GYPSUM AS A SOIL AMELIORANT FOR BLACK PEPPER (*Piper nigrum* L.) IN ACID SOILS OF WAYANAD

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by
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KERALA, INDIA

2016

DECLARATION

I, hereby declare that this thesis entitled **"GYPSUM AS A SOIL AMELIORANT FOR BLACK PEPPER (*Piper nigrum* L.) IN ACID SOILS OF WAYANAD"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Date: 22.09.2016

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CERTIFICATE

This is to certify that this thesis entitled **"GYPSUM AS A SOIL AMELIORANT FOR BLACK PEPPER (*Piper nigrum* L.) IN ACID SOILS OF WAYANAD"** is a record of research work done independently by Mr. Aloka, Y. G. (2014-11-198) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of Mr. Aloka, Y. G. (2014-11-198), a candidate for the degree of **Master of Science in Agriculture** with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **"GYPSUM AS A SOIL AMELIORANT FOR BLACK PEPPER (*Piper nigrum* L.) IN ACID SOILS OF WAYANAD"** may be submitted by Mr. Aloka, Y. G. in partial fulfilment of the requirement for the degree.

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Aloka, Y. G.

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LIST OF ABBREVIATIONS

% : Percentage
°C : Degree Celsius
Al : Aluminium
$Al(OH)_3$: Aluminium hydroxide
$Al_2(SO_4)$: Aluminium sulphate
As : Arsenic
B : Boron
Ca : Calcium
$Ca(OH)_2$: Calcium hydroxide
$CaCO_3$: Calcium carbonate
CaO : Calcium oxide (Burnt lime)
$CaSO_4 . 2H_2O$: Calcium sulphate dihydrate (Gypsum)
Cd : Cadmium
CEC : Cation Exchange Capacity
cm : Centimetre
cm^2 : Centimetre square
$cmol (P^+) kg^{-1}$: Cent mol (proton) per Kilogram
CoA : College of Agriculture
Cr : Chromium
CRD : Completely Randomized Design
Cu : Copper
DAI : Days after incubation
DAP : Days after planting
$dS\ m^{-1}$: Deci Siemens per metre
EC : Electrical Conductivity
et al : And others
Fe : Iron
Fig. : Figure
g : Gram
Hg : Mercury

K	: Potassium
K_2O	: Potassium oxide
KCl	: Potassium chloride
kg ha^{-1}	: Kilogram per hectare
KVK	: Krishi Vigyan Kendra
m	: Metre
meq $100g^{-1}$	: Mili-equivalence per 100 gram
meq/L	: Mili-equivalence per litre
Mg	: Magnesium
mg kg^{-1}	: Milligram per Kilogram
ml	: Millilitre
mm	: Milimeter
Mn	: Manganese
N	: Nitrogen
Na	: Sodium
Ni	: Nickel
P	: Phosphorus
P_2O_5	: Diphosphate pentaoxide
Pb	: Lead
PG	: Phosphogypsum
ppm	: Parts per million
PVC	: Polyvinyl chloride
RARS	: Regional Agricultural Research Station
S	: Sulphur
T	: Treatment
t ha^{-1}	: Tonnes per hectare
Zn	: Zinc

Introduction

1. INTRODUCTION

Black pepper is known as "king of spices", most popular since ancient times. Black pepper grows well in humid tropics; requires high rainfall and humidity. The hot and humid climate of sub mountainous tracts of Western Ghats is ideal for its cultivation. It grows well between 20° North and South latitudes, and up to 1500 metres above sea level. Optimum soil temperature for root growth is 26-28° C. The ideal range of relative humidity for the crop is 75-80 per cent. A well distributed annual rainfall of 125-200 cm is considered ideal for black pepper. Black pepper can be grown in a wide range of soils with a pH of 5.5 to 6.5, though in its natural habitat it thrives well in red laterite soils.

In India black pepper was grown in about 1,16,320 hectares with production of 37,000 tonnes (2013-14). The average yield of pepper in India is estimated to be 500 kg ha^{-1} (2013-14) as against 4067 kg ha^{-1} in Malaysia.

Pepper requires a porous friable soil, with good drainage, adequate water holding capacity, rich in humus and essential plant nutrients. Wayanad is a major pepper growing district in Kerala. The pepper production in Wayanad is declining year after year mainly due to the poor soil health status, improper land management practices, with changes in climatic factors leading to the incidence of biotic and abiotic stresses. The laterite soils of Wayanad possess high soil acidity, low in nutrient status, toxic exchangeable aluminium and low cation exchange capacity (CEC) with weak retention capacity of bases applied as fertilizers or as amendments, coupled with low Ca content. Micronutrient deficiencies also occur frequently in pepper cultivated these soils. These unfavourable physical and chemical properties might restrict the root volume of pepper to surface layers. Hence the crop is subjected to increased moisture stress in summer months. However, proper management strategies help to overcome these constraints in pepper cultivation.

Calcium is an important nutrient element for the growth of pepper plants. This is a nutrient utilized by the plants at its maximum level. Application of Ca increased the exchangeable Ca content in the soil and their status in pepper leaf, there by indicating the significant role Ca in pepper nutrition.

Gypsum is a widely occurring mineral that has been used for many years as a soil conditioner and ameliorant for sodic and clay rich soils. Gypsum is a nutrient source of calcium and sulphur. However, recent research has shown that the utility of gypsum has extended to acidic, infertile soils as an ameliorant for subsoil acidity and it also reduces exchangeable Al concentration present in the soil. Application of gypsum resulted in substantial increase in root growth and high rate of infiltration into soils resulting in improved yield (Sumner, 1993). Moreover it serves as an alternate liming material with better efficacy for ameliorating subsoil acidity and enhancing deep root growth of crops. Many examples of gypsum as a successful ameliorant in overcoming physical and chemical constraint in subsoil resulting in improved growth and yield includes alfalfa (*Medicago sativa* L.), bermudagrass (*Cynodon dactylon* L.), fescue pastures (*Festuca arundinacea* L.), turf (*Zoysia* sp.), cotton (*Gossypium hirsutum* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolour* L.), and soybean (*Glycine max* L.) (Hammel *et al.*, 1985; Sumner, 2009).

In this context, an investigation was carried out to evaluate the effect of gypsum in amelioration of soil acidity in lateritic pepper garden soils of Wayanad, Kerala.

The investigation was carried out with following objectives,

1. To assess the performance of gypsum as a soil ameliorant in growth and development of black pepper, and
2. To evaluate gypsum suitability in promoting root growth in deep soil layers of Central plateau of Wayanad (AEU 20).

Review of Literature

2. REVIEW OF LITRATRE

Acidification of soil is a natural process with major ramifications on plant growth. As soils become more acid, particularly when the pH drops below 4.5, it becomes increasingly difficult to produce crops. Soil acidity is common in humid tropical regions where precipitation is high enough to leach appreciable quantities of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) from the surface layer of soils. Exchangeable hydrogen and exchangeable aluminium are responsible for soil acidity. These problems are particularly acute in humid tropics.

In acid soils with pH below 5.5 the content of mobile Al is rather high. Simultaneously, there is an increase in the uptake of this element by plants which cause damage to roots and a decrease the uptake of other nutrient elements.

Very few plants can grow well in strong acid soils. Plant roots are badly affected if the pH value exceeds limits of crop tolerance. High degree of soil acidity (pH 5 to 6.5) decreases the availability of plant nutrients particularly phosphorus, calcium, magnesium, molybdenum, potassium, sulphur, nitrogen and boron.

2.1 LATERITE SOILS AND ITS CHARACTERISTICS

On a global scale, about 80 per cent of the Ultisols are in tropical region and about 18 per cent of the tropics are covered by Ultisols (Eswaran, 1993). Laterite soils (Ultisols) predominate in humid tropics of India (Velayutham *et al.*, 1999). These soils are characterized by undulating topography and high rainfall (>3000 mm), which accentuate the process of leaching of nutrients. The CEC of these soils is quite low (3–14 cmol kg^{-1}) resulting in poor nutrient retention capacity (Shivaprasad *et al.*, 1998). These soils are poor in native soil fertility with abundant sesquioxides and low bases (Babu, 1981). Deficiency of nitrogen, potassium and zinc is reported (Badrinath *et al.*, 1998). Availability of P is low as the soils are rich in hydrated as well as amorphous oxides of Fe and Al, which are potent phosphorus fixers (Perur, 1996; West *et al.*, 1997). Kaolinite is the dominant clay mineral low in K fixation. These soils are deficient in zinc and possess a high zinc fixing capacity.

2.2 NATURE OF SOIL ACIDITY IN LATERITIC SOIL

In highly weathered laterite soils, an appreciable fraction of the permanent negative charge is contributed by aluminium and hydrogen ions and this fraction is generally known as exchangeable acidity. Initially, soil acidity was thought to be caused by exchangeable hydrogen because it could be leached out of acid soils by neutral salts, but titration curves of clay suspension suggested that acid clays behave like weak acids and that hydrogen ions adsorbed on clays when exchanged by neutral salts immediately dissolves hydrated aluminium in the soil which cause Al^{3+} to appear in the extract (Coulter, 1969).

Result of studies conducted by Coleman and Thomas (1967) and McCart and Kamprath (1965) concluded that in highly weathered acid soil, exchangeable aluminium was the predominant cation contributing to soil acidity rather than other ions.

Pavan (1983) reported that the cation exchange capacity of acid soil of Brazil has a very large pH dependent charge, which have aluminium as the dominant cation in the exchange complex and only a small proportion of the exchange capacity was balanced by basic metals.

Studies by Kaminiski and Bohnen (1976) suggested that exchangeable aluminium and organic matter levels showed higher level of soil acidity. While studying the inter relationship between the natural soil acidity, exchangeable aluminium and percent aluminium saturation, the authors consider soil acidity as a poorly defined parameter and recommended that percent aluminium saturation calculated on the basis of effective cation exchange capacity could be taken as measure of soil acidity.

Duchanfour and Souchier (1980) observed that Al^{3+} is more harmful to plant than H^+ in acid soil. But negative relationship was obtained by Manrique (1986) between Al saturation and pH in 1molar KCl Ultisoils. Sarkar *et al.* (1989) and Jose *et al.* (1998) in Kerala reported that more than 60 percent of soils are of lateritic type with pH value less than 5.5. Soil acidity and other allied problems are major chemical drawbacks for crop production in these soils.

Sharma *et al.* (1990) reported that in red soils of Trivandrum about 6 per cent contribution is from exchangeable aluminium and 60 percent contribution from pH dependent acidity for total acidity in soil. However exchangeable aluminium all together contributed more than 90 percent. These factors are considered as the major source of exchangeable acidity in these soils. Nambiar and Meelu in 1996 reported that the use of long-term acid forming fertilizers increases soil acidity in lateritic soil.

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(P^+) kg^{-1}, respectively, in red and lateritic soil of West Bengal (Chand and Mandal, 2000).

Dolui and Sarkar (2001) also recorded that in red soil profile of Odisha, exchangeable acidity contributed to 9 to 19 per cent of total acidity, whereas pH dependent acidity constituted around 81 percent of total potential acidity. But, in the red soils of West Bengal, the mean values of exchangeable and pH dependant acidity were 12.4 and 87.6 percent of total potential acidity (Rahman and Karak, 2001).

Recent study on soil fertility status of Kerala revealed that about 90% of the soils are acidic in nature. Among them 35 per cent of the soil samples showed excess nitrogen, 31 per cent high in potassium, 62 per cent high in phosphorus, 74 per cent low in Mg and 59 per cent are deficient in Boron (GOK, 2013)

2.3 EFFECT OF LIME ON SOIL ACIDITY

Amelioration of subsoil acidity was accelerated in the red Oxisols of the Cerrados region of Central Brazil (Lathwell, 1979) by applying amendments containing mobile anions such as sulfate, nitrate, or chloride, which facilitated the leaching of bases into the subsoil (Pleysier and Juo 1981; Pavan *et al.*, 1984).

The surface application of lime has a limited ameliorant effect on subsurface acidity due to the slow solubility and mobility of lime into the subsurface (Shainberg *et al.*, 1989; Farina *et al.*, 2000a; Liu and Hue, 2001; Conyers *et al.*, 2003).

Amelioration of naturally occurring subsoil acidity in highly weathered soils has shown that surface incorporation of $CaCO_3$ alone does not significantly affect the untreated subsoil because of poor leaching ability (Sumner, 1993).

Bouldin (1979) has concluded through substantial amount of research done at the research station near Brasilia, Brazil, on the effects of subsoil acidity on crop yields, water uptake, root growth, and amelioration of subsoil acidity, that liming the surface soil was usually successful in reducing subsoil acidity within 2-4 years.

Incorporation of lime into the plough layer has not always been successful in reducing subsoil acidity (Bouldin *et al.*, 1987). Due to low lime solubility in water, the lime application results in slow amelioration of subsoil chemical attributes mainly in clay soils as compared to sandy soils (Caires *et al.*, 2000).

Deep incorporation of lime can be effective but is impractical due to the lack of suitable machinery, the high cost and the negative effect on soil structure (Sumner *et al.*, 1986; Farina *et al.*, 2000a; Liu and Hue, 2001).

2.4 EFFECT OF GYPSUM ON SUBSOIL ACIDITY

Surface applied gypsum ($CaSO_4.\ 2H_2O$) has efficiently and sustainably reduced Al saturation in naturally acidic subsoil through the incorporation of Ca^{2+} and exchange of Al^{3+} in the subsoil without neutralizing the subsoil acidity (Wendell and Ritchey, 1996; Toma *et al.*, 1999).

The amelioration of subsoil acidity through surface application of amendments depends on transport of base cations from the surface horizon and the reaction of these cations with the acidity in the subsoil horizons. Transport is dependent on the amount of water and the concentration of cations in the leaching water, latter is dependent on concentrations of accompanying anions such as sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-) and bicarbonates (HCO_3^-). The reaction of subsoil acidity depends upon the ability of the base cations in solution to displace or react with the exchangeable Al^{3+} on subsoil particle surfaces, determined by the ratio of acidity to base cations in the incoming leachate (Pleysier and Juo, 1981; Pavan *et al.*, 1984; Cahn *et al.*, 1993).

Ritchey *et al.* (1980) confirmed and explained the concept that gypsum was an effective non-invasive ameliorant for subsoil acidity in a leaching experiment.

Research on the non-invasive amelioration of subsoil acidity was started in the early 1960s, in South Africa by Sumner (1970) and Reeve and Sumner (1972). These studies showed that the toxic Al^{3+} ion in acid subsoil could be neutralised by the surface application of gypsum. Being much more soluble than lime, the gypsum was able to move down into the subsoil where, as a result of the so-called 'self-liming effect', the Al was precipitated.

Gypsum has been proposed as an effective amendment for subsoil acidity (Alva *et al.*, 1990; McLay and Ritchie,1994).

Gypsum appears to have a minimal effect on pH, it is much more soluble than lime and enables Ca^{2+} to move through the soil with SO_4^{2-} in a larger quantity and at greater speed than when supplied by lime (Sumner *et al.*, 1986; Shainberg *et al.*, 1989).

Gypsum ($CaSO_4.2H_2O$) application can be an attractive alternative due to the fact that it promotes increase and decrease of Ca and Al activities, respectively, in the subsoil (Pavan *et al.*, 1984).

Several research studies concerning the gypsum application in tropical and subtropical soils have been carried out (Quaggio *et al.*, 1993; Caires *et al.*, 2003). This study reports the effects of surface gypsum application on soil chemical attributes, mineral nutrition, and yield of grape grown in conditions of high subsoil acidity.

Movement of the exchangeable Mg from the top cultivable layers to the subsoil by gypsum application has been frequently observed (Quaggio *et al.*, 1993; Oliveira and Pavan 1996), but less intense in clayey soils (Caires *et al.*, 2003).

Phosphogypsum, a by-product from phosphoric acid plant, which has Ca in soluble form can correct subsoil acidity also even when applied to the surface (Deepa, 2008; Alcordo and Recheigl, 1993).

Gypsum does not change the soil pH much, the dissociated sulfates (SO_4^{2-}) from gypsum combine with detrimental Al^{3+} ions which cause acidity in bottom soil layers to form aluminium sulfate that is less phytotoxic to crops (Evanylo, 1989; Ismail *et al.*, 1993; Sumner, 1993).

In groundnut, the use of gypsum has been widespread because of its ability to supply readily soluble, available Ca to the developing pods (Snyman, 1972; Walker, 1975; Cox *et al.*, 1982).

When gypsum was applied to the soil surface, gypsum was shown to be more effective than surface applied limestone in improving crop yields on soils with acidic subsoil in Brazil, South Africa and the United States (Shainberg *et al.*, 1989; Sumner 1993).

To reduce Al toxicity in acid soils and to overcome Al phytotoxicity a frequent practice is the employment of Ca amendments (Toma and Saigusa, 1997; Mora *et al.*, 2002) such as lime, gypsum or phosphogypsum (PG) (Campbell *et al.*, 2006; Takahashi *et al.*, 2006a).

Merino-Gergichevich *et al.* (2010) reviewed the Al^{3+}- Ca^{2+} interaction in plants growing in acid soils in comparison to the Al-phytotoxicity response to calcareous amendments and pointed out the importance of gypsum amendments in the reduction of toxic Al without altering pH conditions (Franzen *et al.*, 2006). This occurs due to the replacement of exchangeable Al^{3+} by Ca^{2+} particularly in the subsoil and the formation of Al-hydroxyl-sulfate or aluminium sulfate complexes (Mora *et al.*, 2002), which are less toxic to plants.

An acid Ultisol was packed in a 50-cm long column with the top 15 cm being amended with either lime ($CaCO_3$), gypsum ($CaSO_4.2H_2O$), yard waste compost, bio-solids-based compost (Nitrohumus), or a combination of compost and lime. The column was leached with 40mL deionized water daily at a rate of 10 mL per 15 min for 27 days (40 cm water). Thereafter, the column was dismantled and cut into 15, 10, 10, 10 cm layers from the top for chemical analysis. Results showed that lime markedly increased pH and reduced exchangeable Al of the surface layer, but had little effect on subsoil pH. Only 7.6 per cent of the applied Ca from lime moved from the applied layer to the next 10-cm layer, while more than 60% of the applied Ca from gypsum moved past the applied layer. Composts effectively reduced exchangeable Al of the top layer, and of the top two layers when applied together with lime. More Ca was found in deeper soil layers when lime and the Nitrohumus compost were applied together than when either material was applied alone. The downward Ca movement was mainly assisted by SO_4^{2-} even in the compost treatments. (Liu and Hue, 2001).

Hammel *et al.* (1985) proved significant yield increases due to surface application of gypsum for soybean (*Glycine max* L.), maize (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) in field tests, perhaps by increasing Ca and decreasing soluble and/or exchangeable Al of the subsoil.

Gypsum being much more soluble, readily moves down the profile where it has been shown to reduce levels of toxic Al^{3+}, increase soluble Ca^{2+} and reduce the soil acidity of which encourage root coverage of the subsoil (Reeve and Sumner, 1972; Radcliffe *et al.*, 1986).

2.5 SOIL ACIDITY DUE TO ALUMINIUM AND EFFECT ON CROPS

Soil acidity is of three kinds, namely a) active acidity, b) exchangeable acidity and c) reserve acidity. The hydrogen ions in the soil solution contribute to active acidity. It may be defined as the acidity developed due to concentration of hydrogen (H^+) and aluminium (Al^{3+}) ions in the soil solution. In strongly acidic soils, the concentration of exchangeable aluminium and hydrogen ions contribute to exchangeable acidity. It may be defined as the acidity developed due to adsorbed hydrogen (H^+) and aluminium (Al^{3+}) ions on soil colloids. However, this exchangeable aluminium and hydrogen concentration is meagre in moderately acid soils. Aluminium hydroxy ions, hydrogen and aluminium ions present in non-exchangeable form with organic matter and clays account for the reserve or potential acidity. It contributes to titrable or total acidity.

Pavar and Marshall (1984) considered exchangeable Al as the major criterion of soil acidity rather than hydrogen ion concentration, due to which Al toxicity causes poor root penetration, as well as reduced plant growth.

Evans and Kamprath (1970) suggested that concentration of soil solution Al in mineral soils was related to the per cent aluminium saturation of the effective CEC. Liming increased the growth of corn on mineral soils when the aluminium saturation was greater than 70 per cent and the concentration of soil solution Al was greater than 0.4 meq/litre. Soybeans responded to liming when the Al saturation was greater than 30 per cent and soil solution Al concentration was 0.2 meq/litre.

Mc Lean (1970) noticed that liming has little favorable effect on phosphate availability to plants in highly weathered semitropical and tropical soils because of the presence of so much reactive surface area composed of Al and Fe hydroxides or hydroxy-Al-hydroxy-Fe ions for fixing P.

Black (1973) noted that poor crop growth in acid soils was directly related with Aluminium saturation of soils and that pH had minimum effect on plant growth, except below 4.2. Sartain and Kamprath (1975) concluded that soybean yields on Oxisols were sharply reduced at Al saturations greater than 10 per cent.

Sanchez (1976) reported soil acidity as a poorly defined parameter and suggested that percentage aluminium saturation of the effective CEC should be taken as a useful measure of soil acidity. He has recommended the liming of acid soils to pH 5.5 to 6.0 to bring about the precipitation of exchangeable Al as $Al(OH)_3$.

Martini *et al.* (1977) have suggested lime rates to increase soil pH from 4.8 to 5.7 and to reduce exchangeable Al to 1.5 meq 100^{-1} g soil as a more effective means of optimizing the yield than rising of soil pH to neutrality. Soil acidity is a major constrain for crop production worldwide, and yield losses are frequently attributed to aluminium (Al) toxicity (Foy, 1983).

The response of shoot and root depends on the concentration of Al, the age of plants, and the cultivar. The growth of shoots and roots were significantly stimulated by one mgL^{-1} concentration of Al. Higher concentrations of aluminium causes severe inhibition of shoot and root growth. Older plants showed higher Al tolerance than young ones. There was a relationship between sensitivity of the plants to Al and ability to increase solution pH (Aniol, 1996).

Aluminium was reduced the cell growth drastically. Peanut cultures treated with 200 micromolar Al could achieve 90 per cent relative growth when compared to the control if the culture period was extended to more than two weeks. Growth of cultures containing 400 micromolar Al remained low throughout the experiment. The levels of both monomeric and total aluminium remaining in the media decreased as cell growth progressed. Maximum effects of aluminium toxicity could occur during the initial six days of culture (Marziah, 1991).

Tobacco cell growth inhibited at a minimum dose of 1×10^{11} Al atoms per cell at the logarithmic phase of growth. Cells of stationary phase were resistant to Al and not take up Al, an indication that the uptake of Al depends on the active growth of cells (Yamamoto *et al.*, 1994).

Aluminium toxicity affects 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 and Bingham, 1982; Scott *et al.*, 1991) and fresh weight of wheat (Scott *et al.*, 1991) were also observed. 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.

2.6 ROLE OF ALUMINIUM IN SOIL ACIDITY AND ITS EFFECT ON ROOT GROWTH

Abraham (1984) in rice reported that, aluminium concentration in the range of 20 to 40 mg kg^{-1} in the nutrient solution reduced root elongation and caused decrease 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 were found to be stubby and brown (Narayanan and Shyamala, 1989; Ryan *et al.*, 1993).

In legumes, the growth of root hairs and nodule initiation were affected by trivalent aluminium (Munns and Francis, 1982; Carvalho *et al.*, 1982; Narayanan and Shyamala, 1989). The low content of calcium (Ritchey *et al.*, 1982) and aluminum toxicity (Pavan and Bingham, 1982) cause poor root growth absorption of water and nutrients by plants, usually causing reduction in crop yields in acid soils (Sumner *et al.*, 1986).

At high acidity ($pH < 4$), low levels of aluminium have been shown to stimulate root growth and protect against hydrogen ion damage (Thornton *et al.*, 1986). Briggs *et al.* (1989) reported that root responses are more sensitive to aluminium than leaf responses.

With the increase in the concentration of aluminium, the concentration of phosphors, calcium and iron decreased to 1/10 of the original (Aniol, 1996).

The primary symptom of aluminium (Al) toxicity in higher plants is inhibition of root growth. The visible injuries incurred by roots during Al stress are not associated directly with the inhibition of root growth. Furthermore, the removal of root cap had no effect on the Al induced inhibition of root growth in solution experiments and argues against the root cap providing protection from Al stress of serving an essential role in the mechanism of toxicity (Ryan *et al.*, 1993).

The roots of aluminium treated wheat seedlings exhibited typical symptoms of aluminium toxicity including stunting, brittleness and browning of the root tips. Symptoms, especially reduced root length were more prominent in the aluminium sensitive cultivars than in the aluminium resistant cultivar and line (Kymberly *et al.*, 1994).

Aluminium in acidic subsoil restricts root development, increasing the susceptibility of crop plants to drought (Dennis *et al.*, 1994). Hutchinson (1983) observed that aluminium ions were potentially toxic to plant roots.

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.

2.7 RECLAMATION OF ACIDITY IN LATERITE SOIL

The problem of overcoming acidity in laterite soils through liming had received attention from a very early period. To increase the productivity of acid soils, liming is the first step because of its direct effect for neutralizing the acidity and indirect effect of increasing the availability of nitrogen by hastening the decomposition of organic matter, making available the nutrient element to the crop and decreasing the toxicity of Al, Fe and Mn.

Moralli *et al.* (1971) reported that in an oxic soil, liming decreased exchangeable and total acidity and affected pH down to a depth of 100 cm. Liming also causes marked vertical and slight lateral migration of Ca and Mg.

Raji (1982), in a five year liming trial reported that neutralization of soil acidity below the plough layer was insignificant. Liming ameliorated soil acidity to a favourable limit and substantially augmented calcium plus magnesium status and lime potential in soil.

Maria *et al.* (1985) found that liming raised the pH values insignificantly. Samonte (1985) obtained optimum yields when the pH was raised above 6. The N status of plants were improved by lime application.

Liming is one of the .most beneficial management options in laterite soil where soil acidity posses the major challenge for successful crop production. Liming though a relatively costly remedial treatment, it is the most promising solution for correcting the problem of soil acidity (Ukrainetx, 1984; Malhi *et al.*, 1995).

Calcium applied on the surface soil in the form of lime leached from the 0-30 cm horizon, but only limited amounts accumulated in the subsoil. Base saturation below 45 cm was less than 50 per cent at the end of the experiment regardless of lime treatment. Roots of maize were concentrated in the 0-30 cm layers in limed plots and the 0-20 cm layers in unlimed plots (Cahn *et al.*, 1993).

Soil samples in PVC columns were treated with a number of liming materials in combination with gypsum, and the movement of Ca, Al and Mg was followed for each treatment. Downward movement of Ca increased with increasing levels of gypsum in the treatment, causing a decrease in Al saturation at the lower depths (Jacob and Venugopal, 1993).

Even at the highest application rate, lime had minimal effects on acidity below the depth of incorporation. Gypsum, however, markedly improved the rooting environment to a depth of 0.75 cm (Farina *et al.*, 2000a).

Compost had no effect on the subsoil. When $CaCO_3$ or gypsum was added to the surface, extractable calcium increased in the subsoil, but there was no relevant increase in subsoil pH. Even in the first 5 cm of subsoil material, extractable aluminium did not decrease very much, possibly because a jurbanite-like solid phase controlled subsoil Al^{3+} activities. During the reclamation of highly acidic mined soil material; one should therefore not expect significant effects of the surface treatment on the untreated subsoil. A sufficient root zone would have to be achieved by incorporating the liming agent down to the desired rooting depth (Willert *et al.*, 2003).

2.8 LIME AND SLAKED LIME AS AN AMELIORANT FOR SOIL ACIDITY

Abruna *et al.* *(*1964) proposed that liming increased yields of grasses in the humid tropics markedly by increasing the pH of the upper 15 cm to about 4.8 with bases to 8.0 meq 100^{-1} g soil and by decreasing exchangeable Al to 2 meq/100 gm soil. Awan (1964) reported highly significant yield increases for sorghum, corn, beans, cow pea and green manure, when the acid soil (pH 5.5) was limed to raise the pH to 6.5.

Abruna *et al.* (1964) reported that exchangeable Al and Mn content of humid tropical soils were sharply increased by fertilization alone but decreased by liming. Base content was increased by surface liming followed by heavy fertilization. Ross *et al.* (1964) explained that liming did not appreciably affect the amount of exchangeable Mg and K or extractable P in the soils.

Varghese and Mooney (1965) showed that the acidic pH of red and laterite soils of Vellayani, could be raised by calcium and magnesium compounds. Liming improved the soil aggregation, maximum water holding capacity and the hydraulic conductivity of the soil. The exchangeable cations and the per cent base saturation almost doubled due to addition of lime @ 17.90 t ha^{-1} as per Peech's

$BaCl_2$- TEA method (Black *et al.*, 1965). Liming significantly decreased the exchange acidity as well as pH dependent acidity. The available nitrogen, phosphorus and potassium increased significantly with higher doses of lime; however the DTPA extractable micronutrients decreased gradually with the higher doses of liming.

Helyar and Anderson (1974) demonstrated that calcium carbonate application increased exchangeable Ca and decreased exchangeable Al and Mn but had little effect on the exchangeable levels of other cations. All soil solution cations except calcium decreased in concentration with calcium carbonate application. Rojas and Adams (1980) proposed that the K: Ca and K: Mg ratios decreased with increased lime application while the Ca + Mg: K ratio increased.

Haynes and Ludecke (1981) explained that liming resulted in an increase in exchangeable Ca and per cent base saturation with concomitant decreases in levels of exchangeable Al, Fe and Mn. Increasing lime rates significantly reduced concentrations of Mg, K and Na in saturation paste extracts but had no effect on exchangeable Mg, K and Na levels. With increasing lime additions available P increased.

The role of lime materials (burnt lime or quick lime, slaked lime, calcite, dolomite and limestone) in reducing solubility of Al, Fe, Mn etc. and increasing nutrients availability of Ca & P and crop yields have been well recognised by Mandal *et al.*(1975) and Tripathi *et al.* (1997).

Prasad *et al.* (1984) reported beneficial effects of lime application @ 2.5 t ha^{-1} in promoting availability of P and Ca with higher yield of barley and maize in a strongly acid soil (pH 4.3).

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

Field lime trials conducted by Edmeades *et al.* (1985) showed that liming reduced exchangeable Mg. Similar results were obtained by Grove *et al.* (1981) and Myers *et al.* (1988). This effect increased with increasing rate of lime and with time following lime application. A decrease in exchangeable Al was best correlated with exchangeable aluminium, supporting the hypothesis that Mg fixation is due to the occlusion or co-precipitation of Mg with Al upon liming.

Blaszcyk *et al.* (1986) proposed that liming at the rate of 18.4 t ha^{-1} significantly increased calcium, magnesium and potassium concentration in the topsoil. Bishnoi *et al.* (1987) proposed that liming reduced extractable and exchangeable Fe, Al and Mn in acid soils. Gama (1987) reported that application of calcium carbonate resulted in the release of non-exchangeable potassium and slight magnesium fixation in acid soils. Exchangeable aluminium was reduced to very low levels. It is suggested that this reduction may improve adsorption of Mg solubilised by weathering.

Amelioration of acid soils by conventional liming materials such as calcium oxide, calcium carbonate, calcium hydroxide etc. are limited to a 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).

Abraham (1984) reported that lime @1200kg 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)

Nakayama *et al.* (1987) found that liming increased nitrogen, phosphorus, potassium, calcium and magnesium contents of the soil. Studies conducted by Bertic (1988) revealed that by the application of hydrated lime at the rate of 20 t ha^{-1}, the Fe content in soil decreased from 34.1 to 14.1 ppm, titrable acidity from 16.0 to 1.6 meq/100g soil and exchangeable acidity from 3.0 to 0.1 meq/100g soil. The pH in KCl increased from 4.03 to 6.42.

Noble and Sumner (1988) in nutrient solution culture experiment with soybean concluded that increasing Al in solution significantly depressed Ca, Mg, P and Mn concentration in the shoots over all the treatments. Calcium content of soybean shoots is controlled by the interaction between calcium and aluminium monomeric species in solution.

Incubation studies conducted on acid soils of Sikkim by Patiram and Rai (1988) showed that CEC, pH, potential buffering capacity and labile K increased after lime application while exchangeable aluminium and activity ration of potassium decreased.

Gupta *et al.* (1989) concluded that available contents of calcium, pH, effective CEC and lime potential of soil increased with liming whereas available contents of potassium, iron and aluminium, aluminium saturation and free energy decreased. On most soils, lime responses appeared to be due either to enhanced soil nitrogen mineralization or to the alleviation of aluminium toxicity (Bailey and Stevens, 1989).

Liming increased the Ca levels in the soil which enhanced the root penetration of soybean in to the deeper layers and also induced the normal distribution of nodules on the tap root and lateral root by Rhizobium (Balatti *et al.*, 1991)

Results of field studies showed that the movement of lime to depth varies according to timing and rates of liming, lime application forms, soil type, weather conditions, addition of acidic fertilizers, and cropping systems (Oliveira and Pavan, 1996; Caires *et al.*, 2000; Rheinheimer *et al.*, 2000; Gascho and Parker, 2001; Conyers *et al.*, 2003; Pires *et al.*, 2003; Tang *et al.*, 2003)

In a soil column experiment to study the effects of slaked lime [$Ca (OH)_2$] and gypsum ($CaSO_4. 2H_2O$) on soil acidity , soil solution chemistry and nutrient leaching in an acid soil, results showed that application of sufficient slaked lime to initially increase the pH of the topsoil by one unit caused an increase in pH to 5 cm deeper than the layer of application as a result of bicarbonate leaching. With leaching of Ca from slaked lime or gypsum from the topsoil to the subsoil, there was a decrease in exchangeable Al in the subsoil. Surface application of slaked lime or gypsum or both decreased the activity of toxic Al (Sun *et al.*, 2000).

Lime amended soil had 0.5 to 1.1 unit 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.* (2002), Whalen *et al.* (2002), Nkana and Tonye (2003) and Tang *et al.* (2003). Concurrent application of lime in to planting furrows and surface application raised soil pH and decreased exchangeable aluminium in acid soil (Pires *et al.*, 2003).

2.9 MECHANISM INVOLVED IN THE AMELIORATION OF SOIL ACIDITY BY GYPSUM

Gypsum 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 group 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. (Alva *et al.*, 1990).

3. Cosorption of SO_4^{2-} and Al^{3+}, which involves a preferential salt absorption 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.*, 1991) which involves formation of ion pairs such as $AlSO_4^+$ (Cameron *et al.*, 1986; Mclay and Ritchie, 1994; Pavan *et al.*, 1984) and AlF^{2+} in the case of gypsum (Cameron *et al.*, 1986) and

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

2.10 NUTRIENT MANAGEMENT IN BLACK PEPPER

Yellowing of black pepper vines reduced and the crop yield improved considerably by the integrated application of organic manure and inorganic fertilizers at the rate of 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 110 kg Mg ha^{-1}. The fertilizer application advocated should contain 11-13% N, 5-7% P_2O_5, 6-18% K_2O, 4-5% MgO and trace elements. Organic farming can improve black pepper productivity and addition of organic matter enhanced the growth and biomass of the vines. Biofertilizers and vermicompost application also enhanced the growth, biomass, nutrient uptake, yield and quality of black pepper (Thangaselvabal *et al.*, 2008).

Materials and Methods

3. MATERIALS AND METHODS

An investigation was carried out at College of Agriculture, Padannakkad and Krishi Vigyan Kendra, Kannur during 2015-2016 to study the performance of Gypsum as a soil ameliorant in growth and development of black pepper (*Piper nigrum* L.) and to evaluate its suitability in promoting root growth in profile soil layers of acid soils of Wayanad.

The whole investigation was carried out as three experiments, an incubation study at College of Agriculture, Padannakkad to know the effect of different amendments on soil acidity and pot culture studies (Column experiment and Double/dual root experiment) at Krishi Vigyan Kendra, Kannur to know the growth and development of black pepper by incorporating different types of amendments.

The details of experiments and analytical techniques adopted in the present investigation are presented in this chapter.

3.1 MATERIALS

3.1.1 Collection of soil samples

3.1.1.1 Initial soil sample collection

Initial soil samples from different depths (first layer: 0-25 cm, second layer: 25-50 cm, third layer: 50-75 cm and fourth layer: 75-100 cm from top soil surface) were collected from black pepper garden of block number 10, Regional Agricultural Research Station, Ambalavayal, Wayanad.

The samples were analysed for bulk density, particle density, porosity, texture, EC, pH (1: 2.5 water), organic carbon, exchangeable Al and available nutrients such as N, P_2O_5, K_2O, Ca, Mg, S, Fe, Cu, Mn and Zn on following standard procedures (Table 1). The results are represented in Table 2 and 3.

Table 1. Analytical methods followed in soil analysis

Sl. No	Parameter	Method	Reference
1	Bulk density	Disturbed soil method	Black *et al.* (1965)
2	Particle density	Pycnometer method	Black *et al.* (1965)
3	Porosity	-	Black *et al.* (1965)
4	Texture analysis	International pipette method	Robinson (1992)
5	Electrical conductivity	Conductivity meter	Jackson (1973)
6	pH	pH meter	Jackson (1973)
7	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
8	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
9	Available P_2O_5	Bray's extraction and photoelectric Colorimetry	Jackson (1973)
10	Available K_2O	Flame photometry	Pratt (1965)
11	Available Ca	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
12	Available Mg	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
13	Available S	Photoelectric Colorimetry	Massouni and Comfield (1963)
14	Available Fe	Atomic absorption Spectroscopy	Sims and Johnson (1991)
15	Available Mn	Atomic absorption Spectroscopy	Sims and Johnson (1991)
16	Available Zn	Atomic absorption Spectroscopy	Emmel *et al.* (1997)
17	Available Cu	Atomic absorption Spectroscopy	Emmel *et al.* (1997)
18	Available B	Photoelectric Colorimetry	Binghum (1982)
19	Exchangeable Al	Atomic absorption Spectroscopy	Emmel *et al.* (1977)

Table 2. Physical properties of the soil

Sl No.	Parameter	Profile soil layers			
		0-25 cm	25-50 cm	50-75 cm	75-100 cm
1	Bulk density (g cm^{-1})	1.21	1.23	1.27	1.22
2	Particle density (g cm^{-1})	2.15	2.01	2.10	2.11
3	Porosity (%)	39.19	38.80	35.20	42.18
Mechanical Composition					
1	Sand (%)	39.2	28.75	23.7	34.5
2	Silt (%)	20.32	16	14.28	22.22
3	Clay (%)	32.52	41.66	42.85	38.88
4	Texture	Clay loam	Clay	Clay	Clay loam

Table 3. Chemical properties of the soil

Sl. No	Parameter	Profile soil layers			
		0-25 cm	25-50 cm	50-75 cm	75-100 cm
1	pH (1: 2.5 water)	4.55	4.35	3.64	3.42
2	Electrical conductivity (dS m^{-1})	0.15	0.22	0.26	0.33
3	Organic carbon (%)	1.14	0.69	0.29	0.15
4	Available N (kg ha^{-1})	625.23	423.56	302.69	112.36
5	Available P_2O_5 (kg ha^{-1})	44.12	26.42	10.46	1.86
6	Available K_2O (kg ha^{-1})	293.88	243.71	232.96	179.20
7	Available Ca (mg kg^{-1})	355.00	376.87	362.50	205.00
8	Available Mg (mg kg^{-1})	15.24	12.50	10.25	18.73
9	Available S (mg kg^{-1})	15.75	8.87	5.75	3.50
10	Available Fe (mg kg^{-1})	38.00	27.70	22.60	30.70
11	Available Mn (mg kg^{-1})	9.57	11.20	10.70	20.40
12	Available Zn (mg kg^{-1})	2.08	3.01	1.30	2.58
13	Available Cu (mg kg^{-1})	1.63	1.21	0.92	0.75
14	Available B (mg kg^{-1})	4.60	6.52	3.25	2.10
15	Exchangeable Al (mg kg^{-1})	65.36	54.25	65.36	68.99
16	CEC meq $100g^{-1}$	8.70	12.00	10.60	8.20

3.1.1.2 Bulk soil sample collection

Bulk soil samples were collected each depth (0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm from top soil surface) and incubation and pot culture experiment were conducted.

3.1.2 Collection of ameliorants

The ameliorants Gypsum, $CaCO_3$, Burnt lime (CaO) and Dolomite, were purchased from instructional farm, College of Agriculture, Padannakkad. All four amendments were analyzed for pH, free acidity/ alkalinity, total Ca and Mg and heavy metals (Al, Pb, Hg, Cd, As, Ni and Cr) as per standard procedures (Table 4). The results are presented in Table 5.

Table 4. Analytical methods followed for amendments analysis

Sl No.	Parameter	Method	Reference
1	Total Al	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
2	Total Pb	Atomic absorption Spectroscopy	Page *et al.* (1970)
3	Total Hg	Atomic absorption Spectroscopy	Perkin-Elmer (1979)
4	Total Cd	Atomic absorption Spectroscopy	Issac and Kerber (1971)
5	Total As	Atomic absorption Spectroscopy	Issac and Kerber (1971)
6	Total Ni	Atomic absorption Spectroscopy	Piper (1966)
7	Total Cr	Atomic absorption Spectroscopy	Emmel *et al.* (1977)
8	Total Ca and Mg	Atomic absorption Spectroscopy	Issac and Kerber (1971)

Table 5. Chemical analysis of amendments

Sl No.	Parameter	Amendments			
		Gypsum	Burnt lime	$CaCO_3$	Dolomite
1	pH	6.1	13.1	12.4	11.4
2	Free Acidity (meq $100g^{-1}$)	1.8	-	-	-
3	Free alkalinity (meq $100g^{-1}$)	-	4.2	3.5	3.1
4	Total Ca (%)	19.52	65.14	40.18	21.45
5	Total Mg (%)	-	-	-	12.74
Heavy metals					
6	Al (mg kg^{-1})	12	10	14	11
7	Pb (mg kg^{-1})	1.1	0.5	1.1	1.2
8	Hg (mg kg^{-1})	0.4	0.3	0.1	0.2
9	Cd (mg kg^{-1})	1.5	0.6	0.9	1.1
10	As (mg kg^{-1})	1.9	1.1	1.5	1.7
11	Ni (mg kg^{-1})	0.1	0.2	0.1	0.1
12	Cr (mg kg^{-1})	12	10	14	11

The quantity of amendments for different treatments was calculated as follows.

1. Soil (kg) required to fill the column (A) = πr^2 × h × BD (r = radius of column, h = height of column, BD = bulk density of soil sample taken).
2. Initial CEC (meq 100^{-1} g soil) of soil = B (10 meq 100^{-1} g soil)
3. Ca content in initial soil (C) = (B × equivalent weight of Ca) / 100 g soil.
4. Ca required for one column to increase CEC to 100 per cent (D) = C × A in g.
5. Ca required to be added for make up 100 per cent CEC through amendment = D × (100 / per cent of Ca in amendment) in gram.

3.3 Columns for incubation and pot culture experiments

PVC pipe columns of length 1 metre and diameter 0.063 metre were taken and soil collected from Wayanad was filled in such a way that at bottom 4th layer of soil (75-100 cm depth soil) placed up to 0.25 m height, above that 0.25 m height 3rd layer soil (50-75 cm depth soil), after that 0.25 m height 2nd layer soil (25-50 cm depth soil). Finally top soil was filled, 4 leaf stage pepper cuttings were planted and ameliorants were added with proper mixing with top soil.

For incubation study, the same procedure which is stated above was followed, except planting of vines.

3.2 METHODS

3.2.1 Incubation study/ experiment

The incubation experiment was conducted at College of Agriculture, Padannakkad. The different amendments were incorporated to the columns filled with soil by proper mixing of soil and irrigation was regularly carried out once in a day and maintained at 50 per cent field capacity. The layout of incubation study experiment is shown in fig 1.

3.2.1.1 Design and layout

Design	: CRD (Completely Randomized Design)
Replication	: 3
Treatments	: 8

3.2.1.2 Treatments

T_1 – Ca as Gypsum at the rate 50% of CEC (14g gypsum column^{-1})

T_2 – Ca as Burnt lime (CaO) at the rate of 50% of CEC (6g CaO column^{-1})

T_3 – Ca as Dolomite at the rate of 50% of CEC (14g dolomite column^{-1})

T_4 – Ca as Gypsum at the rate of 25% of CEC + Burnt lime (CaO) at the rate of 25% of CEC (7g gypsum + 3g CaO column^{-1})

T_5 – Ca as Gypsum at the rate of 25% of CEC + Dolomite at the rate of 25% of CEC (7g gypsum + 7g dolomite column^{-1})

T_6 – Ca as $CaCO_3$ at the rate of 50% lime requirement (10g $CaCO_3$ column^{-1})

T_7 – Ca as $CaCO_3$ at the rate of 100% lime requirement (20g $CaCO_3$ column^{-1})

T_8 – Control

Fig. 1 Layout of incubation experiment

T_2R_2	T_8R_2	T_1R_3
T_4R_3	T_2R_3	T_4R_1
T_3R_1	T_5R_1	T_3R_2
T_4R_2	T_7R_3	T_6R_1
T_7R_1	T_6R_3	T_2R_1
T_1R_2	T_5R_2	T_8R_3
T_7R_2	T_3R_3	T_8R_1
T_5R_3	T_1R_1	T_6R_2

3.2.2 Column experiment

Column experiment was conducted at KVK, Kannur, by planting single node 4 leaf stage rooted pepper cuttings var. Panniyur-1 in the PVC columns of length 1 meter and width 0.063 meter. The columns were filled with soil collected from Wayanad. Treatments were applied at the time of planting, irrigation was regularly carried out once in a day and maintained at 50 per cent field capacity in soil. The layout of column experiment is shown in fig 2.

3.2.2.1 Design and layout

Crop	: Black pepper (*Piper nigrum* L.)
Variety	: Panniyur-1
Design	: CRD (Completely Randomized Design)
Replication	: 3
Treatments	: 8

3.2.2.2 Treatments

T_1 – Ca as Gypsum at the rate 10% of CEC (3g gypsum column^{-1})
T_2 – Ca as Gypsum at the rate 20% of CEC (6g gypsum column^{-1})
T_3 – Ca as Gypsum at the rate 30% of CEC (9g gypsum column^{-1})
T_4 – Ca as Gypsum at the rate 40% of CEC (12g gypsum column^{-1})
T_5 – Ca as Gypsum at the rate 50% of CEC (15g gypsum column^{-1})
T_6 – Ca as $CaCO_3$ at the rate of 50% lime requirement (10g $CaCO_3$ column^{-1})
T_7 – Ca as $CaCO_3$ at the rate of 100% lime requirement (20g $CaCO_3$ column^{-1})
T_8 – Control

Fig 2. Layout of Column experiment

T_4R_1	T_1R_3	T_5R_1
T_3R_2	T_3R_3	T_7R_1
T_5R_3	T_1R_1	T_4R_2
T_6R_1	T_2R_2	T_8R_2
T_6R_2	T_8R_3	T_6R_3
T_2R_3	T_2R_1	T_1R_2
T_4R_3	T_7R_2	T_3R_1
T_8R_1	T_7R_3	T_5R_2

3.2.3 Double/dual root experiment

Double root experiment was conducted at KVK, Kannur, two node paired rooted serpentine layers were used for the dual root study. It was planted in such a way that the roots are allowed to grow in two different columns arranged side by side. The amendments were applied on column where sprouts emerged. Here also the same PVC columns of length 1 meter and width 0.063 meter filled with laterite profile soil collected from Wayanad were used for planting of vines. Treatments were applied to the column, from which sprout was emerged. Irrigation was carried out once in a day. The layout of double root experiment is shown in fig 3.

3.2.3.1 Design and layout

Crop	: Black pepper (*Piper nigrum* L.)
Variety	: Panniyur-1
Design	: CRD (Completely Randomized Design)
Replication	: 3
Treatments	: 8

3.2.3.2 Treatments

T_1 – Ca as Gypsum at the rate 50% of CEC (14g gypsum column^{-1})

T_2 – Ca as Burnt lime (CaO) at the rate of 50% of CEC (6g CaO column^{-1})

T_3 – Ca as Dolomite at the rate of 50% of CEC (14g dolomite column^{-1})

T_4 - Ca as Gypsum at the rate of 25% of CEC + Burnt lime (CaO) at the rate of 25% of CEC (7g gypsum + 3g CaO column^{-1})

T_5 – Ca as Gypsum at the rate of 25% of CEC + Dolomite at the rate of 25% of CEC (7g gypsum + 7g dolomite column^{-1})

T_6 – Ca as $CaCO_3$ at the rate of 50% lime requirement (10g $CaCO_3$ column^{-1})

T_7 – Ca as $CaCO_3$ at the rate of 100% lime requirement (20g $CaCO_3$ column^{-1})

T_8 – Control

Fig 3. Layout of Double/dual root experiment

T_3R_3	T_1R_1	T_8R_3
T_7R_1	T_6R_2	T_4R_1
T_4R_2	T_8R_2	T_2R_3
T_4R_3	T_7R_3	T_8R_1
T_5R_1	T_7R_2	T_2R_1
T_1R_2	T_1R_3	T_3R_2
T_6R_3	T_3R_1	T_5R_3
T_2R_2	T_6R1	T_5R_2

3.2.4 Soil and plant sample collection for analysis

Soil samples were collected at 60, 120 and 180 days interval from all soil layers in separate polythene covers and nutrient analysis is carried out and meanwhile root growth observations were also taken.

Plant samples were also collected for nutrient analysis from column root and double root experiment.

3.2.5 Biometric observations

The biometric observations such as plant height, number of leaves per plant, intermodal length, leaf area, root weight (both fresh and dry) and length of longest root were recorded at different stages from both column and double root experiments.

3.2.5.1 Plant height

Height of the plant was taken at 30, 60, 90, 120 and 180 DAP and mean was recorded in cm.

3.2.5.2 Number of leaves

The total number of leaves in each plant was counted from all the treatments at 30, 60, 90, 120 and 180 DAP and mean is recorded.

3.2.5.3 Internodal length

Third inter node from base of the plant was taken for measurement of length from each plant at 30, 60, 90, 120 and 180 DAP and mean readings were recorded in cm.

3.2.5.5 Leaf area

The leaf which was fully opened, fourth leaf from the shoot tip was considered for estimation of leaf area. Initially the leaf length and width was measured and leaf area was calculated by multiplying leaf length and leaf width with K factor (for black pepper 0.7) and expressed in cm^2. The leaf area was estimated at 30, 60, 90, 120 and 180 DAP and mean is recorded in cm^2.

3.2.5.6 *Root weight*

The fresh and dry root weights were measured from each plant sample and mean was recorded in grams at 60, 120 and 180 DAP.

3.2.5.7 Length of longest root

The length of longest root from all plant samples were measured at 60, 120 and 180 days after planting from each plant and mean was recorded in cm.

3.2.6 Collection of plant samples for analysis

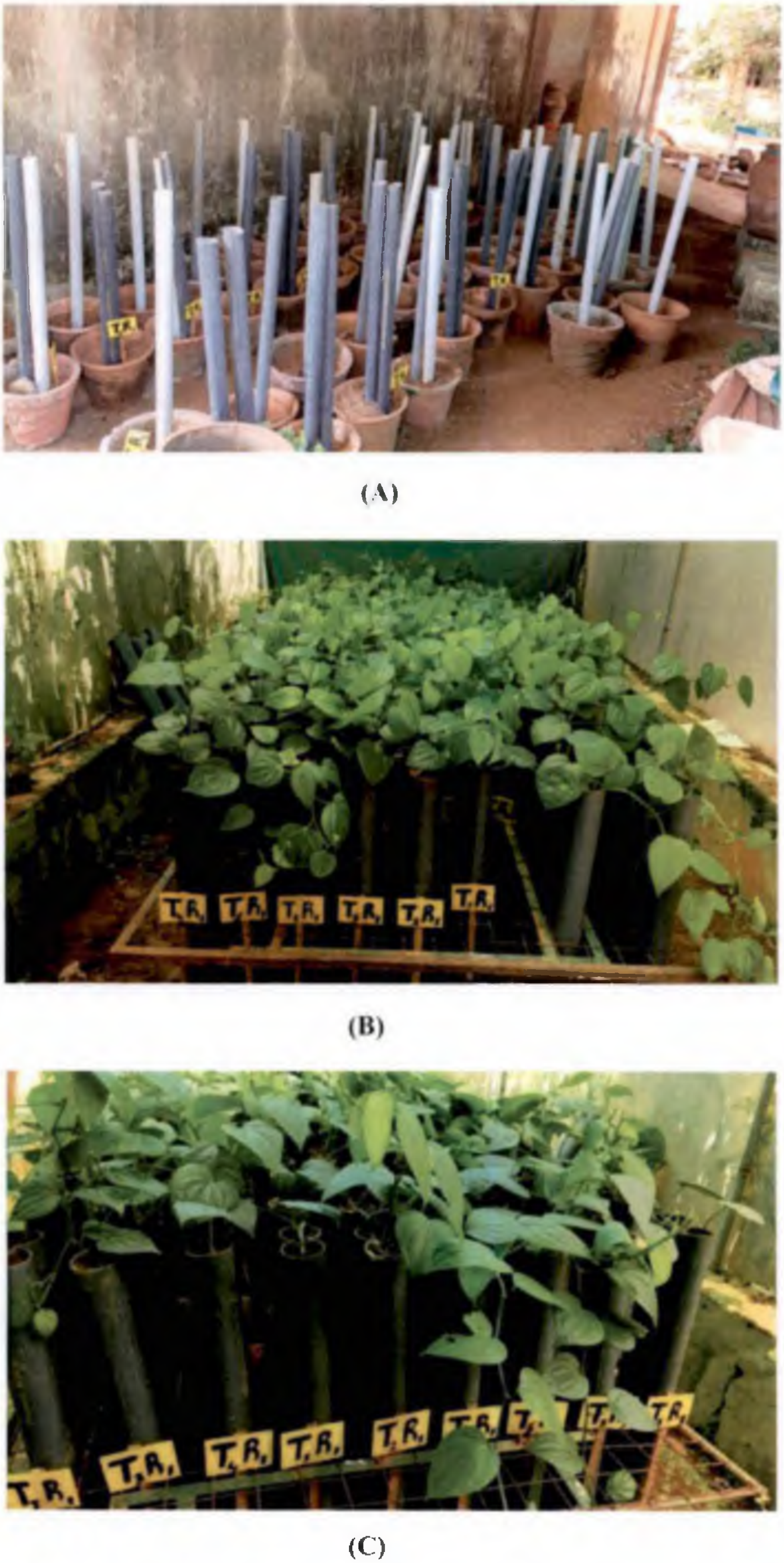
The leaves which are fully matured after 60,120 and 180 days of planting were collected from each treatment and analysed for total concentration of N, P, K, Ca, Mg, S and Al by standard procedures as given in table 6.

3.2.7 Statistical analysis

The results of various parameter obtained by incubation, column and double root experiments were analysed statistically for the test of significance by standard procedure using MSTAT-C package.

Table 6. Analytical methods followed for plant analysis

Sl. No	Parameter	Methods	Reference
1	Total N	Modified Kjeldhal digestion method	Jackson (1973)
2	Total P	Vanadomolybdate yellow colour method	Piper (1966)
3	Total K	Flame photometer	Jackson (1973)
4	Total Ca, Mg	Atomic Absorption Spectrometry	Issac and Kerber (1971)
5	Total S	Turbidometric method	Bhargava and Raghupathy (1995)
6	Total Al	Atomic Absorption Spectrometry	Emmel *et al.* (1977)



(A)

(B)

(C)

Plate 1. Different experiments carried out under investigation included (A) Incubation experiment at CoA, Padannakkad, (B) Column experiment at KVK, Kannur, (C) Double root experiment at KVK, Kannur.

Results

4. RESULTS

The investigation was carried out to study the performance of Gypsum as a soil ameliorant in growth and development of black pepper (*Piper nigrum* L.) and to evaluate its suitability in promoting the root growth into deeper soil layers of acid soil of Wayanad.

The whole investigation was carried out as three experiments, a incubation experiment was conducted at College of Agriculture, Padannakkad to know the effect of different amendments on soil acidity and pot culture studies (Column experiment and Double root experiment) at Krishi Vigyan Kendra, Kannur to know the influence of gypsum and other ameliorants (burnt lime, dolomite and $CaCO_3$) on growth and development of black pepper in acidic soil. The data were analysed statistically and results are presented in this chapter.

4.1 INCUBATION EXPERIMENT

Soils were collected from four different layers (0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm from top surface soil) of black pepper garden RARS, Ambalavayal. The treatments were kept under incubation in one metre column pipes depicting soil profile. Soil samples of four different layers in each column were collected at 60 and 120 DAI and analysed for soil pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al and results were interpreted as below.

4.1.1 Effect of amendments on soil chemical properties

4.1.1.1 Soil pH/acidity

Result of the soil pH at different layers of the incubation experiment were estimated and presented in Table 7.

There was a significant difference for soil pH in all four layers at 60 and 120 DAI. In all treated columns there was linear increase in soil pH with respect to period of incubation. Among the treatments in first layer (0-25 cm), T_7 (Ca as $CaCO_3$ at the rate of 100% lime requirement) recorded highest pH (5.69 and 6.45) at 60 and 120 DAI (Table 7). Treatments *viz.,* T_6, T_5, T_4 and T_3 were on par with best treatment (T_7) at both the intervals.

In second layer, (25-50 cm) treatment T_5 (Ca as gypsum the rate of 25% of CEC + dolomite at the rate of 25% of CEC) recorded maximum pH of 4.82 and 4.88 at 60 and 120 DAI, respectively, and was on par with T_4 and T_1 at 120 DAI. The treatment, T_1 (Ca as gypsum at the rate 50% of CEC) recorded highest pH of 4.45 and 4.31 at 60 DAI, 4.86 and 4.20 at 120 DAI in third (50-75 cm) and fourth (75-100 cm) layers respectively and was on par with the treatments T_2, T_4 and T_5 at 120 DAI in fourth soil layer. The lowest pH was recorded by control in all layers at both interval ranged from 4.21 at top layer to 3.15 on bottom third soil layer at 120 DAI (Table 7).

Table 7. Effect of soil amendments on soil pH in incubation experiment

	pH							
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	4.34	4.65	4.70	4.53	4.45	4.86	4.31	4.20
T_2	4.92	5.78	4.03	4.46	4.11	4.05	4.19	4.03
T_3	5.49	6.05	3.82	4.12	3.96	4.13	4.23	4.08
T_4	5.47	6.12	4.42	4.56	4.24	4.80	4.27	4.11
T_5	5.52	6.01	4.82	4.88	4.11	4.31	4.10	4.00
T_6	5.52	6.35	4.55	4.25	4.08	4.05	3.68	3.87
T_7	5.69	6.45	4.67	4.44	4.11	4.07	3.76	3.91
T_8	4.06	4.21	3.54	3.45	3.19	3.15	3.42	3.58
SEm (±)	0.15	0.17	0.13	0.12	0.12	0.12	0.11	0.11
CD (0.05)	0.45	0.50	0.38	0.37	0.35	0.36	0.34	0.34

4.1.1.2 Available Nitrogen

The mean value of available N content of the soil in four different layers at 60 and 120 DAI were revealed in the table 8.

There was increased significant difference for soil available N among the treatments in all the layers of soil at both the intervals (60 and 120 DAI), except first layer at 60 DAI.

Among the treatments, T_4 (Ca as gypsum at the rate of 25% of CEC + burnt lime (CaO) at the rate of 25% of CEC) recorded highest available N content of 658.5 and 625.5 kg ha^{-1} in first and 185.2 and 175.9 kg ha^{-1} in third layers soil at 60 and 120 DAI, respectively.

The treatment T_1 (Ca as gypsum at the rate 50% of CEC) noticed highest available nitrogen content of 458.3 and 435.3 kg ha^{-1} in second layer, 87.5 and 83.1 kg ha^{-1} in fourth layer at 60 and 120 DAI, respectively. The lowest available nitrogen content was ranged 560.2 to 46.8 kg ha^{-1} from first to fourth depth soil layers by control at both intervals.

Table 8. Effect of soil amendments on soil available N in incubation experiment

Nitrogen (kg ha^{-1})								
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	627.5	596.1	458.3	435.3	178.9	169.9	87.5	83.1
T_2	615.6	584.8	425.6	382.1	150.6	143.0	56.2	53.3
T_3	589.5	560.0	385.5	366.2	158.3	150.3	55.3	51.6
T_4	658.5	625.5	412.3	391.6	185.2	175.9	58.5	55.5
T_5	612.5	581.8	406.9	386.5	145.6	138.3	78.1	74.2
T_6	578.5	549.5	389.5	370.0	123.8	135.2	56.2	53.4
T_7	584.3	555.0	362.4	344.2	154.9	147.1	85.2	80.9
T_8	560.2	498.1	356.2	338.3	128.4	121.9	49.3	46.8
SEm (±)	17.5	16.4	11.5	10.9	4.4	4.2	1.9	1.8
CD (0.05)	NS	49.3	34.6	32.7	13.3	12.8	5.8	5.5

4.1.1.3 Available Phosphorus

The available phosphorus content showed significant difference among the treatments at 60 and 120 DAI in all the four different soil layers (Table 9).

The maximum available phosphorus content was recorded by T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) in top and bottom most soil layers (29.57 and 5.48 kg ha^{-1} at 60 DAI and 35.78 and 6.63 kg ha^{-1} at 120 DAI in first and fourth layers, respectively). In second and third soil layers T_1 (Ca as gypsum at the rate 50% of CEC) had maximum available P content of 15.48 and 5.63 kg ha^{-1} at 60 DAI, 18.73 and 6.81 kg ha^{-1} at 120 DAI respectively. The treatment, T_3 recorded least available phosphorus of 10.25 and 12.40 kg ha^{-1} at 60 and 120 DAI, respectively in first layer. While, control had minimum available phosphorus in other soil layers *viz.*, second, third and fourth, each showed 4.81 and 5.82 kg ha^{-1}, 1.21 and 1.46 kg ha^{-1}, 0.15 and 0.18 kg ha^{-1} at 60 and 120 DAI, respectively (Table 9).

Table 9. Effect of soil amendments on soil available P_2O_5 in incubation experiment

Phosphorus (kg ha^{-1})								
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	22.15	26.80	15.48	18.73	5.63	6.81	3.48	4.21
T_2	15.48	18.73	8.59	10.39	2.15	2.60	2.56	3.10
T_3	10.25	12.40	7.84	9.49	1.53	1.85	1.54	1.86
T_4	24.50	29.65	10.84	13.12	4.50	5.45	4.84	5.86
T_5	29.57	35.78	12.47	15.09	4.85	5.87	5.48	6.63
T_6	15.46	18.71	5.65	6.84	2.15	2.60	1.48	1.79
T_7	14.84	17.96	6.46	7.82	1.87	2.26	0.86	1.04
T_8	20.59	24.91	4.81	5.82	1.21	1.46	0.15	0.18
SEm (±)	0.58	0.70	0.28	0.34	0.10	0.12	0.09	0.11
CD (0.05)	1.73	2.09	0.83	1.01	0.29	0.36	0.27	0.33

4.1.1.4 Available Potassium

The analysis revealed that in all treatments available potassium recorded significantly higher value than control. The treatment T_4, which contain combination of gypsum and burnt lime, showed the highest potassium content ranging from 274.1 to 209.7 kg ha^{-1} in all layers of soil except in third layer at both stages of sampling. At third layer the T_7 (Ca as $CaCO_3$ at the rate of 100% lime requirement) recorded maximum available potassium content (248.8 and 270.0 kg ha^{-1} at 60 and 120 DAI, respectively). In all top three soil layers the T_4, T_5 and T_7 were on par for available K content, whereas control recorded the minimum available K ranging from 190.1 kg ha^{-1} in first layer at 60 DAI to 168.2

kg ha^{-1} in fourth layer at 120 DAI (Table 10). It was noticed that there was no much difference in soil available K content from first to fourth soil layers.

Table 10. Effect of soil amendments on soil available K_2O in incubation experiment

Potassium (kg ha^{-1})								
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	247.6	268.6	229.9	249.5	227.4	246.7	185.7	201.5
T_2	204.6	222.0	214.7	233.0	195.8	212.4	209.7	227.5
T_3	214.7	233.0	220.9	229.5	214.7	233.0	185.7	201.5
T_4	252.6	274.1	252.6	274.1	240.0	260.4	231.1	250.8
T_5	237.5	257.7	250.6	264.1	242.5	263.2	195.8	212.4
T_6	222.3	241.2	246.3	267.3	203.4	220.7	189.5	205.6
T_7	240.0	260.4	223.6	242.6	248.8	270.0	178.1	193.2
T_8	190.1	188.3	185.3	180.2	175.3	172.2	170.5	168.2
SEm (±)	6.5	7.0	6.6	7.1	6.3	6.8	5.6	6.0
CD (0.05)	19.6	21.1	19.9	21.4	19.0	20.5	16.8	18.8

4.1.1.5 Available Calcium

The results of the soil analysis at 60 and 120 DAI for the available calcium content are presented in Table 11.

There was increased significant difference among the treatments in which the treatment, T_1 (Ca as gypsum at the rate 50% of CEC) recorded highest calcium content in all soil layers from top to bottom. At 60 DAI the treatment T_1 recorded a maximum calcium content of 620, 589, 699 and 559 mg kg^{-1} at first, second, third and fourth soil layers, respectively. At 120 DAI the calcium content was recorded maximum in bottom soil layers (870 and 887 mg kg^{-1} in third and fourth layers respectively) as compared to top 2 soil layers (810 and 658 mg kg^{-1} in first and second layers, respectively). At 60 DAI the treatments T_1, T_4 and T_7 are on par each other in all soil layers. Similar trend was observed in all most all treated columns particularly where gypsum was added as soil ameliorant.

Table 11. Effect of soil amendments on soil available Ca in incubation experiment

Calcium (mg kg^{-1})								
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	620	810	589	658	699	870	559	887
T_2	510	510	484	493	575	598	460	609
T_3	528	628	501	511	595	740	476	754
T_4	410	440	379	390	488	353	350	370
T_5	420	420	399	406	473	480	379	489
T_6	456	468	433	441	514	520	411	530
T_7	580	582	551	562	654	674	523	687
T_8	215	213	204	204	242	244	194	195
SEm (±)	14.6	16.5	13.9	14.4	16.5	18.8	13.2	19.1
CD (0.05)	43.9	49.7	41.7	43.2	49.5	56.4	39.6	57.3

4.1.1.6 Available Magnesium

The treatments showed significantly higher values of available magnesium in all four soil layers at 60 and 120 DAI. The treatment, T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) showed highest magnesium content in first and third soil layers (26.5 and 33.1 mg kg^{-1}, 24.4 and 30.5 mg kg^{-1} in first and third layers at 60 and 120 DAI respectively) and also in second layer at 120 DAI (23.1 mg kg $^{-1}$). The treatment, T_3 (Ca as dolomite at the rate of 50% of CEC) recorded highest available Mg content of 20.3 mg kg^{-1} at 60 DAI in second layer and at both 60 and 120 DAI in fourth soil layer (25.9 and 32.4 mg kg^{-1}). The lowest available Mg content was recorded by T_2 in first layer at 60 and 120 DAI. In second and third soil layers T_6 at 60 DAI and control at 120 DAI showed least available Mg content. At other soil layers control recorded minimum available Mg content at all stages of sampling (Table 12).

Table 12. Effect of soil amendments on soil available Mg in incubation experiment

	Magnesium (mg kg^{-1})							
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	19.8	24.7	18.0	20.5	17.4	21.8	22.3	27.8
T_2	10.4	13.0	15.3	19.1	18.8	23.5	22.0	27.5
T_3	20.9	26.1	20.3	22.5	21.1	26.4	25.9	32.4
T_4	19.0	23.8	14.9	20.1	15.7	19.6	23.7	29.6
T_5	26.5	33.1	18.5	23.1	24.4	30.5	23.0	28.8
T_6	12.8	16.0	14.2	18.6	13.8	17.2	23.5	29.4
T_7	17.6	22.0	17.5	21.9	18.4	23.0	20.4	25.5
T_8	13.8	14.2	16.1	17.8	18.0	17.2	18.8	18.2
SEm (±)	0.5	0.6	0.4	0.5	0.5	0.6	0.6	0.7
CD (0.05)	1.5	1.9	1.4	1.7	1.6	1.9	1.9	2.3

4.1.1.7 Available Sulphur

The available sulphur content was showed significant difference in all four soil layers at all stages. The data were presented in Table 13.

The results from incubation experiment with respect to available sulphur content showed that, treatment T_1 (Ca as gypsum at the rate 50% of CEC) was significantly higher from rest of the treatments with maximum available S in all four soil layers at both 60 and 120 DAI. The treatment T_1 at 60 days after incubation recorded maximum values of 25.3, 35.5, 24.5 and 18.3 mg kg^{-1} and at 120 days after incubation 30.6, 43.0, 29.7 and 22.2 mg kg^{-1} in first, second, third and fourth soil layers respectively. The maximum of quadruple per cent increase in available S of T_1 over control was noticed in fourth layer at 120 DAI. Next to T_1 the treatments T_5 and T_4 recorded superior available soil S content. The lowest value was recorded by control in all depth of soil layers at both intervals. The available sulphur content showed increased trend from 60 to 120 DAI at all soil layers.

Table 13. Effect of soil amendments on soil available S in incubation experiment

Sulphur (mg kg^{-1})								
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	25.3	30.6	35.5	43.0	24.5	29.7	18.3	22.2
T_2	18.4	22.3	20.7	25.1	15.8	19.1	9.2	11.1
T_3	16.5	19.9	18.0	21.7	12.7	15.4	8.7	10.5
T_4	20.0	24.2	24.4	29.6	22.5	27.2	15.6	18.9
T_5	20.2	24.5	25.4	30.8	23.8	28.8	17.3	21.0
T_6	15.6	18.8	14.6	17.7	10.6	12.8	7.8	9.4
T_7	16.8	20.4	15.4	18.7	11.5	14.0	6.4	7.8
T_8	15.2	15.2	12.3	12.2	8.4	8.2	4.5	4.2
SEm (±)	0.5	0.6	0.6	0.7	0.5	0.6	0.3	0.4
CD (0.05)	1.6	1.9	1.9	2.2	1.5	1.8	1.0	1.2

4.1.1.8 Exchangeable Aluminium

A perusal of the data on soil exchangeable aluminium indicated that, the control recorded the highest value of exchangeable aluminium in all soil depth at both intervals of incubation experiment except in first layer at 60 DAI. In first layer at 60 DAI T_3 (Ca as dolomite at the rate of 50% of CEC) recorded highest value of 68.91 mg kg^{-1} of exchangeable aluminium. The control showed maximum exchangeable Al content of 75.6 and 75.3 mg kg^{-1} at 60 and 120 DAI respectively in third layer over other soil layers.

At both 60 and 120 DAI lowest exchangeable aluminium (54.6 and 44.8 mg kg^{-1}) was recorded by T_1 in first, treatment T_5 in second (52.6 and 43.1 mg kg^{-1}) and third (52.6 and 43.1 mg kg^{-1}) soil layers. The treatment T_4 had minimum exchangeable aluminium of 35.6 and 28.1 mg kg^{-1}in fourth layer at 60 and 120 DAI, respectively. The treatments T_1, T_5 and T_4 were on par at each incubation period in all layers. The treatment T_4 recorded 45.8 and 58.8 percent decreased exchangeable Al over control in most bottom soil layer at 120 DAI. The results on exchangeable aluminium in all four layers at 60 and 120 DAI are presented in Table 14.

Table 14. Effect of soil amendments on soil exchangeable Al content in incubation experiment

	Aluminium (mg kg^{-1})							
Treatment	0-25 cm		25-50 cm		50-75 cm		75-100 cm	
	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI	60 DAI	120 DAI
T_1	54.6	44.8	54.9	45.0	54.2	44.4	36.5	29.2
T_2	65.6	53.8	60.1	45.5	62.5	51.2	45.5	37.6
T_3	68.9	48.0	58.6	48.0	61.2	50.2	54.6	44.7
T_4	57.5	47.2	54.9	45.0	57.8	47.4	35.6	28.1
T_5	55.4	45.4	52.6	43.1	52.6	43.1	38.7	31.7
T_6	56.3	46.2	68.5	56.2	68.4	54.3	52.9	43.4
T_7	58.6	56.5	59.1	48.5	65.4	53.6	49.5	40.6
T_8	67.1	68.3	69.7	63.2	75.6	75.3	65.7	68.3
SEm (±)	1.7	1.5	1.7	1.4	1.8	1.4	1.4	1.2
CD (0.05)	5.2	4.4	5.2	4.3	5.4	4.4	4.1	3.6

4.2 COLUMN EXPERIMENT

4.2.1 Growth parameters

4.2.1.1 Plant height

The mean data on plant height recorded at different growth stages *viz.,* 30, 60, 90, 120 and 180 DAP are presented in the Table 15.

Biometric observation on plant height showed that there was no significant differences among treatments at 30 DAP, but showed increased significant difference at 60, 90, 120 and 180 DAP. Among the treatments, T_5 (Ca as gypsum at the rate of 50% of CEC) recorded maximum plant height (31.67 cm) at 60 DAP. While T_4 recorded the highest plant height of 54.59, 67.53 and 87.16 cm at 90, 120 and 180 DAP, respectively. The treatments *viz.,* T_2, T_5 and T_6 were on par with best treatment (T_4), which showed 38.99 per cent increased plant height than control at 180 DAP. The control was recorded with minimum plant height in all the stages ranged 16.21 to 53.17 cm from 30 to 180 DAP.

Table 15. Influence of soil amendments on plant height in column experiment

Plant height (cm)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	17.86	29.76	42.20	56.92	62.92
T_2	17.00	30.80	43.59	65.57	76.67
T_3	16.37	31.65	40.08	59.80	68.49
T_4	18.01	30.39	54.59	67.53	87.16
T_5	17.25	31.67	39.43	56.27	71.36
T_6	17.22	27.35	51.49	63.23	71.60
T_7	17.39	28.55	40.18	63.01	68.43
T_8	16.21	25.10	36.78	46.27	53.17
SEm (±)	0.84	1.07	1.73	5.05	2.75
CD (0.05)	NS	2.32	3.66	5.66	5.83

4.2.1.2 Number of leaves

The mean value of leaf count was presented in Table 16. The amendment treated plants showed increased significance difference at all the stages of plant growth for number of leaves per plant. Among the treatments, T_5 (Ca as gypsum at the rate of 50% of CEC) recorded maximum number of leaves per plant (5.06) at 30 DAP, while T_2 (Ca as gypsum at the rate of 20% of CEC) showed highest number of leaves per plant of 5.06 and 7.63 at 30 and 60 DAP, respectively. The treatments *viz.*, T_4, T_3, T_5 and T_7 on par with best treatment (T_2) at 60 DAP.

In the subsequent stages, treatment T_4 (Ca as gypsum at the rate of 40% of CEC) recorded maximum number of leaves per plant (10.73, 13.52 and 16.00 at 90, 120 and 180 DAP respectively) and was on par with T_6, T_7, T_5, T_2 and T_1.

The lowest number of leaves per plant at all observation stages was recorded in control. The T_4 plants noticed 66.67 per cent increased number of leaves than control plants at 180 DAP.

Table 16. Influence of soil amendments on number of leaves in column experiment

	Number of leaves per plant				
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	4.14	6.83	8.90	10.47	13.74
T_2	5.06	7.63	9.83	11.38	14.51
T_3	4.17	7.57	9.33	11.07	12.67
T_4	4.93	7.61	10.73	13.52	16.00
T_5	5.06	7.34	7.87	12.23	15.52
T_6	4.53	6.49	10.33	10.68	15.95
T_7	4.11	7.13	8.41	11.67	15.67
T_8	3.56	5.93	7.54	8.69	9.60
SEm(±)	0.44	0.27	0.42	0.83	1.42
CD (0.05)	0.94	0.58	0.89	1.75	3.00

4.2.1.3 Internodal length

The mean data pertaining to the effect of treatment on internodal length are accounted in the Table 17.

There was no significant difference among the treatments at 30, 60, 90 and 120 DAP. Among the treatments, T_4 (Ca as gypsum at the rate of 40% of CEC) recorded maximum internodal length of 4.23, 4.35, 4.45 and 4.51 cm at 30, 60, 90 and 120 DAP respectively. While, minimum internodal length was recorded by control (3.68 cm) at 30 DAP, but treatment, T_1 (Ca as gypsum at the rate of 10% of CEC) recorded lowest internodal length of 3.84, 3.98 and 4.18 cm at 60, 90 and 120 DAP, respectively.

After 180 days of planting the treatment differ significantly, in which treatment, T_4 recorded maximum internodal length of 5.33 cm and was on par with T_2, T_3 and T_8, mean while T_1 showed lowest internodal length of 4.26 cm. T_4 recorded 25.11 per cent increase internodal length over T_1.

Table 17. Influence of soil amendments on intermodal length in column experiment

Internodal length (cm)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	3.78	3.84	3.98	4.18	4.26
T_2	3.92	4.25	4.75	4.96	5.03
T_3	4.15	3.95	4.25	4.35	4.86
T_4	4.23	4.35	4.45	4.51	5.33
T_5	3.69	4.01	4.09	4.29	4.68
T_6	4.10	4.32	4.32	4.66	4.68
T_7	3.89	4.05	4.31	4.44	4.54
T_8	3.68	4.09	4.34	4.71	4.82
SEm (±)	0.30	0.28	0.40	0.32	0.27
CD (0.05)	NS	NS	NS	NS	0.57

4.2.1.4 Leaf area

The leaf area of black pepper was significantly influenced by the treatments in all growth stages and data are represented in Table 18.

There was a significant difference among the treatments for leaf area. Whereas treatment, T_6 (Ca as $CaCO_3$ at the rate of 50% lime requirement) recorded highest leaf area of 36.70, 37.67, 38.00 and 38.38 cm^2 at 30, 60, 90 and 120 DAP, respectively. While, treatment, T_5 (Ca as gypsum at the rate 50% of CEC) recorded maximum leaf area of 39.27 cm^2 at 180 DAP, it was on par with T_6, T_4, and T_3. Control showed minimum leaf area in all the growth stages. T_5 recorded 18.71 per cent increase leaf area over control at 180 days after planting.

4.2.1.5 Fresh root weight

The mean value of fresh root weight per plant recorded at different growth stages *viz.,* 60, 120 and 180 DAP were presented in the Table 19.

The biometric observation of fresh root weight per plant recorded higher significant difference at all stages of plant growth. Among treatments, T_4 (Ca as gypsum at the rate of 40% of CEC) recorded the maximum fresh weight of root per plant of 6.06, 9.25 and 10.07 g plant^{-1} at 60, 120 and 180 DAP, respectively. The treatments T_5 and T_3 were on par with T_4 at 180 DAP. Control had least fresh weight per plant of 3.28, 5.79 and 6.97 g plant^{-1}at all stages of observation *viz.*, 60, 120 and 180 DAP respectively. Treatment, T_4 recorded 84.75, 59.76 and 44.48 per cent increased fresh root weight per plant over control at 60, 120 and 180 DAP respectively.

Table 18. Influence of soil amendments on leaf area in column experiment

Leaf area (cm^2)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	30.10	30.57	31.92	32.62	33.61
T_2	32.52	33.15	34.09	34.44	35.27
T_3	33.32	34.33	34.68	35.43	36.22
T_4	35.41	36.20	36.64	37.15	38.00
T_5	36.01	36.85	37.35	38.28	39.27
T_6	36.70	37.67	38.00	38.38	39.24
T_7	30.67	31.49	31.98	33.22	34.07
T_8	28.89	30.18	31.18	32.04	33.08
SEm (±)	1.66	1.69	1.78	1.68	1.57
CD (0.05)	3.51	3.58	3.78	3.57	3.34

Table 19. Influence of soil amendments on fresh weight of root in column experiment

Fresh weight of root (g plant^{-1})			
Treatment	60 DAP	120 DAP	180 DAP
T_1	4.29	7.62	8.37
T_2	4.04	7.54	8.55
T_3	4.23	8.76	10.04
T_4	6.06	9.25	10.07
T_5	5.51	8.94	9.91
T_6	4.19	7.02	7.74
T_7	3.55	6.74	7.50
T_8	3.28	5.79	6.97
SEm (±)	0.25	0.49	0.35
CD (0.05)	0.54	1.03	0.73

Plate 2: Collection soil sample; (a) Column pipe with black pepper plants, (b) Cutting of column pipe, (c) Separation of cutted pipe into two parts, (d) Marked soil column with four layers of each 25 cm. (e) Collection of soil from each layer in polythene cover.

4.2.1.6 *Dry root weight*

The mean values of dry root weights per plant at different stages of observation *viz.,* 60, 120 and 180 DAP were depicted in Table 20.

All the amended treatments significantly differed and showed superior dry root weight than control. At all stages treatment T_4 (Ca as gypsum at the rate of 40% of CEC) noticed maximum dry root weight per plant (0.82, 2.53 and 2.86 g plant^{-1} at 60, 120 and 180 DAP respectively) and it was on par with the treatments T_3 (Ca as gypsum at the rate of 30% of CEC) and T_5 (Ca as gypsum at the rate of 50% of CEC) at both 120 and 180 DAP. The control showed minimum dry root weight per plant of 0.32, 0.94 and 1.32 g plant^{-1} at 60, 120 and 180 DAP respectively. The treatment T_4 recorded 156.25, 169.14 and 116.67 per cent increased dry root weight per plant over control at 60, 120 and 180 DAP, respectively.

Table 20. Influence of soil amendments on dry weight of root in column experiment

Dry weight of root (g plant^{-1})			
Treatment	60 DAP	120 DAP	180 DAP
T_1	0.51	1.71	1.83
T_2	0.54	1.58	1.93
T_3	0.56	2.26	2.75
T_4	0.82	2.53	2.86
T_5	0.78	2.04	2.52
T_6	0.66	1.20	1.59
T_7	0.43	1.59	1.82
T_8	0.32	0.94	1.32
SEm (±)	0.04	0.26	0.26
CD (0.05)	0.09	0.55	0.56

4.2.1.7 *Length of longest root*

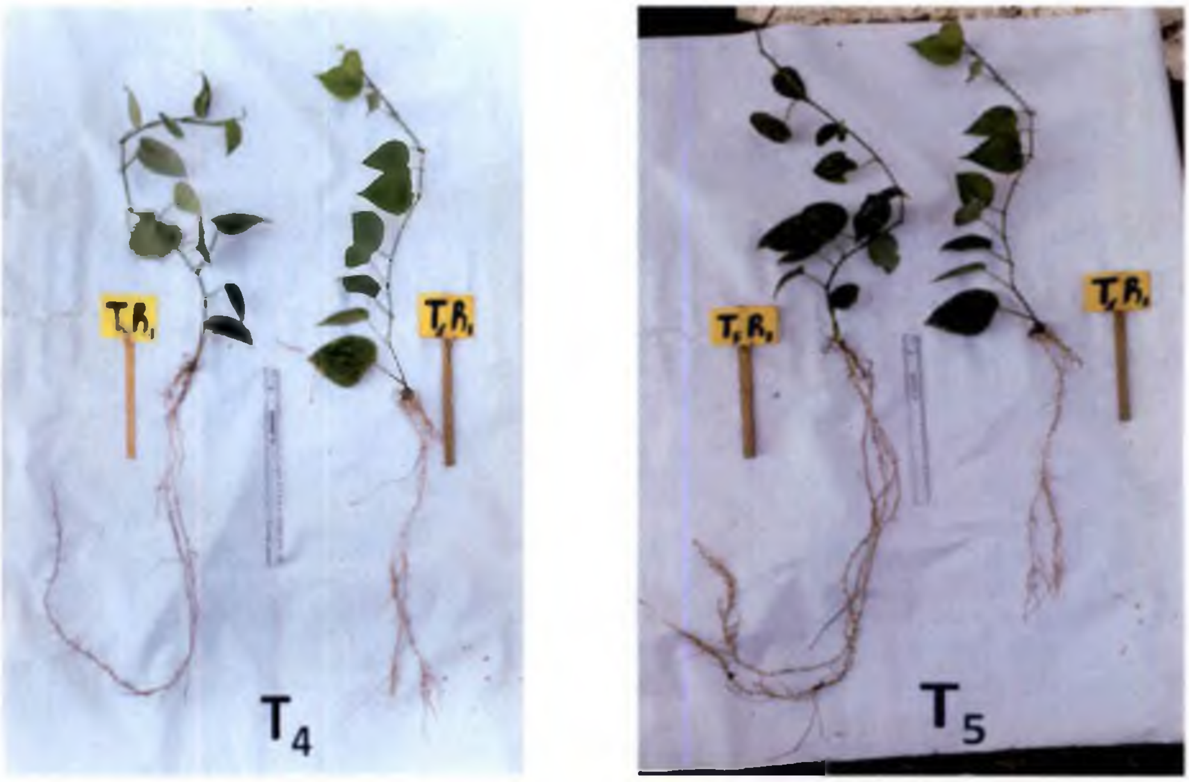
The mean values of length of longest root per plant are given in the Table 21. The data revealed that treatments had significant effect on length of longest root compared to control. At 60 and 120 DAP, T_4 recorded maximum length of longest root per plant (46.00 and 70.00 cm). At 180 DAP T_5 showed highest length of longest root per plant (97.00 cm) and was on par with T_4 (96.50 cm), T_2 (94.50 cm), T_3 (92.40 cm) and T_1 (90.80 cm). The control showed minimum length of longest root per plant of 17.40, 32.20 and 75.00 cm at 60, 120 and 180 DAP. The treatment T_5 noticed 29.34 per cent increased length of longest root per plant over control at 180 DAP.

Table 21. Influence of soil amendment on length of longest root in column experiment

Length of longest root (cm plant^{-1})			
Treatment	60 DAP	120 DAP	180 DAP
T_1	32.50	45.40	90.80
T_2	27.00	42.50	94.50
T_3	24.50	68.00	92.40
T_4	46.00	70.60	96.50
T_5	23.60	67.00	97.00
T_6	32.50	63.60	82.50
T_7	25.00	68.30	86.50
T_8	17.40	32.20	75.00
SEm (±)	1.20	2.39	3.66
CD (0.05)	2.54	5.07	7.76

4.2.2 Effect of amendments on soil chemical properties

Destructive soil samples from all the treatments with respect to root growth were collected in such a way that at 60 DAP the soil samples were collected only from first and second soil layers, but at 180 and 120 DAP the samples were collected from all four soil layers. The soil samples were analysed for pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al and results are as follows.



(A) (B)

Plate 3: Influence of soil amendments on root growth in column experiment; (A) Treatment T_4 in comparison with control; (B) Treatment T_5 in comparison with control.

4.2.2.1 Soil pH/acidity

The data on pH was illustrated in Table 22. There was significance difference among treatments with higher values in all soil layers at all stages of analysis. In first depth soil layer T_5 recorded maximum soil pH values of 4.86, 6.51 and 5.41 at 60, 120 and 180 DAP, respectively and it was on par with the treatments *viz.*, T_4, T_7 and T_3 at all intervals. Control had minimum pH values of 4.58 and 4.20 at 120 and 180 DAP in first soil layer. In second soil layer also T_5 showed maximum pH (5.41) at 60 DAP, but at 120 DAP T_4 recorded highest pH of 5.83 and at 180 DAP again T_5 showed superior pH of 4.70.

In third depth soil layer at 120 DAP T_5 (5.61) and at 180 DAP T_4 (4.61) shares maximum pH value and they were on par among them and also with T_3. The T_4 showed highest pH at both 120 and 180 DAP (5.12 and 4.86) in fourth soil layer. The control showed maximum acidity in second, third and fourth soil layers at every interval of soil analysis. The pH of control was ranged from 4.58 in first layer at 120 DAP soil sample to minimum of 3.24 in second layer of 60 DAP soil sample.

Table 22. Effect of soil amendments on soil pH in column experiment

pH										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	3.97	6.15	5.19	3.98	5.41	4.28	5.30	3.81	4.92	4.00
T_2	4.14	6.30	5.28	4.06	5.60	4.30	5.28	3.92	4.95	3.73
T_3	4.51	6.45	5.20	4.18	4.78	4.48	5.50	4.65	5.02	4.70
T_4	4.37	6.40	5.12	4.22	5.83	4.30	5.57	4.61	5.12	4.86
T_5	4.86	6.51	5.41	4.28	5.43	4.70	5.61	4.59	5.02	4.58
T_6	4.22	6.49	5.19	4.11	4.19	4.31	4.95	3.67	5.10	4.31
T_7	4.45	6.27	5.26	3.55	4.99	4.44	4.40	3.95	4.94	4.73
T_8	4.24	4.58	4.20	3.24	4.60	3.82	4.00	3.50	4.12	3.52
SEm (±)	0.50	0.26	0.22	0.14	0.22	0.18	0.20	0.16	0.2	0.18
CD (0.05)	0.37	0.54	0.46	0.32	0.44	0.38	0.43	0.33	0.43	0.37

4.2.2.2 Available Nitrogen

The perusal of the data on available soil nitrogen content was presented in Table 23. There was a significant difference among treatments in all soil layers at all stages except at 60 and 120 DAP in first soil layer. The treatment T_4 (Ca as gypsum at the rate 40% of CEC) recorded highest available N content of 665.0, 675.1 and 658.9 kg ha^{-1} in first layer, 526.2, 503.2 and 489.2 kg ha^{-1} in second layer at 60, 120 and 180 DAP, respectively.

In third layer at 120 and 180 DAP again T_4 showed maximum N content (321.2 and 225.6 kg ha^{-1}). In fourth soil layer at 120 DAP T_3 (95.6 kg ha^{-1}) and at 180 DAP T_4 (56.3 kg ha^{-1}) noticed highest available N content with respect to remaining treatment. The gypsum treated soil samples showed higher available nitrogen content than control in all surface and subsurface soil layers. The T_4 recorded 48.97, 75.9, 113.6 and 398.2 per cent increased soil available N content than control in first, second, third and fourth soil layers at 180 DAP respectively. Available N content showed a decreasing trend in all soil layers at all growth stages from top to bottom soil layers.

4.2.2.3 Available Phosphorus

Statistical analysis of the data pooled over three periods for soil of different depths revealed that application of higher dose of gypsum (T_4 and T_5) significantly increased the soil available phosphorus (Table 24). The T_5 significantly recorded maximum available P content in all initial three layer depth soils at all stages of soil analysis ranged 75.5 kg ha^{-1} in first layer of 60 DAP to 18.7 kg ha^{-1} in third layer of 180 DAP. The treatment T_5 recorded 24.9, 33.5 and 53.3 per cent increased available P over control at 180 DAI in first, second and third soil layers respectively. At bottom last layer T_4 recorded maximum available P at both 120 and 180 DAP (3.5 and 4.7 kg ha^{-1}). The phosphorus content noticed decreased availability from surface soil layer to bottom soil layers upto a depth of 100 cm. The minimum P content was noticed in treatments T_3, T_2 and T_1 in first layer at 60, 120 and 180 DAP respectively. In second and third

Table 23. Effect of soil amendments on soil available N in column experiment

Nitrogen (kg ha^{-1})										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	624.3	615.2	652.3	524.0	456.0	425.3	316.5	154.3	70.2	45.3
T_2	654.5	602.3	642.7	512.0	425.3	486.0	312.3	168.3	75.6	48.3
T_3	645.0	612.2	623.9	524.0	468.5	461.2	256.3	145.6	95.6	38.6
T_4	665.0	675.1	658.9	526.2	503.2	489.2	321.2	225.6	81.4	56.3
T_5	645.3	586.4	631.2	456.3	435.0	423.5	278.3	215.3	86.3	25.6
T_6	663.2	645.6	586.4	520.1	486.0	256.3	152.3	100.3	56.3	10.2
T_7	615.5	614.0	456.3	487.3	436.7	241.9	253.6	121.5	85.6	16.9
T_8	623.7	560.5	442.3	456.3	415.3	278.1	106.3	105.6	41.23	11.3
SEm (±)	26.22	24.57	24.19	20.48	18.54	15.21	11.19	6.56	3.10	1.46
CD (0.05)	NS	NS	51.28	43.41	39.31	32.24	23.72	13.91	6.57	3.10

layers T_2 and in fourth layer control recorded the minimum available P at all interval of soil analysis.

Table 24. Effect of soil amendments on soil available P_2O_5 in column experiment

	Phosphorus (kg ha^{-1})									
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	54.2	40.3	45.2	25.3	20.5	23.7	10.2	13.0	2.8	4.0
T_2	56.2	33.2	53.2	18.2	16.5	19.7	8.3	11.1	2.1	3.3
T_3	48.5	39.5	47.2	24.5	24.3	27.5	15.2	18.0	2.8	4.0
T_4	58.2	39.5	54.6	24.5	22.5	25.7	14.2	17.0	3.5	4.7
T_5	75.5	47.0	60.2	32.0	28.3	31.5	15.8	18.7	3.2	4.4
T_6	58.6	41.3	52.3	26.3	24.7	27.9	12.4	15.2	2.4	3.7
T_7	63.2	40.4	52.3	25.4	24.5	27.7	11.2	14.0	2.4	3.7
T_8	58.2	39.1	48.2	24.1	20.4	23.6	9.4	12.2	1.4	1.2
SEm (±)	2.4	1.6	2.1	1.0	0.9	1.0	0.5	0.6	0.1	0.1
CD (0.05)	5.1	3.4	4.4	2.1	1.9	2.2	1.0	1.3	0.2	0.3

4.2.2.4 Available Potassium

The results of available potassium content of soil samples collected from the column root experiment at 60, 120 and 180 DAP from all four depth soil layers. The data are represented in Table 25.

The treatments were significantly differed from control and in the first soil layer at 60 DAP T_5 (309.12 kg ha^{-1}) and at 120 and 180 DAP T_4 (288.75 and 328.35 kg ha^{-1}) recorded maximum soil available potassium content. The treatment T_4 recorded 125.2 per cent of increased K content over control at 180 DAP in first soil layer. In the second layer at 60 DAP (120.9 kg ha^{-1}) T_7 and at 120 (252.0 kg ha^{-1}) and 180 DAP (253.2 kg ha^{-1}) T_4 recorded highest available K content compared to other treatments and control. The bottom soil layers showed low quantity of potassium availability than above three soil layers in all stages. Gypsum applied treatments T_1 in third layer (250.0 and 145.2 kg ha^{-1} at 60 and 120 respectively) and gypsum with burnt lime contained treatment T_4 in fourth layer (175.0 and 135.2 kg ha^{-1} at 60 and 120 respectively) had significantly higher available potassium content in all stages of soil analysis. The treatment T_4 recorded 83.2 and 68.6 per cent of increased K content than control in bottom most soil layer. In all soil layer at each interval of soil analysis control recorded with minimum soil available potassium content.

Table 25. Effect of soil amendments on soil available K_2O in column experiment

Potassium (kg ha^{-1})										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	241.9	160.3	225.0	94.0	168.0	145.2	250.0	145.2	125.0	95.3
T_2	255.3	201.2	285.2	98.4	140.0	136.2	175.0	124.5	125.0	112.2
T_3	228.4	143.7	252.2	94.0	140.0	115.2	175.0	142.3	150.0	114.2
T_4	295.0	288.7	328.3	67.2	252.0	253.2	150.0	135.2	175.0	135.2
T_5	309.1	287.5	315.4	67.2	224.0	186.4	155.0	135.2	125.0	135.2
T_6	180.6	170.0	222.5	53.7	196.0	165.2	150.0	112.3	125.0	112.3
T_7	201.6	196.2	155.2	120.9	210.0	235.6	150.0	112.3	150.0	98.2
T_8	174.7	121.2	145.8	54.5	65.3	108.4	105.3	84.6	95.5	80.2
SEm (±)	9.0	2.9	13.5	4.5	7.9	7.1	6.7	4.8	5.6	4.5
CD (0.05)	19.2	13.2	28.7	9.6	16.8	15.1	14.2	10.2	12.0	9.6

4.2.2.5 Available Calcium

The data on available calcium content of soil at 60, 120 and 180 are accounted in the Table 26. The calcium content examined at different period showed that there was a significant difference among the treatments and all the treatments showed superior available calcium content than control.

At 60 DAP, T_7 showed maximum available Ca content in first (697.2 mg kg^{-1}) and second soil layers (725.1 mg kg^{-1}). At later stages (120 and 180 DAP) the data on application of amendment into soil reveals that gypsum applied at higher levels, increase the soil calcium availability. In first (748.1 and 897.6 mg kg^{-1} at 120 and 180 DAP respectively) and second soil layers (733.4 and 815.3 mg kg^{-1} at 120 and 180 DAP respectively) treatment T_5 recorded highest Ca content.

In third and fourth soil depth layers the higher amount of calcium was recorded in T_5 (Ca as gypsum at the rate 50% of CEC) (769.5 and 761.4 mg kg^{-1} at 120 DAP, 973.0 and 913.2 mg kg^{-1} at 180 DAP in third and fourth layer respectively). The Ca availability in the bottom fourth soil layer was maximum at 180 DAP, which was highest over rest of soil layers. At 180 DAP in third and fourth layer T_5 recorded 222.72 and 484.51 per cent increased available Ca concentration than control.

4.2.2.6 Available Magnesium

In the case of soil available magnesium, the treatments are significantly differed with one another and all are superior to control. At the top surface T_3 (Ca as gypsum at the rate 30% of CEC) (75.4 mg kg^{-1}) at 60 DAP and T_1 (Ca as gypsum at the rate 10% of CEC) at 120 and 180 DAP recorded maximum available Mg content of 83.5 and 81.2 mg kg^{-1}. In second layer at 60 (55.6 mg kg^{-1}) and 120 DAP (56.0 mg kg^{-1}) T_1 and at 180 DAP (49.3 mg kg^{-1}) T_4 had maximum available Mg content. In third soil layer at both 120 and 180 DAP (43.6 and 45.2 mg kg^{-1}) and in fourth layers at 180 DAP (39.21 mg kg^{-1}) T_7 recorded higher Mg content but at 120 DAP in fourth layer T_4 showed maximum available Mg content. The data are presented in the Table 27.

Table 26. Effect of soil amendments on soil available Ca in column experiment

Treatment	Calcium (mg kg^{-1})									
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DA4	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	562.0	618.0	741.6	584.7	605.5	673.5	635.6	642.8	628.3	753.6
T_2	588.4	646.5	775.2	611.7	633.6	704.7	664.2	566.5	657.0	788.4
T_3	562.0	588.5	645.6	572.5	682.1	683.3	696.1	718.4	653.4	751.6
T_4	586.7	644.2	772.8	609.8	631.3	702.5	662.3	766.7	655.6	786.0
T_5	680.0	748.1	897.6	707.4	733.4	815.3	769.5	973.0	761.4	913.2
T_6	498.2	547.7	656.4	518.1	536.5	596.4	562.5	560.0	556.3	667.2
T_7	697.2	686.3	823.2	725.1	672.9	747.9	705.4	791.1	697.7	836.4
T_8	235.0	248.7	141.2	214.3	185.7	185.3	212.2	301.5	168.8	156.2
SEm (±)	15.5	16.7	19.9	16.1	16.3	18.5	17.1	19.9	16.9	20.2
CD (0.05)	46.6	50.1	59.6	48.4	48.9	54.3	51.3	59.7	50.6	60.6

Table 27. Effect of soil amendments on soil available Mg in column experiment

Magnesium (mg kg^{-1})										
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
Treatment	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	71.7	83.5	81.2	55.6	56.0	45.3	27.1	28.3	39.7	25.3
T_2	73.3	75.0	65.2	51.9	39.9	34.5	28.5	27.5	36.7	25.1
T_3	75.4	81.5	78.2	46.1	33.0	31.2	40.2	28.5	35.7	26.8
T_4	70.3	79.0	75.2	48.9	53.5	49.3	33.7	31.2	39.5	31.2
T_5	74.5	77.5	75.3	45.4	49.8	49.0	36.7	35.1	37.2	38.1
T_6	62.1	76.0	73.2	53.8	40.4	38.2	32.5	34.2	31.6	33.2
T_7	64.0	75.0	71.2	48.3	53.0	47.2	43.6	45.2	34.4	39.2
T_8	54.5	65.4	48.3	43.5	28.3	24.8	23.2	20.4	27.3	15.3
SEm (±)	2.8	3.1	2.9	2.0	1.8	1.6	1.3	1.3	1.4	1.2
CD (0.05)	5.9	6.6	6.2	4.2	3.9	3.5	2.9	2.7	3.0	2.6

4.2.2.7 Available Sulphur

The available sulphur content was estimated at 60, 120 and 180 DAP from each profile layers of soil samples and data were presented in Table 28.

The statistical analysis on data of soil available sulphur described that, the treatment are differed significantly among treatments in all layers and intervals of soil analysis. In surface soil layer treatment T_6 (Ca as $CaCO_3$ at the rate of 50% lime requirement) recorded with minimum sulphur content, followed by control in bottom three depth soil layers. The values indicated that, availability of sulphur is more at all gypsum treated soils; while T_5 (Ca as gypsum at the rate 50% of CEC) recorded maximum sulphur value in all the soil layers. The treatment, T_5 recorded maximum sulphur content of 40.2, 68.2 and 55.3 mg kg^{-1} at 60, 120 and 180 DAP, respectively in first soil layer. In second layer T_5 recorded highest available S content of 11.1, 15.2 and 15.3 mg kg^{-1} at 60, 120 and 180 DAP, respectively. Third soil layer (19.5 and 20.3 mg kg^{-1} at 120 and 180 DAP respectively) had higher available sulphur in soil compared to second soil layer. In fourth soil layer maximum of 10.4 and 11.2 mg kg-1 available S content was also recorded by T_5 and was on par with T_4 at 180 DAP.

Table 28. Effect of soil amendments on soil available S in column experiment

Treatment	Sulphur (mg kg^{-1})									
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T$_1$	9.6	25.3	23.2	6.9	15.2	18.2	16.2	18.3	9.2	9.2
T$_2$	18.4	32.2	28.3	10.4	10.2	13.2	12.5	14.2	10.2	10.3
T$_3$	29.5	48.2	35.2	8.1	11.2	10.2	14.2	15.3	9.5	10.2
T$_4$	36.5	55.3	32.3	11.8	15.2	17.2	18.2	19.2	9.2	11.2
T$_5$	40.2	68.2	55.3	11.1	15.2	15.3	19.5	20.3	10.4	11.2
T$_6$	6.5	8.2	6.3	3.1	6.5	8.3	5.2	6.2	2.5	3.2
T$_7$	10.0	11.2	10.2	3.5	10.2	11.2	8.3	7.4	1.2	2.2
T$_8$	13.8	13.2	8.5	0.3	1.2	1.3	0.4	0.5	0.2	0.3
SEm (±)	0.9	1.5	1.1	0.3	0.4	0.5	0.5	0.5	0.3	0.3
CD (0.05)	2.0	3.22	2.4	0.6	1.0	1.1	1.1	1.2	0.7	0.8

4.2.2.8 Exchangeable Aluminium

With respect to aluminium content of soil the control showed higher value in all four soil layers at all soil analysis interval of experiment. The treatments are significantly different, and T$_5$ showed minimum exchangeable aluminium content compared to rest of the treatment in each four depth soil layers. In first soil layer 24.4, 26.3 and 22.7 mg kg^{-1} of exchangeable Al and in second layer 22.7, 30.1 and 26.3 mg kg^{-1} of exchangeable Al at 60, 120 and 180 DAP respectively was recorded by treatment T$_5$. The treatment T$_5$ also at third (36.4 and 32.4 mg kg^{-1} at 120 and 180 DAP respectively) and fourth (27.5 and 18.2 mg kg^{-1} at 120 and 180 DAP respectively) soil layers recorded minimum exchangeable Al. Next to the T$_5$, the treatment T$_4$ recorded minimum exchangeable Al. The higher exchangeable aluminium content was noticed in third soil depth layer than rest of the soil layers. The data on exchangeable soil layer are depicted in the Table 29. The treatment T$_5$ showed 49.8, 46.6, 41.3 and 57.0 per cent decreased exchangeable Al content over control in first; second, third and fourth soil layers respectively at 180 DAP.

Table 29. Effect of soil amendments on soil exchangeable Al in column experiment

Aluminium (mg kg^{-1})										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	31.9	28.8	25.6	34.2	31.6	30.1	40.7	37.6	31.9	26.1
T_2	30.1	27.5	24.9	36.4	30.2	28.6	40.3	37.7	28.9	22.9
T_3	32.1	28.8	26.4	33.4	28.9	27.9	39.9	36.1	28.1	22.2
T_4	28.8	26.5	24.0	32.6	27.1	26.4	37.8	36.1	28.8	21.5
T_5	24.4	26.3	22.7	30.1	26.3	22.6	36.4	32.4	27.5	18.2
T_6	34.4	31.9	33.1	42.2	30.2	30.9	41.7	43.6	31.6	27.4
T_7	33.4	30.9	31.7	40.9	30.0	30.1	41.1	40.7	30.1	26.7
T_8	43.2	43.5	45.2	52.1	45.2	42.3	55.4	55.2	41.5	42.3
SEm (±)	1.3	1.2	1.2	1.5	1.2	1.2	1.7	1.6	1.2	1.0
CD (0.05)	2.8	2.6	2.6	3.3	2.7	2.6	3.6	3.5	2.7	2.3

4.2.3 Influence of amendments on nutrient status of leaves

Plant samples also collected at each soil sampling from all the treatments and analysed for leaf concentration of total N, P, K, Ca, Mg, S and Al and results are as follows.

4.2.3.1 Total Nitrogen, Phosphorus and Potassium

The leaf total nitrogen, phosphorus and potassium content were estimated at 60, 120 and 180 DAP and data are presented in Table 30.

There was a significant difference among the treatments with respect to nitrogen in leaf. The treatments which contain gypsum showed higher nitrogen content as compared to control and treatment which contain $CaCO_3$. At all the stages treatments, T_4 (Ca as gypsum at the rate 40% of CEC) and T_5 (Ca as gypsum at the rate 50% of CEC) recorded maximum value (2.24, 2.80 and 3.22 per cent at 60, 120 and 180 DAP respectively) and lowest value was recorded in control.

The treatments are significantly differ for P content in leaves and maximum P content was recorded in T_4, which was ranged from 0.34 to 0.44 per cent. The lowest content was noticed in control.

Regarding K content in leaves, all the treatments are superior to control and are significantly different among the treatments. At 60, 120 and 180 DAP the highest K content of 1.60, 1.76 and 1.94 per cent respectively was recorded in treatment T_4 and was on par with T_5 and T_3.

Table 30. Effect of soil amendments on total N, P and K content of leaves in column experiment

Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP
T_1	1.68	1.78	1.93	0.10	0.30	0.34	0.97	1.09	1.30
T_2	2.24	2.34	2.58	0.21	0.25	0.29	1.03	1.15	1.37
T_3	2.24	2.74	3.15	0.18	0.21	0.24	1.35	1.49	1.74
T_4	2.24	2.80	3.22	0.34	0.39	0.44	1.60	1.76	1.94
T_5	2.24	2.80	3.22	0.28	0.31	0.36	1.48	1.63	1.89
T_6	1.12	1.68	1.93	0.19	0.21	0.24	1.02	1.14	1.35
T_7	1.68	2.24	2.58	0.13	0.19	0.22	1.10	1.23	1.45
T_8	1.12	1.32	1.52	0.09	0.18	0.20	0.66	0.87	0.98
SEm (±)	0.05	0.07	0.07	0.01	0.01	0.01	0.06	0.07	0.07
CD (0.05)	0.16	0.20	0.22	0.02	0.02	0.03	0.19	0.20	0.22

4.2.3.2 Total Calcium, Magnesium and Sulphur

Leaf samples collected at 60, 120 and 180 days after planting were analysed for total Ca, Mg and S content and data were depicted in Table 31.

The treatments showed significantly higher difference for total Ca content in leaves at 60, 120 and 180 DAP. At 60 DAP T_5 (2.33 per cent) and in subsequent two periods T_4 (2.91 and 3.20 per cent at 120 and 180 DAP) recorded maximum leaf Ca content. At all stages control showed minimum value of total Ca content in leaves.

The Mg content of leaves reveals that in treated plants the Mg content showed less value as compared to control plants. The lowest value was recorded in T_2 (Ca as gypsum at the rate 20% of CEC) ranged from 214 to 317 mg kg^{-1}. Among treatments, treatment T_7 recorded higher Mg concentration (336, 395 and 397 mg kg^{-1} at 60, 120 and 180 DAP, respectively) in leaves at all stages.

Based on total S content of leaves, data describes that treatments were significantly different with control and also among them. In all growth period T_5 (Ca as gypsum at the rate 50% of CEC) showed highest sulphur content (365 to 438 mg kg^{-1}).

Table 31. Effect of soil amendments on total Ca, Mg and S content of leaves in column experiment

Treatment	Calcium (%)			Magnesium (mg kg^{-1})			Sulphur (mg kg^{-1})		
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP
T_1	2.18	2.65	2.92	240	363	324	335	402	466
T_2	2.19	2.45	2.70	214	328	317	345	414	480
T_3	1.86	2.42	2.66	231	392	336	328	393	456
T_4	2.24	2.91	3.20	248	375	346	352	422	489
T_5	2.33	2.90	3.19	278	374	354	365	438	508
T_6	2.13	1.45	1.60	312	365	326	265	276	297
T_7	2.14	2.75	2.95	336	395	397	270	287	312
T_8	1.15	1.24	1.26	406	414	460	250	256	265
SEm (±)	0.06	0.07	0.08	10.49	11.28	12.44	9.14	10.62	12.12
CD (0.05)	0.18	0.21	0.23	27.43	29.82	33.28	27.40	31.83	36.34

4.2.3.3 Total Aluminium

The Al content of leaves showed significance difference among treatments, in which control showed higher value of Al compared to other treatments. At early stage of plant growth (60 DAP) T_2 recorded minimum Al content (1.23 mg kg^{-1}) and at later T_5 (2.45 and 2.56 mg kg^{-1}) recorded least value of Al at leaves of black pepper. The control showed a higher value of Al content ranged from 1.37 to 4.56 mg kg^{-1}. The data on Al content of leaves was given in Table 32.

Table 32. Effect of soil amendments on total Al content of leaves in column experiment

Aluminium (mg kg $^{-1}$)			
Treatment	60 DAP	120 DAP	180 DAP
T_1	1.25	2.60	2.68
T_2	1.23	3.52	3.63
T_3	1.27	3.71	3.82
T_4	1.32	2.56	2.64
T_5	1.28	2.45	2.52
T_6	1.33	3.01	3.10
T_7	1.25	2.62	2.70
T_8	1.37	4.45	4.56
SEm (±)	0.05	0.09	0.09
CD (0.05)	0.16	0.28	0.28

4.3 DOUBLE ROOT EXPERIMENT

4.3.1 Growth parameter

In double root experiment, the biometric observations of the plants were recorded at 30, 60, 90, 120 and 180 DAP.

4.3.1.1 Plant height

The observation on plant height of eight treatments including control was subjected to pooled analysis over the six month period and the results are given in Table 33.

For all treatments there was a steady increase in plant height. The rate of increase or the difference between treatments was significant at all growth period except at 120 days after planting. Overall performance of the treatments were evaluated by taking average of six month data and it indicates that ameliorant treated plants were superior to control. The combined amendment T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) showed higher level of plant height than rest of the treatments at all stages of plant growth. The T_5 recorded maximum plant height of 32.97, 65.00, 106.98, 123.72 and 176.51 cm height at 30, 60, 90, 120 and 180 DAP respectively. The control had minimum plant height of 141.28 cm at the end of the experiment. The T_5 recorded 24.93 per cent increased plant heights over control at 180 DAP.

Table 33. Influence of soil amendments on plant height in double root experiment

Plant height (cm)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	26.93	44.83	67.45	110.58	150.52
T_2	27.15	45.03	95.62	120.19	166.32
T_3	28.19	42.14	75.97	105.39	159.57
T_4	32.35	63.49	91.76	108.30	149.00
T_5	32.97	65.00	106.98	123.72	176.51
T_6	32.78	61.43	91.75	121.79	173.79
T_7	31.50	53.29	90.79	112.87	145.08
T_8	26.75	44.91	63.67	97.67	141.28
SEm(±)	2.37	1.94	3.43	9.65	10.63
CD (0.05)	5.03	4.10	7.26	NS	22.53

4.3.1.2 Number of leaves

The mean data for number of leaves per plant at different stages of observation were illustrated in Table 34.

There was no significance difference at 30, 120 and 180 DAP for number of leaves per plant, but showed increased significant difference at 60 and 90 DAP. Among the treatment, T_5 recorded maximum number of leaves per plant at 60 and 90 days after planting (11.44 and 14.39 respectively), compared to control (7.89 and 9.89). As growth continues among the treatments steady increase in number of leaves was observed but there was no significant difference between the treatments after 120 and 180 days of planting. All treated plants showed higher number of leaves than the control plants. At 180 DAP T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) showed maximum number of leaves (25.00) which greater than all other treatments and is showed 40.21 per cent increased number of leaves per plant than control (17.83).

Table 34. Influence of soil amendments on number of leaves in double root experiment

Number of leaves per plant					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	5.78	7.89	11.11	16.89	23.00
T_2	6.00	9.78	14.78	17.39	20.00
T_3	5.94	8.67	9.89	14.55	22.00
T_4	5.78	10.67	13.00	15.00	21.33
T_5	6.22	11.44	14.39	16.78	25.00
T_6	5.67	10.67	12.28	15.44	20.33
T_7	5.55	11.00	12.67	16.89	21.67
T_8	5.00	7.89	9.89	13.50	17.83
SEm(±)	0.67	0.98	1.52	1.26	1.91
CD (0.05)	NS	2.07	3.23	NS	NS

4.3.1.3 Internodal length

The mean values for internodal length at different stages *viz.*, 30, 60, 90, 120 and 180 DAP were presented in Table 35.

There was no significant difference for internodal length in all stages plant growth observation under study. Which indicates no variation was exist among the treatments. Hence all treatments are recommendable. .

Table 35. Influence of soil amendments on internodal length in double root experiment

Internodal length (cm)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	6.77	6.83	6.89	7.00	7.25
T_2	6.52	6.64	6.68	6.72	6.87
T_3	6.27	6.62	6.66	6.76	6.95
T_4	6.18	6.21	6.63	6.89	7.22
T_5	6.73	6.54	6.60	6.65	6.83
T_6	6.01	6.22	6.28	6.48	6.78
T_7	5.93	6.17	6.41	6.60	6.81
T_8	5.55	5.82	6.14	6.45	6.71
SEm(±)	0.49	0.39	0.48	0.45	0.42
CD (0.05)	NS	NS	NS	NS	NS

4.3.1.4 Leaf area

The mean data on leaf area were recorded and presented in the Table 36. It describes that treatments are differed significantly among each other. The treatment T_4 (Ca as gypsum at the rate of 25% of CEC + burnt lime (CaO) at the rate of 25% of CEC) showed maximum leaf area over all the period, with a range of 49.63 cm^2 to 65.64 cm^2 and was on par with T_5 and T_6 upto 120 days after planting. But at the end at 180 DAP T_4 recorded maximum leaf area, and treatments T_2, T_6, T_1, T_5, T_3 and T_7 are on par. Control was recorded lowest leaf area in all intervals of growth observation *viz.*, 30, 60, 90, 120 and 180 DAP.

Table 36. Influence of soil amendments on leaf area in double root experiment

Leaf area (cm^2)					
Treatment	30 DAP	60 DAP	90 DAP	120 DAP	180 DAP
T_1	43.39	44.92	46.38	47.96	59.92
T_2	45.37	46.64	48.08	49.88	61.21
T_3	46.07	47.42	48.97	49.83	58.11
T_4	49.63	51.15	52.87	55.34	65.64
T_5	49.07	50.64	52.07	52.69	58.92
T_6	48.64	49.55	51.17	52.85	60.29
T_7	43.40	45.73	47.68	51.47	57.92
T_8	42.45	43.93	45.42	46.23	50.69
SEm(±)	1.12	1.21	1.18	1.22	1.63
CD (0.05)	2.38	2.56	2.52	2.59	3.46

4.3.1.5 Fresh root weight

Root samples from both amended and unamended columns were collected and analysed statistically for characters like fresh root weight, dry weight and length of longest root per plant and results are as follows.

At 60, 120 and 180 DAP, in treated column; there was increased significant difference among treatments. At 60 DAP T_4 (Ca as gypsum at the rate of 25% of CEC + Burnt lime (CaO) at the rate of 25% of CEC) recorded the maximum fresh weight of root per plant (2.50 g $plant^{-1}$). The treatment T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) recorded highest fresh root weight per plant of 10.52 and 10.73 g plant^{-1} at 120 and 180 DAP, respectively and was on par with T_4. The lowest fresh root weight per plant was recorded in treatments T_3 (Ca as dolomite at the rate of 50 % of CEC) at 60 DAP (1.49 g plant^{-1}) and T_2 (Ca as burnt lime (CaO) at the rate of 50% of CEC) at 120 (5.09 g plant^{-1}) and 180 DAP (5.48 g plant^{-1}).

Meanwhile on untreated soil column treatments also showed increased significance difference among treatments. At 60 DAP, treatment T_5 (1.91 g plant^{-1}) had higher fresh root weight and at 120 and 180 DAP, T_6 showed maximum fresh root weight of 8.71 and 9.05 g plant^{-1}. The data are given in the Table 37.

Table 37. Influence of soil amendments on fresh weight of root in double root experiment

Fresh weight of roots (g plant^{-1})						
Treatment	60 DAP		120 DAP		180 DAP	
	Treated column	Untreated column	Treated column	Untreated column	Treated column	Untreated column
T_1	1.59	0.86	6.10	6.97	6.53	7.87
T_2	1.81	0.60	5.09	6.16	5.48	7.32
T_3	1.49	0.93	8.63	5.58	9.41	6.80
T_4	2.50	1.52	10.48	5.52	10.64	6.76
T_5	1.61	1.91	10.52	5.81	10.73	6.86
T_6	1.61	1.03	5.23	8.71	5.88	9.05
T_7	1.53	1.41	5.64	4.63	6.15	5.58
T_8	1.64	1.37	5.97	5.44	6.47	6.27
SEm (±)	0.09	0.06	0.53	0.28	0.42	0.30
CD (0.05)	0.18	0.13	1.13	0.60	0.90	0.63

4.3.1.6 Dry root weight

The oven dry weight of fresh roots was recorded increased significant difference in all growth stages. This indicates the presence of variation between the treatments. In all the stages T_4 (Ca as gypsum at the rate of 40% of CEC) recorded maximum dry root weight per plant (0.77, 3.10 and 3.12 g plant^{-1} at 60, 120 and 180 DAP respectively) and it was on par with T_5 at 120 and 180 DAP. The treatment T_4 recorded 86.8 per cent higher dry root weight over control at 180 DAP.

In the case of untreated column dry weight roots per plant at 60 DAP, treatment T_4 (1.21 g) recorded highest dry weight. The treatment T_6 (Ca as $CaCO_3$ at the rate of 50% lime requirement) had highest dry root weight per plant (2.10 and 2.22 g at 120 and 180 DAP respectively) in the last two intervals *viz.*, 120 and 180 DAP. The data on dry root weight values were recorded in Table 38.

Table 38. Influence of soil amendments on dry weight of root in double root experiment

Dry weight of roots (g plant^{-1})						
Treatment	60 DAP		120 DAP		180 DAP	
	Treated column	Untreated column	Treated column	Untreated column	Treated column	Untreated column
T_1	0.34	0.36	1.67	1.96	1.85	2.12
T_2	0.38	0.33	1.33	1.73	1.48	1.90
T_3	0.41	0.34	2.04	1.51	2.06	1.74
T_4	0.77	1.21	3.10	1.55	3.12	1.75
T_5	0.34	0.78	3.05	1.69	3.06	1.87
T_6	0.57	0.53	1.46	2.10	1.49	2.22
T_7	0.52	0.58	1.66	1.34	1.68	1.48
T_8	0.50	0.53	1.67	1.59	1.67	1.73
SEm (±)	0.04	0.04	0.20	0.15	0.19	0.15
CD (0.05)	0.09	0.09	0.42	0.33	0.41	0.31

4.3.1.7 Length of longest root

The length of longest root is also measured from both treated and untreated columns and values are illustrated in Table 39.

It describes that the combined amendment treated columns showed superior significant different from rest of the treatments. Among the treatments at 60 DAP, T_4 (40.00 cm) and at 120 and 180 DAP, T_5 (88.50 cm and 108.40 cm) recorded maximum length of longest root per plant.

In untreated column pipes also there was increased significance difference among treatments except at 60 DAP. The control at 60 DAP (32.00 cm) and T_5 (78.00 cm and 90.00 cm) at 120 and 180 DAP noticed maximum length of longest root per plant. The treatment T_3 at 60 DAP (24.00 cm) and control showed minimum length of longest root per plant at 120 (65.70 cm) and 180 DAP (78.60 cm).

Table 39. Influence of soil amendments on length of longest root in double root experiment

Length of longest root (cm plant^{-1})						
Treatment	60 DAP		120 DAP		180 DAP	
	Treated column	Untreated column	Treated column	Untreated column	Treated column	Untreated column
T_1	32.00	30.00	80.60	74.00	100.50	84.60
T_2	32.50	28.00	82.00	70.50	102.40	86.50
T_3	38.00	24.00	83.00	68.00	105.60	88.60
T_4	40.00	31.00	86.50	71.00	105.70	87.20
T_5	31.00	26.00	88.50	78.00	108.40	90.00
T_6	35.00	29.40	78.50	70.50	98.36	81.60
T_7	37.00	31.00	80.50	75.40	100.55	83.20
T_8	30.00	32.00	77.50	65.70	90.56	78.60
SEm (±)	1.41	1.19	3.36	9.41	4.23	3.47
CD (0.05)	2.99	2.51	7.12	NS	8.97	7.37

(A) (B)

Plate 4: Influence of soil amendments on root growth in double root experiment; (A) Treatment T_4 in comparison with control; (B) Treatment T_5 in comparison with control.

4.3.2 Effect of amendments on soil chemical properties

Analysis of soil samples from all the ameliorant treated column with respect to root growth are collected at 60, 120 and 180 DAP in first and second depth soil layers and 120 and 180 DAP in third and fourth soil layers and analysed for soil pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al and results are as follows.

4.3.2.1 Soil pH/ acidity

The soil pH showed significant difference between treatments. This indicates presence of variation among the treatments. The results revealed that in first layer treatment, T_7 (6.65, 6.47 and 6.62 at 60, 120 and 180 DAP respectively), in second layer T_1 (5.18, 4.52 and 4.50 at 60, 120 and 180 DAP respectively) recorded maximum pH over other treatments. In third (4.33 and 4.53 at 120 and 180 DAP respectively) and fourth (5.04 and 4.62 at 120 and 180 DAP respectively) layer soils also T_1 (Ca as gypsum at the rate 50% of CEC) showed maximum pH at both 120 and 180 DAP. Control recorded lowest value of pH at all stages of observation. The results are shown in Table 40.

Table 40. Effect of soil amendments on soil pH in double root experiment

	pH									
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	6.12	6.24	6.15	5.18	4.52	4.50	4.33	4.53	5.04	4.62
T_2	6.56	5.42	5.35	5.07	4.19	4.28	4.23	4.35	4.68	4.48
T_3	6.40	6.46	5.94	4.88	4.39	4.31	4.29	3.37	4.53	4.26
T_4	6.46	5.96	5.57	5.14	4.48	4.37	4.33	3.74	4.44	4.50
T_5	5.78	5.57	5.89	4.82	4.47	4.29	4.16	4.04	4.35	4.13
T_6	5.97	6.33	6.09	5.17	4.49	4.25	3.94	4.39	4.30	4.18
T_7	6.65	6.47	6.62	5.08	4.50	4.15	4.75	4.33	4.97	4.43
T_8	4.35	4.40	4.35	4.25	4.10	3.74	3.70	3.45	3.60	3.89
SEm (±)	0.17	0.17	0.16	0.15	0.12	0.12	0.12	0.11	0.13	0.12
CD (0.05)	0.52	0.50	0.49	0.44	0.37	0.35	0.37	0.34	0.9	0.36

4.3.2.2 Available Nitrogen

Among the treatments there was a significant difference for available nitrogen content in soil. Among the treatments, T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) at 60 (650.1 kg ha^{-1}) and T_1 (Ca as gypsum at the rate 50% of CEC) at 120 (664.8 kg ha^{-1}) and 180 DAP (563.2 kg ha^{-1}) showed higher available soil N content in first layer of soil, as compared to other treatments. In second soil layer at 60 DAP T_4 (562.2 kg ha^{-1}) and in rest of intervals T_2 (351.2 and 268.2 kg ha^{-1} at 120 and 180 DAP respectively) recorded maximum N content. In third soil layer treatments T_5 (288.5 kg ha^{-1}) and T_4 (213.2) at 120 and 180 DAP, respectively showed highest soil available N content. In fourth layer T_1 (141.1 and 86.6 kg ha^{-1} at 120 and 180 DAP respectively) at both period showed superior N content. The control showed minimum available N in all soil layers at every interval of destructive sampling. The data are depicted in the Table 41.

4.3.2.3 Available Phosphorus

The treatment showed significant difference in soil available P content at each layer of soil with respect to all intervals of soil analysis. The influence of treatments showed that in first depth of soil T_5 at 60 DAP (54.23 kg ha^{-1}) and T_1 at 120 (54.23 kg ha^{-1}) and 180 DAP (51.36 kg ha^{-1}) recorded maximum available P content as compared to other treatments. In second soil layer at every interval T_4 (28.32, 30.14 and 19.36 kg ha^{-1} at 60. 120 and 180 DAP respectively) showed maximum P content and was on par with T_5. In third soil layer T_4 (12.35 kg ha^{-1}) and T_3 (5.26 kg ha^{-1}) at 120 and 180 DAP respectively noticed maximum P content. In fourth soil layer T_1 (5.60 and 2.36 kg ha^{-1} at 120 and 180 DAP respectively) at both period showed superior P content. The control showed minimum value of P in all layers at every interval. The data on soil P content are presented in the Table 42.

Table 41. Effect of soil amendments on soil available N in double root experiment

	Nitrogen (kg ha^{-1})									
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	621.3	664.8	563.2	475.3	288.5	256.3	225.3	145.8	141.1	86.6
T_2	625.3	627.2	542.1	512.3	351.2	268.2	250.8	156.2	107.2	59.2
T_3	642.3	501.7	486.2	485.2	338.6	215.3	250.8	145.3	101.6	25.3
T_4	625.4	443.7	469.3	562.2	263.4	245.3	250.8	213.2	99.4	26.3
T_5	650.1	451.5	425.3	548.2	301.0	236.2	288.5	125.3	89.3	35.2
T_6	586.2	439.0	523.2	524.2	288.5	225.3	250.8	135.2	109.6	20.3
T_7	645.2	426.5	542.3	541.3	275.9	257.2	263.4	119.3	107.0	19.3
T_8	610.2	338.6	458.3	458.3	225.7	203.7	213.2	75.3	83.3	15.3
SEm (±)	18.0	14.1	14.5	14.8	8.4	6.9	7.2	4.1	3.06	1.23
CD (0.05)	NS	42.3	43.5	44.5	25.4	20.7	21.6	12.4	9.18	3.70

Table 42. Effect of soil amendments on soil available P_2O_5 in double root experiment

	Phosphorus (kg ha^{-1})									
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
Treatment	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	52.32	54.23	51.36	24.53	24.53	15.36	10.23	5.23	5.60	2.36
T_2	45.23	47.25	45.26	23.53	25.35	16.36	8.35	4.25	1.86	1.24
T_3	50.21	48.53	40.23	21.32	22.35	12.36	8.25	5.26	1.56	1.02
T_4	52.32	53.21	45.23	28.32	30.14	19.36	12.35	4.23	3.21	0.31
T_5	54.23	50.26	48.25	27.35	27.25	21.23	9.58	4.25	2.76	1.00
T_6	48.32	48.23	42.36	24.35	26.35	15.36	7.52	4.36	3.21	1.52
T_7	51.23	49.25	40.25	24.35	21.25	15.45	5.63	4.25	1.23	1.03
T_8	38.23	40.25	32.02	18.44	15.24	10.32	5.36	2.56	0.86	0.58
SEm (±)	1.42	1.42	1.25	0.70	0.71	0.46	0.25	0.13	0.08	0.04
CD (0.05)	4.26	4.25	3.76	2.09	2.11	1.39	0.75	0.38	0.25	0.11

4.3.2.4 Available Potassium

Statistical analysis of the data pooled over three periods for soils of different depths revealed that application of ameliorants significantly increased the soil available K (Table 28). In the initial surface soil layer the treatments T_5 (185.0 kg ha^{-1}), T_4 (210.0 kg ha^{-1}) and T_6 (195.7 kg ha^{-1}), in second soil depth layer T_7 (126.0 kg ha^{-1}), T_4 (158.0 kg ha^{-1}) and T_6 (135.3 kg ha^{-1}) at 60, 120 and 180 DAP, respectively recorded highest K content as compare to rest of the treatments and control. In third layer T_1 (119.0 and 110.3 kg ha^{-1} at 120 and 180 DAP respectively) and at last in bottom layer T_5 (142.0 and 110.2 kg ha^{-1} at 120 and 180 DAP respectively) recorded maximum available K content at both interval of soil analysis. Also the available K content decreases from top to bottom soil layers. The data for available K content are presented in the Table 43.

Table 43. Effect of soil amendments on soil available K_2O in double root experiment

Potassium (kg ha^{-1})										
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
Treatment	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	152.0	178.0	153.0	98.0	129.0	124.7	119.0	110.3	95.0	75.3
T_2	146.0	196.0	125.3	86.0	120.0	112.4	109.0	105.3	75.0	60.2
T_3	135.0	158.0	156.0	94.0	104.0	91.2	105.0	96.3	74.0	58.3
T_4	125.0	210.0	185.5	92.0	158.0	102.3	98.0	62.3	77.0	64.5
T_5	185.0	200.0	180.5	94.0	145.0	111.0	96.0	57.1	142.0	110.2
T_6	176.0	200.0	195.7	112.0	154.0	135.3	85.0	75.3	79.0	70.0
T_7	156.0	209.0	185.7	126.0	119.0	105.8	92.0	86.3	72.2	56.3
T_8	89.0	126.0	105.0	86.0	109.0	83.4	76.0	48.3	71.0	40.2
SEm (±)	4.28	5.39	4.77	2.87	3.79	3.16	2.84	2.40	2.56	2.01
CD(0.05)	12.83	16.15	14.29	8.60	11.35	9.47	8.51	7.19	7.66	6.02

4.3.2.6 Available Calcium

The Ca content of the soil after 60, 120 and 180 DAP indicated that all the ameliorated columns were significantly differed with each other and control recorded lowest value of available Ca in all soil depth layers. The treatment, T_1 (Ca as gypsum at the rate of 50 % of CEC) showed a significant higher value in all intervals and also at each four depth soil layers. The Ca content of T_1 in first layer was 615.0, 676.5 and 913.2 mg kg^{-1}, in second layer 664.2, 704.0 and 957.5 mg kg^{-1} at 60, 120 and 180 DAP respectively. The treatment, T_1 had available Ca of 739.2 and 967.0 mg kg^{-1} in third layer and 754.0 and 984.0 mg kg^{-1} in fourth layer at 120 and 180 DAP respectively. Next to the treatment T_1, T_5 showed a higher Ca availability. At each interval of Ca analysis the rate of Ca content increases drastically in all treatments and maximum was recorded at 180 DAP over 60 and 120 DAP. It also reveals that compare to top soil layer at bottom soil layers (third and fourth) contained more available Ca as experiment period prolongs. The data are presented in Table 44.

Table 44. Effect of soil amendments on soil available Ca in double root experiment

	Calcium (mg kg^{-1})									
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T$_1$	615.0	676.5	913.2	664.2	704.0	957.5	739.2	967.0	754.0	984.0
T$_2$	486.0	534.6	721.7	524.8	556.3	756.6	584.1	800.3	595.8	815.2
T$_3$	512.0	563.2	760.3	552.9	586.1	797.1	615.4	843.1	627.7	854.0
T$_4$	410.0	451.0	608.8	442.8	469.3	638.3	492.8	675.1	502.6	754.0
T$_5$	586.0	644.6	870.2	632.8	670.8	912.3	704.4	922.0	718.4	935.0
T$_6$	435.0	475.0	584.0	438.0	482.0	597.0	506.1	623.0	501.2	475.0
T$_7$	576.0	602.0	745.0	584.0	615.0	785.0	645.7	810.0	623.1	654.0
T$_8$	216.0	210.0	156.3	201.4	186.2	201.3	202.5	185.3	224.3	165.3
SEm (±)	14.2	15.5	20.3	15.1	16.0	21.3	16.8	22.0	17.0	21.6
CD (0.05)	42.7	46.5	61.0	45.3	48.0	64.0	50.4	66.1	50.9	64.8

4.3.2.6 Available Magnesium

Table 45 showed the data on available Mg content in soil at different layers. It was noticed that Mg content was higher in top two soil depth (0-25 cm and 26-50 cm) as compare to bottom soil layers and treatments are significantly differed at all the experimental soil layers on all three intervals. The treatments recorded higher value than to control. In first (65.4, 75.3 and 72.2 mg kg^{-1} at 60, 120 and 180 DAP respectively), second soil layers at 60, 120 and 180 DAP (59.6, 60.6 and 60.1 mg kg^{-1} at 60, 120 and 180 DAP respectively) and third layer at 120 DAP (45.1 mg kg^{-1}) treatment T$_3$ (Ca as dolomite at the rate of 50% of CEC) recorded maximum soil available Mg content. In third layer at 180 DAP (45.2 mg kg^{-1}) and fourth layer at both 120 (38.7 mg kg^{-1}) and 180 DAP (35.7 mg kg^{-1}) T$_5$ (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) had highest available Mg content of soil.

Table 45. **Effect of soil amendments on available Mg in double root experiment**

Magnesium (mg kg^{-1})										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	60.2	62.5	56.3	54.2	54.5	54.2	29.0	24.2	25.9	26.3
T_2	58.6	65.5	64.2	48.2	51.5	40.2	40.0	38.4	26.2	20.1
T_3	65.4	75.3	72.2	59.6	60.6	60.1	45.1	42.2	26.0	24.1
T_4	49.0	55.0	45.2	35.3	25.1	25.5	31.2	30.2	29.1	32.4
T_5	51.2	67.5	60.2	47.2	33.1	45.2	44.0	45.2	38.7	35.7
T_6	57.0	67.5	53.7	25.3	33.5	42.1	39.8	35.0	29.4	24.2
T_7	52.0	68.0	54.2	31.2	29.0	31.4	24.5	22.1	29.1	25.1
T_8	40.2	40.6	35.6	28.3	25.6	20.3	20.3	15.6	18.3	17.4
SEm (±)	1.5	1.8	1.6	1.2	1.1	1.2	1.0	0.9	0.8	0.7
CD (0.05)	4.7	5.5	4.8	3.7	3.5	3.6	3.0	2.8	2.4	2.2

4.3.2.7 Available Sulphur

With respect to soil S content the results showed that the treatments which contain gypsum as the ameliorant showed significantly maximum S content. At 60 DAP (24.5 mg kg^{-1}) in first layer and at both 60 (26.6 mg kg^{-1}) and 120 DAP (30.5 mg kg^{-1}) in second soil layers T_1 (Ca as gypsum at the rate of 50 % of CEC) recorded highest available S content. In first layer at 120 (30.2 mg kg^{-1}) and 180 DAP (28.5 mg kg^{-1}) and second layer at 180 DAP (27.2 mg kg^{-1}) T_5 showed highest available S content. In third soil layer at both 120 and 180 DAP T_1 recorded with maximum available S content of 24.6 and 26.3 mg kg^{-1} respectively. In fourth soil layer T_5 at120 DAP (16.47 mg kg^{-1}) and T_1 at 180 DAP (22.15 mg kg^{-1}) recorded with maximum available S content. In all soil depth layers minimum available S content was noticed in control. Table 46 showed data on soil available S content.

Table 46. Effect of soil amendments on soil available S in double root experiment

Sulphur (mg kg^{-1})										
Treatment	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	24.5	25.3	26.3	26.6	30.5	19.2	24.6	26.3	13.5	22.1
T_2	14.5	15.3	16.5	18.3	17.8	15.2	12.3	10.2	8.5	6.2
T_3	15.3	13.6	12.2	15.3	15.2	14.1	10.2	8.2	9.5	8.1
T_4	20.5	22.5	23.2	20.3	25.6	26.5	16.5	19.4	12.5	18.2
T_5	21.3	30.2	28.5	24.5	28.5	27.2	20.3	24.2	16.4	21.2
T_6	12.3	10.5	11.2	10.2	12.5	10.8	6.3	8.4	4.5	4.3
T_7	13.2	13.2	12.3	12.3	10.2	8.3	7.6	6.2	8.3	7.1
T_8	10.2	9.2	8.2	10.1	11.2	10.2	4.5	5.2	1.2	1.4
SEm (±)	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.3
CD (0.05)	1.4	1.6	1.6	1.5	1.7	1.5	1.2	1.3	0.9	1.1

4.2.3.8 Exchangeable Aluminium

The data on soil exchangeable Al reveals that there was a significant difference among the treatments and amended soil contained less content of Al than control at all intervals of soil samples in each layer. The data describes that in the top first soil layers treatments T_7 (30.2, 30.5 mg kg^{-1} at 60 and 120 DAP, respectively) and T_1 (32.3 mg kg^{-1} at 180 DAP) showed least exchangeable Al content. At all three intervals treatment T_1 had minimum exchangeable Al soil content in second layer (38.2, 32.2 and 30.2 mg kg^{-1} at 60, 120 and 180 DAP respectively). In third soil layer lowest exchangeable Al content was recorded by treatments T_1 and T_4 at 120 DAP (35.3 mg kg^{-1}) and T_5 at 180 DAP (29.3 mg kg^{-1}). The treatment, T_4 showed minimum exchangeable Al content in fourth soil layer at both intervals *viz.*, 120 (30.7 mg kg^{-1}) and 180 DAP (27.2 mg kg^{-1}). The results on soil Al content are given in the Table 47.

Table 47. Effect of soil amendments on soil exchangeable Al in double root experiment

Treatment	Aluminium (mg kg^{-1})									
	0-25 cm			25-50 cm			50-75 cm		75-100 cm	
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	120 DAP	180 DAP	120 DAP	180 DAP
T_1	40.2	42.3	32.3	38.2	32.2	30.2	35.3	31.2	32.3	24.3
T_2	45.2	48.6	45.2	45.2	42.3	40.2	54.1	38.7	35.3	38.3
T_3	47.2	52.3	44.3	42.5	44.2	41.2	52.3	40.5	38.3	40.2
T_4	38.5	41.2	38.3	38.5	37.2	34.2	35.3	30.2	30.7	27.2
T_5	40.2	40.3	39.2	39.4	35.3	35.2	40.2	29.3	34.2	28.3
T_6	32.4	35.6	46.3	40.2	35.3	44.3	40.2	47.3	31.2	41.3
T_7	30.2	30.5	44.3	39.2	35.3	42.3	42.3	45.2	31.2	42.6
T_8	55.2	53.2	52.3	56.2	55.2	57.3	64.3	69.2	65.3	65.2
SEm (±)	1.1	1.2	1.2	1.2	1.1	1.2	1.3	1.1	1.0	1.0
CD (0.05)	3.4	3.7	3.7	3.7	3.4	3.6	3.9	3.4	3.0	3.1

4.3.3 Influence of amendments on nutrient status of leaves

Plant samples were collected at the period 60, 120 and 180 DAP and analysed for total N, P, K, Ca, Mg, S and Al. The results are as follows.

4.3.3.1 Total Nitrogen, Phosphorus and Potassium

N content in leaves showed significant difference in all intervals of analysis, T_5 recorded maximum N content, which was ranged from 2.24 to 3.06 per cent and control was showed least value of N. Rest of the treatments also showed increasing trend of N content in leaves also superior to control.

In case of total P and K of leaves treatments are significantly differed, the treatments T_4 (0.36, 0.43 and 0.48 per cent at 60, 120 and 180 DAP respectively) and T_5 (1.56, 1.67 and 1.70 per cent at 60, 120 and 180 DAP respectively) are recorded maximum P and K content of leaves respectively. In control the minimum value of P and K was recorded implies that treatment had positive influence on plant leaves nutrient status. The Table 48 showed data on total N, P and K content of leaves.

Table 48. Effect of soil amendments on total N, P and K content of leaves in double root experiment

Treatment	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP
T_1	1.68	2.24	2.55	0.22	0.27	0.38	1.43	1.51	1.54
T_2	1.68	1.78	1.92	0.13	0.16	0.16	1.26	1.33	1.35
T_3	2.24	2.40	2.74	0.12	0.14	0.14	1.42	1.56	1.59
T_4	1.68	2.56	2.92	0.36	0.43	0.48	1.42	1.54	1.57
T_5	2.24	2.68	3.06	0.21	0.36	0.41	1.56	1.67	1.70
T_6	1.68	1.74	1.98	0.24	0.23	0.29	1.21	1.28	1.30
T_7	1.12	2.12	2.42	0.28	0.30	0.35	1.34	1.41	1.43
T_8	1.12	1.68	1.92	0.10	0.14	0.20	0.75	0.78	0.82
SEm (±)	0.05	0.06	0.07	0.01	0.01	0.01	0.07	0.07	0.07
CD (0.05)	0.15	0.19	0.21	0.02	0.02	0.03	0.20	0.21	0.21

4.3.3.2 Total Calcium, magnesium and sulphur

For leaf Ca levels over three intervals, there was a significant difference among the treatments and T_5 (Ca as Gypsum at the rate of 25% of CEC + Dolomite at the rate of 25% of CEC) recorded maximum Ca content ranged from 1.86 to 2.28.

The maximum leaf Mg content was recorded by control at all three stage leaf analysis (372, 440 and 465 mg kg^{-1} at 60, 120 and 180 DAP respectively). Next to the control the treatments T_3, T_5 and T_7 also recorded higher content of leaf Mg content. It was noticed that as the growth progress the Mg content also increased.

The sulphur content of leaves also had significant difference and at 60 and 120 DAP T_4 (421 and 484 mg kg^{-1}) and at 180 DAP T_5 (526 mg kg^{-1}) recorded maximum sulphur content and they were on par with T_1.

There was a steady increase in this nutrient accumulation in all treatments and control plants showed minimum of these nutrients in their leaves. The data illustrated in Table 49.

Table 49. Effect of soil amendments on total Ca, Mg and S content of leaves in double root experiment

Treatment	Calcium (%)			Magnesium (mg kg^{-1})			Sulphur (mg kg^{-1})		
	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP	60 DAP	120 DAP	180 DAP
T_1	1.78	2.05	2.15	359	361	372	410	467	498
T_2	1.60	2.14	2.35	331	361	372	321	354	375
T_3	1.45	1.98	2.20	365	430	437	315	362	380
T_4	1.72	2.20	2.25	315	354	368	421	484	520
T_5	1.86	2.24	2.28	386	438	475	418	482	526
T_6	1.41	2.12	2.16	367	406	420	325	327	386
T_7	1.72	2.15	2.18	318	416	458	354	345	421
T_8	1.10	1.12	1.11	372	440	465	187	201	220
SEm (±)	0.07	0.07	0.09	10.95	11.01	12.67	10.39	11.45	12.54
CD (0.05)	0.15	0.22	0.27	24.82	31.00	32.99	31.14	34.32	37.58

4.3.3.3 Total Aluminium

There was a significant difference among the treatments with respect to leaf Al content and maximum Al content was recorded in control at each interval of plant growth, which was ranged from 2.70 to 4.12 mg kg^{-1}. The minimum Al content was recorded in T_4 at 60 (1.34 mg kg^{-1}), 120 (1.48 mg kg^{-1}) and 180 (1.65 mg kg^{-1}) DAP. The Table 50 showed data on Al content of leaves.

Table 50. Effect of soil amendments on total Al content of leaves in double root experiment

	Aluminium (mg kg^{-1})		
Treatment	60 DAP	120 DAP	180 DAP
T_1	1.73	2.42	2.44
T_2	1.97	1.96	2.10
T_3	1.74	1.85	2.01
T_4	1.34	1.48	1.65
T_5	1.75	1.68	1.70
T_6	2.68	2.90	2.94
T_7	2.31	2.74	2.77
T_8	2.70	3.90	4.12
SEm (±)	0.06	0.07	0.07
CD (0.05)	0.18	0.21	0.22

Discussion

5. DISCUSSION

The investigation was carried out in two different studies (Incubation and Pot culture) under the title "Gypsum as a ameliorant for black pepper (*Piper nigrum* L.) in acid soils of Wayanad" The results obtained from each experiments were discussed here.

5.1 INCUBATION EXPERIMENT

The soil samples were incubated with different ameliorants as Ca at various levels of percentage CEC. The samples were maintained at 50 per cent field capacity and the samples taken from all the four layers were analysed for soil pH and nutrient status at 60 and 120 days after incubation.

5.1.1 Effect of amendments on soil chemical properties

5.1.1.1 Soil pH/acidity

There was a significant increase in soil pH in all the treatments at 60 and 120 DAI. Among the treatments, treatment with $CaCO_3$ (Ca as $CaCO_3$ at the rate of 100% lime requirement) recorded highest pH at the surface layer. It could be due to the decrease in the level of exchangeable Al in the surface layer. The result obtained was in conformity with those reported earlier by Helyar and Anderson (1981) and Enright (1984). In case of subsurface soil layers, treatments with gypsum and combination of gypsum with liming materials (burnt lime and dolomite) recorded higher pH value. It was probably due to higher solubility of gypsum, resulting in enhanced Ca and S movement towards deeper soil layers (Reeve and Sumner, 1972). This might have helped in ligand substitution on the surface of soil particle involving Fe and Al hydrated oxides and SO_4^{2-} displacing OH^- promoting neutralization of soil acidity (Caires *et al.*, 2003).

5.1.1.2 Available Nitrogen

The treatments *viz.*, gypsum, gypsum in combination with burnt lime and dolomite (T_4 and T_5) recorded increased available nitrogen content; and was significantly superior over control. The beneficial effect of the treatments on soil nitrogen may be due to improvement of soil properties by the addition of large amount of Ca into soil helps in rapid decomposition of organic matter (Silva *et al.*, 2013). The higher solubility of gypsum leaches sulphate into subsurface soil layers in addition to Ca, helps nitrogen fixing micro-organisms activity to form nitrogenase enzyme was suggested by Liu and Hue (2001). Hence in fourth soil layer (75-100 cm depth) the nitrogen availability is more in gypsum treated soils over rest of the treatments and control.

5.1.1.3 Available Phosphorus

The available P in soil was significantly higher in all treatments and all soil layers at 60 and 120 DAI. The treatments with gypsum and its combination with dolomite recorded highest P content. Similar result has been found by Phillips *et al*, (2000), that the application of gypsum reduces the fixation of P with Fe and Al and promotes precipitation of P with Ca to form calcium phosphate. This calcium phosphate immediately after microbial action releases P into soil solution. The liming materials (burnt lime, calcite and dolomite) reduced solubility of Al, Fe, Mn and increased the availability of Ca and P was reported by Mandal *et al.*, 1975 and Tripathi *et al.*, 1983.

5.1.1.4 Available Potassium

The soil available K was noticed more in the treatments T_4 (Ca as gypsum at the rate of 25% of CEC + burnt lime at the rate of 25% of CEC), T_5 (Ca as gypsum at the rate of 25% of CEC + dolomite at the rate of 25% of CEC) and T_7 (Ca as $CaCO_3$ at the rate of 100% lime requirement). These treatments showed, addition of liming material with gypsum have positive influence on K availability in soil. Similar result was reported by Mathew and Joost (1989), where use of lime in conjunction with surface application of gypsum and other SO_4^{2-} salts increases K and Mg availability in soil. Blaszcyk *et al.*, suggested that liming significantly increased Ca, Mg and K concentration in the topsoil. This may be the reason $CaCO_3$ and combination of gypsum with burnt line and dolomite treatments showed higher available K in surface soil.

5.1.1.5 Available Calcium

Treatment (T_1) which contained highest per cent of Ca as gypsum among all the treatments showed maximum content of available Ca in all soil layers due to higher solubility and leaching of Ca along with SO_4^{2-} into deeper profile soil layers. The conformity statement was reported earlier by Sumner *et al*, (1986), Shainberg *et al*, (1989) and Liu and Hue (2001). The gypsum combined with dolomite and burnt lime also recorded higher Ca content in surface and subsurface soil layers over control which might be due to higher per cent of calcium content in these amendments.

5.1.1.6 Available Magnesium

The maximum soil available Mg content with respect to all four soil layers was noticed in the treatments with dolomite alone and combination of gypsum with dolomite. As dolomite contained Mg, this might have caused the increased Mg availability (Verlengia and Gargantini, 1972). Quaggio *et al.* (1993), Oliveira and Pavan (1993) conclusion, that the exchangeable Mg from the top cultivable layers to the subsoil by gypsum application also confirms that gypsum had a significant effect on available Mg in all soil layers.

5.1.1.7 Available Sulphur

The increased soil available sulphur content was recorded in all treatments over control. The treatment T_1 (Ca as gypsum at the rate of 50% of CEC), which incorporate more quantity of gypsum into soil recorded significantly higher S content than other treatments. The gypsum combined with burnt lime and dolomite treatments also showed increased available S over sole burnt lime, dolomite and $CaCo_3$ applied treatments. It may be due to the solubility of gypsum, which increases extractable S in all profile soil layers (Liu and Hue, 2001).

5.1.1.8 Exchangeable Aluminium

The exchangeable Al was recorded maximum in control, which was significantly higher than all other treatments in all four soil layers at both 60 and 120 DAI except at 60 DAI in first layer. In first layer dolomite showed higher exchangeable Al at 60 DAI. It might be due to lesser solubility of dolomite in the initial stage. The acid soils which were ameliorated by gypsum noticed decreased exchangeable Al. Gypsum as soil ameliorant had lowest exchangeable Al content in first soil layer. The increased solubility of gypsum might have caused reduced the exchangeable Al through Ca and SO_4^{2-} (Reeve and Sumner, 1972; Ritchey *et al.*, 1980; Hammel *et al.*, 1985; Sumner, 1993, 1995). In second and third soil layers gypsum with dolomite and in fourth soil layer gypsum with lime recorded minimum exchangeable Al. The minimum exchangeable Al in subsurface soil might be due to complexion of Al with SO_4^{2-} released from applied gypsum. Moreover gypsum also causes increased leaching of Ca into deeper soil layers restrict exchangeable Al content of soil (Pavan, Bingham and Pratt 1984). This occurs due to the replacement of exchangeable Al^{3+} by Ca^{2+} particularly in subsoil and formation of Al-hydroxyl-sulphate or aluminium sulphate complex, which was a non toxic, unavailable Al compound for plants (Mora *et al.*, 2002).

5.2 COLUMN EXPERIMENT

Column experiment was laid out at KVK, Kannur, by planting 4 leaf stage rooted pepper cuttings var. Panniyur-1 in the PVC columns of length 1m and diameter 0.063m to know the effect of ameliorants on growth of black pepper vines at 30, 60, 90, 120 and 180 days after planting. The treatments imposed were gypsum at different levels in 5 treatments *viz.,* Ca as gypsum at the rate of 10, 20, 30, 40 and 50 per cent of CEC (T_1 to T_5) and Ca as $CaCO_3$ in two treatments at the rate 50 and 100 per cent of lime requirement (T_6 and T_7) along with one control (T_8).

5.2.1 Influence of soil amendments on plant growth parameters

5.2.1.1 Plant height

The plant height at different stage of intervals showed significantly higher values among the treatments, except at 30 DAP. The lower dissolution of amendments had no significant effect on soil properties and plant growth at 30 DAP. But there was an increased plant height over control in all the treatments. The treatments with higher dose of gypsum (T_4 and T_5) recorded maximum plant height at all the growth stages. This could be due to presence of gypsum which enhances the uptake of N, P, K and Ca. This inturn helps in plant growth and development. Similar result was reported by Hossain (1997). The data were represented in fig 4.

5.2.1.2 Number of leaves

The data on number of leaves at different stages were illustrated in fig 5. The gypsum treated (T_4 and T_5) plants showed more number of leaves over control and were significantly superior. The number of leaves was recorded highest in treatment T_4 (Ca as gypsum added at the rate of 40 % CEC) at 90, 120 and 180 DAP. The incubation experiment soil sample analysis data revealed that there was an increased availability of soil nutrients at both surface and subsurface soil layers in gypsum applied soil columns over control. Increased availability of nutrients from the soil, plant produce superior number of leaves than control. Similar result was reported by Nasrin *et al.* (1988).

5.2.1.3 Internodal length

The results on internodal length did not show any significant difference, except at 180 DAI of observation. The treatment, T_4 (Ca as gypsum at the rate of 40 per cent CEC) plants showed significant higher intermodal length possibly due to the influence of gypsum induced additional uptake of nutrients in all four soil layers, which favours rapid growth of plant through increased intermodal length. The results were given in fig 6.

5.2.1.4 Leaf area

The treatments recorded superior leaf area than control at all stage of plant growth period. The treatment, T_6 showed maximum leaf area at 30, 60, 90 and 120 DAP. While treatment, T_5 recorded highest leaf area at 180 DAP. It might be due to higher uptake of N by the influence of calcium and sulphur through lime and gypsum applied to soil. The comparable result was also reported by Rasool *et al.*, 2013. The data for leaf area at different growth stages were presented in fig 7.

5.2.1.5 Root weight and length of longest root

The treatments with gypsum at the rate of 40 and 50 per cent CEC showed maximum weight (fresh and dry) and length of longest root over control at 60, 120 and 180 DAP. The gypsum being readily soluble, improved soil physical properties like flocculation of soil particles increases soluble Ca^{2+} and also reduced the Al^{3+} toxic level, and encourages root coverage to subsoil. This resulted in increased weight and maximum length of roots as noticed (Reeve and Sumner, 1972; Radcliffe *et al.*, 1986). The applied gypsum encourages root hairs; results in supplementary root surface area and also enhance soil SO_4^{2-} content which reduce P fixation with exchangeable Al. These supports additional uptake of nutrients like soil immobile P and provides well developed root system through modification of soil root environment (Farina *et al.*, 2000a). The data for root weight and length of longest per plant were illustrated in fig 8, 9 and 10.

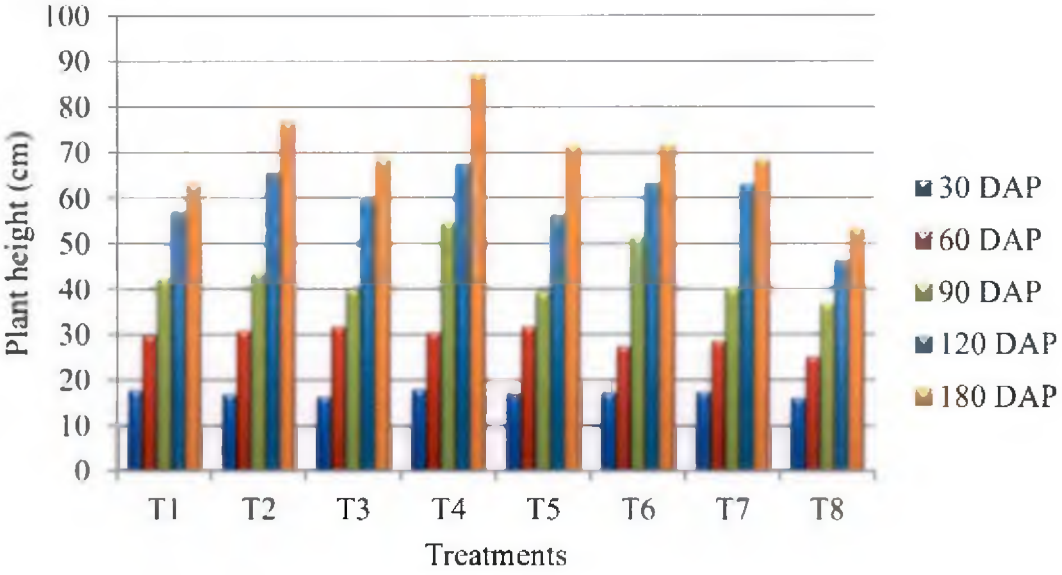


Fig 4. Effect of soil amendments on plant height at various growth stages of plant in column experiment

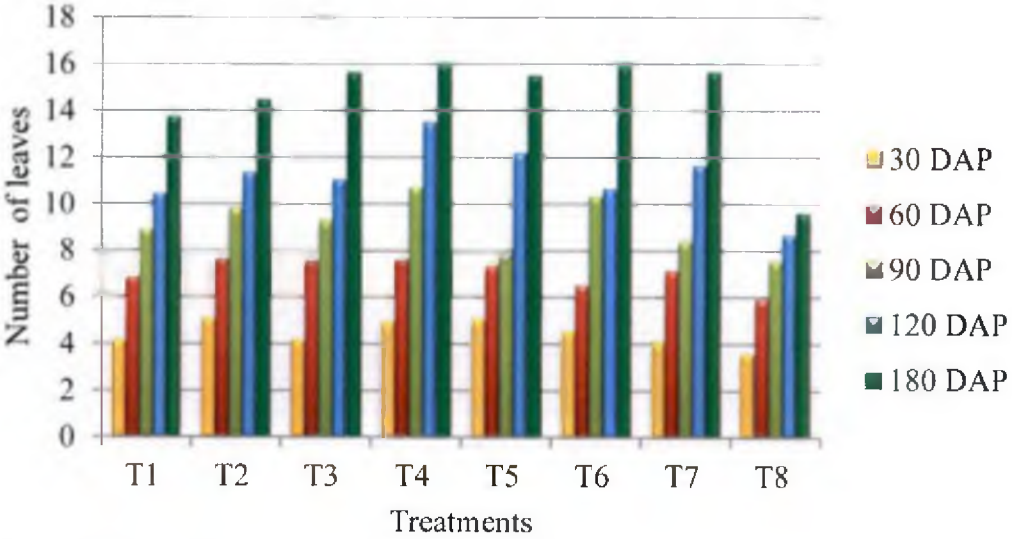


Fig 5. Effect of soil amendments on number of leaves at various growth stages of plant in column experiment

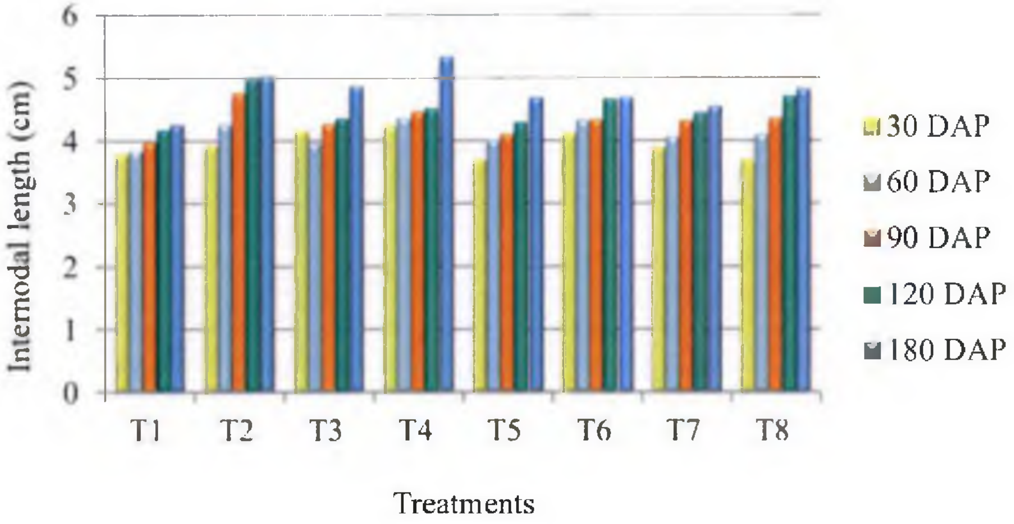


Fig 6. Effect of soil amendments on internodal length at various growth stages of plant in column experiment

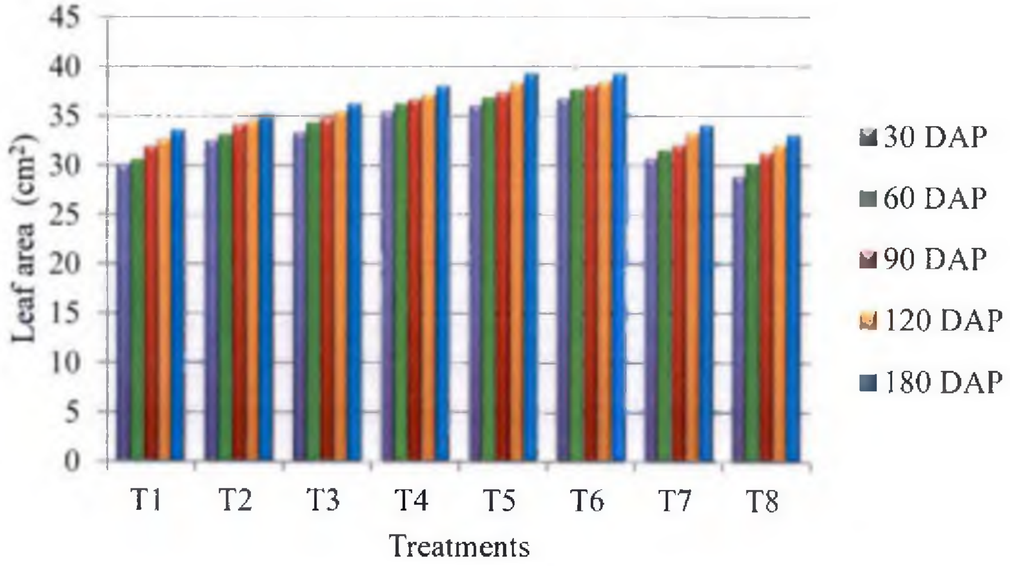


Fig 7. Effect of soil amendments on leaf area at various growth stages of plant in column experiment.

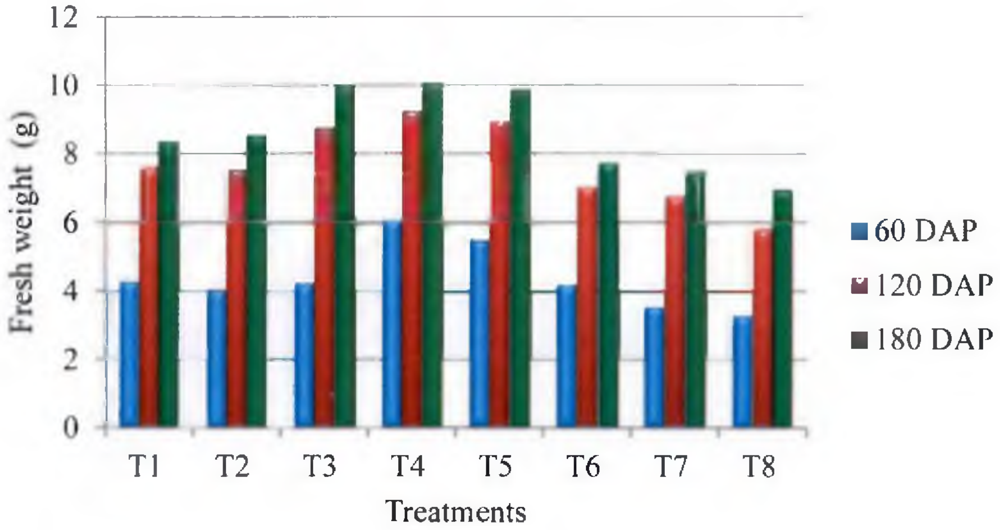


Fig 8. Effect of soil amendments on fresh weight of root per plant at various growth stages of plant in column experiment

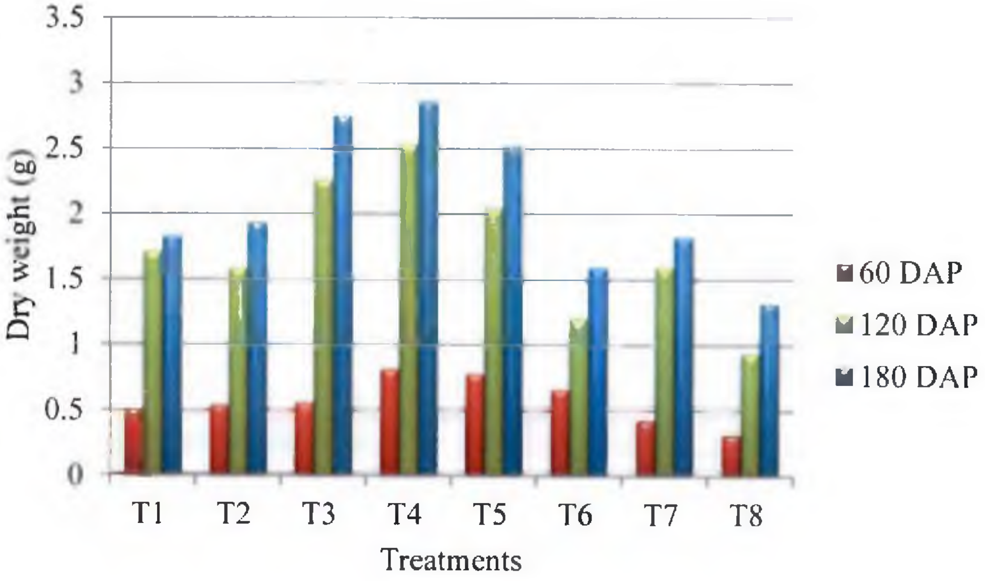


Fig 9. Effect of soil amendments on dry weight of roots per plant at various growth stages of plant in column experiment

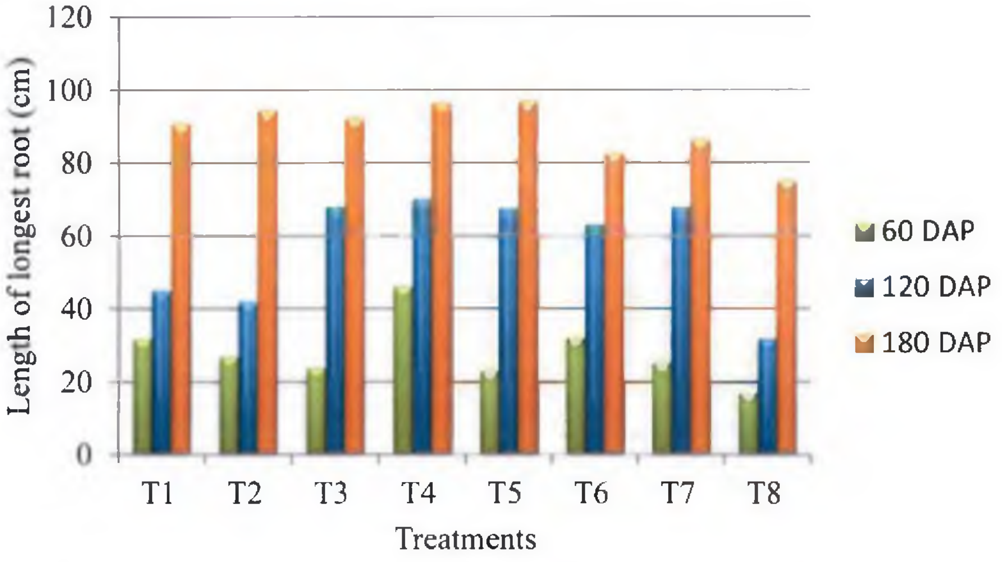


Fig 10. Effect of soil amendments on length of longest root per plant at various growth stages of plant in column experiment

5.2.2 Influence of amendments on soil chemical properties

The data on soil pH in four layers at all three intervals revealed that there was increased significant difference among treatments with respect to control. At 60 DAP slight increase in soil pH on amended soils was noticed in all treatments, but at 120 DAP the soil analysis showed that the gypsum applied treatments have a greater impact on neutralization of soil acidity. In gypsum and also $CaCO_3$ treated soil, pH was nearly neutral at surface. In subsurface soil layers (below 25 cm depth) gypsum treated soil showed significant effect on increased soil pH than $CaCO_3$ treated soil. The treatments with Ca as gypsum at the rate of 40 and 50 per cent CEC showed superior increased pH than gypsum applied at lesser amount. This might be due to the mechanism that ligands exchange of SO_4^{2-} for OH^- from Fe and Al oxides at higher level (which are major contributors on acidity development in laterite soils) (Hammel *et al.*, 1985).

The soil analysis on available N, K_2O and P_2O_5 at 60, 120 and 180 DAP in all four depth soil layers showed that the amelioration effect of amendments was significantly superior over control.

The higher application of gypsum (Ca as gypsum at the rate of 40 and 50 per cent CEC) enhance the soil available N, P and K than control in all soil layers from surface to subsurface soil layers (upto the depth of 100 cm) over control. This may be due to gypsum which contained Ca improved soil physical properties and thereby favours organic matter decomposition, results in the increased nitrogen content in soil. The Ca leached into deeper soil layers inhibits the toxic level of Al, hence reduced P fixation with Al all along the soil layers. The SO_4^{2-} derived from gypsum enhances leaching of Ca to subsurface and improve soil K content (Liu and Hue, 2001; Mathew and Joost, 1989). The available nutrients N and P showed decreased trend from top to subsurface soil, but in the case of available K no much difference in its concentration all along the four different soil depth layers.

Significantly higher difference was recorded between control and amended soil columns for available Ca and S in all layers at all stages. Among the treatments, T_5 showed increased soil available Ca and S content over rest of the treatments in all soil layers. This might be due to higher application of gypsum increased the soil Ca which was readily soluble and available in surface and surface soil layers. There was a difference between Ca content in all four soil layers at each interval of soil analysis clearly indicated that, due to higher solubility and leaching of gypsum, Ca moves downward from top surface to deeper soil layers (Sumner *et al.*, 1986; Jacob and Venugopal, 1993). The gypsum in addition to Ca also supplies S to the soil was suggested by Sumner *et al.* (1986).

The amended columns showed significant higher available Mg content in soil over control. The treatments which contain gypsum showed maximum available Mg than the control may be due to reduced soil acidity.

The gypsum treatment showed significantly decreased soil available Al than the control. As the applied quantity of gypsum increased, Al content recorded reducing trend. The effect of gypsum was superior in bottom soil layers as compared to surface soil. The treatment, T_5 recorded minimum Al value among the treatments and was on par with T_4. The findings of Franzen *et al*, (2006) and Merino-Gergichevich *et al*, (2010), reduction in the exchangeable Al in treatments receiving gypsum well supported to the above conclusion.

5.2.3 Influence of amendments on nutrient status of leaves

The N, P and K nutrients showed significantly higher in amendment treated soils than the control. It was observed that there was a linear increase in these nutrients at plant leaves from 60 DAP to 180 DAP. The data revealed that application of gypsum beneficially influenced in uptake of these nutrients. The increased pH and nutrient availability in soil may be the reason for higher uptakes of these nutrients by plants.

Chemical analysis of leaves for Ca and S showed that the treatments are significantly different and higher total Ca and S was recorded in treatments T_4 and T_5. The maximum total of Ca and S concentration in gypsum treatments may be due to the enhanced supply of these nutrients into soil at all growth stages.

The Mg content of leaf showed less value than control due to the antagonistic effect of Ca on Mg uptake of plants.

All the treatments showed less Al concentration in their leaves over control. The treatments T_4, T_5 and T_7 recorded minimum Al accumulation, which were significantly differed from other treatments. The available Ca content was recorded maximum on these treatment soils and showed reduced exchangeable Al concentration in soil. As a result of decreased availability of Al in soil, the concentration of Al in leaves was found to be lower.

5.3 DOUBLE ROOT EXPERIMENT

Double root experiment was laid out to know the effect of ameliorants on growth of black pepper vines at different stages of plant *viz.,* 30, 60, 90, 120 and 180 days after planting. The root behaviour in ameliorant treated and untreated soil roots within a single plant were mainly studied with the same treatment combination used in incubation study.

5.3.1 Influence of soil amendments on plant growth parameters

5.3.1.1 Plant height

The results for plant height at different growth stages *viz.,* 30, 60, 90, 120 and 180 DAP showed significant difference among the treatments. There was a steady increase in plant height in all treatments, where treatments, T_6 and T_4 recorded maximum plant height at 30 and 60 DAP. It could be due to influence of liming materials ($CaCO_3$ and burnt lime) on uptake of plant nutrients at surface soil layer. But after 90 days treatment, T_5 recorded maximum plant height and was on par with T_6, T_2 and T_3. This may be due to, the combination of gypsum and dolomite increased the soil pH in surface as well as subsurface and releases the available nutrient into soil may help the plant to grow with full efficient. The data were depicted in fig 11.

5.3.1.2 Number leaves

The treatments recorded higher number of leaves in all growth stages than control, but noticed significant difference only at 60 and 90 DAP. While at 30 and 60 DAP the treatment, T_2 recorded with maximum number of leaves and as growth continued at 90, 120 and 180 DAP the treatment T_5 showed higher number of leaves possibly due to leaching of gypsum into deeper soil layers helped in maximum number of leaves by adequate nutrient supply. The data on number of leaves were represented in fig 12.

5.3.1.3 Internodal length

The plants from treated soil columns showed higher internodal length than control. Internodal length showed constant increase in all treatment as well as control at all stages of biometric observation. Among all the treatments treatment with (T_1) gypsum ameliorant showed maximum internodal length at all intervals, which might be due increased soil pH at subsurface soil layers and also additional supply of Ca along with S.

5.3.1.4 Leaf area

The treatments showed beneficial impact on leaf area, which were significantly superior over control. The treatment with gypsum and burnt lime in combination registered maximum leaf area in all growth stages. The adequate supply of nutrients and reduced soil acidity at surface as well as subsurface soil layers may be the reason for increased leaf area.

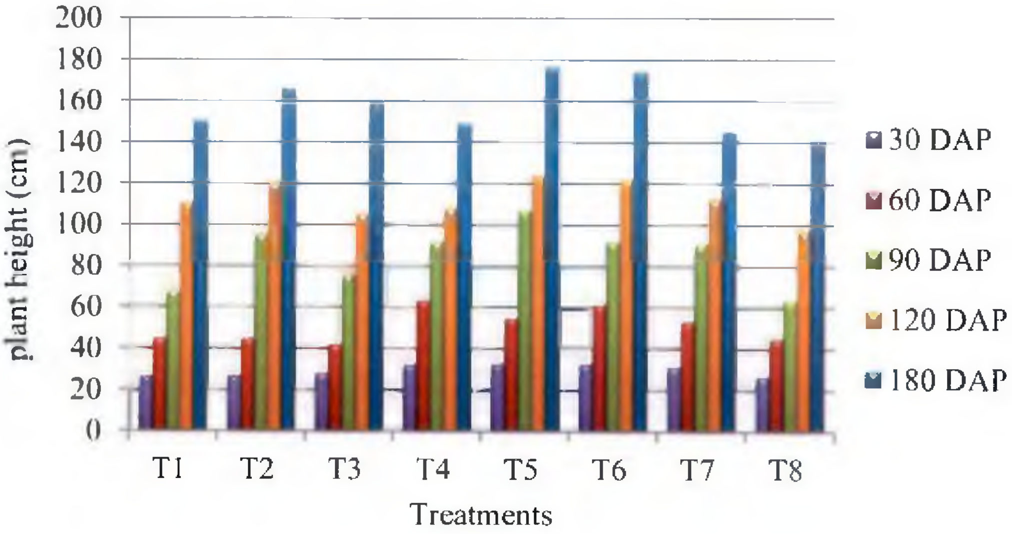


Fig 11. Effect of soil amendments on plant height at various growth stages of plant in double root experiment

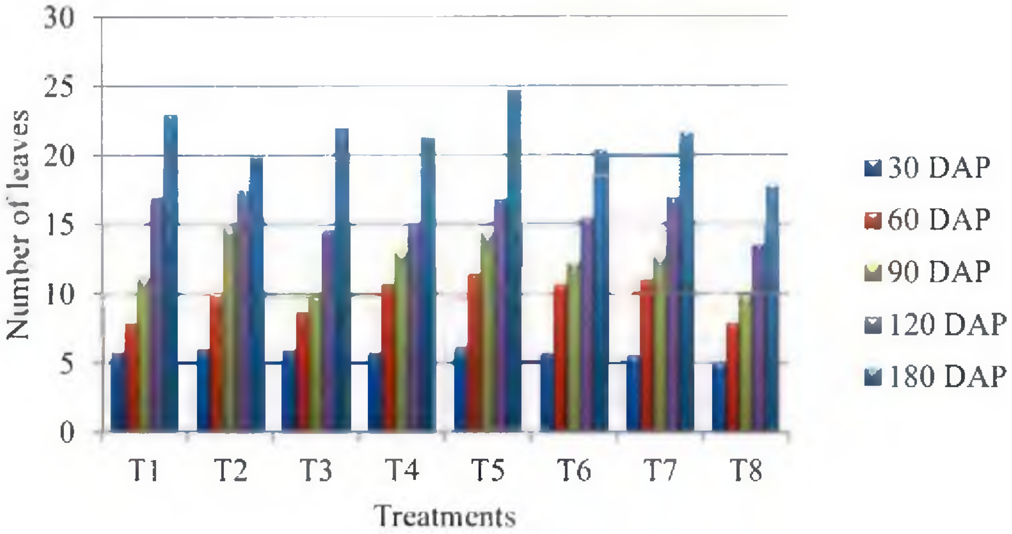


Fig 12. Effect of soil amendments number of leaves at various growth stages of plant in double root experiment

5.3.1.5 Root fresh and dry weight per plant

The treated columns showed significantly higher fresh and dry root weight at 60, 120 and 180 DAP. In all plants there was a increased fresh as well dry weight of roots from 60 to 120 DAP, but after 120 DAP, the increase in root weight at decreased rate on both fresh and dry root weights was recorded. At 60 DAP T_4 and at 120 and 180 DAP T_5 recorded maximum fresh weight of root and T_5 was on par with T_4 at both 120 and 180 DAP. Both the superior treatments T_4 and T_5 contained gypsum along with burnt lime and dolomite respectively. The liming materials (burnt lime and dolomite) had neutralization effect on reducing soil acidity at surface and gypsum on subsurface soil layers due to readily soluble nature. The amendments induced intensified uptake of plant nutrients and regulate Al toxicity all along the soil layers may increase root weight.

The untreated columns also showed significant difference among the treatments in both fresh and dry weight of root. Treatment, T_5 had maximum fresh as well as dry weight at 60 DAP but in subsequent observations treatment with $CaCO_3$ at 50 per cent lime requirement showed maximum weight. Treatment with $CaCO_3$ also recorded higher available soil nutrients at surface and subsurface soil layers over control. Due to superior availability of nutrient there may be a higher nutrient transformation from amendment treated root column to untreated root column. The data regarding root fresh and dry weight at both amendments treated and untreated soil columns were presented in fig 13, 14, 15 and 16.

5.3.1.6 Length of longest root per plant

Length of longest root in treated column was significantly superior over control. The gypsum with dolomite treated column showed higher length in both treated and untreated columns. This might be due to decreased soil acidity in both surface and subsurface soil layers and optimum supply of nutrients all along the profile soil by reduced toxic Al content in soil. In some control plant the root growth was severely restricted to top two soil layers with cluster like deformed roots may be due to higher acidity and Al toxicity in soil. The data on length of longest roots in treated and untreated soil columns were showed in fig 17 and 18.

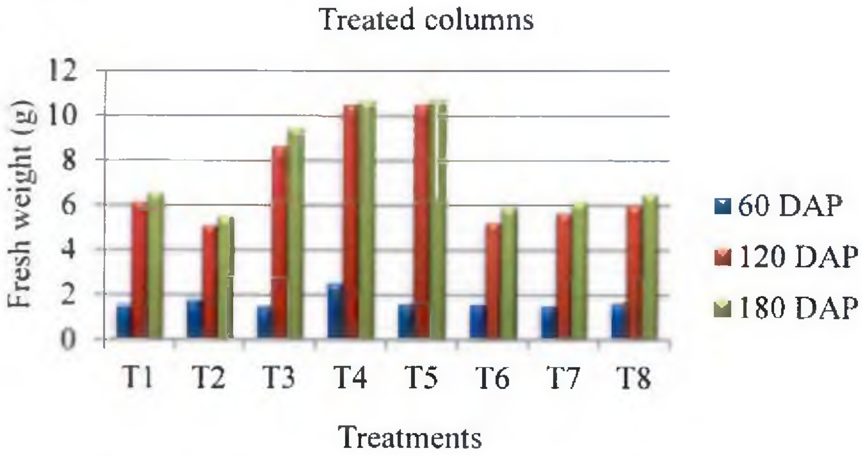


Fig 13. Effect of soil amendments on fresh root weight of treated columns at various growth stages of plant in double root experiment

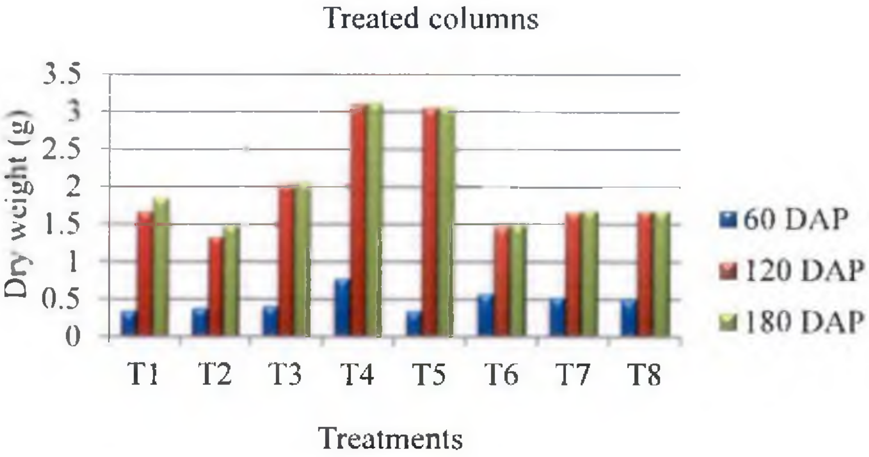


Fig 15. Effect of soil amendments on dry root weight of treated columns at various growth stages of plant in double root experiment

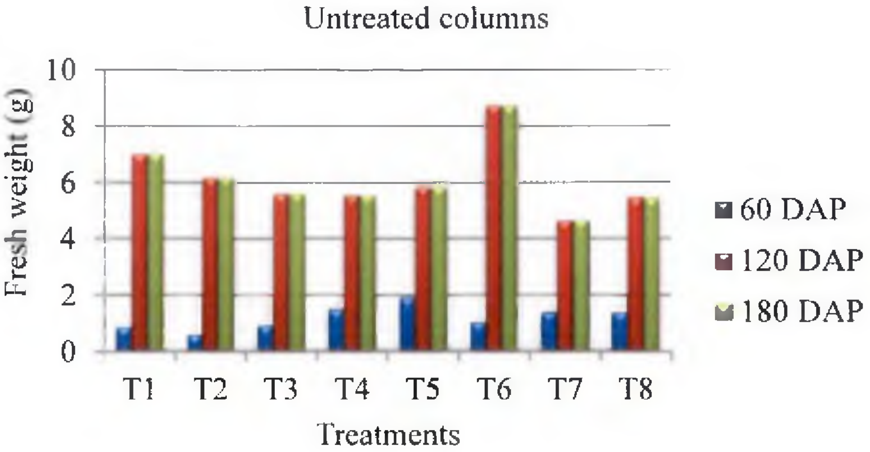


Fig 14. Effect of soil amendments on fresh root weight of untreated columns at various growth stages of plant in double root experiment

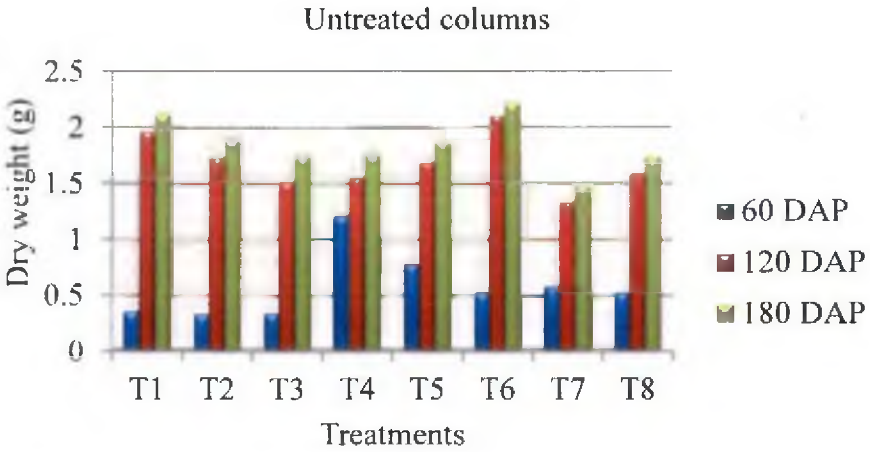


Fig 16. Effect of soil amendments on dry root weight of untreated columns at various growth stages of plant in double root experiment

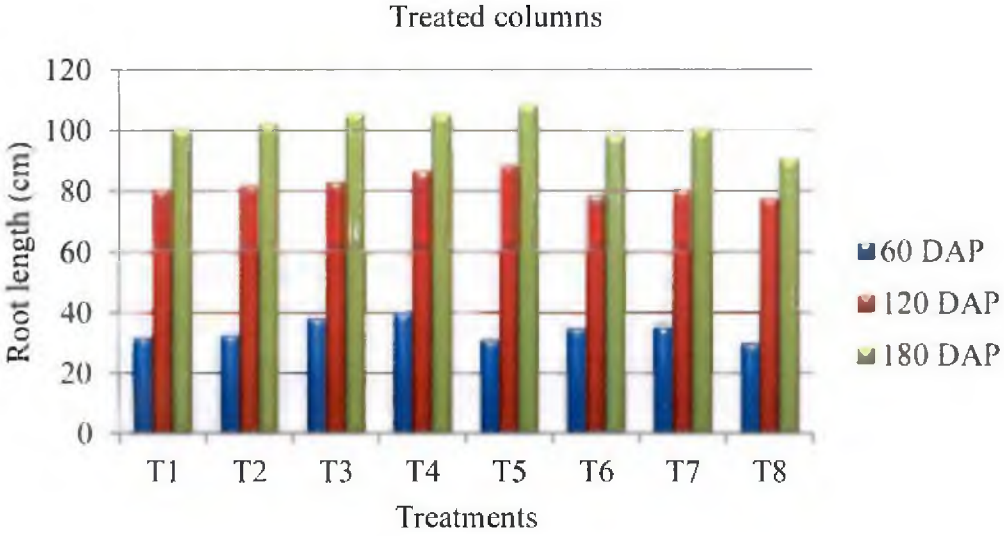


Fig 17. Effect of soil amendments on length of longest root of treated columns at various growth stages of plant in double root experiment

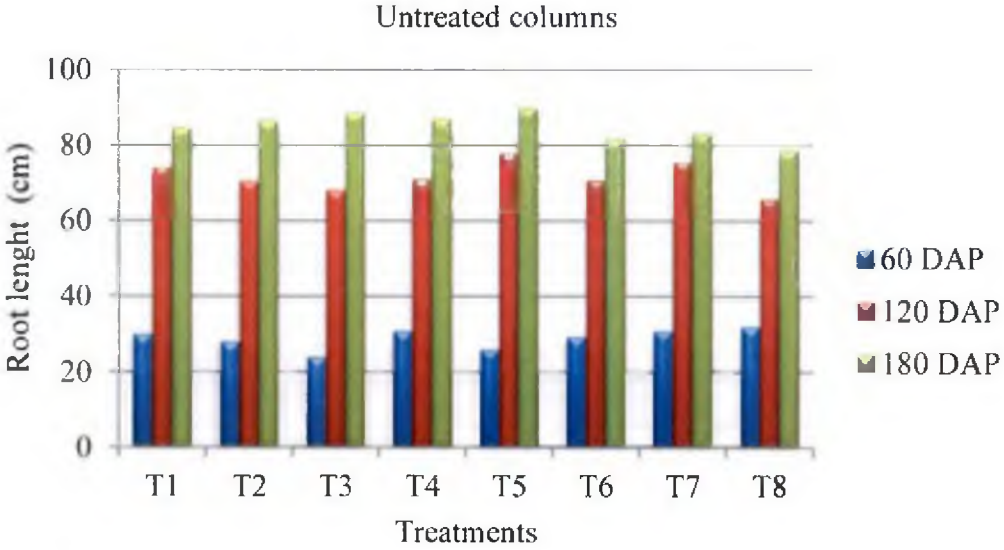


Fig 18. Effect of soil amendments on length of longest root of untreated columns at various growth stages of plant in double root experiment.

5.3.2 Influence of amendments on soil chemical properties

Destructive soil samples collected at 60, 120 and 180 DAP for first and second soil layers. While for third and fourth soil layers samples were collected at 120 and 180 DAP with respect to plant root growth from all the treated column and analysed for soil pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al.

The soil pH was significantly higher in treated soil columns in all four soil layers at all interval of analysis. The treatments with $CaCO_3$ and gypsum at surface and subsurface respectively recorded maximum pH at all stages of soil analysis. The observations were supported by the statements, that is the surface applied lime decreases hydrolytic and exchangeable acidity given by Oyanagi *et al*, (2001) and Repsiene (2002) and gypsum being much soluble readily moves down the profile soil layer, where it reduced the soluble or exchangeable Al (Hammel *et al.*, 1986), which reduced soil acidity and also decreases the toxic Al content. The combined application of gypsum with dolomite raised pH and decreased Al saturation was observed by Mora *et al*, (2002) may be the reason for increase in pH on treatment T_5 soil.

Available nitrogen showed higher values in the treatments with sole gypsum and combination of gypsum with burnt lime and dolomite than rest of the treatments. At surface layers gypsum with dolomite and lime treated soil samples showed higher available N. This might be due to lime and dolomite amelioration action against soil acidity through reduced soil pH, enhance nitrogen availability by organic matter decomposition. In deep soil layers sole gypsum treated soil noticed maximum available N, possibly due to more leaching of Ca into soil cause increased level of nitrogen by improving soil structure.

Sulphur added through gypsum reduced the P fixation with exchangeable Al, which was the major acidity inducing factor in acid soils. Hence in all soil layers, treatments with gypsum increased the available P content by reducing the toxic level of aluminium.

Soil samples treated with ameliorants showed increased level of soil available K content over control. At top surface soil lime materials beneficially effect on available K but in bottom subsoil layers gypsum treated at higher level treatment showed raised level of available K content may be due to reduced soil acidity.

The beneficial effect of treatments also indicated that the higher availability of soil Ca and S in treated soil over control. The increased solubility of gypsum releases more exchangeable Ca and S into deeper profile soil from top surface to subsoil layers. There was uniform distribution of available S in all soil layers but as days continued attributed to higher leached gypsum increases exchangeable Ca rate in bottom soil layer than surface soil. This refluxed in the better root proliferation and reduced augmenting effect of toxic Al.

The treatments T_3 (dolomite) and T_5 (gypsum + dolomite) showed superior available Mg content in all soil layers at all interval of soil analysis. Mg is one of the main component in dolomite might be the reason; these treatments recorded maximum soil available Mg content.

The control recorded maximum exchangeable Al in all four soil layers at all interval of soil analysis. Higher level $CaCO_3$ contained treatment had lesser exchangeable Al at top two soil layers, the finding was high lightened by Pires *et al*, (2003) that the surface application of lime increases the soil pH and reduces the exchangeable aluminium in acid soil. In bottom soil layers gypsum decreases the exchangeable Al greatly than the other treatments. It also supports for better root growth in soil up to the depth of 100 cm and more and to extract ample quantity of nutrients from bottom soils also.

5.3.3 Influence of amendments on nutrient status of leaves

There was a significant difference among the treatments for total N, P and K content in leaves and the treatments which possess the combined amendments (treatments T_4 and T_5) recorded maximum N, P and K content in leaf compared to rest of the treatments. The better proliferated root system and soil availability of these nutrients at higher level may induced the higher uptake of nutrients into leaves.

The Ca, Mg and S content of leaves recorded at 60, 120 and 180 DAP revealed that a linear steady increase in all three nutrients at leaf.

Ameliorant treated plants showed lesser Mg content than control in all stages of plant growth. This might due to the antagonistic effect of Ca on the uptake of Mg into plant system. But the treatments which contain dolomite showed higher leaf Mg next to the control possibly due abundant availability of Mg in soil. The leaf Ca and S recorded highest in gypsum added treatments due to the increased availability of Ca and S in all along the soil depth (Stehouwer *et al.*, 1996). It also noticed that the root growth had a great dependence on soluble Ca and S in the soil.

Al content of leaf recorded highest in control as compared to others. The data on leaf Al concentration revealed that, the amendments added to soil have been reduced the toxic effect of Al on soil, which induced less uptake of Al by plant roots. The combined amended treatments that gypsum with burnt lime showed lesser aluminium accumulation in leaves signified the role of Ca in well root development by reducing toxic exchangeable Al in soil layers.

Summary

6. SUMMARY

A study entitled "Gypsum as a soil ameliorant for black pepper (*Piper nigrum* L.) in acid soil of Wayanad" was carried out to evaluate the effect of gypsum along with other amendments on growth and development of black pepper, as well as its root behaviour into deeper soil layers on acidic soils of Wayanad.

The study was conducted in three experiments. An incubation study, at College of Agriculture, Padannakkad and two pot culture studies; column and double root experiments at Krishi Vigyan Kendra, Kannur. All the three experiments consist of eight treatments, including control.

Incubation study was carried out in 1m length and 0.063 cm diameter plastic PVC column pipes. The columns were filled with soil of four different layers depicting profile soil ((0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm from top soil surface). The amendments were applied as Ca at different per cent CEC rate and field capacity were maintained for a period of 120 days during incubation experiment. The destructive soil samples were collected at 60 and 120 DAI from four different soil layers and examined for their soil pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al.

Analysis of incubated soil samples revealed that soils treated with amendments had higher pH on surface and subsurface layers. The treatment with higher proportion of $CaCO_3$ and gypsum as one of the amendment showed increased soil pH at surface and subsurface soil respectively. The soil available N, P_2O_5 and K_2O recorded higher values over rest of the treatment in gypsum with the combination of burnt lime and dolomite and gypsum as a sole amendment applied treatments in all four soil layers (0-100 cm depth) at 60 and 120 DAI.

The available soil Ca and S was recorded maximum in lone gypsum ameliorated soils in all four soil layers at both stages of incubation. The dolomite amended treatments were noticed higher soil available Mg content in all soil layers at 60 and 120 DAI.

The treatments with gypsum, combination of gypsum with burnt lime and dolomite as amendments recorded minimum exchangeable Al in surface and subsoil layers at both 60 and 120 DAI soil samples, highest exchangeable Al was observed in control.

Based on the incubation study, two pot culture studies as column and double root experiments were carried out for standardizing the dose of gypsum and gypsum in combination with other liming materials in ameliorating soil acidity. The biometric observations were recorded at 30 days interval to examine influence of treatments on plant growth and development. The destructive soil samples were collected at 60,120 and 180 DAP and analysed for soil pH, available N, P_2O_5, K_2O, Ca, Mg, S and exchangeable Al in all soil layers. The plant samples were also collected for leaf nutrient analysis and root parameters observation.

Column experiment was conducted with two amendments gypsum and $CaCO_3$ at different per cent of CEC rate. The variety *viz.,* Panniyur 1 was planted in one metre column pipes which are imposed with different treatments. The biometric observation revealed that the treatments with higher dose of gypsum (T_4 and T_5) recorded maximum values on plant height, number of leaves, internodal length, and leaf area. The observation on root characters fresh, dry root weight and length of longest root per plant were also showed similar results with gypsum as ameliorant.

The soil analysis results at 60, 120 and 180 DAP from all soil layers revealed that the treatments T_4 and T_5 was found to be the best in soil pH for managing soil acidity. Available N, P_2O_5, K_2O, Ca and S, also showed higher values from surface to subsurface soil layers at all interval. The available Mg content recorded maximum in amendment treated soil columns over control. The treatments with lowest level of gypsum (T_1) in first and second soil layers and $CaCO_3$ (T_7) in third and fourth soil layers recorded maximum available Mg content.

The treatment T_5 recorded significantly lowest exchangeable Al content over control in all soil layers at all stages.

The leaf analysis showed higher content of total N, P, K, Ca and S with treatments T_4 and T_5 and lowest was recorded by control in all stages of plant growth. In case of total leaf Mg content control had maximum Mg concentration than rest of the treatments. The Al content was recorded maximum in control where no amendment was added. The lowest Al was recorded in gypsum amendment treated plant samples *viz.*, treatment T_2 at 60 DAP and treatment T_5 at 120 and 180 DAP.

Two node rooted serpentine layers were used for the dual root study. It was planted in such a way that the roots are allowed to grow in two different columns arranged side by side. The same treatments used for incubation study were allotted and the amendments were applied in column where sprouts emerged. The data on biometric observation revealed that combination of gypsum with dolomite and burnt lime treatments showed superior value, over control for plant height and leaf area at various stages of plant growth.

Root parameters were examined in both columns at 60, 120 and 180 DAP. Among the treatments there was significant difference at treated soil columns in root growth over control. The treatments T_4 and T_5 had higher fresh, dry weight and length of longest root at all stages of plant growth in soil columns treated with amendments. The treatment T_5 at 60 DAP and treatment T_6 at 120 and 180 DAP recorded maximum fresh and dry root weight, and. The length of longest root per plant was recorded superior in T_5 at 120 and 180 DAP in unamended soil columns.

The ameliorant treated soil samples were collected from all four soil layers at 60, 120 and 180 DAP. The data revealed that the soil acidity was highest in control in all soil layers hindering the growth of roots. The soil pH was showed highest by treatment T_7 in first soil layer and treatment T_1 in bottom three soil layers at all intervals. The soil available nitrogen, phosphorus and potassium was more within gypsum over burnt lime, dolomite and $CaCO_3$ ameliorated soils in all soil layers. The lowest was recorded in control at all stages of plant growth.

Available soil Ca and S recorded highest value with treatment T_1 in all soil layers at each stage of sampling and it was significantly superior over control. The maximum soil available Mg content was recorded with dolomite contained treatment (T_3) at both surface and subsurface layers followed by treatment T_3, where dolomite was applied in combination with gypsum.

The soil exchangeable Al was showed maximum content in control than amendment treated soil columns in all four soil layers at all interval. In first layer treatment T_7 (60 and 120DAP) and T_1 (180 DAP) recorded lowest Al content and in bottom layers treatments T_1 (gypsum), T_4 (gypsum + burnt lime) and T_5 (gypsum + dolomite) treated columns showed minimum exchangeable Al.

Leaf analysis of double root plant samples revealed that, the total N, K, P, Ca and S were more in ameliorant treated columns and gypsum treated plant samples showed significantly superior of these nutrients at all stages of plant growth.

Total Al concentration on leaves had significant difference among treatments and maximum Al leaf content was noticed in control and minimum was recorded in treatment T_2 at 60 DAP and T_4 at 120 and 180 DAP.

Future line of work:

1. The application of gypsum as soil ameliorants along with other liming materials for black pepper in different agro-ecological units to be explored.

2. Beneficial effect of gypsum with liming materials on soil micro flora also has to be studied.

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Abstract

GYPSUM AS A SOIL AMELIORANT FOR BLACK PEPPER (*Piper nigrum* L.) IN ACID SOILS OF WAYANAD

by

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ABSTRACT

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ABSTRACT

The experiment entitled "Gypsum as a soil ameliorant for black pepper (*Piper nigrum* L.) in acid soils of Wayanad" was carried out with the objectives to study the performance of gypsum as a soil ameliorant in growth and development of black pepper and to evaluate its suitability in promoting root growth into deep soil layers of central plateau of Wayanad. The entire investigation was carried out as three experiments, an incubation experiment at College of Agriculture, Padannakkad and two pot culture studies (Column experiment and Double/dual root experiment) done at KVK, Kannur during 2015- 2016. The soil samples for all three experiments were collected from different soil layers (1st layer: 0-25 cm, 2nd layer: 25-50 cm, 3rd layer: 50-75 cm and 4th layer: 75-100 cm from top soil surface) of pepper garden of RARS, Ambalavayal.

The incubation study was laid out in CRD with 8 treatments, 3 replications each and 3 columns were maintained in each replication, the columns were filled layer wise depicting soil profile. The treatments were T_1- Ca as gypsum at the rate of 50 per cent of CEC, T_2- Ca as burnt lime at the rate of 50 per cent of CEC, T_3- Ca as dolomite at the rate of 50 per cent of CEC, T_4- Ca as gypsum at the rate of 25 per cent of CEC + burnt lime at the rate of 25 per cent of CEC, T_5- Ca as gypsum at the rate of 25 per cent of CEC + dolomite at the rate of 25 per cent of CEC, T_6- Ca as $CaCO_3$ at the rate of 50 per cent of lime requirement, T_7- Ca as $CaCO_3$ at the rate of 100 per cent of lime requirement, T_8- Control. The results of the experiment revealed that the treatments had a significant influence on available soil nutrient status. Application of gypsum showed increase in pH in the lower soil layers as compared to surface layer. Addition of ameliorants particularly gypsum recorded maximum Ca content in all soil layers as compared to sole application of burnt lime and dolomite. This is attributed to high solubility of gypsum, which permits Ca availability in lower soil layers also. The exchangeable Al, the major ion contributing to surface and subsurface acidity in lateritic soils was found minimum with addition of all soil ameliorants among

which the maximum reduction was observed with respect to gypsum treatments. The soil available N, P_2O_5, K_2O contents also showed higher values in all surface and subsurface soil layers in gypsum ameliorated soil columns.

The column experiment was conducted with 8 treatments and 3 replication under the design CRD at KVK, Kannur. The black pepper var. Panniyur -1 was planted in each column and the treatments imposed were gypsum at different levels in 5 treatments, Ca as gypsum at the rate of 10, 20, 30, 40 and 50 per cent of CEC (T_1 to T_5) and Ca as $CaCO_3$ in two treatments at the rate 50 and 100 per cent of lime requirement (T_6 and T_7) along with one control (T_8). The results obtained with respect to biometric observations revealed that T_4 (Ca as gypsum at the rate of 40% of CEC) showed maximum plant height, number of leaves, internodal length, fresh and dry root weight at all the stages of plant growth and was on par with T_5 (Ca as gypsum at the rate of 50% of CEC). The root length was maximum in T_4 at 60 and 120 DAP and later at in 180 DAP T_5 recorded highest root length and was on par with T_4. The soil analysis of column experiment revealed that the treatments T_5 and T_4 significantly increased soil pH, available N, P_2O_5, K_2O, Ca, S and significantly decreased exchangeable Al due to increased solubility and leaching of gypsum in all four soil layers, hence treatments T_4 and T_5 showed superior plant growth and root proliferation at various stages of plant growth. T_4 and T_5 also recorded highest total N, P, K, Ca, S and lowest total Al accumulation in leaf samples in all stages of plant analysis.

The second pot culture study with double root experiment was conducted at KVK, Kannur with similar treatments as in incubation experiment with var. Panniyur -1. The ameliorants were added into one root column in which the sprout emerged. The results with respect to biometric observations differed significantly at different growth stages. The treatment T_5 (Ca as gypsum at the rate of 25 per cent of CEC + dolomite at the rate of 25 per cent of CEC) recorded maximum plant height and number of leaves.

The observation on root growth recorded at 60, 120 and 180 DAP differed significantly in both ameliorant treated and the dual untreated columns. In treated columns the treatment T_4 (Ca as gypsum at the rate of 25 per cent of CEC + burnt lime at the rate of 25 per cent of CEC) recorded significantly superior dry root weight at 60, 120 and 180 DAP and fresh root weight at 60 DAP. The treatment T_5 recorded maximum fresh root weight at 120 and 180 DAP. In the case of untreated root columns at 60 DAP T_4 had significant maximum dry root weight, where T_5 had maximum significant effect on fresh root weight. The fresh and dry root weight was significantly influenced by T_6 at 120 and 180 DAP. The root length also showed significance difference, in both treated and untreated columns treatment T_4 at 60 DAP and T_5 at 120 and 180 DAP recorded maximum root length.

The soil analysis of double root experiment shows that the gypsum treated (T_1, T_4 and T_5) soils were significantly superior to $CaCO_3$ and control treatments. The sole gypsum and gypsum in combination with burnt lime and dolomite treated soils showed increased soil pH, available nutrient content and decreased exchangeable Al in all the four soil depths and at each interval of soil analysis. The plant analysis carried out at 60, 120 and 180 DAP showed significance difference, among treatments T_5 and T_4 recorded highest total N, P, K, Ca and S content, where T_4 recorded lowest exchangeable Al and was on par with T_5.

The results of investigation indicated that application of gypsum as an amendment alone or in combination with burnt lime and dolomite reduced the surface and subsurface acidity and increased the available nutrient status in the surface as well as sub surface soil layers, which might have resulted in better root proliferation favouring vigorous plant growth and development of black pepper in acid soils.