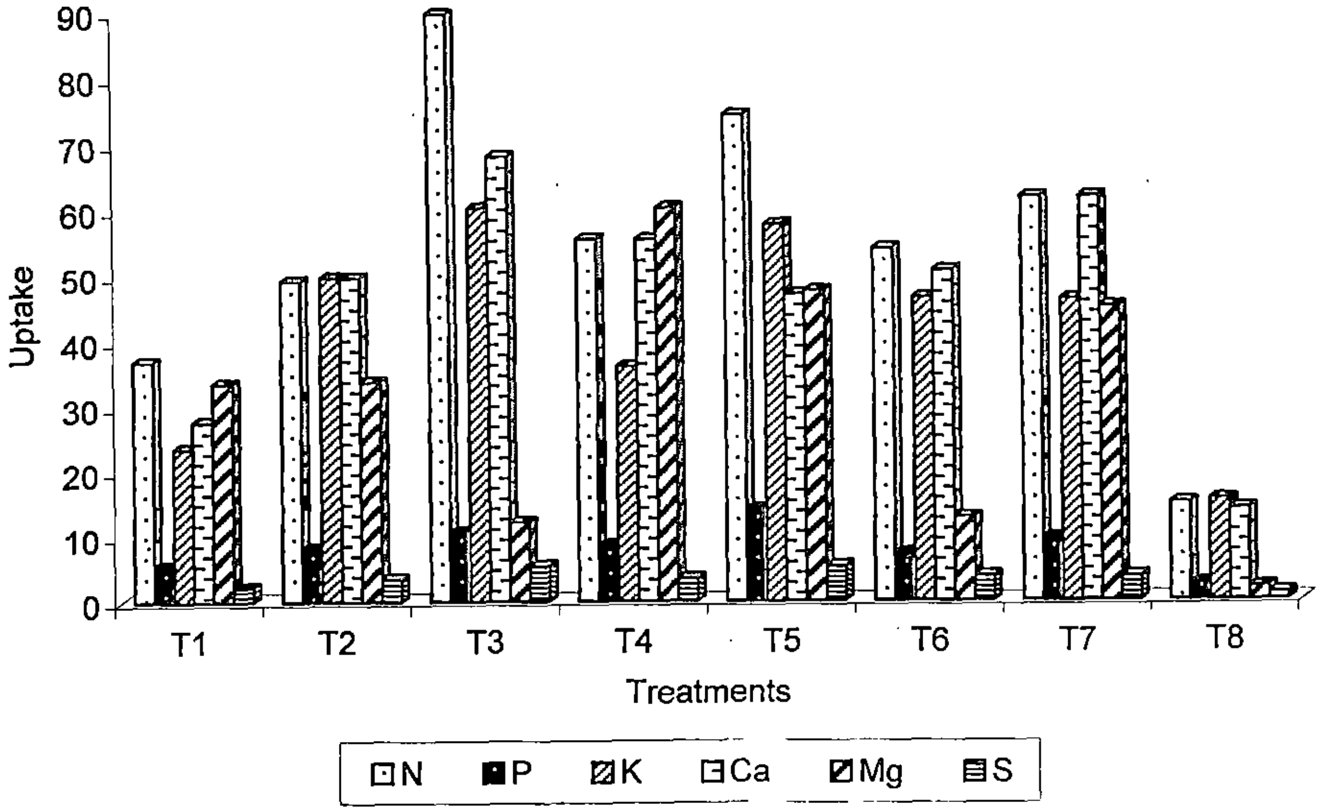


Fig. 17 Uptake of nutrients by bhusa - Main crop

When the rate of phosphogypsum was reduced to half LR, the displacement effect might not be that much and hence the concentration was also not affected. Eventhough the grain yield and bhusa yield was higher for PG @ full LR, because of the low concentration, the total uptake was much reduced. Similar results were reported by Farina and Channon (1988).

The sulphur concentration was favourably influenced by phosphogypsum which is evident from the higher values compared to lime treatment. The readily available SO_4^{2-} form of sulphur from phosphogypsum may be the reason for this. The positive influence of phosphogypsum on the S content and uptake was reported by Misra *et al.* (1990).

Though the influence of amendments on the micronutrient concentration in the bhusa of the main crop was significant, a clear trend was not noticed. The combination treatment showed the highest value for Fe at fifty per cent flowering whereas at harvest phosphogypsum at half LR (T_5) showed the highest value. The cation exchange reaction resulting in the release of micronutrient cations may account for this. Iron might not be translocated to the grain portion and hence it was not detectable. For Mn content in the bhusa highest value was shown by phosphogypsum treated plot. But the grain manganese concentration was highest for the treatment with POP recommendation. Mn was mainly translocated to bhusa than to the grain and this may account for low concentration of Mn in the grains. The total uptake of Mn was highest for plot treated with phosphogypsum at full LR. The content in bhusa and high dry matter production may have contributed to this.

The highest copper concentration in the bhusa at harvest was shown by the treatment that received POP recommendation and for grain, the copper concentration was undetectable. The highest uptake was shown by T_7 which received amendments at one fourth LR each. The dry matter production may have contributed to the highest uptake by T_7. For zinc the highest concentration in bhusa at harvest was shown by T_1. The absolute control recorded the highest content of Zn in grains which may be because, its translocation was facilitated only at absolute control which received no fertilizers and amendments. The total uptake was highest for phosphogypsum treated plot due to the high dry matter production.

5.3 RESIDUE CROP

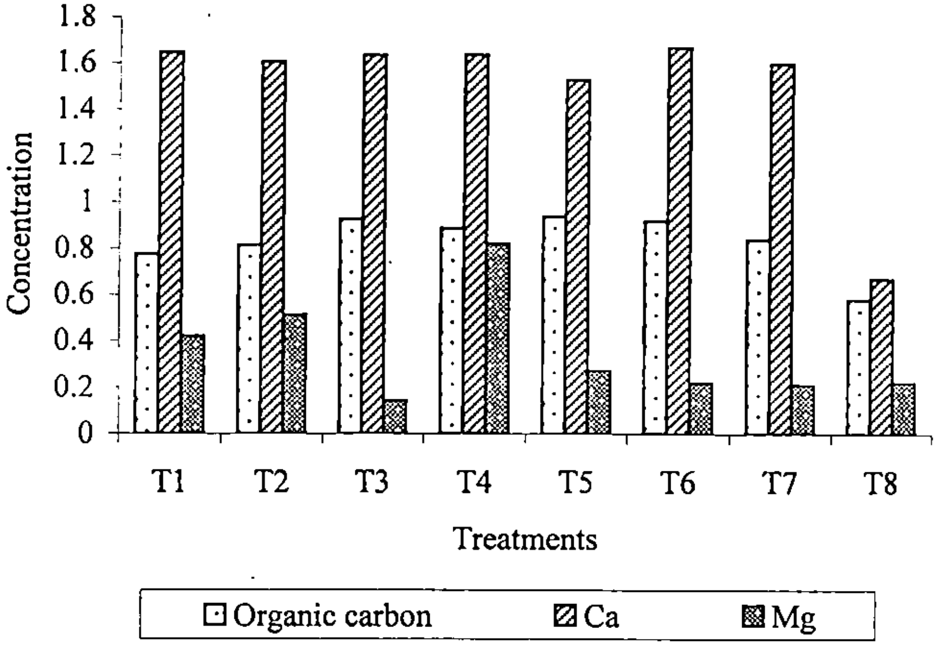
5.3.1 Effect of Phosphogypsum on Nutrient Availability

The residual effect of phosphogypsum was pronounced in the available nutrient status (Table 38, Fig.18) of the soil. The organic carbon content of the soil was highest for treatment which received PG @ half LR followed by T_3 and the trend was same as at the time of harvest of main crop. Biological activity promoted by the better crop growth in phosphogypsum treated plot accounted for the higher organic carbon content of residue crop. Here also, most of the treatments were on par with each other.

The available phosphorus content of the soil was highest for phosphogypsum at full LR, whereas the effect was non-significant during the harvest of main crop. Thus in the residue crop, phosphogypsum promoted the release of fixed P and hence the P content in the soil was improved.

The available K content was maximum for the lime treated plots, compared to those treated with PG @ full LR. The mobile Ca from phosphogypsum might have displaced K to the lower layers and hence the content was less.

The calcium content of phosphogypsum treated plots were less than that with lime or in combination. This may be attributed to the greater



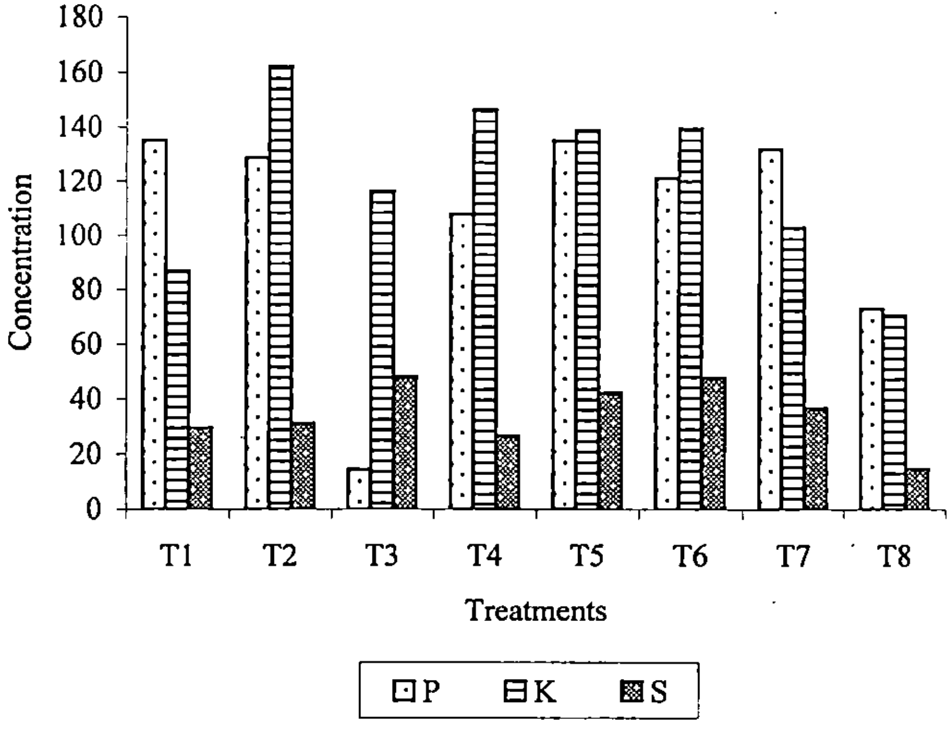


Fig. 18 Chemical analysis of soil - residue crop

movement of calcium to lower soil layers. The trend was almost the same as that of main crop. The downward movement of Ca due to gypsum application was reported by Jacob (1992) and Liu and Hue (2001).

The phosphogypsum treated plot recorded lowest values for exchangeable Mg. This may be because it might have leached beyond the root zone as in the case of main crop and hence the lowest value was recorded by phosphogypsum treated plots. The downward movement of Mg due to gypsum application in laterite soil was reported by Jacob (1992).

The sulphur content of phosphogypsum favourably influenced the available soil sulphur during the residue crop also. The highest value was shown by T_3 (PG @ full LR). The sulphate form of sulphur may have contributed to this property. The trend was same as the case of main crop. The increased soil sulphur content after gypsum application in red and laterite soils of Vellayani was reported by Beena (2000).

For all the treatments, a general increase in pH compared to that of main crop was noticed, except at absolute control. Here also lime @ half LR recorded higher pH values compared to lime @ full LR, but the highest pH value was shown by treatment with lime and fertilizer applied as per POP. The increase in pH in phosphogypsum treated plot may due to the alleviation of aluminium toxicity by phosphogypsum. Similar results were reported by Ritchey *et al.* (1980).

The EC value of the phosphogypsum treated plots in the residue crop was less than that for the treatment scheduled as per POP. This may be because of its high solubility and mobility as result of which it might have leached to the lower layers. However for the treatment as per POP, fertilizers supplied may have contributed the high EC value.

5.3.2 Influence of Phosphogypsum on the Root Characteristics

Though there was no significant difference between the treatments in the root weight and number of nodules, the maximum root weight was shown by T_3 which received at full LR. Application of phosphogypsum alleviated aluminium toxicity, which is major constraint for root growth in laterite soils. This in turn might have enabled the roots to proliferate greater soil volume.

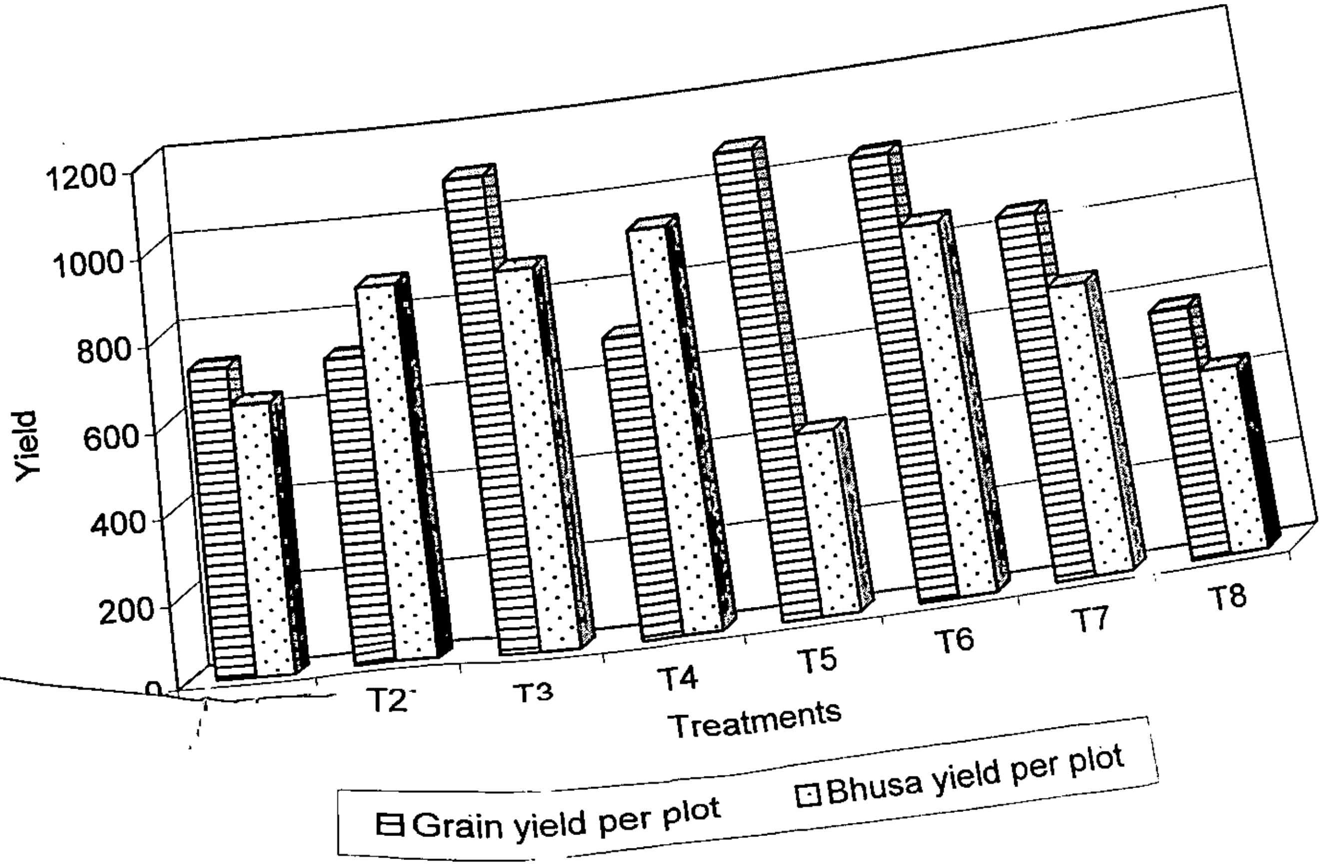
5.3.3 Yield and Yield Components

The highest value for grain yield and pod yield was shown by phosphogypsum treated plots and hence its residual effect on the yield attributes is pronounced much. However the bhusa yield was highest for plots treated with lime at half LR and was followed by T_3. This may be because the vegetative growth may be better with lime treatment and hence had highest bhusa yield. But the total dry matter production was highest for the plots treated with the phosphogypsum at full LR which is because of the highest pod yield.

5.3.4 Influence of Phosphogypsum on Nutrient Content and Uptake

The highest nitrogen content in bhusa (Fig. 20) and grain was recorded by treatment with lime at full LR whereas the uptake (Fig. 21) was maximum for phosphogypsum treated plots. The higher N concentration in lime treated plots may be due to the better assimilation of nitrogen facilitated by the enhanced vegetative growth. The protein content of the grain was maximum for treatment with phosphogypsum at full LR due the better assimilation of nitrogen.

The phosphorus content in bhusa was highest for phosphogypsum treated plots compared to that with lime. But the P translocation to grain was less for treatment with phosphogypsum. The highest P content in



1200
1000
800
600
400
200
0
Yield
T2
T3
T4
T5
T6
T7
T8
Treatments
Grain yield per plot
Bhusa yield per plot

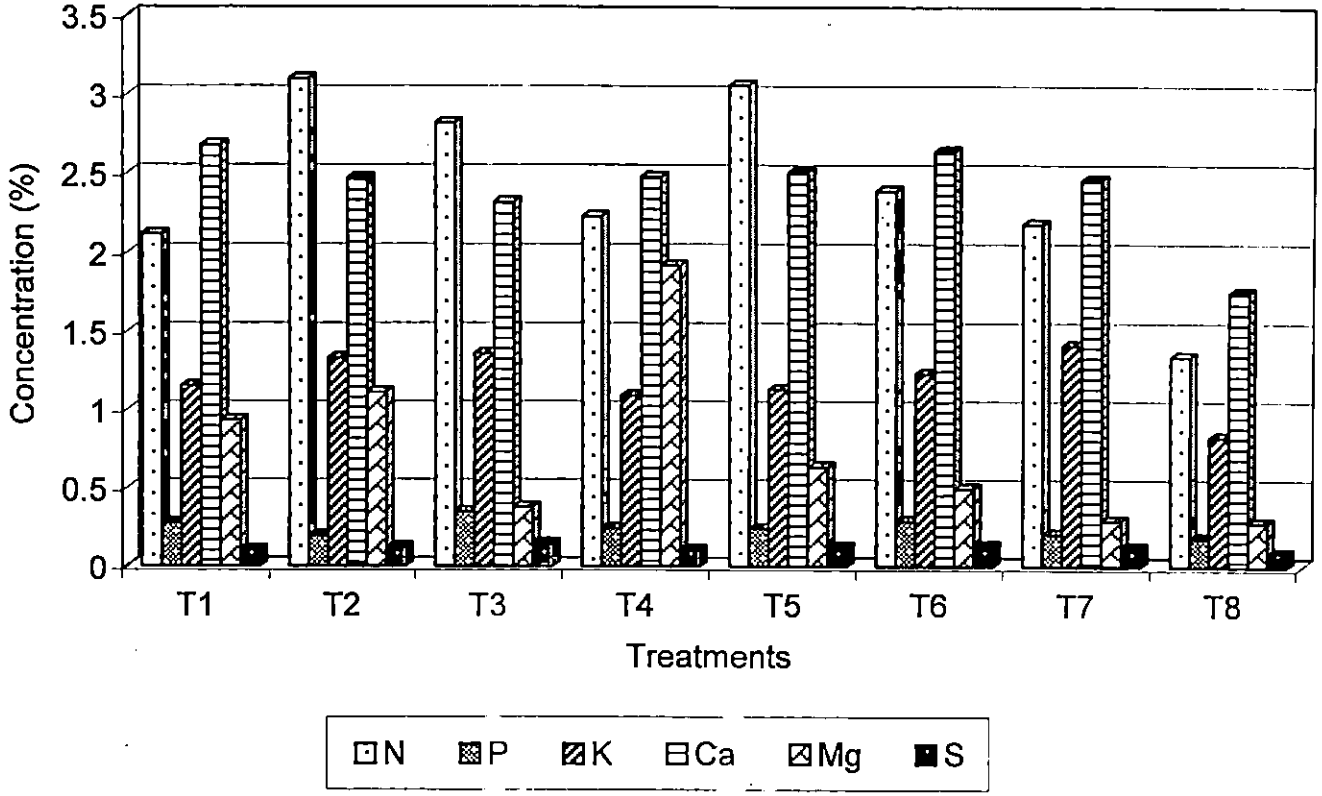


Fig. 20 Concentration of nutrients in bhusa - residue crop

grain was shown by T_1 which may be because of the P supplied through phosphatic fertilizers. However the total uptake was highest phosphogypsum treated plot because of the dry matter production.

The potassium content in grain and bhusa was highest for the combination treatment, than the phosphogypsum treated plots because K might have leached beyond the root zone. However uptake was maximum due to the dry matter production. Similar result was reported by Jacob (1992).

The calcium content in bhusa was highest for the plot treated with fertilizer and amendment as per POP. This may be due to the fact that in phosphogypsum treated plots calcium might have moved to lower layers by the time of reside crop. However, in the grain, the combination treatment facilitated the greater translocation of calcium to the grain. The total uptake of Ca was also maximum for the combination treatment which received PG and lime each @ half LR.

The Mg content as in the case of main crop was lower for both grain and bhusa in phosphogypsum treated plots because of its displacement to lower layers in the soil. Hence the crop uptake was also affected and the highest uptake was noticed for the lime treated plots, though the dry matter production of phosphogypsum treated plots were the highest.

The readily available form of sulphur from phosphogypsum resulted in increased concentration and uptake of sulphur in grain and bhusa of the residue crop. The trend was almost the same in the main crop.

The concentration and uptake of Fe and Mn in the residue crop was highest with phosphogypsum. At lower rates it may have favoured the release of Fe and Mn and thereby enhanced its uptake. The content in uptake of Zn in bhusa was highest for T_2 (Lime @ full LR) whereas for grain the content was highest in the combination treatment which received the amendments at one fourth LR. Lime might have favoured the release of zinc.

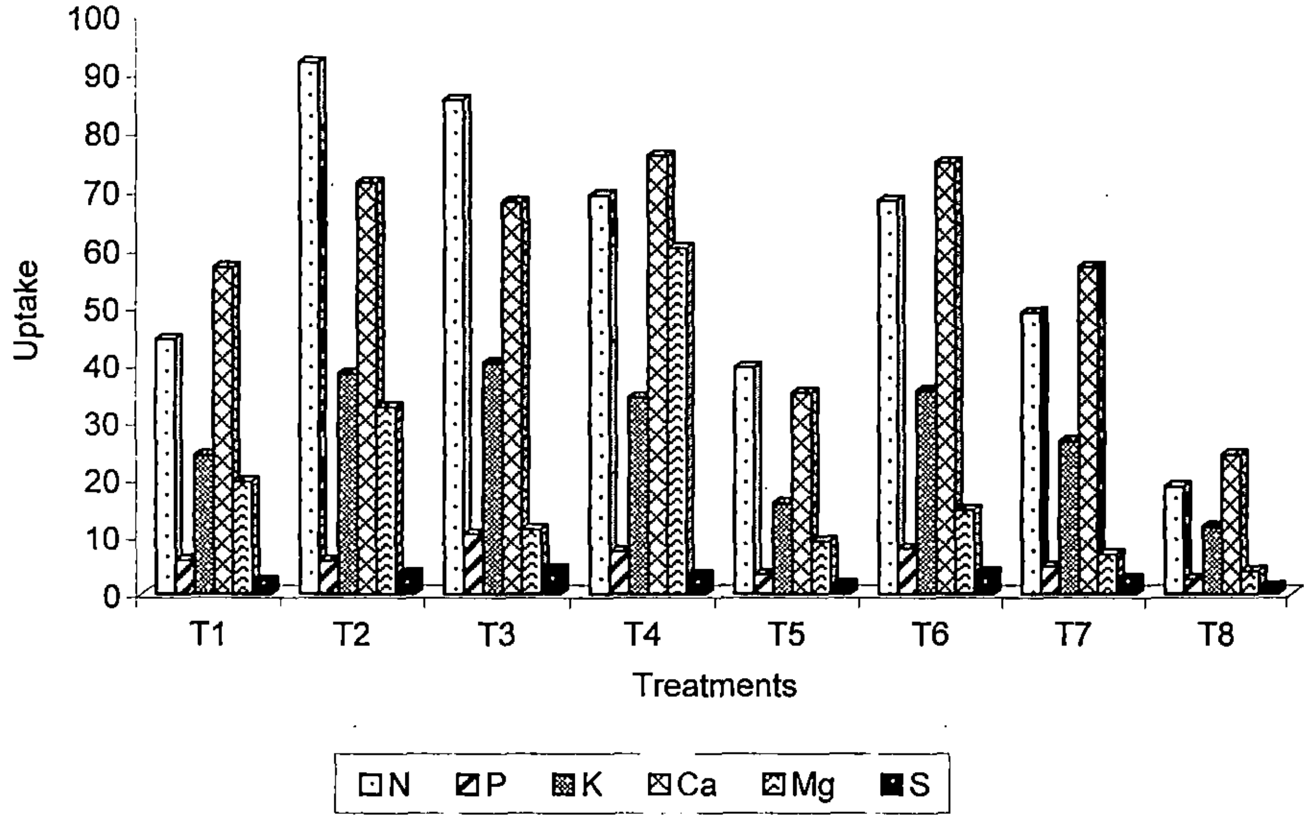


Fig. 21 Nutrient uptake of plant – residue crop

SUMMARY

6. SUMMARY

An investigation consisting of an incubation study and a microplot field experiment was carried out at College of Agriculture, Vellayani with phosphogypsum to study its suitability as an amendment for correcting soil acidity in laterite soil with cowpea as the test crop. The results of the study are summarised below.

INCUBATION STUDY

On evaluating the individual nutrient contents of soil during the period of incubation the following observations were made. There was a gradual increase in available P concentration up to the 24^{th} day of incubation, followed by a decrease. The P status of different treatments did not show a definite pattern of variation at various sampling stages. All the treatments showed the maximum values for available K at 12^{th} DOI followed by a gradual decrease during the course of incubation. The absolute control recorded the lowest value for both P and K.

The exchangeable Ca and S contents were highest throughout the incubation period for T_3 which was significantly superior to all other treatments and the lowest value was recorded by the absolute control. Exchangeable Mg content was not significantly influenced by the treatments.

Application of amendments had decreased the exchangeable aluminium since it was highest for absolute control, at all stages of sampling. All the treatments that received lime either alone or in combination with PG showed an increasing trend while that received PG alone showed a decreasing trend. The influence of treatments and period of incubation on exchangeable H^+ was not significant. Exchangeable acidity showed a trend almost similar to that for exchangeable aluminium, which is the major component of exchangeable acidity. However, for soil pH, the lowest value throughout the period was recorded by absolute control and the highest value by lime @ full LR but treatments with phosphogypsum showed an increasing trend. The electrical conductivity was maximum on 24th DOI and decreased thereafter.

Among the micronutrients, Fe was not significantly influenced by the treatments. Though the Mn content was significantly influenced, its pattern of variation with days on incubation was erratic for most of the treatments. The Cu content gradually decreased from the 12th DOI to non detectable levels at 60th DOI. Available Zn also did not show any trend in variation with days of incubation though the effect was significant.

MICROPLOT FIELD EXPERIMENT

Main Crop

Availability of nutrients estimated at fifty per cent flowering and at harvest was significantly influenced by the treatments. In general, a higher nutrient status was observed at fifty per cent flowering, evidently due to the crop removal.

The organic carbon content at fifty per cent flowering was highest for treatment that received lime and PG @ half LR each (T_6) followed by PG @ full LR and PG and lime @ ¼ LR each. The available phosphorus content of the soil was significantly influenced at fifty per cent flowering stage only. The highest value was noticed for the treatment which received PG @ half LR followed by T_3 which received PG at full LR. Regarding the available K content, the lowest value was noticed in treatment with PG @ full LR

The available Ca content of the soil at fifty per cent flowering and at harvest did not show a definite trend. However, phosphogypsum increased soil available calcium content than treatments with lime alone, at fifty per cent flowering. By the time of harvest, the treatment that received phosphogypsum showed lower Ca content than that with lime. Phosphogypsum have a significant negative influence on the exchangeable Mg content of the soil. At fifty per cent flowering, the lowest value was shown by absolute control and T_3 (PG @ full LR) preceded it. The availability of sulphur was increased by the application of phosphogypsum at both stages.

Regarding the micronutrients, application of amendments either lime or phosphogypsum increased their availability throughout the crop growth period. In general application of phosphogypsum had favourably influenced the available nutrient status when they are applied at a rate less than or equal to 1.5 times exchangeable aluminium.

Perusal of the data on pH indicated that lime is the most effective material for increasing soil pH and that too, lime @ half LR seems to be the best treatment. The treatment with phosphogypsum did not increase soil pH considerably.

The growth characters like height and number of branches plant^{-1} were significantly influenced. The maximum height and number of branches plant^{-1} at both stages were recorded by the combination treatment, T_6. However the number of nodules per plant was highest for treatments with phosphogypsum and its influence was significant at fifty per cent flowering only.

Phosphogypsum application have significantly enhanced the yield and all the yield attributing characters The grain yield plot^{-1} was maximum for treatment receiving phosphogypsum at full LR and was on par with the combination treatment receiving lime and phosphogypsum at one fourth LR.

Application of phosphogypsum increased the content of plant available nutrients in soil. Hence the concentration of nutrients in bhusa and grain were also favourably influenced. The highest N content in both bhusa and grain was recorded by the treatment with phosphogypsum at full LR and was significantly superior to others. Treatments that received phosphogypsum at half LR showed highest concentration of P in bhusa, while PG @ full LR, showed the highest value in grain. Total uptake of P was also highest for T_5 (PG @ half LR). The K content in grains was also highest for treatments which received phosphogypsum either alone or in combination with lime. The calcium and sulphur concentration in bhusa and grain were highest for the treatment containing phosphogypsum @ full LR while magnesium concentration was very much reduced in that treatment. Though the influence of amendments on the micronutrient concentration was significant, a definite trend was not noticed.

RESIDUE CROP

The residual effect of phosphogypsum was pronounced in the available nutrient status of the soil as evidenced by higher organic carbon, available phosphorus and available sulphur content while its influence on availability of potassium, calcium and magnesium was not so encouraging. For all the treatments, a general increase in pH compared to that of main crop was noticed, except at absolute control. Here also the behaviour of lime was as that in the case of main crop.

The residual effect of PG on grain yield and dry matter production was much pronounced as evidenced by higher values for the same.

The influence of amendments on nutrient concentration and uptake was highly variable. The nitrogen content was highest for treatment with lime at full LR while phosphorus was highest for phosphogypsum treated plots. Similarly the other nutrients also showed differential response to the application of lime and phosphogypsum.

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*Original not seen

FEASIBILITY OF PHOSPHOGYPSUM AS AN AMELIORANT FOR SOIL ACIDITY IN LATERITE SOIL

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Abstract of the
thesis submitted in partial fulfilment of the requirement
for the degree of

Master of Science in Agriculture

Faculty of Agriculture
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2003

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ABSTRACT

An investigation was carried out at College of Agriculture, Vellayani, to study the feasibility of using phosphogypsum as an ameliorant for correcting soil acidity in laterite soil with cowpea as the test crop. The experiment comprises of an incubation study and a micro plot field experiment.

The incubation study was carried out to understand the kinetics of dissolution of phosphogypsum and the nutrient release pattern in laterite soils after its application with the following seven treatments T_1 (absolute control) T_2 (Lime @ full LR), T_3 (PG @ full LR) T_4 (Lime @ half LR), T_5 (PG @ half LR) T_6 (Lime and PG each @ half LR) T_7 (Lime as per POP). The study was conducted for a period of 60 days and the chemical parameters were analysed at an interval of 12 days as per standard procedures.

The results revealed the enhanced solubility of phosphogypsum which was evident from the higher EC values in the treatments with phosphogypsum through out the study period. Most of the plant available nutrients were solubilised by the 24^{th} day of incubation.

A reduction in exchangeable acidity was noticed by the application of phosphogypsum after a period of 24 days, which is mainly due to reduction in exchangeable aluminium. But this was not efficient as lime in decreasing the exchangeable H^+ and hence the pH, remained unaltered.

The micro plot field experiment was laid in RBD with a main crop and a residue crop of cowpea var. Kanakamoni. The treatments include T_1 (POP), T_2 (Lime @ full LR), T_3 (PG @ full LR), T_4 (Lime @ half LR), T_5 (PG @ half LR), T_6 (Lime and PG each @ half LR), T_7 (Lime and PG each @ ¼ LR) and T_8 (absolute control). Fertilizers and amendments were applied on the basis of soil test data except in T_1 where, they were applied on the basis of POP of Kerala Agricultural University. In the residue crop, the amendments were not added and was taken immediately after the main crop.

The available nutrients in soil like, P, Ca and S were increased by the application of phosphogypsum. However, considerable leaching was noticed in the case of Mg and K.

The growth characteristics of cowpea were improved by the application of phosphogypsum. The highest grain yield was recorded with phosphogypsum applied at full LR and was on par with the combination treatment which received the amendments at one fourth LR. But considering the cost factor treatment with phosphogypsum at full LR is the best. Its B: C ratio was also the highest among other treatments. The yield attributes were also improved by the treatment with phosphogypsum at full LR.

The concentration and uptake of N, P, K, Ca, and S in bhusa were favourably influenced by the application of phosphogypsum either at full LR or at half LR.

The residual effect of phosphogypsum was visualized in the crop, taken after the main crop. The application of phosphogypsum increased the organic carbon content, P, and S. The leaching of calcium, Mg and K beyond the root zone was much pronounced in the residue crop.

The yield attributes of cowpea were also positively related with phosphogypsum treatment. But by the time of residue crop, the bhusa yield was more for lime treated plots.

The concentration of N, Ca and Mg were more in lime treated plots, but the uptake of nutrients was more for treatment with phosphogypsum. This also emphasizes the mobility and downward leaching property of phosphogypsum. The micronutrient content and uptake were also influenced by the application of phosphogypsum.

Phosphogypsum is hence highly beneficial in increasing the yield and yield attributes of cowpea, by mitigating the adverse effects of soil acidity, such as aluminium toxicity, which in effect is the major reason for acidity in laterite soils. Further, utilization of an industrial by product, which otherwise remain unutilized is also facilitated.

APPENDIX

APPENDIX-I

Weather parameters from July 1, 2002 to January 30, 2003

Fortnight	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Rainfall (m)	Number of rainy days
July I	30.6	24.3	83.0	8.9	3
July II	30.4	23.6	80.5	8.1	4
August I	29.3	23.0	85.0	78.8	11
August II	30.0	23.7	85.4	42.2	3
September I	30.7	23.4	77.8	31.1	3
September II	32.0	23.3	72.4	1.3	1
October I	30.1	23.2	85.0	189.1	11
October II	29.5	23.0	87.9	212.2	11
November I	30.1	23.4	86.6	59.5	9
November II	30.2	23.0	83.7	51.2	4
December I	31.2	22.8	78.6	8.2	1
December II	30.8	21.2	77.6	0	0
January I	31.6	21.9	76.5	0	0
January II	31.4	21.4	74.8	1.6	1