AMELIORATION OF SUBSOIL ACIDITY BY CALCIUM SOURCES IN LATERITE SOILS OF BLACK PEPPER GARDEN

By

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THESIS

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DECLARATION

I, Deepa. K. Kuriakose (2005-11-125) hereby declare that the thesis entitled **“Amelioration of subsoil acidity by calcium sources in laterite soils of black pepper garden”** is a bonafide record of research work done by me during the course of research and that it has not been 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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Certified that this thesis entitled **"Amelioration of subsoil acidity by calcium sources in laterite soils of black pepper garden"** is a record of research work done independently by **Ms. Deepa. K. Kuriakose** 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 her.

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1. INTRODUCTION

Black pepper, known as the king of spices, is the most important and widely used spice in the world. The spice with its characteristic pungency and flavour is an ingredient in many food preparations, and at the dining table it is the only spice invariably served. The stout glabrous climbing herb is indigenous to the Malabar coast of Kerala preferring a humid tropical climate.

Pepper requires a porous friable soil, with good drainage, adequate water holding capacity, rich in humus and essential plant nutrients. In Kerala, pepper is growing in laterite soil, which is acidic (pH 5.0- 6.2) generally having low level of plant nutrients, low cation exchange capacity (CEC) with weak retention capacity of bases applied as fertilizers or as amendments. The soils are low in P status and having high P fixing capacity because of the abundance of Fe and Al, deficient in S, and N loss through leaching is substantial in high rainfall area. The high exchangeable aluminium, can become toxic to plants. This coupled with low Ca content may limit root volume in subsurface layers and increases moisture stress in summer months. The micronutrient deficiencies are also frequent in this soil. But it has been proved beyond doubt by several workers that under proper management, the laterite soils hold a great promise for pepper cultivation.

Calcium is an important nutrient element for the growth of pepper plants. This is one nutrient utilized by the plants at the maximum level. Application of Ca increased the exchangeable Ca content in the soil and their status in pepper leaf thereby indicating the significance of these elements in the balanced nutrition of pepper vines.

Seventy nine per cent of the total production of pepper in India is from Kerala with 90 per cent of the total area, which is indicative of the importance of the crop, its potential and problems in the state's economy. The average yield of pepper in Kerala is estimated to be 279 kg ha^{-1} as against 4067 kg ha^{-1} in

Malaysia. One of the reasons often attributed to the low productivity of the vines in Kerala is soil related stress mainly due to acidity.

The common practice of surface incorporation of lime neutralises acidity and toxic factors only in the surface soil while subsoil acidity, low base status and toxicity continue to exist as a problem below the normal plough depth. Sumner (1970) has reported that gypsum could act as an ameliorant for subsoil acidity prevalent in laterite soil. Considering the cost factor and availability, phosphogypsum is a suitable ameliorant. Huge piles of this material is available as by product of phosphatic fertilizer industry of Fertilizers and Chemical Travancore (FACT). Phosphogypsum is highly suitable for the correction of acidity especially subsoil acidity, aluminium toxicity and surface crusting in soils dominated by active Al and Fe. It also serves as a source for Ca and S (Alcordo and Recheigl, 1993). Calcium hydroxide, an ameliorant for acidity problem is the popularly used material at present.

Isotopic techniques which offer a quick and reliable means of studying the movement of ameliorants through the soil and the distribution of active roots at lower depths of soil column was also employed in this study.

In the light of these findings, an investigation with the following objectives was undertaken at College of Horticulture, Vellanikkara.

1. To assess the extent of subsoil aluminium concentration in a typical laterite soils of black pepper cultivation
2. To assess the effect of different sources of calcium in reducing exchangeable aluminium concentration
3. To evaluate different sources of calcium with respect to downward movement from surface application
4. To monitor pepper root growth in soil columns treated with ameliorants on surface

2. REVIEW OF LITERATURE

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 layers of soils. Two adsorbed cations, hydrogen and aluminium thus dominates and these ions largely responsible for soil acidity. The mechanism by which these two cations exert their influence depends on the degree of soil acidity and on the source and nature of soil colloids. Other factors which influence soil acidity are organic matter, clay minerals, compounds of iron, manganese, sulphur, nitrogen, acid rains and so on. Historically, however, soil scientists and agronomists have addressed the problem of soil acidity in the context of the plough layer and consider this zone as readily accessible to amelioration by conventional liming and ploughing procedure. But now, the scientists are giving more attention towards the subsoil acidity.

Some of the important works on amelioration of soil acidity in the top soil and subsoil has been reviewed and presented below.

2.1 Nature of soil acidity in laterite soil

An appreciable fraction of the permanent negative charge of acid soils is encountered by aluminium and hydrogen ions 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 are weak acids and that hydrogen ions adsorbed on clays when exchanged by neutral salts immediately dissolves hydrated aluminal in the soil which caused Al^{3+} to appear in the extract. (Coulter, 1969)

Studies conducted by various scientists concluded that exchangeable aluminium was the predominant cation in highly weathered acid soils rather than exchangeable hydrogen (Coleman and Thomas, 1967; Mc Cart and Kamprath, 1965; Schofield, 1949)

Coleman *et al.* (1959) proposed that the cation exchange capacity of low activity clays have a very large pH dependent charge and found that 1N KCl exchangeable acidity was caused predominantly by aluminium ions and to a negligible extent by exchangeable hydrogen ions.

Aluminium toxicity and calcium deficiency are the important limitations for the crop growth in acid soil. Poor root penetration and proliferation are commonly observed in acid soils (Pearson, 1966)

Exchangeable aluminium and organic matter levels showed the greatest effect in soil acidity (Kaminiski and Bohnen, 1976). While studying the inter-relationships between the nature of soil acidity, exchangeable aluminium and per cent aluminium saturation, Sanchez (1976) considered soil acidity as a poorly defined parameter and recommended that per cent aluminium saturation calculated on the basis of effective cation exchange capacity should be taken as a useful measure of soil acidity.

Dunchanfour and Souchier (1980) observed that Al^{3+} is more harmful to plants than H^{+}, in acid soils. A good indication of the harmful effects of acidity is given by the ratio Al/T, where T is the total exchange capacity measured at the soil pH.

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

Manrique (1986) obtained a negative relationship between Al saturation and pH in 1M KCl for Ultisols. For Oxisols, soil acidity was better expressed in terms of exchangeable Al which correlated best with pH in KCl.

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

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

According to Nambiar and Meelu (1996) soil acidity in laterite soil is increasing over the years due to long-term fertilizer use.

Varghese and Usha (1997) reported that the wet lands of red and laterite soils of Vellayani have an active acidity of 4.46 Cmol kg^{-1}, exchangeable acidity of 0.5 Cmol kg^{-1}, non exchangeable acidity of 13.2 Cmol kg^{-1} and potential acidity of 13.78 Cmol kg^{-1}

Chand and Mandal (2000) found that the values of total potential acidity, total acidity, pH dependent acidity, hydrolytic and exchangeable acidity ranged from 1.5 to 11.25, 0.93 to 4.75, 1.41 to 10.35, 0.89 to 3.85 and 0.04 to 1.03 Cmol kg^{-1} respectively in red and laterite soil of West Bengal.

Dolui and Sarkar (2001) noticed that in the red soil profiles of Orissa, exchangeable acidity contributed to 9 to 19 per cent of total acidity where as pH dependent acidity constituted 81 per cent of total potential acidity. In the red soils of West Bengal, the mean values of exchangeable and pH dependent acidity were 12.4 and 87.6 per cent of total potential acidity (Rahman and Karak, 2001)

2.2 Form of aluminium in soil as influenced by pH

Aluminium is the most abundant element in the earth's crust next to oxygen and silica, and in the majority of rocks and soils. As Al_2O_3, it ranges up to 20 to 60 per cent in highly weathered soils and laterites (Jackson, 1973). The higher percentage of Al_2O_3 is generally associated with a high percentage of gibbsite, as in bauxite ore. As SiO_2 decreases and Al_2O_3 is enriched, the molar ratio of SiO_2/Al_2O_3 in soil clays decreases from over 4 in crystalline clays high in crystalline layer silicate minerals to less than 1 in clays high in allophane (amorphous).

Buffering under these severely acid conditions is attributed to acid hydrolysis of alumino silicate clays. Dissolved Al^{3+} activity appears to be directly related to pH, as pH rises, aluminium is precipitated as hydroxide or basic sulphate (Van Breeman, 1976).

Moore and Patrick (1991) observed that jurbanite $Al(SO_4)OH.5H_2O$ governs Al^{3+} activity under low pH and amorphous $Al(OH)_3$ at high pH. Most of the pH dependent CEC sites were due to organic matter which complex with aluminium

The primary mechanisms of Al toxicity are inherently difficult to evaluate. One reason is that primary effects evidently can occur during the first minutes or hours of exposure to Al, but they can become masked after longer periods of Al exposure by numerous indirect effects (Rengel, 1992)

2.2.1 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 meager 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 (1934) considered exchangeable Al as the criterion of soil acidity rather than hydrogen ion concentration. Aluminium toxicity and calcium deficiency are the important limitations for the crop growth in acid soil. Poor root penetration and proliferation are commonly observed in acid soils (Pearson, 1966)

Evans and Kamprath (1970) proposed 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 me/litre. Soybeans responded to liming when the Al saturation was greater than 30 per cent and soil solution Al concentration was 0.2 me/litre.

Mc Lean (1970) proposed that liming has little favourable 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 no direct effect on plant growth, except below 4.2. Sartain and Kamprath (1975) explained that soybean yields on Oxisols were sharply reduced at Al saturations greater than 10 per cent.

Sanchez (1976) considered soil acidity as a poorly defined parameter and recommended 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 bring soil pH from 4.8 to 5.7 and to reduce exchangeable Al to 1.5 me/100 gm soil as a more effective means of increasing yield than raising of soil pH to neutrality. Soil acidity is a major growth limiting factor in crop production worldwide, and yield losses are frequently attributed to aluminium (Al) toxicity (Foy, 1983).

Shoot and root response depended on the concentration of Al, the age of plants, and the cultivar. The one mgL^{-1} concentration of Al significantly stimulated the growth of shoots and roots. Higher concentrations of aluminium drastically inhibited 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 is reducing 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 through out 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 a*l., 1986). Reduction in the length of coffee roots (Pavan *et al.*, 1982; Scott *et al.*, 1991) and fresh weight of wheat (Scott *et al.*, 1991) were also 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.

2.2.2 Role of aluminium in soil acidity and its effect on root growth

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

In legumes, the growth of root hairs and nodule initiation were impaired 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 *et al.*, 1982) affect 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 to the root (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 P, Ca and Fe 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. Futhermore, 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).

Aluminum in acidic subsoil restricts root development, increasing the susceptibility of crop plants to drought (Dennis *et al.*, 1994). Hutchinson (1983) reported 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.

2.3 Reclamation of acidity in laterite soil

The problem of overcoming the acidity in laterite soils through liming had received attention from very early period. To increase the productivity of acid soils, liming is the first step because it's 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) found that in an oxic soil, liming decreased exchangeable and titrable acidity and affected pH down to a depth of 100 cm. Liming also caused marked vertical and slight lateral migration of Ca and Mg.

Raji (1982), in a five year liming trial found 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) reported 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 important 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 effective 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*., 2000)

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 mine 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)

2.3.1 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 me/100gm soil and by decreasing exchangeable Al to 2 me/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 Money (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.,* (1983)

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. Decreases 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 postassium 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 solubilized 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 increase 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 ppm to 14.1 ppm, titrable acidity from 16.0 to 1.6 me/100gm soil and exchangeable acidity from 3.0 to 0.1 me/100gm 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)

Substantial amounts of Ca were leached from lime from the 0-30 cm horizon during the experimental period, but only limited amounts accumulated in the subsoil. Base saturation below 45 cm depth 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).

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 & Pavan, 1996; Caires *et al.*, 2000; Rheinheimer *et al.*, 2000; Gascho & Parker, 2001; Conyers *et a*l., 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 units pH higher than unlimed soil from a single application @ 4.5 to 6.5 t ha^{-1} in acid soils of Canada (Beckie and Ukrainetz, 1996). The increase in the pH of acid soil by the application of 800 kg ha^{-1} of Ca in the form of lime was reported by Oyanagi *et al.* (2001) Repsiene (2002) reported that hydrolytic and exchangeable acidity decreased as much as 64 per cent by liming in podzolic soils.

Mora *et al. (*2002) reported that combined application of limestone, dolomite and gypsum raised pH and decreased aluminium saturation from 20 per cent to less than 1 per cent in acid soil. The positive influence of lime in soil pH after liming was also reported by Staley (2002), Caires *et al.* (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)

2.3.1.1 Effect of Liming on the Uptake of Nutrients

Koshy (1960) and Nair (1970) noted that potassium content of plant was decreased by the application of high levels of lime. Abruna *et al.* (1964) noted that liming increased the calcium and decreased the manganese content of grasses. However the phosphorus and magnesium content were unaffected.

Bhor *et al.* (1970) obtained significant effect on the uptake of phosphorus and manganese and the uptake of calcium was directly proportional to the lime content of the soil in paddy and jowar plants. White (1970) reported that dolomitic limestone applied to an acid podsol decreased tissue manganese levels of beans (*Phaseolus vulgaris*), barley (*Hoardeum vulgare*) and peas (*Pisum sativum*)

Kuruvila (1974) proposed that the application of lime alone or in combination with MnO_2 or nitrate results on decrease in the nitrogen and phosphorus content of straw. Mandal (1976) reported that liming had been found to depress the uptake of iron, manganese, copper and zinc in soybean.

A notable increase in the uptake of N,P,K,Ca and Mg with increased dose of lime by rice was reported by Anilakumar (1980); Kabeerathumma (1969) and Kunishi (1982). Blasko (1983) proposed that in order to ensure adequate uptake of phosphorus, the lime status of the soil should be at an optimal level.

Baligar *et al.* (1985) found that liming increased shoot concentration of calcium in all the legumes and decreased the concentration of magnesium, potassium and zinc. Marykutty (1986) found that the total uptake of N, P, Ca and Mg by rice plant increased with lime application whereas uptake of K decreased with increase in levels of lime.

Meena (1987) proposed that a reduction in exchangeable Al and per cent Al saturation values has resulted in an increased uptake of N, P, Ca and Mg in cow pea. Gupta *et al.* (1989) explained that liming increased the uptake of phosphorus, calcium and potassium in plants.

2.3.2 Phosphogypsum as an ameliorant for soil acidity

During 1970's the ability of phosphogypsum to correct soil acidity in laterite soil rich in Fe & Al was revealed by Sumner (1970). Afterwards lot of research has been undertaken on the ability of phosphogypsum for the control of soil acidity in iron and aluminium rich soils

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

Gypsum moves downward much more rapidly than lime, increasing soil solution calcium ion activity to a depth of 0.8m within 5 months of application. There were differences in clay content between replicate plots and calcium movement was faster where the clay content was less (Mc Cray *et al.*, 1991).

Application of gypsum and the lime: gypsum combination at 25 per cent: 75 per cent improved the yield of groundnut grown on an acid soil more than the application of lime alone (Aniol, 1996)

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

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

A decrease in pH after gypsum application was noticed by Black and Cameroon (1984). Soil pH decreased to the extent of 0.5 to 0.9 units after gypsum application in non allophanic andosol (Toma and Saigusa, 1997). In highly weathered Palexerult soils also the decrease in pH was noticed by Arias and Fernandez (2001) whereas no change in pH due to phosphogypsum application was reported by Hammel *et al.* (1985), Oates and Caldwell (1985) and Sumner *et al.* (1986). The detoxification of subsoil aluminium by the flouride content of phosphogypsum was reported by Alva *et al.* (1988) and Alva and Sumner (1988)

Alva and Sumner (1989) found that application of phosphogypsum alleviated aluminium toxicity and increased soyabean root growth in nutrient solutions. Both phosphogypsum and mined gypsum can ameliorate aluminium toxicity in the subsoil horizon of highly weathered soil belonging to soil orders such as ultisol and oxisol (Martin *et al*., 1988) and also in soils such as non allophanic andosol (Saigusa *et al.*, 1996; Toma and Saigusa, 1997). In Dystric Luvisol, Aluminium toxicity was alleviated by phosphogypsum at the rate of 12.5 to 25 t ha^{-1} (Mesi, 2001; Borisov, 2001)

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

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

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

2.3.2.1 Mechanism involved in the amelioration of soil acidity by phosphogypsum

Phosphogypsum could act as ameliorant for soil acidity in soils rich in Fe and Al. This is made possible through several mechanisms such as 1) Self liming effect which involves a ligand exchange of hydroxyl 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. (Hue *et al.*, 1985; Alva *et al.*, 1991). 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; Mc lay and Ritchie, 1993; Pavan *et al.*, 1982) and AlF^{2+} in the case of phosphogypsum (Cameron *et al.*, 1986) and 5) Increasing ionic strength of solution, which reduces activity of Al^{3+} in solution (Pavan and Bingham, 1982)

2.4 Soil solution chemistry and fine root aluminium and calcium concentration

The ratio of Al/Ca has been suggested as a more sensitive indicator of potential Al damage to root tissues than using Al activities or concentrations alone (Rost-Siebert, 1983).

The rate of root elongation slows and increased root injury occurs as the Al/Ca ratios become higher. Damage to spruce roots was shown to occur when the Al/Ca molar ratio of the soil solution was higher than one (Randy *et al.*, 1991)

2.5 Removal of aluminium

Once Al concentrations reached toxic levels in root tissues, root senescence would be an effective mechanism for removal of Al from the living biological tissues (Vogt *et al.*, 1987)

A study was conducted to examine aluminum exclusion by roots of two differentially tolerant soybean genotypes. Following exposure to 80µM aluminium for up to 2 hr, roots were rinsed with 10mM potassium citrate solution and rapidly dissected to allow estimation of intracellular Al accumulation in morphologically distinct root regions. More Al accumulation in all root regions were noticed in the Al sensitive genotype. The genotypic difference in Al accumulation was particularly apparent at the root apex, both in the tip and in the adjacent root cap and mucilage (Dennis *et al.*, 1994)

2.5.1 Genetics of acid tolerant plant

Aluminium tolerance in wheat is a dominant character and majority of observed variability could be explained by the hypothesis of two or three gene pairs, each gene affecting the same character, with complete dominance of each gene pair. Genes controlling the aluminium tolerance in ditelosomic lines of Chinese spring wheat cultivar are located on the short arm of chromosome 5A and the long arm of chromosome 2D and 4D. (Aniol, 1996).

2.5.2 Effect of calcium and magnesium

Both calcium (Ca) and magnesium (Mg) ameliorate aluminium (Al) toxicity in plants. The effects of both Ca and Mg are additive, but together could not completely eliminate the deleterious effect of aluminium. Magnesium ameliorated Al toxicity in the tolerant wheat genotype. Calcium either had no effect, or at low Mg levels, exacerbated the effects of Al toxicity. (Edmeades *et al*., 1991)

Aluminium induced growth inhibition was due to Mg deficiency. By increasing the Mg supply, uptake of Mg increased and symptoms of Mg deficiency disappeared. Higher Ca, on the other hand, depressed Mg uptake and did not increase growth of the Al stressed plants. Besides differences of nutritional nature, Mg was much more effective than Ca in protecting roots against adsorbed/precipitated Al and in excluding Al from roots and shoots. (Keltjens and Dijkstra, 1991).

2.5.8 Uptake of aluminium

Aluminium is taken up by endocytotic mechanisms, either via non-saturable, fluid-phase endocytosis or through saturable, membrane receptor-mediated endocytosis involving specific carriers. These uptake modes are respectively exemplified by aluminium internalization involving polysaccharides and carriers, perhaps present in the rhizosphere. Given the complexity of endocytotic processes, genetic defects of the plasma membrane or at internal membrane probably lead to deficiencies in aluminium's uptake and intracellular routing respectively (Haug and Shi, 1991).

2.6 Effect of aluminium and boron

Root growth inhibition is an early symptom of Al toxicity and B deficiency. Incorporation of supplemental B prevented Al inhibition of root growth. Boron concentrations may need to be increased under acidic 'high Al' soil conditions to promote root penetration in to these soil zones, and this could be especially important during periods of drought stress (Aniol, 1996).

Aluminium toxicity is an important factor limiting plant growth on acid soils. Symptoms of B deficiency and Al toxicity are very similar and generally associated with impaired membrane function and root growth. Protection was apparent at all levels of organization examined- primary root and lateral root lengths; primary cell elongation, cell production rate, tissue organization and cell structure; primary root morphology and maturation. Protection against Al inhibition was also apparent for shoot growth (Lenoble *et al*., 1996).

2.7 Radioactive studies on plants

A comparison of the relative concentration of ^{32}P in leaf, berry and rachis of black pepper indicated that the accumulation of absorbed ^{32}P was more in leaf compared to spike (Jayasree, 1985). The radioactivity recovered in the leaves was not influenced by their relative position in the canopy as evidenced from the lack of statistical significance in the variation of ^{32}P content of leaves sampled from various canopy heights viz., top, middle and lower one thirds (Jayasree, 1985).

3. MATERIALS AND METHODS

An investigation was carried out at the pepper garden, College of Horticulture, Vellanikkara, to study the extent of subsoil acidity contributed by exchangeable aluminium and amelioration of subsoil acidity by using three calcium sources, lime, slaked lime and phosphogypsum along with it's influence on growth of black pepper (*Piper nigrum*) in lateritic soil (Vellanikkara series).

The experiment as carried out in five steps.

1. Collection of soil samples, and determination of depth wise distribution of exchangeable Al.
2. Incubation experiment, to evaluate the ameliorating effect of different ameliorants on soil properties with special reference to exchangeable aluminium.
3. Soil column study using black pepper, to evaluate the effect of different surface applied ameliorants on root growth in sub surface layers.
4. Leaching study using radio labelled calcium (^{45}Ca), to evaluate the movement of Ca from the surface applied sources.
5. Solution culture experiment to evaluate tolerance of pepper roots to Al.

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

3.1 Collection of Soil samples

Soil samples from twenty spots representing lateritic soil classified under Vellanikkara series were collected from the unfertilized area of main block of pepper garden, College of Horticulture. Soil samples were collected from four depths, at 20 cm interval up to a depth of 80 cm. The fresh soil was packed in polythene bags labeled and transported to the laboratory and air dried. The air dried soil samples were ground and then passed through 2 mm sieve and stored in air tight containers. The samples were analysed for exchangeable Na, K, Ca, Mg, Fe, Mn and Al, cation exchange capacity and pH by standard procedures (Table 1). The physico-chemical properties of the soil are shown in Table 2.

Table 1. Analytical methods followed in soil analysis

Sl. No	Parameter	Method	Reference
1	Mechanical composition	International Pipette Method	Robinson, 1922
2	Particle density	Pycnometer method	Black *et al*., 1965
3	Bulk density	Undisturbed core sample	Black *et al*., 1965
4	Water holding capacity	Undisturbed core sample	Black *et al*., 1965
4	pH	pH meter	Jackson, 1973
5	Electrical conductivity	Conductivity meter	Jackson, 1973
6	Cation exchange capacity	Atomic Absorption Spectrophotometer	Hendershot and Duquette (1986)
7	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
8	Available P	Bray extraction and photoelectric colorimetry	Jackson, 1973
9	Available K	Flame photometry	Pratt, 1965
10	Exchangeable acidity	Extraction using KCl	Yuan, 1959
11	Lime requirement of soil	S M P buffer method	Shoemaker *et al*., 1961

3.1.1 Cation Exchange Capacity

The cation exchange capacity was estimated by the method proposed by Hendershot and Duquette (1986). The exchangeable cations (Ca, Mg, Na, K, Al, Fe and Mn) present in the exchange sites in soil were replaced by Ba after equilibrating the soil with 0.1 M $BaCl_2$ solutions and the thus extracted cations were estimated.

Table 2. Physico- chemical properties of surface soil

Sl No.	Parameter	Content
A	**Mechanical Composition**	
1	sand (%)	55.18
2	silt (%)	16.38
3	clay (%)	28.44
4	Texture	Sandy clay loam
B	**Physical Properties**	
1	Particle Density (Mg m^{-3})	2.1
2	Bulk Density (Mg m^{-3})	1.26
3	Pore space (%)	40.0
4	Water holding capacity (%)	20.4
5	Volume expansion (%)	9.96
C	**Chemical Properties**	
1	pH	5.0
2	Electrical conductivity (dS $m^{-1)}$	0.1
3	Cation exchange capacity (Cmol (p^+) kg^{-1})	10.19
4	Base saturation (%)	68.48
5	Exchangeable acidity (m eq kg^{-1})	81
6	Organic carbon (%)	1.15
7	Available P (kg ha^{-1})	6.09
8	Available K (kg ha^{-1})	48.33
9	Lime requirement of soil (t ha^{-1})	15.00

Four grams of soil sample was taken in a 100 ml conical flask and 40 ml of 0.1M $BaCl_2$ solution was added. The suspension was then shaken for 2 h and filtered through Whatman No.42 filter paper. From the filtrate, Ca, Mg, Fe, Mn and Al were determined by using Perkin Elmer Atomic Absorption Spectrophotometer and Sodium and potassium by Elico flame photometer. The sum of exchangeable cations expressed in Cmol (p^+) kg^{-1} soil was recorded as CEC of the soil.

3.2 Bulk soil sample collection

Bulk soil samples were collected from few random locations of unfertilized area of the pepper garden and pooled together for incubation study, soil column experiment and leaching study. For that the soil was collected from four depths at 20 cm interval up to a depth of 80 cm in the pepper garden of College of Horticulture, Vellanikkara. Sampling was done from four depths and collected soil samples were air dried and sieved through 2mm sieve and kept for further investigation.

3.3 Incubation Experiment

The incubation study was conducted to evaluate the liming materials *viz*., lime, slaked lime and phosphogypsum on pH and Ca content along with its ameliorating effect on exchangeable Al.

3.3.1 Experiment details

Lime, slaked lime and phosphogypsum were mixed with the soil as per the lime requirement calculated for the soil. Phosphogypsum for the experiment had been obtained from Fertilizers and Chemicals Travanore Ltd. (FACT), Udyogamandal and lime and slaked lime were purchased locally. Ca and P content of the amendments are shown in Table 3.

Table 3. Chemical composition of amendments

Sl.No.	Parameter	Parameter		
		Phosphogypsum	Lime	Slaked lime
1	Calcium (%)	13.8	40	53
2	Phosphorus (%)	0.14	-	-

For incubation study, 100 gm of soil from 4 different depths (0-20, 20-40, 40-60 and 60-80 cm.) were taken and filled in separate bottles. Lime, slaked lime and phosphogypsum were applied at three levels of LR to the above soil samples collected from four depths and incubated. Treatments imposed were three sources, four soil depths and three levels based on lime requirement (LR). Soil samples were then incubated for different interval. The details of the experiment are presented below.

Sources : 3

S1: Calcium carbonate

S2: Phosphogypsum

S3: Calcium hydroxide

Depths : 4

D1 : 0-20 cm

D2 : 20-40 cm

D3 : 40-60 cm

D4 : 60-80 cm

Levels: 3

A: ½LR

B: LR

C: 1½LR

Time: 3

T1: 60 days

T2: 120 days

T3: 180 days

Treatment combination: 3 × 4 × 3 × 3

Replication: 3

Design: CRD

The samples were drawn and analyzed for EC, pH, exchangeable Ca and Al at 2 months, 4 months and 6 months after incubation. Moisture content of the soil was calculated by oven dry method. The soil pH was measured in soil-water suspension (1: 2.5). Electrical conductivity was determined in the supernatant liquid of the soil: water suspension (1: 2.5). The samples were extracted with 0.1N $BaCl_2$ and analyzed for Ca and Al by using atomic absorption spectrophotometer. The data interpreted on the basis of analysis of variance for four factor experiment in a completely randomized design.

3.4 Soil column study using black pepper

An experiment to study the influence of surface applied ameliorants, on root growth of pepper plants was taken up using pepper vines planted in PVC columns of 10 cm diameter and 100 cm length. Bulk soil samples collected at four depths as mentioned in section 3.2 were filled in the PVC column, depth wise and compacted to bulk density to simulate field condition. A total of 7.8 kg of soil was used to fill each column ie, 2 kg 0-20 cm layer, 1.9 kg 20-40 cm layer, 1.9 kg 40-60 cm layer and 1.9 kg 60-80 cm layer. The details of the preparation of soil column are given in Table 3.

Table 4. Quantities of soil taken for preparing the soil column

Depth	Bulk Density (Mg m^{-3})	Weight of soil taken (kg)
0-20	1.26	2
20-40	1.24	2
40-60	1.20	1.9
60-80	1.20	1.9
Total		7.8

3.4.1 Design of Experiment

Sources : 3

S1: Calcium carbonate

S2: Phosphogypsum

S3: Calcium hydroxide

Levels: 3

A: ½LR

B: LR

C: 1½LR

Treatment combination: 3 × 3 + 1 control

Replication: 3

Design: CRD

Accordingly, Ca sources were applied at the surface of soil column.

3.4.2 Planting

After the application of amendments on the surface of soil, soil column was irrigated and moisture was maintained at field capacity. Rooted black pepper

Plate 1 a.

Plate 1b

Plate 1c.

Plate 1. Soil column experiment

Layout of PVC column

cuttings were planted in each soil column. Compost mixed with the top soil was applied over it. PVC columns were fixed well by using bamboo polls cut at 1.5 m, in the open field. Moisture at field capacity was maintained throughout the study period by replenishing the moisture lost by evapotranspiration. Factomphos and murate of potash were applied at 3 months interval at the rate equivalent to paskage of practices recommendation of KAU. Akomin at the rate of 0.02 per cent was applied to the base of plant for the control of foot rot disease. The layout of this experiment is shown in Plate. 1

3.4.2.1 Biometric Observation

The following biometric observations were taken at bimonthly interval for a period of 360 days. Plant height was measured from the base of the stem to the tip of the youngest leaf using a meter scale and expressed in cm. Number of leaves per plant was also noted.

3.4.3 ^{32}P application

In order to examine the effect of Ca sources towards the growth of black pepper roots to lower layers, radio-labelled P solution was applied in to the soil holes at a depth of 50 cm one year after planting the pepper cuttings. For this, soil was irrigated well and a hole was made up to a depth of 50 cm. PVC tubes of 1 cm diameter inserted in to the hole and 4 ml of KH_2PO_4 solution (4mg P) with a specific activity of 2 µCi mg^{-1} P was dispensed with at 50 cm depth through the tube. ^{32}P application device designed by Jayasree *et al*. (1985) developed for the purpose of applying desired volume of ^{32}P solution at a given depth was used for this purpose. Total 4 ml ^{32}P solution having an activity of 8 µCi was applied at a depth of 50 cm in each tube. The radioactivity remaining in the sides of the access tube was washed down with distilled water using wash bottle. The plant was kept free of irrigation for a period of one week.

3.4.3.1 Leaf sampling and radioassay

Fully mature and healthy leaf samples from the pepper vines planted in the column were collected from each treatments 8 days after ^{32}P application for radio assay. These leaf samples were oven dried, weighed and digested with 2:1 nitric acid - perchloric acid mixture. Once the digestion is over, the contents were quantitatively transferred in to a 20 ml glass scintillation counting vial and made to a final volume of 20 ml by repeated washings of the flask. The radioactivity was determined by Cerenkov counting done in a multi-label three in one counter (Triathler), Hidex, Finland and expressed as counts per minute per gram sample (cpm g^{-1}).

3.5 Leaching Study Using Radioisotope of Calcium (^{45}Ca)

PVC column of size 1” diameter was used for the leaching experiment. Bulk soil sample collected from the pepper garden was filled depth wise at 20 cm interval up to a depth of 80 cm depicting field situation. The details of the preparation of soil column are given in Table 5.

Table 5. Soil column preparation for leaching study

Depth	**Bulk Density (Mg m^{-3})**	**Weight of soil taken (g)**
0-20	1.26	123.64
20-40	1.24	121.68
40-60	1.20	117.50
60-80	1.20	117.75
Total		480.57

Liming materials were labelled with ^{45}Ca and applied to the soil column at the rate of 1½ LR as per the treatment details given.

Sources : 3

S1: Calcium carbonate

S2: Phosphogypsum

S3: Calcium hydroxide

Depths : 4

D1 : 0-20 cm

D2 : 20-40 cm

D3 : 40-60 cm

D4 : 60-80 cm

Treatment combination: 3 × 4

Replication: 3

Design: CRD

3.5.1 Preparation of Radiolabelled Compounds

Radioisoptope of Calcium (^{45}Ca) was obtained from Board of Radiation and Isotope Technology (BRIT), Mumbai having an activity of 2.18 mCi in 3.6 ml as $CaCl_2$ solution. This was made up to a total volume of 100 ml by using 1M $CaCl_2$ and made carrier based. From this, 25 ml mixed with 100 ml of 1M $CaCl_2$ and 100 ml 0.1M Na_2CO_3 and precipitated as radiolabelled $CaCO_3$, which was filtered and dried for use.

For preparing radiolabelled $Ca(OH)_2$, 25 ml $^{45}CaCl_2$ was taken and allowed to mix with 200 ml 0.1M $CaCl_2$ solution which was treated with 400 ml 0.1M NaOH and $^{45}Ca(OH)_2$ obtained as precipitate was filtered and dried.

In the case of phosphogypsum, the slurry of phosphogypsum was taken directly and thoroughly mixed with 25ml ^{45}Ca radiolabelled $CaCl_2$ and allowed to equilibrate for few days and then dried.

After drying at constant temperature of 100^0C in an oven, radiolabelled compounds were taken and weighed based on 1½ LR of the experiment soil. Accordingly 3.76 g $^{45}CaCO_3$, 2.83 g $^{45}Ca\ (OH)_2$ and 10.89 g ^{45}Ca labelled phosphogypsum were applied to the surface of soil column.

Field capacity was maintained throughout the experiment period. This is by weighing the tube along with the soil column each time before irrigation.

After three months, the soil was carefully emptied from the PVC tube without disturbing the soil column and depth wise i.e., 0-20, 20-40, 40-60 and 60-80cm layers were separated. Soil samples were then dried in the oven and used for radio assay. For this, 2 gm of oven dried soil from each depth was taken separately and shaken with 20 ml 0.1 *M* $BaCl_2$ solution for 2 hrs. It is filtered through Whatman No. 42 filter paper. From this, 10 ml filtrate was taken in a 20 ml glass scintillation counting vial and mixed with 10 ml scintillator and radioactivity was determined using liquid scintillation counter (multi-label three in one counter (Triathler), Hidex, Finland and expressed as cpm g^{-1} soil.

3.5.2 Autoradiography

After three months, the soil column was separated out from the PVC tube and used for Autoradiography. Splitted PVC tubes were used for this purpose. Soil column was filled in split PVC tubes without any disturbance and transferred to dark room. From there, the soil column was covered with cling film and exposed to X-ray sheets in dark room condition and kept for 11 days.

After 11 days, X-ray sheet were separated out from the soil column and washed in developer, water, fixer and running water.

3.6 Solution culture experiment

Nutrient solution culture was done for finding out the effect of aluminium concentration on pepper root growth. Hoagland solution for nutrient solution culture was prepared using KNO_3, $Ca(NO_3)_2.4H_2O$, $FeCl_3$, $MgSO_4.7H_2O$, NH_4NO_3, H_3BO_3, $MnCl_24H_2O$, $ZnSO_4.7H_2O$, $CuSO_4$, $Na_2MoO_4.2H_2O$ and KH_2PO_4 having a pH of 6 adjusted by KOH.

Treatments: 8
Replication: 3
T1: 0 mg L^{-1} aluminium (Absolute control)
T2: 5 mg L^{-1} aluminium
T3:10 mg L^{-1} aluminium
T4: 20 mg L^{-1} aluminium
T5: 40 mg L^{-1} aluminium
T6: 60 mg L^{-1} aluminium
T7: 80 mg L^{-1} aluminium
T8: 100 mg L^{-1} aluminium

A total of 330 ml Hoagland solution was filled in each bottle. The bottles were then covered with black polythene and it was made into the above concentrations of aluminium by using standard Al solution. Rooted pepper cuttings were separated from the soil without any disturbance to the roots and washed well to remove soil and other materials sticking on the roots. It is then placed in Hoagland solution and aeration was provided through solution using compressor and tube arrangement. The volume of Hoagland solution was maintained at 330 ml level for the whole period of experiment. The performance

Plate 2a. Solution culture experiment with pepper plants

Plate 2b. Pepper plants in 40,60,80 and 100 mg L^{-1} Al concentration.

Plate 2c. Pepper plant exposed to 0 mg L^{-1} Al concentration

Plate 2d. Pepper plant exposed to 5 mg L^{-1} Al concentration

Plate 2. Arrangement of pepper plants in solution culture (after 3 days)

of plants as well as roots was evaluated every day. The pH and Al concentrations of the Hoagland solution were also analyzed.

3.7 Anatomical observation of roots

The structural differences in roots of black pepper that were kept in different concentration of aluminium were studied to determine the effect of different concentrations of Al on root development. The rooted cuttings of Panniyur 1 kept in 0 and 5 mg L^{-1} Al concentrations in Hoagland solution for 27 days were used for this purpose. All plants kept in Al concentration beyond 10 mg L^{-1} to 100 mg L^{-1} were decayed and could not be used for further observation. Differences in the morphology and anatomy of the roots in the different treatments were observed. For anatomical studies, roots were cut and after washing in distilled water for 5 min, freehand cross sections of the roots were taken, stained with safranin for 2-3 min, washed in distilled water and mounted in glycerine. The stained sections were visualized under research microscope.

3.8 Statistical Analysis

Analysis of variance for the characters under study was done. The data was analysed by CRD, Factorial experiment employing appropriate statistical procedures in a personal computer using MSTAT software.

4. RESULTS

An investigation was carried out to examine the extent of subsoil acidity contributed by exchangeable aluminium in a typical laterite soil in the pepper garden of College of Horticulture, Vellanikkara. The experiment consisted of study of depth wise distribution of exchangeable Al in the soil, incubation experiment to evaluate the ameliorants, soil column experiment to evaluate the performance of surface applied ameliorants on root growth of pepper plants in subsoil layers, leaching study to monitor the movement of surface applied Ca through different ameliorants and a solution culture experiment using black pepper to study the effect of Al on plant growth.

4.1 Characterisation of the soils used for the study

Soil samples at 20 cm depth interval up to a depth of 80 cm were collected from 20 locations of the block No. 33 of the pepper garden, College of Horticulture. Thus a total of 80 samples were collected, 4 each from 20 locations. The results of various analysis done are being described here. The important parameters included in the study were pH, exchangeable Ca, Mg, Al, Na, K, Fe, Mn and cation exchange capacity (Appendix I). The data were subjected to analysis of variance and the results of various parameters are presented in Table 6.

4.1.1 Soil pH

The pH of soil in distilled water (1: 2.5) for the top soil (0- 20 cm) range from 4.9 to 5.2. The second depth (20- 40 cm) soil has a pH between 4.60 to 4.80. At third depth (40- 60 cm) soil exhibited values ranging from 4.8 to 4.9. The final depth under investigation (60- 80 cm) was having pH values from 5.0 to 5.2.

The pH values showed a significant difference between lower depth and upper depth. Soil pH at 60-80 cm and 0-20 cm layer were higher than the middle layers. The second layer showed significantly lower values compared to top and bottom layers. This suggests the existence of a subsoil acidic layer between 20-40 cm depth.

4.1.2 Exchangeable iron and aluminium

Exchangeable Fe content in different layers were compared and the differences were statistically not significant. Exchangeable iron status varied from 0.21 to 2.51 with a mean value of 1.08 mg kg^{-1} in top 0-20 cm soil. At lower depths, iron values ranged from 0.2 to 1.9 (mean: 0.95 mg kg^{-1}), 0.05 to 1.48 (mean: 0.92 mg kg^{-1}) and 0.16 to 2.11 (mean: 0.83 mg kg^{-1}) in the 20- 40, 40- 60 and 60- 80 cm depths respectively. The mean Fe content does not show any significant difference in the samples at various depths. Distribution of Fe was found to be uniform throughout the soil layers.

A perusal of the data on exchangeable Al indicated that the aluminium content in the middle two depths of soil was higher than the lower depths. 0-20 cm soil having exchangeable aluminium content ranged from 4.1 to 122.2 (mean: 34.95 mg kg^{-1}). Second depth has Al values ranging between 9.8 and 145 (mean: 69.65 mg kg^{-1}). Third depth (40-60 cm) having a value 6.6 to 159 (mean: 65.54 mg kg^{-1}). 60-80 cm depth soil was having an exchangeable Al content varied from 4.9 to 202 (mean: 37.36 mg kg^{-1}). Exchangeable aluminium at the surface and bottom layer were lower. But at 20-60 cm depth, it was high. Exchangeable aluminium values were significant at 5 per cent level

4.1.3 Exchangeable sodium and potassium

Content of Na in the study area is found to be less compared to K. Top 0-20 cm layer having Na value ranging from 260 to 380 (mean: 309 mg kg^{-1}). 20-40 cm depth soil showing Na values in between 260 and 360 (mean: 311 mg kg^{-1}).

40-60 cm layer depicts Na content of 260 to 360 (mean: 312 mg kg^{-1}). Final depth i.e., 60-80 cm was having Na values ranging from 260 to 360 (mean: 313 mg kg^{-1}).

Top soil (0-20 cm) showed K content ranging from 400 to 720 (mean: 514 mg kg^{-1}). Second layer has a value of 302 to 640 (mean: 514 mg kg^{-1}). Potassium value between 360 to 600 mean: (478 mg kg^{-1}) is shown by the third depth soil. Soil from final depth showed a value ranging from 360 to 640 (mean: 474mg kg^{-1}). Statistical analysis of the data suggest that there is no significant difference between exchangeable Na and K values of sample at various depth.

4.1.4 Exchangeable calcium and magnesium

Exchangeable Ca content in the surface soil varies from 301.1 to 1148 (mean: 595.4 mg kg^{-1}). Second depth having Ca content between 183 to 761.1 (mean: 349.7 mg kg^{-1}). 40-60 cm depth soil has exchangeable Ca values ranging from 225 to 636.5 (mean: 421 mg kg^{-1}). Final depth of soil from 60 to 80 cm layer shows Ca values from 137.6 to 838.7 (mean: 542.9 mg kg^{-1}).

Exchangeable Mg content in the surface soil ranged from 77.2 to 151.8 (mean: 110.96 mg kg^{-1}). Second layer having 35.7 to 146.3 (mean: 76.77 mg kg^{-1}) Ca value. Third depth soil having a content of 31.9 to 127.4 (mean: 68.78 mg kg^{-1}) and the 60-80 cm, final depth having an exchangeable Mg content ranging from 18.2 to 723.8 (mean: 127.06 mg kg^{-1}).

Exchangeable Ca and Mg at the surface layer and bottom layer were significantly higher than the middle two layers.

4.1.5 Exchangeable manganese

Surface soil have an exchangeable Mn content ranging from 18 to 43 (mean: 25.8 mg kg^{-1}). Second depth having value ranging from 14 to 45 (mean:

27.25 mg kg^{-1}). Third depth soil having an exchangeable Mn content of 15 to 53 (mean: 32.4 mg kg^{-1}). Final depth (60-80 cm) having a value of exchangeable Mn ranging from 8 to 45 (mean: 28 mg kg^{-1}). Exchangeable manganese was almost same at all depths.

Table 6. Chemical characteristics of soil samples at various depths collected from pepper garden

Depth (cm)		pH	Exchangeable cations (mg kg^{-1})							CEC Cmol (+)kg^{-1}
			Fe	Al	Na	K	Ca	Mg	Mn	
0-20	Mean	4.9	1.08	34.95	309	514	595.4	110.96	25.8	7.05
	Range	4.9-5.2	0.21-2.51	4.1-122.2	260 -380	400-720	301.1 - 1148	77.2-151.8	18-43	5.06-10.19
20-40	Mean	4.7	0.95	69.65	311	514	349.7	76.77	27.2	5.94
	Range	4.6-4.8	0.2-1.90	9.8-145	260-360	302-640	183-761.1	35.7-146.3	14-45	4.34-6.75
40-60	Mean	4.8	0.92	65.54	312	478	421.0	68.78	32.4	6.11
	Range	4.8-4.9	0.05-1.48	6.6-159	260-360	360-600	225-636.5	31.9-127.4	15-53	5.07-7.22
60-80	Mean	5.0	0.83	37.36	313	474	542.9	127.06	28.0	6.87
	Range	5.0-5.2	0.16-2.11	4.9-202	260-360	360-640	137.6 - 838.7	18.2-723.8	8- 45	4.65-11.77
CD (0.05)		0.04	N.S.	25.20	N.S.	N.S.	110.2	47.51	N.S.	0.72
Standard error			0.116	-	7.1	17.6	-	-	1.97	-

4.1.6 Cation exchange capacity

Cation exchange capacity at the surface layer and bottom layer are higher than the middle two layers. The mean value of CEC at 0-20 cm depth is 7.05, 20-40 cm depth is 5.94, 40-60 cm depth is 6.11 and the bottom layer is 6.87 Cmol(+) kg^{-1}.

4.2 Incubation Study

As a second part of the investigation, an incubation experiment was undertaken to study the ameliorating effect of three calcium sources on the various properties of the soil with special reference to exchangeable aluminium and pH. The three sources tried were calcium carbonate, calcium hydroxide and phosphogypsum and the levels were ½ LR, LR and 1½ LR. The data on various parameters during the period of incubation are presented in Tables 7, 8, 9 and 10.

4.2.1 Soil pH

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

The lowest value for soil pH throughout the period was recorded by Phosphogypsum and highest value by $CaCO_3$. All the sources showed an increasing trend of pH with time, while $Ca(OH)_2$ showed a decreasing trend after 120 days (Fig. 5). Consequent to liming with Ca sources, pH values measured after a period of 180 days it is observed that the surface layer showed significantly higher values. The middle layers showed uniform values and the bottom layer showed significantly lower values (Fig. 7 and Table 9). When considering the level of application of amendments pH increased with increase in level of application of amendments (Fig. 3 and Table 8).

4.2.2 Electrical conductivity

Statistical analysis of the data pooled over three periods for soils of different depths revealed that application of phosphogypsum significantly increased the electrical conductivity (Fig. 1 and Table 7). Electrical conductivity increased with increase in period of application. Increase in level of application, increased the EC values. EC values were higher in the second depth (20-40 cm) while the values were almost same at 1st, 3rd and 4th depth (Table 9).

4.2.3 Exchangeable calcium

Exchangeable calcium content was significantly highest with the application of phosphogypsumfollowed by $CaCO_3$ and the lowest value recorded for $Ca(OH)_2$ (Table 8). Exchangeable Ca content at the third layer of soil (40-60 cm) is significantly higher than other three depths (Table 10). The values increased with time up to 120 days and then decreased (Fig. 6).1 ½ level of application showed highest increase in calcium compared to ½ LR and LR. When the levels of ameliorants were examined, it is noticed that calcium content increased with increase in level of application. When considering the period after the addition of ameliorants, exchangeable calcium increasds upto 120 days after application whereas it decreased afterwards. In this case steep increase and decrease were noticed in phosphogypsum (Fig. 6).

4.2.4 Exchangeable aluminium

A perusal of the data indicated that $CaCO_3$ treated soil recorded the lowest value of exchangeable aluminium where as $Ca(OH)_2$ and phosphogypsum showed significantly higher values (Table 7). When the levels of ameliorants was compared, it is noticed the three levels produced significant differences in exchangeable Al. The lowest value was noticed in 1 ½ LR and the highest in ½ LR. Top two depths recorded significantly higher values of exchangeable aluminium compared to lower depths. In the case of time, exchangeable aluminium content considerably decreased in the second period.

Table 7. Chemical properties of soil as influenced by various ameliorants after 6 months

Source	**pH**	**EC (dS m^{-1})**	**Ca (mg kg^{-1})**	**Al (mg kg^{-1})**
$CaCO_3$	6.69	0.42	1413.30	4.64
Phosphogypsum	4.72	1.24	1587.93	16.62
$Ca(OH)_2$	6.19	0.37	1040.11	15.90
CD (0.05)	0.11	0.03	94.22	0.71

Table 8. Chemical properties of soil as influenced by various levels of sources after 6 months

Levels	**pH**	**EC (dS m^{-1})**	**Ca (mg kg^{-1})**	**Al (mg kg^{-1})**
½ LR	5.30	0.54	849.02	15.20
LR	5.94	0.70	1333.95	12.10
1 ½ LR	6.36	0.78	1858.37	9.85
CD (0.05)	0.11	0.03	94.22	0.71

Table 9. Chemical properties of soil as influenced by various depths after 6 months

Depth (cm)	**pH**	**EC (dS m^{-1})**	**Ca (mg kg^{-1})**	**Al (mg kg^{-1})**
0-20	6.13	0.67	1290.42	13.05
20-40	5.86	0.7	1271.72	15.23
40-60	5.85	0.67	1556.34	10.78
60-80	5.63	0.67	1269.98	10.48
CD (0.05)	0.12	0.04	108.80	0.82

Table 10. Chemical properties of soil as influenced by time in the incubation experiment for various calcium sources.

Time period	pH	EC ($dS\ m^{-1}$)	Ca ($mg\ kg^{-1}$)	Al ($mg\ kg^{-1}$)
60 days	5.68	0.64	1225.83	13.13
120 days	5.99	0.69	1487.98	9.54
180 days	5.99	0.70	1327.53	14.48
CD (0.05)	0.11	0.03	94.22	0.71

4.3 Soil column study using black pepper

An experiment to study the influence of surface applied ameliorants, on root growth of pepper variety Panniyur 1 was done in PVC column. Three ameliorants, calcium carbonate, calcium hydroxide and phosphogypsum were applied to the surface at a rate equivalent to ½ LR, LR and 1 ½ LR and black pepper is planted. Growth of black pepper is noted at weekly interval. Biometric observations taken at bimonthly interval is shown in Tables 11 and 12.

4.3.1 Influence of calcium sources on growth characters

The growth characters like number of leaves per plant and length of vine were influenced by the level of application of calcium sources. The highest plant height was noticed 360 days after planting (DAP). But the growth pattern of the vines did not show any linear uniform pattern.

The data on the leaf number per plant attributes observed at different time interval of plant growth is given in Table 11. Number of leaves per plant did not show any regular pattern among different sources.

Table 11. Effect of liming on leaf number per plant in black pepper

Treatment		60 DAP	120 DAP	180 DAP	240 DAP	300 DAP	360 DAP
$CaCO_3$	½ LR	2	3	4	6	7	9
	LR	3	3	4	4	6	10
	1 ½ LR	4	4	6	6	7	8
PG	½ LR	4	4	5	6	8	12
	LR	3	4	4	6	9	15
	1 ½ LR	3	3	4	5	7	11
$Ca(OH)_2$	½ LR	3	4	5	7	7	9
	LR	2	3	5	6	8	12
	1 ½ LR	3	3	4	6	8	11
Control		3	3	3	4	5	6

Table 12. Effect of liming on black pepper plant height

Treatment		60 DAP	120 DAP	180 DAP	240 DAP	300 DAP	360 DAP
$CaCO_3$	½ LR	3	4	6	11	27	50
	LR	4	5	7	12	19	60
	1 ½ LR	4	5	8	12	20	40
PG	½ LR	5	6	7	11	27	70
	LR	4	6	9	14	26	75
	1 ½ LR	5	6	8	14	29	60
$Ca(OH)_2$	½ LR	4	5	7	13	22	45
	LR	3	4	8	11	30	70
	1 ½ LR	3	5	7	11	28	55
Control		3	3	4	7	11	28

4.3.2 Root activity studies of pepper vines in soil column

Inorder to assess the ameliorating effect of surface applied Ca sources on subsurface soil layers, the root activity of the vines grown in the soil column was measured at 50 cm depth using ^{32}P. Detectable counts of radioactivity were obtained in the leaves are presented in Table 13.

Table 13. ^{32}P activity in the leaves as indicated by counts on leaf samples of black pepper (cpm g^{-1})

Treatment	½ LR	LR	1 ½ LR
$CaCO_3$	2183	2533	2676
Phosphogypsum	3613	4546	5820
$Ca(OH)_2$	3076	3040	2883
Control		1506	

The count obtained from phosphogypsum treated sample was high at all levels followed by $Ca(OH)_2$ and the lowest count value noticed for $CaCO_3$.

4.4 ^{45}Ca leaching experiment

Leaching study was conducted to evaluate the movement of calcium towards the lower depths of soil profile. For this ^{45}Ca labeled in $CaCO_3$, $Ca(OH)_2$ and Phosphogypsum were applied to the surface of soil column and the counts were taken from 2 gm soil sampled from different depths and presented in Table 15. The data pertaining to the radio assay of calcium sources reveled that all the sources recorded comparable count values when added together for all the depths. Higher count value obtained at the surface soil for lime and slaked lime while with increase in depth, count value decreased in both the cases. Highest count

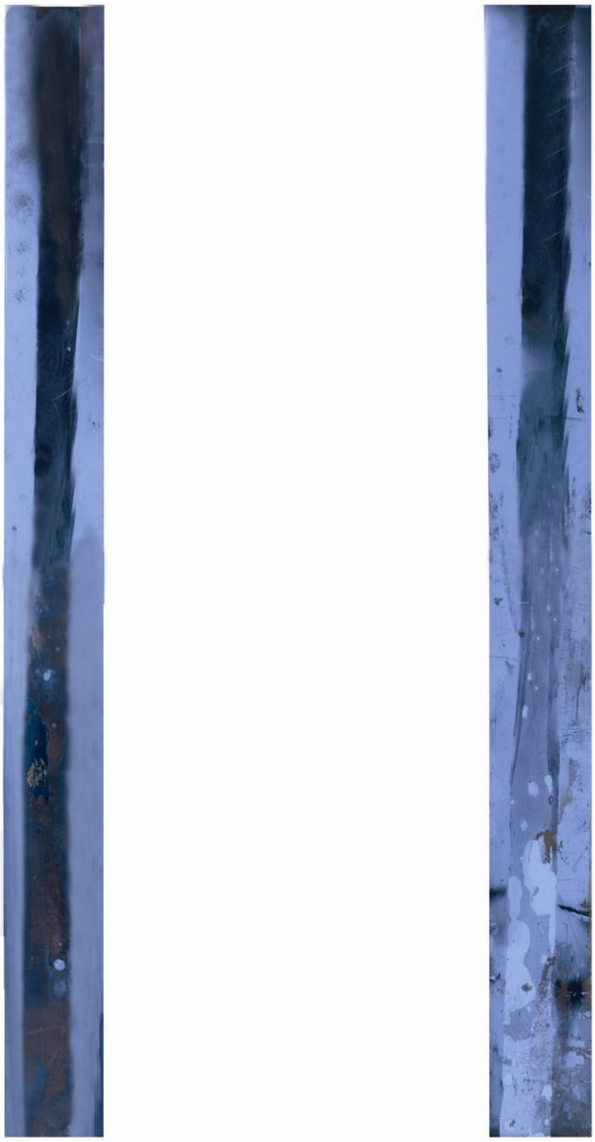

Plate 3a Plate 3b

Plate 3. Autoradiograph of ^{45}Ca labelled soil column a) Phosphogypsum b) $Ca(OH)_2$

value for phosphogypsum was at 0-20 cm layer. Towards the lower depths, phosphogypsum recorded a high count value compared to $CaCO_3$ and $Ca(OH)_2$.

Table 14. ^{45}Ca counts in exchangeable fraction (cpm per g soil)

Depth (cm) / Source	0-20	20-40	40-60	60-80
$^{45}CaCO_3$	2229.5	48.5	42.0	40
$^{45}Ca(OH)_2$	2055.0	67.5	55.5	55
Phosphogypsum	1374.0	855.0	424.0	246
CD (0.05) = 185.99				

4.4.1 Autoradiography

To evaluate the downward movement of calcium from the surface, autoradiographs were developed from the ^{45}Ca lebelled soil column. Radioactivity exposed X-ray sheets were viewed in the light and found more activity in the surface. Towards the lower depths, the activity was found to be decreasing in both sources (^{45}Ca labeled calcium hydroxide and phosphogypsum). The picture was more clear in $^{45}Ca(OH)_2$ treated soil column. In this case, no activity was found in the lower depth (Pllate. 3).

4.5 Solution culture experiment

Solution culture experiment was done in Hoagland solution using graded concentration of Al, in which rooted pepper plants were kept. Black pepper variety Panniyur 1 was used for the study. Individual roots of black pepper were noted every day. The plants kept in an Al concentration of more than 10 mg L^{-1} died within one week of exposure to Al. It is found that the root growth was healthy and vigorous at 5 mg L^{-1} Al concentration. Fresh root growth started after 20 days in 5 mg L^{-1} Al and 0 mg L^{-1} (control) treated plants. But the root growth was low compared to that of 5 mg L^{-1} Al concentration solution. 10 mg L^{-1} Al

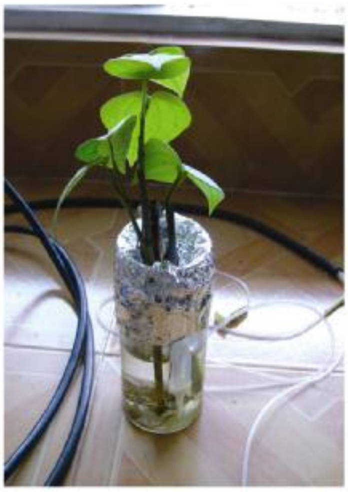

Plate 4a. Pepper plant in Hoagland solution at 0 mg L^{-1} Al concentration

Plate 4b. Pepper plant in Hoagland solution at 5 mg L^{-1} Al concentration

Plate 4c. Pepper plant in Hoagland solution at 10 mg L^{-1} Al concentration

Plate 4. Solution culture experiment (after 27 days)

concentration level does not affect the root growth of black pepper up to 28 days of treatment. But the root rotting started afterwards. In plants exposed to 10 mg L^{-1} Al concentration, there was significant reduction in root growth and all roots started decaying within 30 days.

Table 15. Root characteristics of black pepper before treatment

Treatment	**Root length (cm)**	**Root number**
0 mg kg^{-1} Al	8	5
5 mg kg^{-1} Al	12	6
10 mg kg^{-1} Al	12	6
20 mg kg^{-1} Al	15	6
40 mg kg^{-1} Al	9	5
60 mg kg^{-1} Al	15	6
80 mg kg^{-1} Al	10	5
100 $mgkg^{-1}$ Al	10	6

Table 16. Root characteristics of black pepper after 27 days of treatment

Treatment	**Root length (cm)**	**Root number**
0 mg kg^{-1} Al	5	14
5 mg kg^{-1} Al	9	32
10 mg kg^{-1} Al	8	8

Plate 5a. Pepper roots exposed to
0 mg L^{-1} Al concentration

Plate 5b. Pepper roots exposed to
5 mg L^{-1} Al concentration

Plate 5c. Pepper roots exposed to
10 mg L^{-1} Al concentration

Plate 5. Solution culture experiment
(after 27 days)

4.5.1 Chemical analysis of Hoagland solution

pH and aluminium concentration of the solutions were evaluated at both ends of the experiment. pH of the Hoagland solution was 6 at the beginning of the experiment. In the final stage, pH reaches near neutral level at 0 mg L^{-1} Al concentration. From 5 mg L^{-1} Al concentration onwards, pH was acidic and showed a decreasing trend up to 100 mg L^{-1} level.

Aluminium concentration of the solution also showed a decreasing trend. ie., 10 mg L^{-1} Al concentration decreased to 2.2 mg L^{-1} and 5 mg L^{-1} decreased to 1.73 mg L^{-1}.The results are shown in table 18.

Table 17. pH of Hoagland solution at both ends of the experiment

Treatment (Al con.)	**pH (initial)**	**pH (after 27 days)**
0 mg L^{-1}	6	7.1
5 mg L^{-1}	6	5.9
10 mg L^{-1}	6	4.7
20 mg L^{-1}	6	4.3
40 mg L^{-1}	6	4
60 mg L^{-1}	6	3.8
80 mg L^{-1}	6	3.6
100 mg L^{-1}	6	3.4

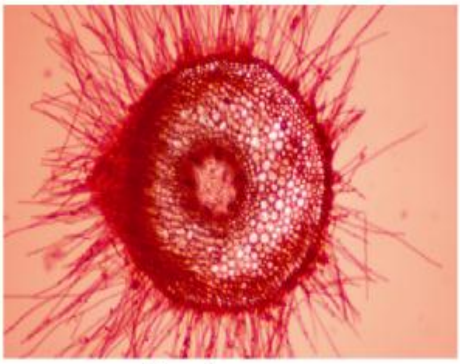

Plate 6a.

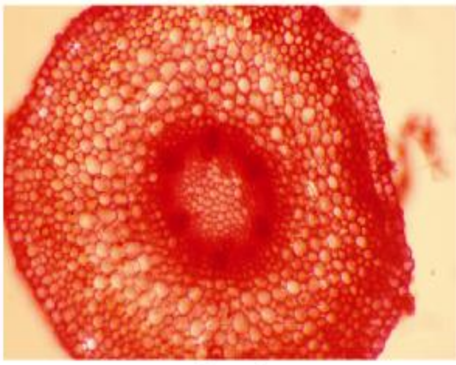

Plate 6b.

Plate 6. Differences in intensity of root hairs in roots exposed to a) 5 mg L^{-1} Al, b) control [10x]

Plate 7a.

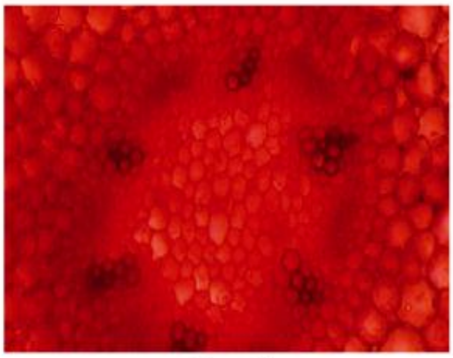

Plate 7b.

Plate 7. Cross section of roots in control
a) 25x, b) 50x

Plate 8a.

Plate 8b.

Plate 8. Cross section of roots in 5mg L^{-1}
a) 25x, b) 50x

Table 18. Change in concentration of aluminium in Hoagland solution after 27 days

Treatment	Al (initial) mg L^{-1}	Al (final) mg L^{-1}
T1	5	1.73
T2	10	2.2

4.5.2 Root anatomy

Transverse root sections of Panniyur 1 grown in 0 and 5 mg L^{-1} Al concentrations were stained with safranin for 2-3 min, washed in distilled water and mounted in glycerine were observed under the research microscope. At 5 mg L^{-1} Al concentration, from the newly emerged roots, many morphologically normal lateral roots with numerous root hairs were formed compared to the control (Plate 6a, b). Anatomy of the roots in the control showed the dicot like structure consisting of an epidermis, a broad cortex and a stele surrounded by endodermis. The number of vascular tissue varied from 6-8 with xylem and phloem in radial arrangement. At the centre, there is large pith (Plate 7a, b). The anatomy of the fresh lateral roots produced in the cuttings treated with 5 mg L^{-1} Al were also similar to the control (Plate 8a, b).

5. DISCUSSION

Results of an investigation carried out at College of Horticulture, Vellanikkara to study the amelioration of subsoil acidity by calcium sources in laterite soils of black pepper garden are discussed here. The investigation comprised of preliminary investigation on the profile of subsoil acidity and exchangeable Al in pepper garden of college of horticulture. This is followed by incubation experiment, soil column study with black pepper, leaching study using ^{45}Ca and solution culture using black pepper.

5.1 Characterisation of soils used for the study

5.1.1 Textural analysis

The texture of the surface soil sample was sandy clay loam in texture. Sand was the predominant size fraction and silt recorded the lowest value (Table 2). This is indicative of a highly weathered laterite soil.

5.1.2 Chemical characteristics

Organic carbon content of the surface soil was low (1.15%) which is characteristic of tropical soils, being depleted because of high mineralization. In tropical highly weathered laterite soil, depleted organic carbon status is unique (Tessy, 1992).

The cation exchange capacity of soils was low and confirm earlier reports of Seena (2000), on low activity clay soils. However comparatively higher percentage base saturation is noticed in the surface soil. This may be due to better management practices adopted in the pepper garden.

The soils are highly weathered and leached with consequent low base saturation values for subsurface layers.

The exchangeable Al content was calculated since this was considered as a useful measure of soil acidity as compared to exchangeable hydrogen as suggested by Sanchez, 1976.

In acid soil reclamation, exchangeable Al rather than exchangeable H^+ has been found to be critical. Hence lime requirement was used as a criterion for supplying sufficient Ca and Mg in reducing the hazards of Al in solution. This approach has considerably reduced conventional lime recommendation required to raise the pH of soil to neutrality.

5.1.2.1 Exchangeable calcium

Among the exchangeable cations, calcium was the dominant divalent cation both in surface and subsurface layers (Table 6). These layers contained significantly higher levels of Ca when compared to 20-60 cm zone. Calcium held by the pH dependent charges are more loosely held under acidic conditions which can be extracted easily by unbuffered salt solutions like that of $BaCl_2$. In the surface soil samples Ca content was more. This could be due to the regular application of lime on the garden. The higher value noticed on the bottom most layer (60- 80 cm) could be possibly due to elluviation of clay particles in the sub-layers. However the middle layer showed lower values. Varghese and Usha (1997) has reported low exchangeable acidity for the surface samples of laterite soil in Vellayani, and these results give similar indications.

5.1.2.2 Exchangeable magnesium

Exchangeable Mg also showed the similar trend as that of Ca at different depths. However the content was only 20 per cent of that of Ca. Contrary to the higher Mg content of soil compared to Ca, dissolved Mg was only 1/5th to that of Ca (Gopinathan, 1986). Magnesium content at the surface and bottom layers were significantly higher than the middle two layers. In some studies, it was reported that high exchangeable Mg content existed in soils where exchangeable Ca was lower. Such observations were not obtained in the study.

5.1.2.3 Exchangeable potassium

There was no significant variation in the depth wise distribution of exchangeable potassium. But, a critical evaluation of the data showed that the K content in the top two depths was higher than the bottom layers though the difference was not significant. This can also be attributed to the regular fertiliser application and in a porous soil with low CEC, this nutrient is not very much retained the surface layers and will be leaching down.

5.1.2.4 Exchangeable manganese

The content of exchangeable manganese does not show any significant variation with depth. The contribution of exchangeable manganese to soil acidity may be almost same at all depths.

5.1.2.5 Exchangeable iron

When compared with exchangeable manganese, exchangeable iron content is very low in both surface and subsurface layers. The highest content was noticed in the surface layer. In laterite soil Fe mostly exist in the oxidised and crystallised form and the extractability of these forms by $BaCl_2$ is lower.

5.1.2.6 Exchangeable aluminium

The content of exchangeable aluminium is high in subsurface soil 20–60 cm layer. This points to the existence of a sub surface zone with predominance of high exchangeable Al. In all the layers, exchangeable Al was the dominant cation contributing to acidity. This observation again highlights the importance of exchangeable Al, contributing to soil acidity, essentially in the subsurface layers. Thus on comparison of the data on exchangeable ions it can be concluded that, of the ions contributing the soil acidity, exchangeable aluminium is the dominant one followed by manganese.

5.1.2.7 Cation exchange capacity (CEC)

The CEC was generally low in both surface and sub surface soils. Since the soil is dominated by1: 1 type kaolinitic clay minerals the CEC is expected to be low. Depth analysis of the data indicated that the same trend was observed in the case of exchangeable calcium and since calcium being the dominant ion in exchange phase contributing to CEC. Low value of pH may be the reason for low CEC of soil.

5.2 Incubation study

Exchangeable aluminium was the predominant cation in highly weathered acid soils rather than exchangeable hydrogen (Coleman and Thomas, 1967). Liming is the most important management option for the control of soil acidity. The high cost of lime and its unavailability often restricts its use by farmers. Hence alternate sources were attempted for the correction of soil acidity. Phosphogypsum, a by-product from phosphoric acid plant was found to be effective in correcting the soil acidity in laterite soil by reducing the exchangeable acidity especially the exchangeable Al content (Sumner, 1970; Reeve and

Sumner, 1972). Since Ca in phosphogypsum is soluble and mobile, it can correct subsoil acidity also even when applied to surface (Alcordo and Recheigl, 1993).

5.2.1 Dissolution of ameliorants

5.2.1.1 Effect on pH and EC

The results of the incubation experiment done to evaluate the suitability of different Ca sources as an ameliorant is presented in Fig. 1. In phosphogypsum treated soils, pH values were significantly lower and EC values were higher when compared to $CaCO_3$ and $Ca(OH)_2$. In phosphogypsum, Ca is present as slightly soluble form and more over this material contain slight amount of free phosphoric acid. This contributed to low pH and high EC values. In other sources, the ameliorating effect on pH was significantly high. Neutralisation of active acidity by these sources bring about increase in pH where as phosphogypsum does not make such a reaction (Jeena, 2003). The highest value for electrical conductivity throughout the incubation was recorded by phosphogypsum at the rate of 1½ LR. This is mainly due to the better solubility of phosphogypsum compared to other Ca sources. Considering effect on samples from various depths, pH is higher at the surface soil. This is due to the lesser Ca need the surface compared to the subsurface layers (Fig. 7).

5.2.1.2 Effect on exchangeable Ca and Al concentration

When considering the effect of the ameliorants on exchangeable aluminium concentration, $CaCO_3$ treated soil showed low concentration of aluminium. But calcium content was high in lime treated soil. From this, it is clear that, even though phosphogypsum is highly mobile, $CaCO_3$ is highly effective in decreasing the exchangeable aluminium concentration, at the site of application, possibly due to its effect on maintaining high pH. However the benefits of this material may be confined to the site of application alone since $CaCO_3$ contain Ca

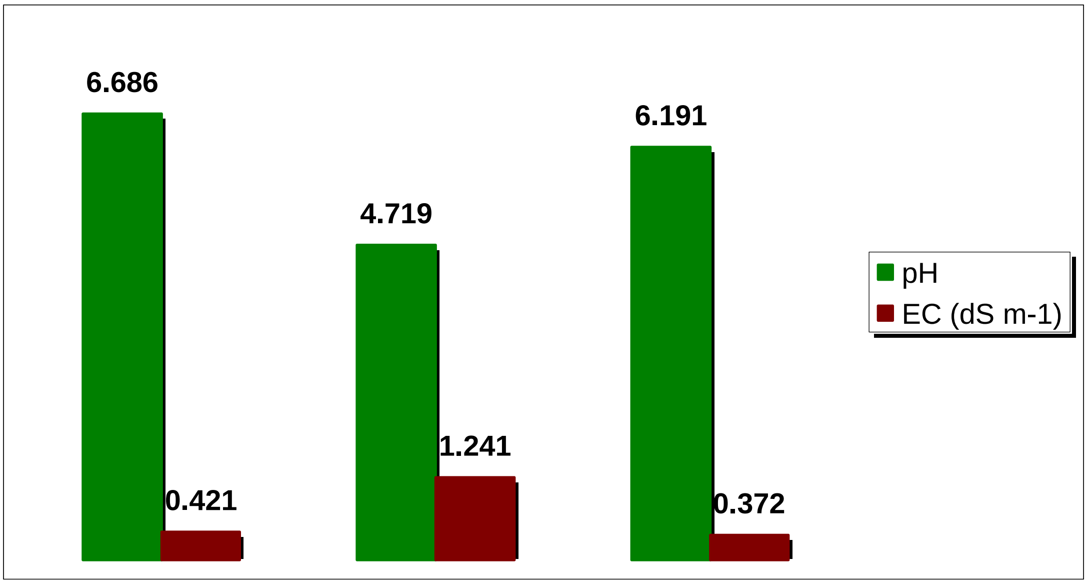

Fig. 1 pH and EC of soil influenced by various Ca sources

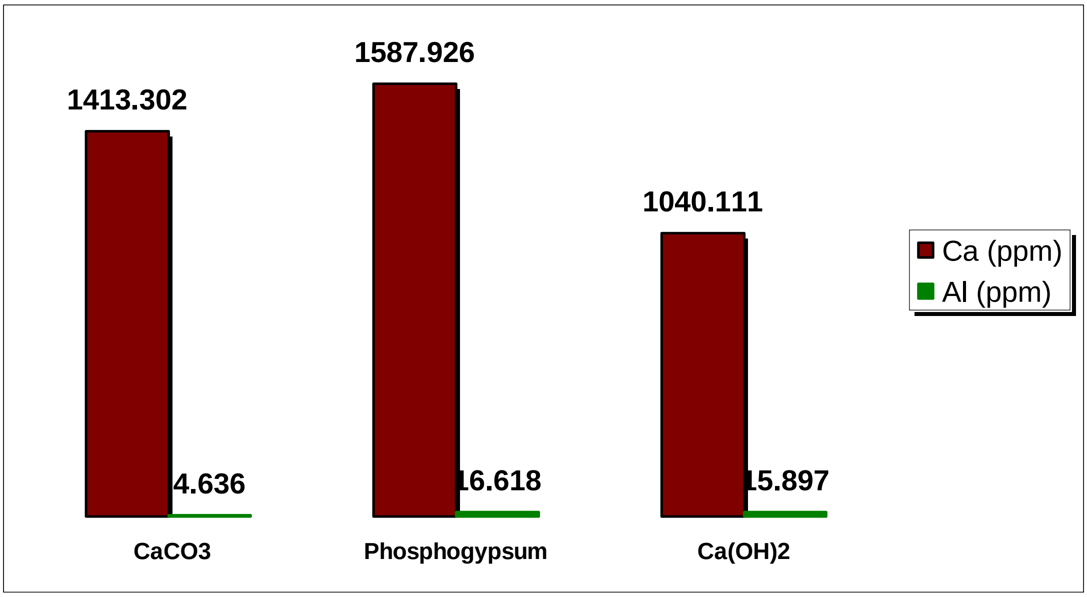

Fig. 2 Ca and Al of soil influenced by various Ca sources

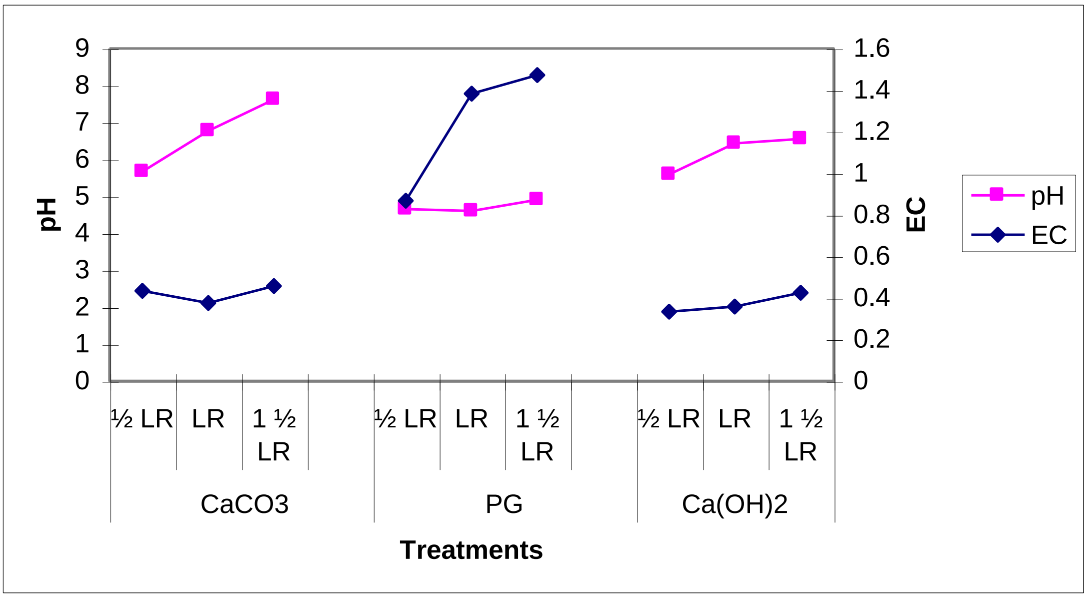

Fig. 3 pH and EC of soil influenced by various levels of Ca sources

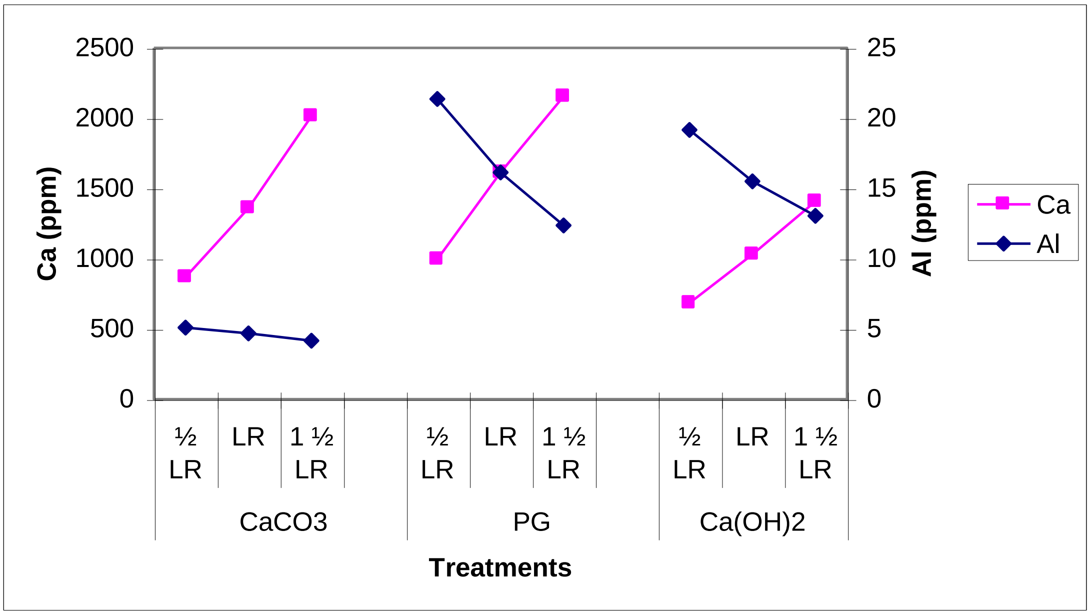

Fig. 4 Ca and Al of soil influenced by various levels of Ca sources

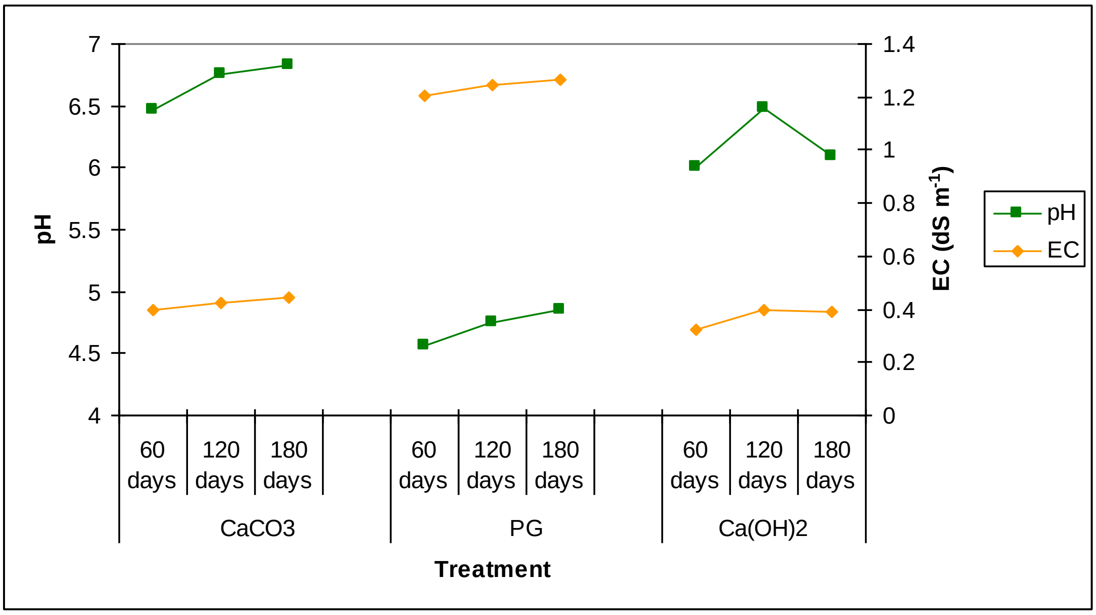

Fig. 5 pH and EC of soil at various time interval

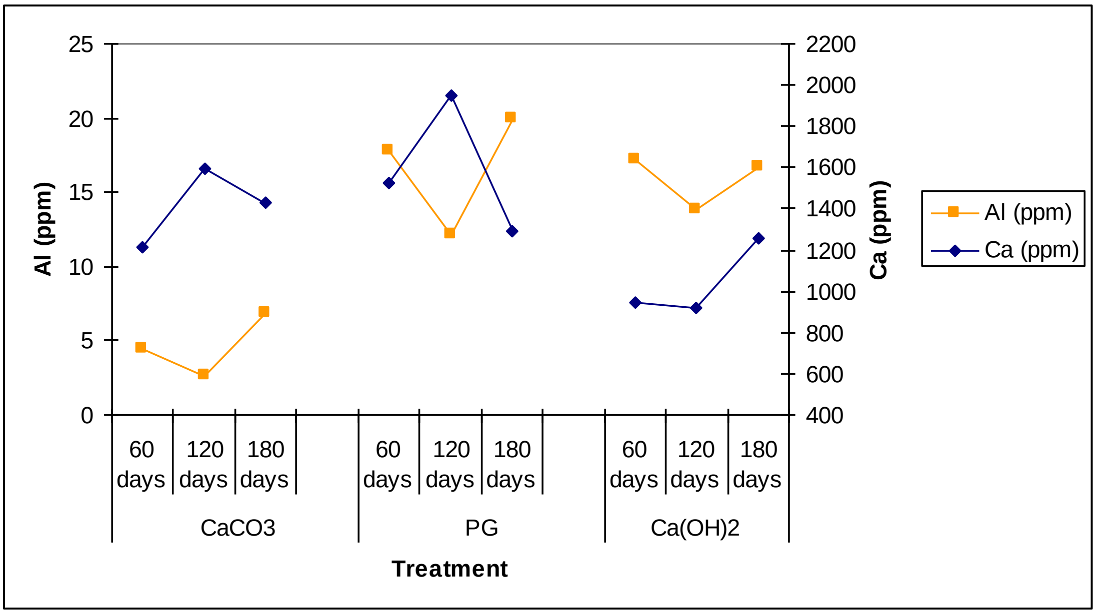

Fig. 6 Ca and Al of soil at various time interval

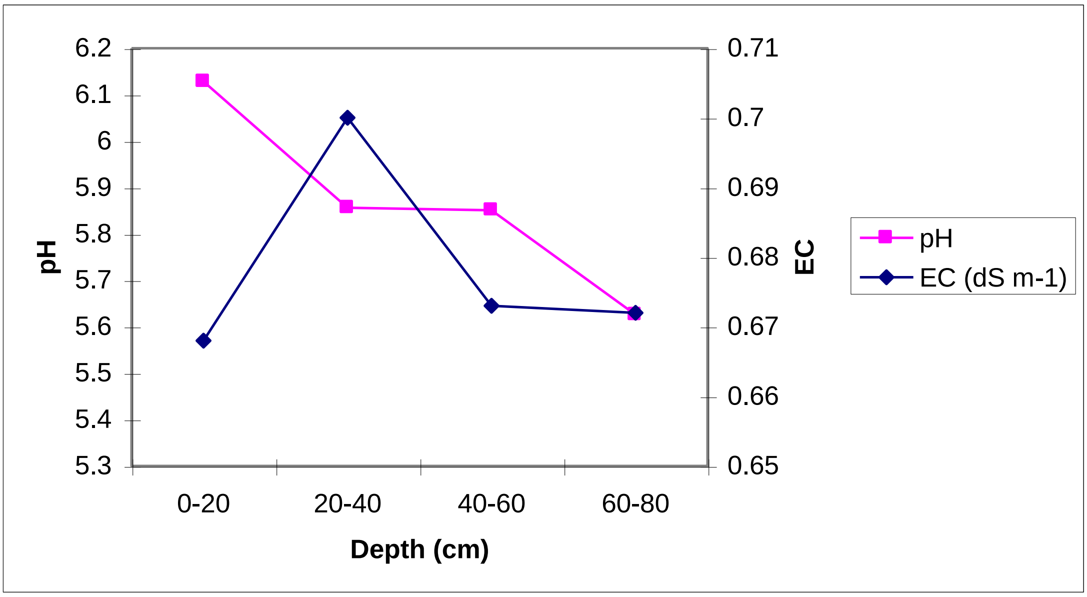

Fig. 7 pH and EC at various depths of soil

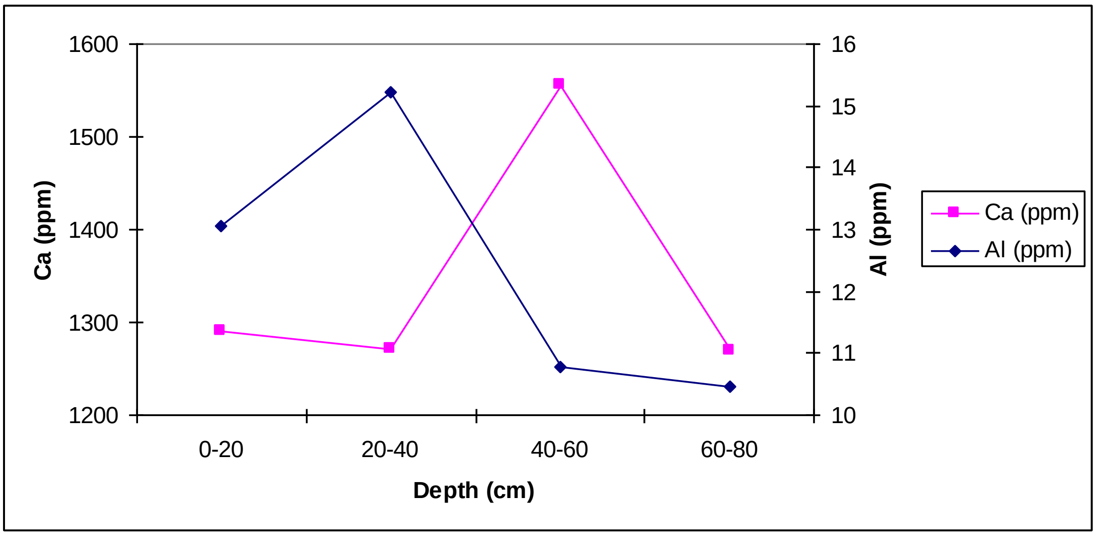

Fig. 8 Ca and Al at various depths of soil

in an insoluble form. Phosphogypsum maintained comparable concentration of exchangeable Ca, with that of $CaCO_3$. However phosphogypsum did not bring any significant decrease in exchangeable Al. This owing to acidic pH prevailing in phosphogypsum treated soil. This points to the need of applying phosphogypsum, mixed with $CaCO_3$ to obtain most benefitting effect.

5.2.1.3 Effect of different levels of Ca sources

Evaluation of the three sources at different levels *viz*., ½ LR, 1 LR and 1 ½ LR on pH and EC are presented in fig. 3. In phosphogypsum treated soils increasing the level of ameliorants does not increase in pH as in other sources. This again can be attributed to the acidic nature of phosphogypsum. The effect of these materials in exchangeable Al and Ca is presented in fig. 4. The effect on EC was not prominent in phosphogypsum due to better solubility of this material. However its influence on increasing the pH was not prominent as other two sources. The exchangeable Ca content in all the three sources increased with increasing level of ameliorant. Suppression of exchangeable Al was not prominent for $CaCO_3$ even at lower level. But for phosphogypsum and $Ca(OH)_2$, the exchangeable Al concentration at lower level of application was higher with a prominent decrease as the level is increased. However this reduction does not reach to the level of $CaCO_3$.

5.2.1.4 Effect of period of incubation on exchangeable Al and Ca concentration

In the present experiment a reduction in exchangeable aluminium and subsequently exchangeable acidity (Fig. 6) was observed due to all calcium sources at a period of 120 days of incubation, but the effect was more evident in $CaCO_3$ treatment. The application of lime was most effective in reducing exchangeable acidity. Rate of application at 1½ LR level was the most effective treatment (Fig. 4). After 120 DOI (days of incubation), exchangeable Al again increased in all cases and the extend of increase was more prominent in phosphogypsum. Suppression of exchangeable Al was not prominent for $CaCO_3$ even at lower level.

The behaviour of soil pH was very much similar to that of exchangeable H^+, since pH is actually the measure of exchangeable H^+. Comparing the three sources, lime, slaked lime lime is more effective than phosphogypsum in increasing the pH.

From this incubation study it is found that pH is increased with $CaCO_3$ where as phosphogypsum does not produce pH increase. There was significant reduction in exchangeable Al by all Ca sources, but $CaCO_3$ produced maximum reduction. Highest value of exchangeable Ca content was showed by phosphogypsum. But this effect was possibly cancelled by low pH of this material. Hence the possibility of blending phosphogypsum with $CaCO_3$ has to be further explored to derive the benefits of both this material.

5.3 Soil column experiment

This experiment was under taken to explore the effect of surface applied ameliorants on root activity pattern of pepper plants in sub soil layer contributing high concentration of exchangeable Al. The ameliorants were applied at ½ LR, LR and 1½ LR rates as lime slaked lime and phosphogypsum on the surface of soil columns in PVC tubes simulated to field condition. Rooted pepper cuttings variety Panniyur 1 grown for a period of 360 days. Biometric observations of the plants were recorded at bimonthly interval and results examined. Radiolabelled phosphorus was applied at a depth of 50 cm and the activity was measured in leaves after a period of 8 days.

5.3.1 Biometric characters

The vine length of black pepper plants did not show any uniform pattern among the different treatments. However liming at 1 LR showed slightly better growth. The reduction in exchangeable aluminium due to ameliorant can be a probable reason for the increased growth of the plant. Similar results were obtained by Tessy (1992) in soybean. The leaf number of the plants showed uniform pattern in all the treatment.

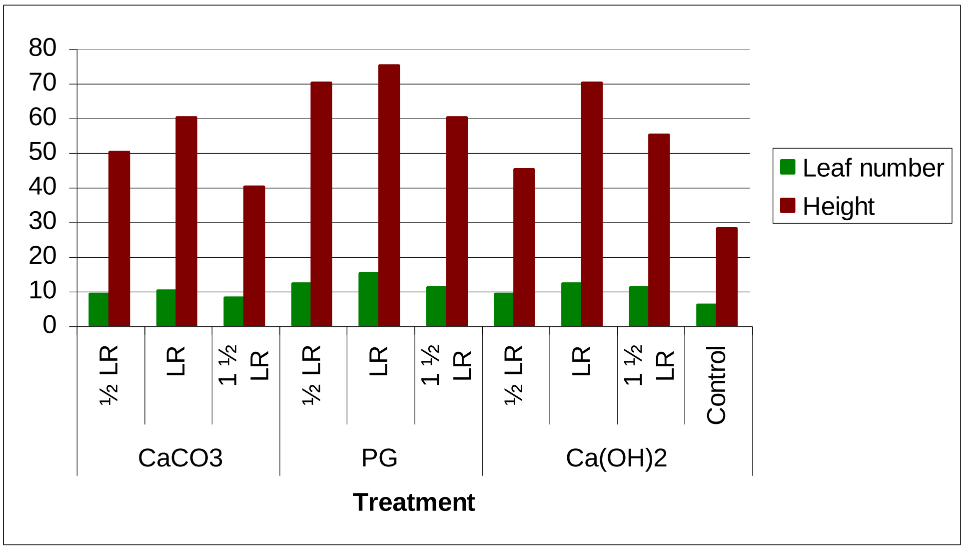

Fig. 9 Length of vine and leaf number of plants in different treatments after 360 days

5.3.2 Influence of calcium sources on growth parameters

All the three calcium sources used in the experiment, calcium carbonate, calcium hydroxide and phosphogypsum influenced the growth characters, height and number of leaves per vine compared to control. The maximum height and number of leaves were noted at LR level of application of sources. The ½ LR and

1½ LR levels of ameliorant does not bring about any enhancement in the growth of black pepper.

5.3.3 Root activity study from the leaf sample of radiolabelled plants

After a period of 360 days of growing pepper vines in the PVC columns ^{32}P was applied at a depth of 50 cm and extent of ^{32}P absorbed by the plants was assessed in the radioactive study. Leaf samples were collected from the lower two-third portion of the canopy as suggested by Jayasree, (1985). The processed leaf samples were subjected to radioassay. The results showed that when the calcium was applied as PG, more count in the leaves could be noticed and also for this material counts were increased as the level of application was increased (Fig. 10).

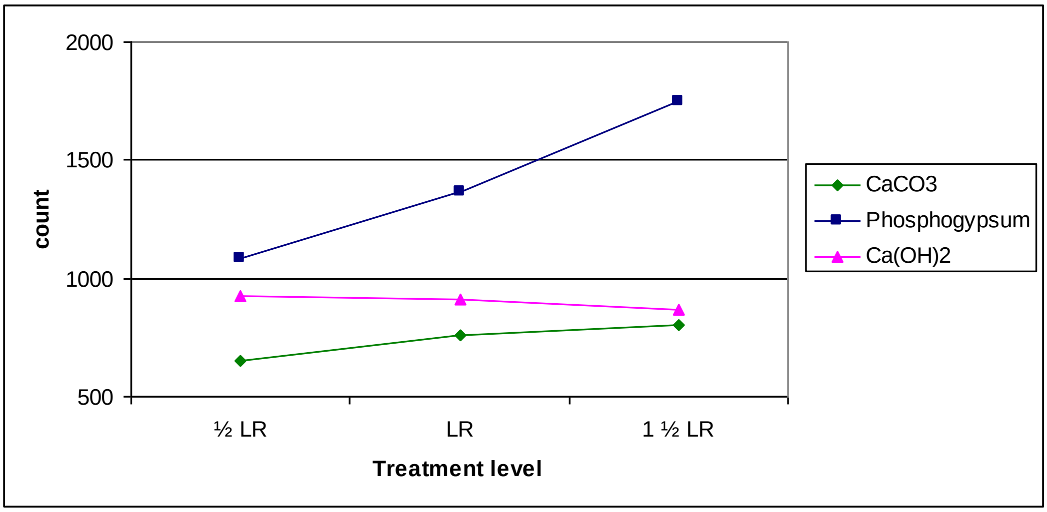

Fig. 10 Root activity noticed at 50 cm depth as ^{32}P count when observed on leaf sample of black pepper treated with different ameliorants

The active roots of black pepper vine were found to reside mostly within 30 cm soil area (Jayasree, 1985). In the PVC column of 10 cm diameter, the lateral spread was limited to this distance though it was up to 30 cm distance as reported by Jayasree (1985). However the spread of roots beyond 30 cm depth was explored in this study. The ameliorating effect of calcium sources decreased the content of exchangeable aluminium up to a depth of 50 cm i.e., surface applied calcium from PG has better moved up to a distance of 50 cm. High counts from higher levels may be an indication of active and vigorous root growth at 50 cm depth.

5.4 Leaching study using radioisotope of calcium (^{45}Ca)

The activity of conventionally applied calcium sources will confine to the surface soil due to the inability of calcium to dissolve and move towards the lower layers of soil profile from these insoluble ameliorants. In the soil under study exchangeable aluminium at the subsurface layer was high. To evaluate the downward movement of calcium sources, a study was conducted using radioisotope calcium (^{45}Ca) labelled ameliorants. The three materials were labelled and surface applied on PVC columns filled with soil simulating field situation. After a period of 120 days of equilibration the soil at each layer was separated out and counts were noted after extracting Ca in 0.1M $BaCl_2$.

The counts for ^{45}Ca labelled calcium carbonate was found to be the least and phosphogypsum gave a high count rate. Calcium hydroxide stands in between calcium carbonate and phosphogypsum. In the case of phosphogypsum, significant counts could be noticed in lower layers though it was reducing from surface to bottom (Table 14). But in $CaCO_3$ and $Ca(OH)_2$ counts were mainly confined to the top layer suggesting very little downward movement of Ca from these sources. Gypsum moved downward much more rapidly than lime, increasing soil solution calcium ion activity to a depth of 0.8 m within 5 months of application (Mc Cray *et al.*, 1991). They had also reported that there were differences in clay content between replicate plots and calcium movement was faster where the clay content was less.

5.4.1 Autoradiography

The autoradiograph showing the movement of ^{45}Ca labelled in Ca $(OH)_2$ revealed that calcium was more confined to surface but for phosphogypsum, radioactivity was noticed in lower layers also. From both the sources, Ca moved downwards, but from phosphogypsum Ca moved deeper compared to calcium hydroxide (Plate. 3).

5.5 Solution culture experiment

Hoagland solution prepared at different concentrations of aluminium were used for growing rooted black pepper plants. Plate 4 showed that at 5 mg L^{-1} Al concentration, plant growth was healthy and vigorous. Large number of new roots were formed at this concentration when compared to control. Shoot growth was not affected by an aluminium concentration of 10 mg L^{-1}, initially. The plant growth was later suppressed after 28 days of treatment. This may be due to the limited carbohydrate reserves in the root tips. Excised root tips, which have limited carbohydrate reserves and can be much less metabolically active than intact ones (Brouquisse *et al*, 1991), are less proficient in excluding Al.

5.5.1 Chemical analysis of Hoagland solution

Before planting black pepper, pH of the Hoagland solution was 6. But after 27 days of treatment, pH of the solutions were found to be decreasing. The tolerance mechanism of pepper plants towards aluminium concentration also would have contributed to this.

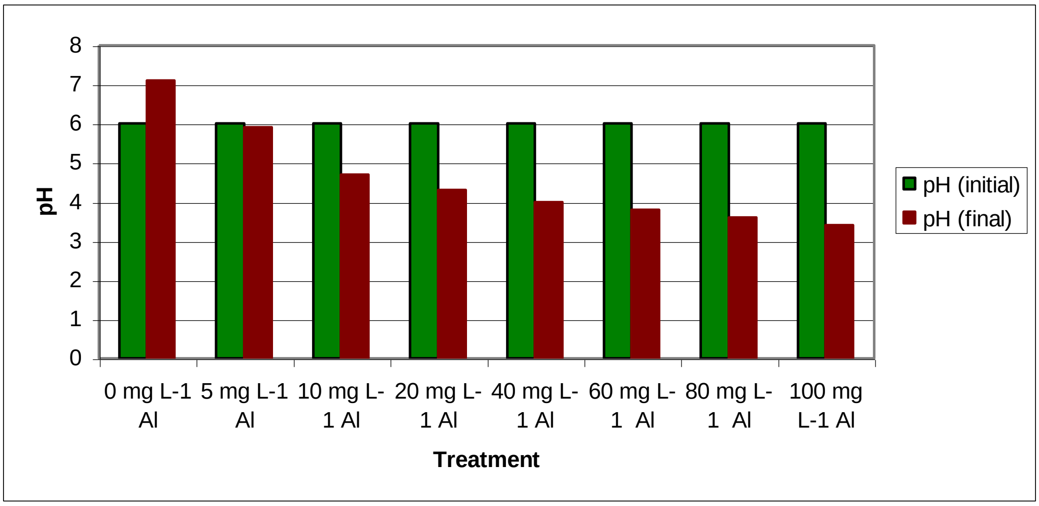

Fig. 11 pH of Hoagland solution at both ends of experiment

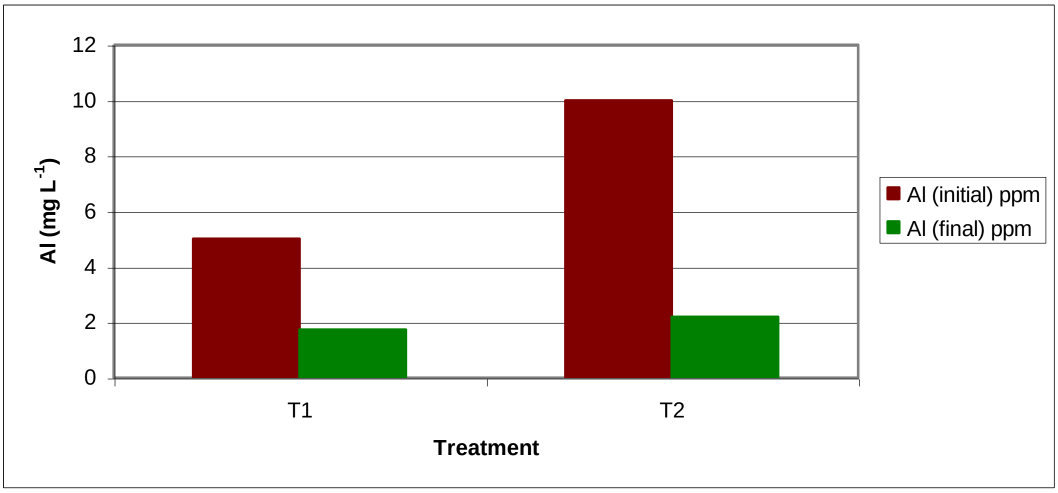

Fig. 12 Change in concentration of Al in Hoagland solution

When the plants exposed to high concentration of aluminium, it will be excluded from the cells in the root apical region. This may be another reason for decreasing pH in Hoagland solution. But, the low value of aluminium concentration in the solution may be definitely due to the absorption of aluminium by the plants as a coping mechanism to avoid toxicity. From this, it is clear that absorbed aluminium will remain in the plants. Detailed experiments on this line will only establish the exact mechanism of plants when exposed to Al concentration.

5.5.2 Root anatomy

The results of root section study of Panniyur 1 grown in 0 and 5 mg L^{-1} Al revealed that 5 mg L^{-1} concentration of Al in Hoagland solution promotes the growth of morphologically normal lateral roots with numerous root hairs from the newly emerged roots. Keser *et al.* (1975) reported that in Sugarbeet 4, 8 and 12 mg L^{-1} Al nutrient solution caused curving of the primary root and the root cap broke away. Also lateral roots emerged as small outgrowths on the primary root axis but their development was abnormal. Emolayev *et al*. (2003) reported normal lateral roots with numerous root hairs in transgenic soybean seedlings tolerant to aluminium grown in modified Hoagland solution. 0 mg L^{-1} Al concentraion in Hoagland solution also favours the normal growth of black pepper. From this solution culture experiment, we observed that pepper plant root growth was better at an aluminium concentration between 0 and 5, while at 10 mg L^{-1} there was decline. The reason for the promoting effect at 5 mg L^{-1} has to be further explored.

From this investigation it can be concluded that there is a subsoil acidity barrier in the soil due to exchangeable aluminium and hydrogen and that zone needs special attention. Phosphogypsum and lime are highly effective in ameliorating acidity due to exchangeable aluminium and hydrogen. Lime is effective at the site of application while phosphogypsum can move to a longer depth in the soil profile. Even though aluminium is not an essential element, a small quantity of the element is needed for the proper growth of plants.

6. SUMMARY

The present study on “Amelioration of subsoil acidity by calcium sources in laterite soils of black pepper garden” was carried out to explore the extent of sub soil acidity and to evaluate the effect of different sources of calcium in ameliorating the exchangeable aluminium concentration in laterite soil with reference to growth of black pepper. The effect of Al concentration on growth of black pepper roots was also studied.

The whole study was conducted as five experiments using the soil collected from the pepper garden, College of Horticulture, Vellanikkara. The first study was to characterize and find out the depth-wise distribution of Al in the laterite soils of pepper garden, College of Horticulture. Analysis of soil sample revealed that the exchangeable aluminium content was 69 mg kg^{-1} at the subsoil layer, which is significantly in higher concentration than the surface. On the basis of this an incubation experiment using three calcium sources, lime, slaked lime and phosphogypsum was done to study the ameliorating effect of these materials on reducing exchangeable Al in soils. In continuation to this, soil column study using PVC columns filled with soil layers simulating field condition was also done. The effect of three surface applied ameliorants on reducing subsoil acidity was evaluated by measuring the root activity of pepper plants, at 50 cm depth, grown in the columns by isotopic method. The movement of Ca from the surface applied material was then confirmed by performing a leaching experiment in PVC columns using ^{45}Ca labelled ameliorants. Further to this a solution culture experiment was also done by growing rooted pepper plants in Hoagland solution containing different levels of Al, in order to understand the response and tolerance level of pepper plants, specifically roots to Al. The results of these investigation are summarised below.

Among the exchangeable cations, calcium was the dominant divalent cation both in the surface and subsurface soil samples of pepper garden. Calcium

and magnesium are more in the surface samples due to the regular application of lime in the garden. The higher value noticed at the bottom layer could be possibly due to elluviation of clay particles in the sub-layer. Exchangeable Fe content was low in this laterite soil since Fe mostly exists in the oxidised and crystallised form and the extractability of these forms by 0.1M $BaCl_2$ is less. Content of exchangeable Al was significantly high in the middle layer (20-60 cm depth) which points to the existence of a sub surface zone with predominance of exchangeable Al. Based on this information, bulk soil sample was collected from few random locations of pepper garden, pooled together, and used for incubation study, soil column experiment and leaching study.

Incubation study using three calcium sources, lime, slaked lime and phosphogypsum revealed that lime is more effective in increasing the pH while phosphogypsum is effective for providing exchangeable Ca in soils. Even then, lime is highly effective in reducing the exchangeable aluminium concentration at the site of application. The ameliorating effect of phosphogypsum in reducing exchangeable Al was entirely by providing Ca, where as in other sources the effect was more prominent due to effect on neutralising the exchangeable H^+ and subsequent increase in pH.

In continuation to this, soil column study with black pepper using PVC columns filled with soil layers simulating field condition was done and this experiment revealed that liming at 1 LR level was better for plant growth. In order to examine the effect of surface applied Ca sources towards ameliorating exchangeable Al in the lower layers, ^{32}P was applied at a depth of 50 cm in the soil columns where pepper vines were grown for a period of 360 days and the counts on leaf after a period of 8 days of ^{32}P application were taken as an indication of presence of active roots at this depth. The counts obtained from the leaf sample of black pepper revealed that count rates increased with increase in level of application of liming materials. In soils columns treated with phosphogypsum, significantly higher counts were noticed which indicates better root growth at subsurface layer of the phosphogypsum treated columns.

The above result was confirmed by performing a leaching experiment in PVC columns using ^{45}Ca labelled ameliorants on the surface, and then tracing its downward movement. Radio assay and autoradiography done on this experiment also proved that, in phosphogypsum, Ca is more mobile compared to $CaCO_3$ and $Ca(OH)_2$. In the case of phosphogypsum, significant counts could be noticed in lower layers, though it was reducing from surface to bottom. But in $CaCO_3$ and $Ca(OH)_2$, counts were mainly confined to the top layer suggesting very little downward movement of Ca from these sources.

Solution culture experiment suggest that the pepper root tolerates an Al concentration of 5 and 10 mg L^{-1} and beyond this level plants die off and roots decay within a period of 10days. However at 5 mg L^{-1} level of Al, profuse root growth was noticed and after a period of 28 days roots completely decay in plants exposed to 10 mg L^{-1}. The anatomical observation of the roots were also done in 5 mg L^{-1} treated and control and some modification in the tissue orientation is noticed in Al exposed roots. 5 mg L^{-1} Al concentration promotes the growth of morphologically normal lateral roots with numerous root hairs compared to the control. Both 0 and 5 mg L^{-1} Al treated plants showed the typical dicot root structure consisting of an epidermis, a broad cortex and a stele surrounded by endodermis. The number of vascular tissue varied from 6 to 8 with xylem and phloem in radial arrangement. There is large pith in the centre.

On the basis of this investigation the following conclusions can be drawn

1. A sub surface zone with high concentration of exchangeable Al exists in laterite soil of the pepper garden of College of Horticulture.
2. Phosphogysum offers a potential option for ameliorating the subsoil layers and to promote root growth of black pepper to deeper soil layers. However its effect is by providing soluble Ca forms and in order to derive the

benefit of increase in pH, this material has to be applied in conjunction with conventional liming materials.

3. Some promoting effect on black pepper root growth is noticed at 5 mg L^{-1} Al, in solution culture. The physiological mechanism of the plant for this type of a response need to be further explored.

In the light of these findings, it is suggested that further investigations are needed on other soil types of major pepper growing tracts and also to validate by elaborate field trials. The acidic nature of phosphogypsum at the zone of its application has to be managed by blending this material with $CaCO_3$ or $Ca(OH)_2$. The physiological and biochemical responses of the black pepper plant to exposure of Al, needs to be studied in detail by more experiments. The present study on this aspect hinds that the coping mechanism operates in roots.

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* Original not seen

APPENDIX I

CHEMICAL CHARACTERISTICS OF SOIL SAMPLES AT VARIOUS DEPTHS

COLLECTED FROM PEPPER GARDEN

Sl. No.	Site	Depth	pH	Fe	Al	Na	K	Ca	Mg	Mn	CEC
1	1	1	4.90	0.69	4.10	280.0	480.0	358.6	77.2	34	5.06
2	1	2	4.70	0.95	9.80	260.0	640.0	252.9	49.0	35	4.69
3	1	3	4.90	0.83	11.00	260.0	440.0	388.7	68.2	47	5.07
4	1	4	5.10	0.72	13.00	260.0	360.0	601.8	81.0	38	6.03
5	2	1	4.90	1.13	66.10	280.0	480.0	641.7	112.8	26	7.43
6	2	2	4.70	1.08	81.00	260.0	440.0	305.7	71.4	43	5.45
7	2	3	4.90	0.97	9.00	260.0	480.0	434.3	78.8	43	5.45
8	2	4	5.10	1.12	8.00	260.0	440.0	651.4	115.9	35	6.71
9	3	1	4.90	1.28	53.90	260.0	480.0	543.2	91.9	29	6.56
10	3	2	4.70	1.51	145.3	300.0	560.0	325.8	67.1	21	6.63
11	3	3	4.90	1.22	159.6	300.0	560.0	225.0	38.4	15	6.02
12	3	4	5.00	1.06	202.2	320.0	640.0	145.0	25.5	28	6.33
13	4	1	4.90	1.52	82.00	260.0	440.0	517.8	99.9	25	6.69
14	4	2	4.80	0.88	83.83	280.0	520.0	398.1	55.1	27	6.04
15	4	3	4.90	1.31	30.20	260.0	440.0	508.2	57.1	36	5.75
16	4	4	5.20	0.65	9.10	280.0	480.0	610.7	72.3	44	6.37
17	5	1	5.10	1.67	66.10	260.0	480.0	301.1	70.6	24	5.29
18	5	2	4.80	1.90	81.10	260.0	440.0	284.2	52.7	34	5.16
19	5	3	4.90	1.15	6.60	300.0	400.0	598.9	125.8	21	6.53
20	5	4	5.10	2.11	9.30	300.0	360.0	629.7	146.3	22	6.79
21	6	1	4.90	1.25	26.60	280.0	400.0	339.7	82.0	43	5.09
22	6	2	4.70	1.11	16.10	280.0	440.0	496.0	124.5	28	6.15
23	6	3	4.90	1.44	13.70	300.0	400.0	563.9	104.7	39	6.33
24	6	4	5.10	1.16	7.47	280.0	400.0	661.3	723.8	26	11.77
25	7	1	4.90	1.29	7.40	320.0	440.0	703.6	151.8	39	7.54
26	7	2	4.60	1.20	44.90	280.0	360.0	329.2	90.1	38	5.18
27	7	3	4.80	1.48	44.20	320.0	360.0	378.7	81.4	37	5.52
28	7	4	5.00	1.48	18.50	300.0	400.0	510.1	80.1	45	5.93
29	8	1	4.80	1.11	4.30	280.0	400.0	463.4	124.0	23	5.73
30	8	2	4.70	1.51	81.30	300.0	440.0	302.6	87.3	22	5.67
31	8	3	4.90	1.19	125.2	280.0	400.0	420.3	70.3	53	6.52
32	8	4	5.00	0.84	4.90	300.0	400.0	700.3	148.0	23	7.21
33	9	1	4.90	2.15	45.00	320.0	440.0	549.7	104.6	18	6.72
34	9	2	4.80	1.26	110.0	300.0	400.0	278.3	78.2	21	5.68
35	9	3	4.90	1.43	73.00	300.0	400.0	319.9	62.0	22	5.35
36	9	4	5.00	1.17	23.20	300.0	440.0	303.7	104.2	33	5.21
37	10	1	4.90	1.26	20.40	320.0	520.0	595.7	130.7	26	7.12
38	10	2	4.70	1.29	39.70	340.0	520.0	761.1	146.3	25	8.38
39	10	3	4.90	1.25	52.50	340.0	520.0	636.5	104.3	25	7.55
40	10	4	5.10	1.63	69.60	340.0	520.0	399.8	110.0	30	6.62
41	11	1	4.80	2.51	31.60	280.0	400.0	448.7	76.3	21	5.56
42	11	2	4.60	1.47	38.70	340.0	520.0	464.0	98.3	34	6.51
43	11	3	4.90	1.01	12.10	320.0	480.0	869.7	116.1	18	8.14
44	11	4	5.00	0.36	8.71	340.0	520.0	838.7	138.7	8	8.29

45	12	1	4.90	0.23	54.30	340.0	600.0	495.7	96.5	18	6.97
46	12	2	4.60	0.79	115.3	340.0	560.0	243.3	56.3	18	5.95
47	12	3	4.80	0.77	83.70	320.0	480.0	582.6	78.9	24	7.22
48	12	4	4.90	0.60	68.60	320.0	480.0	725.4	123.0	20	8.11
49	13	1	4.90	0.48	10.20	320.0	560.0	1148.0	72.9	18	10.19
50	13	2	4.70	0.75	52.80	320.0	520.0	491.4	104.0	25	6.73
51	13	3	4.90	0.05	74.20	320.0	480.0	498.4	6.9	33	6.12
52	13	4	5.10	0.41	14.20	320.0	440.0	712.4	127.4	16	7.36
53	14	1	5.00	1.86	19.30	320.0	560.0	803.8	128.0	25	8.23
54	14	2	4.80	0.31	122.2	320.0	600.0	286.7	54.2	29	6.28
55	14	3	4.90	0.18	53.00	320.0	560.0	418.7	60.1	26	6.11
56	14	4	5.10	0.16	7.50	320.0	560.0	666.9	134.2	27	7.46
57	15	1	4.80	0.44	16.20	320.0	520.0	781.2	134.8	26	8.03
58	15	2	4.70	0.24	51.80	320.0	440.0	306.3	79.9	17	5.36
59	15	3	4.90	0.64	95.90	320.0	440.0	228.5	72.0	30	5.44
60	15	4	5.20	0.67	43.80	320.0	480.0	478.8	93.0	38	6.42
61	16	1	4.90	0.57	10.10	320.0	560.0	855.3	140.5	23	8.48
62	16	2	4.70	0.45	66.50	340.0	560.0	323.2	87.6	23	6.09
63	16	3	4.90	0.86	113.9	340.0	560.0	152.1	45.5	26	5.42
64	16	4	5.00	0.92	100.6	320.0	480.0	137.6	18.2	17	4.65
65	17	1	4.80	0.48	113.9	320.0	560.0	585.9	98.0	27	7.94
66	17	2	4.70	1.02	15.10	320.0	560.0	183.0	38.6	29	4.34
67	17	3	4.80	0.46	103.6	360.0	600.0	170.8	37.4	31	5.54
68	17	4	4.90	0.17	37.40	340.0	600.0	354.1	60.7	29	5.82
69	18	1	4.90	0.21	17.70	360.0	600.0	651.4	111.9	31	7.61
70	18	2	4.70	0.62	28.46	360.0	640.0	460.1	99.5	26	6.75
71	18	3	4.90	0.70	98.80	340.0	560.0	375.5	72.4	48	6.67
72	18	4	5.10	0.24	48.00	360.0	560.0	697.4	97.2	29	7.94
73	19	1	4.80	0.80	22.50	380.0	640.0	563.7	106.9	21	7.33
74	19	2	4.70	0.38	113.3	360.0	600.0	184.7	35.7	36	5.72
75	19	3	4.80	0.83	41.70	360.0	560.0	401.1	63.4	44	6.17
76	19	4	5.10	0.56	18.20	360.0	520.0	650.4	91.0	33	7.24
77	20	1	4.90	0.57	27.30	360.0	720.0	559.6	107.9	19	7.49
78	20	2	4.60	0.20	95.70	340.0	520.0	316.9	59.7	14	6.01
79	20	3	4.80	0.56	108.8	320.0	440.0	248.2	31.9	30	5.35
80	20	4	5.10	0.49	35.00	320.0	400.0	381.4	50.6	19	5.21

APPENDIX II

INCUBATION EXPERIMENT

List Of Variables

Variable Description
R- Replication
T- Time
L- Level
S- Source
D- Depth

Sl. No.	R	T	L	S	D	pH	EC	Al	Ca
1	1	1	1	1	1	6.7	0.3	4.600	1426.00
2	2	1	1	1	1	7.2	0.3	4.700	1424.00
3	3	1	1	1	1	7.3	0.3	4.600	1426.00
4	1	1	2	1	1	6.4	0.4	4.800	1038.00
5	2	1	2	1	1	6.4	0.2	4.800	1038.00
6	3	1	2	1	1	6.4	0.2	4.900	1036.00
7	1	1	3	1	1	7.4	0.7	4.100	1768.00
8	2	1	3	1	1	7.1	0.7	4.100	1764.00
9	3	1	3	1	1	7.1	0.7	4.100	1766.00
10	1	1	1	1	2	5.8	0.3	4.200	1098.00
11	2	1	1	1	2	5.8	0.3	4.200	1098.00
12	3	1	1	1	2	5.9	0.4	4.300	1096.00
13	1	1	2	1	2	5.2	0.4	5.300	486.00
14	2	1	2	1	2	5.0	0.3	5.400	486.00
15	3	1	2	1	2	5.1	0.3	5.400	484.00
16	1	1	3	1	2	7.4	0.4	3.800	1720.00
17	2	1	3	1	2	7.5	0.4	3.700	1740.00
18	3	1	3	1	2	7.3	0.4	3.700	1720.00
19	1	1	1	1	3	6.8	0.4	5.200	832.00
20	2	1	1	1	3	6.7	0.6	5.200	834.00
21	3	1	1	1	3	6.9	0.4	5.200	836.00
22	1	1	2	1	3	5.2	0.4	5.900	742.00
23	2	1	2	1	3	5.3	0.3	5.800	744.00
24	3	1	2	1	3	5.4	0.3	5.900	742.00
25	1	1	3	1	3	7.4	0.3	4.700	1256.00
26	2	1	3	1	3	7.8	0.4	4.800	1256.00
27	3	1	3	1	3	7.8	0.3	4.800	1258.00
28	1	1	1	1	4	6.2	0.3	3.700	1410.00
29	2	1	1	1	4	6.3	0.3	3.700	1406.00
30	3	1	1	1	4	6.2	0.3	3.600	1410.00
31	1	1	2	1	4	5.3	0.8	3.700	838.00
32	2	1	2	1	4	5.4	0.7	3.800	836.00
33	3	1	2	1	4	5.4	0.7	3.800	838.00
34	1	1	3	1	4	7.2	0.3	3.500	1946.00
35	2	1	3	1	4	7.3	0.3	3.400	1946.00

36	3	1	3	1	4	7.3	0.3	3.400	1944.00
37	1	1	1	2	1	4.3	1.3	3.800	928.00
38	2	1	1	2	1	4.7	1.3	3.700	924.00
39	3	1	1	2	1	4.6	1.3	3.700	928.00
40	1	1	2	2	1	4.1	0.7	4.100	798.00
41	2	1	2	2	1	4.7	0.5	4.100	796.00
42	3	1	2	2	1	4.5	0.7	4.000	798.00
43	1	1	3	2	1	5.1	1.7	3.300	1510.00
44	2	1	3	2	1	5.2	1.7	3.200	1510.00
45	3	1	3	2	1	5.1	1.7	3.200	1508.00
46	1	1	1	2	2	4.4	1.1	14.500	1312.00
47	2	1	1	2	2	4.5	1.6	14.500	1308.00
48	3	1	1	2	2	4.4	1.6	14.400	1312.00
49	1	1	2	2	2	4.6	0.8	22.100	810.00
50	2	1	2	2	2	4.5	1.1	22.100	804.00
51	3	1	2	2	2	4.6	1.2	22.100	810.00
52	1	1	3	2	2	4.4	1.2	12.100	1890.00
53	2	1	3	2	2	4.5	1.4	2.200	1892.00
54	3	1	3	2	2	4.6	1.4	12.100	1890.00
55	1	1	1	2	3	4.4	1.7	26.100	2672.00
56	2	1	1	2	3	4.5	1.6	26.200	2672.00
57	3	1	1	2	3	4.3	1.4	26.100	2674.00
58	1	1	2	2	3	4.5	0.5	31.800	1410.00
59	2	1	2	2	3	4.7	0.4	31.900	1408.00
60	3	1	2	2	3	4.6	0.5	31.800	1410.00
61	1	1	3	2	3	4.4	1.3	21.100	3676.00
62	2	1	3	2	3	4.3	1.4	21.100	3676.00
63	3	1	3	2	3	4.4	1.3	21.100	3674.00
64	1	1	1	2	4	4.6	1.1	25.400	938.00
65	2	1	1	2	4	4.6	1.1	25.400	936.00
66	3	1	1	2	4	4.6	1.1	25.300	938.00
67	1	1	2	2	4	4.4	1.1	30.600	626.00
68	2	1	2	2	4	4.4	1.1	30.600	624.00
69	3	1	2	2	4	4.4	1.1	30.500	626.00
70	1	1	3	2	4	4.7	1.5	21.800	1706.00
71	2	1	3	2	4	4.7	1.5	21.800	1704.00
72	3	1	3	2	4	4.7	1.5	21.700	1706.00
73	1	1	1	3	1	6.4	0.4	33.200	938.00
74	2	1	1	3	1	6.4	0.4	33.100	938.00
75	3	1	1	3	1	6.4	0.4	33.200	936.00
76	1	1	2	3	1	5.1	0.2	38.800	522.00
77	2	1	2	3	1	5.1	0.2	38.700	524.00
78	3	1	2	3	1	5.1	0.2	38.700	526.00
79	1	1	3	3	1	6.2	0.3	27.100	1564.00
80	2	1	3	3	1	6.2	0.3	27.200	1564.00
81	3	1	3	3	1	6.2	0.3	27.100	1560.00
82	1	1	1	3	2	5.9	0.3	25.900	748.00
83	2	1	1	3	2	5.9	0.3	25.800	748.00
84	3	1	1	3	2	5.9	0.3	25.900	750.00
85	1	1	2	3	2	6.6	0.3	29.800	354.00
86	2	1	2	3	2	6.7	0.3	29.900	354.00
87	3	1	2	3	2	6.6	0.3	29.900	356.00

88	1	1	3	3	2	6.1	0.2	21.700	934.00
89	2	1	3	3	2	6.1	0.2	21.800	936.00
90	3	1	3	3	2	6.1	0.2	21.700	934.00
91	1	1	1	3	3	6.6	0.4	4.200	1188.00
92	2	1	1	3	3	6.6	0.4	4.100	1190.00
93	3	1	1	3	3	6.6	0.4	4.200	1188.00
94	1	1	2	3	3	4.8	0.3	8.700	836.00
95	2	1	2	3	3	4.8	0.3	8.700	836.00
97	1	1	3	3	3	6.9	0.5	3.800	1444.00
98	2	1	3	3	3	6.9	0.5	3.800	1446.00
99	3	1	3	3	3	6.9	0.5	3.700	1444.00
100	1	1	1	3	4	6.3	0.3	4.000	836.00
101	2	1	1	3	4	6.3	0.3	4.100	838.00
102	3	1	1	3	4	6.3	0.3	4.000	836.00
103	1	1	2	3	4	5.3	0.4	5.100	670.00
104	2	1	2	3	4	5.3	0.4	5.100	670.00
105	3	1	2	3	4	5.3	0.4	5.200	668.00
106	1	1	3	3	4	5.8	0.3	3.700	1262.00
107	2	1	3	3	4	5.8	0.3	3.700	1262.00
108	3	1	3	3	4	5.8	0.3	3.700	1264.00
109	1	2	1	1	1	6.8	0.3	2.800	1680.00
110	2	2	1	1	1	7.2	0.3	2.800	1680.00
111	3	2	1	1	1	7.5	0.3	2.900	1660.00
112	1	2	2	1	1	6.7	0.3	3.100	1216.00
113	2	2	2	1	1	6.7	0.4	3.200	1216.00
114	3	2	2	1	1	6.7	0.2	3.100	1218.00
115	1	2	3	1	1	7.7	0.7	2.500	3218.00
116	2	2	3	1	1	7.7	0.7	2.400	3216.00
117	3	2	3	1	1	7.7	0.7	2.500	3216.00
118	1	2	1	1	2	6.9	0.4	1.900	1306.00
119	2	2	1	1	2	7.0	0.4	1.800	1325.40
120	3	2	1	1	2	7.0	0.4	1.800	1306.00
121	1	2	2	1	2	5.4	0.4	2.100	878.00
122	2	2	2	1	2	5.2	0.3	2.200	878.00
123	3	2	2	1	2	5.1	0.3	2.200	876.00
124	1	2	3	1	2	7.5	0.4	1.470	1654.00
125	2	2	3	1	2	7.6	0.4	1.500	1654.00
126	3	2	3	1	2	7.6	0.4	1.500	1652.00
127	1	2	1	1	3	6.8	0.4	3.600	1540.00
128	2	2	1	1	3	6.9	0.6	3.600	1540.00
129	3	2	1	1	3	6.9	0.5	3.700	1542.00
130	1	2	2	1	3	5.4	0.4	3.800	668.00
131	2	2	2	1	3	5.4	0.3	3.900	664.00
132	3	2	2	1	3	5.5	0.3	3.900	664.00
133	1	2	3	1	3	7.4	0.3	3.500	2046.00
134	2	2	3	1	3	7.8	0.5	3.500	2044.00
135	3	2	3	1	3	7.9	0.3	3.600	2042.00
136	1	2	1	1	4	6.5	0.4	2.200	1458.00
137	2	2	1	1	4	6.4	0.3	2.300	1458.00
138	3	2	1	1	4	6.4	0.3	2.200	1456.00
139	1	2	2	1	4	5.4	0.8	2.600	904.00
140	2	2	2	1	4	5.4	0.8	2.600	906.00

141	3	2	2	1	4	5.5	0.8	2.500	906.00
142	1	2	3	1	4	7.9	0.3	1.500	2556.00
143	2	2	3	1	4	7.8	0.3	1.500	2556.00
144	3	2	3	1	4	7.9	0.3	1.500	2558.00
145	1	2	1	2	1	4.8	1.4	3.600	1530.00
147	3	2	1	2	1	4.7	1.4	3.600	1528.00
148	1	2	2	2	1	4.2	0.7	3.800	862.00
149	2	2	2	2	1	4.9	0.6	3.900	862.00
150	3	2	2	2	1	4.6	0.7	3.800	864.00
151	1	2	3	2	1	5.5	1.7	3.100	2248.00
152	2	2	3	2	1	5.6	1.7	3.200	2246.00
153	3	2	3	2	1	5.5	1.7	3.200	2246.00
154	1	2	1	2	2	4.4	1.2	8.200	1486.00
155	2	2	1	2	2	4.6	1.6	8.100	1486.00
156	3	2	1	2	2	4.4	1.6	8.200	1486.00
157	1	2	2	2	2	4.7	0.9	9.100	1156.00
158	2	2	2	2	2	4.7	1.5	9.100	1156.00
159	3	2	2	2	2	4.7	1.2	9.100	1158.00
160	1	2	3	2	2	4.6	1.2	7.900	2128.00
161	2	2	3	2	2	4.7	1.4	7.800	2128.00
162	3	2	3	2	2	4.6	1.4	7.900	2126.00
163	1	2	1	2	3	4.6	1.7	18.000	3486.00
164	2	2	1	2	3	4.5	1.6	18.100	3484.00
165	3	2	1	2	3	4.4	1.5	18.000	3486.00
166	1	2	2	2	3	4.6	0.5	21.000	2556.00
167	2	2	2	2	3	4.7	0.5	21.100	2558.00
168	3	2	2	2	3	4.7	0.6	21.000	2556.00
169	1	2	3	2	3	4.8	1.5	16.000	4128.00
170	2	2	3	2	3	4.8	1.5	16.100	4128.00
171	3	2	3	2	3	4.9	1.4	16.000	4126.00
172	1	2	1	2	4	4.8	1.1	16.200	1530.00
173	2	2	1	2	4	4.8	1.1	16.100	1530.00
174	3	2	1	2	4	4.8	1.1	16.100	1532.00
175	1	2	2	2	4	4.9	1.1	23.800	620.00
176	2	2	2	2	4	4.9	1.1	23.700	622.00
177	3	2	2	2	4	4.9	1.1	23.800	620.00
178	1	2	3	2	4	4.8	1.4	15.300	1656.00
179	2	2	3	2	4	4.8	1.4	15.200	1654.00
180	3	2	3	2	4	4.8	1.4	15.300	1656.00
181	1	2	1	3	1	6.6	0.4	23.200	746.00
182	2	2	1	3	1	6.6	0.4	23.200	746.00
183	3	2	1	3	1	6.6	0.4	23.100	746.00
184	1	2	2	3	1	5.8	0.3	30.900	556.00
185	2	2	2	3	1	5.8	0.3	31.000	558.00
186	3	2	2	3	1	5.8	0.3	31.000	556.00
187	1	2	3	3	1	6.9	0.5	21.300	1064.00
188	2	2	3	3	1	6.9	0.5	21.400	1064.00
189	3	2	3	3	1	6.6	0.7	24.800	1032.00
191	2	2	1	3	2	6.6	0.7	24.800	1032.00
192	3	2	1	3	2	6.6	0.7	24.700	1034.00
193	1	2	2	3	2	7.4	0.3	28.400	990.00
194	2	2	2	3	2	7.3	0.3	28.500	988.00

195	3	2	2	3	2	7.2	0.3	28.400	990.00
196	1	2	3	3	2	7.3	0.4	21.100	1306.00
197	2	2	3	3	2	3.0	0.4	21.200	1306.00
198	3	2	3	3	2	7.3	0.4	21.200	1304.00
199	1	2	1	3	3	6.5	0.3	1.700	878.00
200	2	2	1	3	3	6.5	0.3	1.700	878.00
201	3	2	1	3	3	6.5	0.3	2.300	568.00
202	1	2	2	3	3	5.6	0.3	2.300	568.00
203	1	2	2	2	3	5.6	0.3	2.400	566.00
204	3	2	2	3	3	5.6	0.3	2.300	568.00
205	1	2	3	3	3	7.2	0.5	1.200	1092.00
206	2	2	3	3	3	7.2	0.5	1.200	1092.00
207	3	2	3	3	3	7.2	0.5	1.300	1090.00
208	1	2	1	3	4	6.9	0.2	3.700	956.00
209	2	2	1	3	4	6.9	0.2	3.700	956.00
210	3	2	1	3	4	6.9	0.2	3.800	958.00
211	1	2	2	3	4	4.3	0.4	4.200	620.00
212	2	2	2	3	4	4.3	0.4	4.100	622.00
213	3	2	2	3	4	4.3	0.4	4.100	620.00
214	1	2	3	3	4	6.8	0.5	3.300	1254.00
215	2	2	3	3	4	6.8	0.5	3.200	1254.00
216	3	2	3	3	4	6.8	0.5	3.300	1256.00
217	1	3	1	1	1	6.9	0.3	4.700	1158.00
218	2	3	1	1	1	7.3	0.3	4.600	1156.00
219	3	3	1	1	1	7.5	0.3	4.800	1158.00
220	1	3	2	1	1	6.7	0.3	5.300	660.00
221	2	3	2	1	1	6.8	0.4	5.200	662.00
222	3	3	2	1	1	6.8	0.2	5.200	660.00
223	1	3	3	1	1	7.8	0.7	3.800	1504.00
224	2	3	3	1	1	7.8	0.7	3.800	1504.00
225	3	3	3	1	1	7.8	0.7	3.700	1506.00
226	1	3	1	1	2	7.0	0.5	7.300	1276.00
227	2	3	1	1	2	7.0	0.4	7.400	1276.00
228	3	3	1	1	2	7.0	0.4	7.500	1278.00
229	1	3	2	1	2	5.5	0.5	7.500	1102.00
230	2	3	2	1	2	5.2	0.3	7.600	1104.00
231	3	3	2	1	2	5.3	0.3	7.500	1102.00
232	1	3	3	1	2	7.6	0.5	6.400	2750.00
233	2	3	3	1	2	7.8	0.5	6.400	2752.00
234	3	3	3	1	2	7.6	0.5	6.400	2750.00
235	1	3	1	1	3	7.0	0.5	6.100	1490.00
236	2	3	1	1	3	7.0	0.6	6.100	1491.20
237	3	3	1	1	3	7.0	0.5	6.000	1492.00
238	1	3	2	1	3	5.4	0.3	6.360	1042.00
239	2	3	2	1	3	5.4	0.3	6.300	1042.00
240	3	3	2	1	3	5.6	0.3	6.300	1044.00
241	1	3	3	1	3	7.5	0.4	5.800	1866.00
242	2	3	3	1	3	7.8	0.5	5.800	1866.00
243	3	3	3	1	3	7.9	0.4	5.900	1868.00
244	1	3	1	1	4	6.7	0.3	9.700	1644.00
245	2	3	1	1	4	6.6	0.3	9.600	1644.00
246	3	3	1	1	4	6.7	0.3	9.600	1644.00

247	1	3	2	1	4	5.4	0.8	10.400	836.00
248	2	3	2	1	4	5.4	0.8	10.200	838.00
249	3	3	2	1	4	5.5	0.8	10.400	836.00
250	1	3	3	1	4	7.9	0.3	8.900	1864.00
251	2	3	3	1	4	7.9	0.4	8.800	1862.00
252	3	3	3	1	4	7.9	0.3	8.800	1864.00
253	1	3	1	2	1	4.4	1.5	5.300	1262.00
254	2	3	1	2	1	4.8	1.5	5.300	1264.00
256	1	3	2	2	1	4.7	0.7	10.800	670.00
257	2	3	2	2	1	4.9	0.6	10.900	668.00
258	3	3	2	2	1	4.6	0.7	10.800	670.00
259	1	3	3	2	1	5.7	1.7	3.900	1626.00
260	2	3	3	2	1	5.6	1.7	3.800	1626.00
261	3	3	3	2	1	5.5	1.7	3.800	1624.00
262	1	3	1	2	2	4.9	1.3	24.600	1426.00
263	2	3	1	2	2	4.7	1.6	24.500	1424.00
264	3	3	1	2	2	4.5	1.6	24.500	1426.00
265	1	3	2	2	2	4.8	1.1	33.200	840.00
266	2	3	2	2	2	4.7	1.5	33.200	842.00
267	3	3	2	2	2	4.8	1.2	33.300	842.00
268	1	3	3	2	2	4.7	1.2	17.900	1768.00
269	2	3	3	2	2	4.9	1.4	17.800	1770.00
270	3	3	3	2	2	4.7	1.4	17.900	1768.00
271	1	3	1	2	3	4.7	1.7	25.100	896.00
272	2	3	1	2	3	4.6	1.6	25.200	898.00
273	3	3	1	2	3	4.4	1.5	25.100	896.00
274	1	3	2	2	3	4.9	0.5	33.800	450.00
275	2	3	2	2	3	4.8	0.5	33.700	450.00
276	3	3	2	2	3	4.9	0.6	33.800	448.00
277	1	3	3	2	3	5.1	1.6	17.500	1332.00
278	2	3	3	2	3	5.2	1.7	17.600	1330.00
279	3	3	3	2	3	5.3	1.4	17.500	1330.00
280	1	3	1	2	4	4.9	1.1	23.200	1894.00
281	2	3	1	2	4	4.9	1.0	23.100	1894.00
282	3	3	1	2	4	4.9	1.0	23.100	1892.00
283	1	3	2	2	4	4.6	1.2	32.100	1144.00
284	2	3	2	2	4	4.6	1.2	32.100	1148.00
285	3	3	2	2	4	4.6	1.2	32.200	1144.00
286	1	3	3	2	4	4.8	1.3	11.900	2204.00
287	2	3	3	2	4	4.8	1.3	11.800	2204.00
288	3	3	3	2	4	4.8	1.3	11.800	2206.00
289	1	3	1	3	1	7.2	0.2	31.200	1600.00
290	2	3	1	3	1	7.2	0.2	31.300	1602.00
291	3	3	1	3	1	7.2	0.2	31.300	1600.00
292	1	3	2	3	1	6.2	0.2	41.200	938.00
293	2	3	2	3	1	6.2	0.2	41.120	936.00
294	3	3	2	3	1	6.2	0.2	41.300	938.00
295	1	3	3	3	1	7.2	0.4	28.200	1824.00
296	2	3	3	3	1	7.2	0.4	28.100	1826.00
297	3	3	3	3	1	7.2	0.4	28.000	1824.00
298	1	3	1	3	2	7.2	0.4	25.000	1132.00
299	2	3	1	3	2	7.2	0.4	25.100	1132.00

300	3	3	1	3	2	7.2	0.4	25.000	1130.00
301	1	3	2	3	2	4.9	0.4	30.100	800.00
302	2	3	2	3	2	4.9	0.4	30.100	802.00
303	3	3	2	3	2	4.7	0.4	30.100	800.00
304	1	3	3	3	2	6.6	0.5	18.100	1942.00
305	2	3	3	3	2	6.6	0.5	18.100	1942.00
306	3	3	3	3	2	6.6	0.5	18.000	1942.00
307	1	3	1	3	3	6.5	0.5	4.700	1288.00
308	2	3	1	3	3	6.5	0.5	4.800	1286.00
309	3	3	1	3	3	6.5	0.5	4.700	1288.00
310	1	3	2	3	3	5.6	0.5	5.400	734.00
311	2	3	2	3	3	5.6	0.5	5.400	728.00
312	3	3	2	3	3	5.6	0.5	5.400	734.00
313	1	3	3	3	3	6.3	0.6	3.100	1910.00
314	2	3	3	3	3	6.3	0.6	3.200	1910.00
315	3	3	3	3	3	6.3	0.6	3.200	1908.00
316	1	3	1	3	4	4.5	0.2	4.200	1002.00
317	2	3	1	3	4	4.5	0.2	4.300	1004.00
318	3	3	1	3	4	4.5	0.2	4.300	1004.00
319	1	3	2	3	4	5.6	0.4	4.800	626.00
320	2	3	2	3	4	5.6	0.4	4.900	624.00
321	3	3	2	3	4	5.6	0.4	4.900	626.00
322	1	3	3	3	4	5.3	0.4	3.700	1288.00
323	2	3	3	3	4	5.3	0.4	3.800	1288.00
324	3	3	3	3	4	5.3	0.4	3.800	1286.00

APPENDIX III

LEACHING EXPERIMENT

Sl. No.	Depth	Source	Replication	Count
1	1	1	1	2345
2	2	1	1	49
3	3	1	1	37
4	4	1	1	41
5	1	1	2	2114
6	2	1	2	48
7	3	1	2	47
8	4	1	2	40
9	1	2	1	1997
10	2	2	1	90
11	3	2	1	54
12	4	2	1	49
13	1	2	2	2113
14	2	2	2	45
15	3	2	2	57
16	4	2	2	61
17	1	3	1	1156
18	2	3	1	880
19	3	3	1	499
20	4	3	1	323
21	1	3	2	1593
22	2	3	2	830
23	3	3	2	349
24	4	3	2	169

AMELIORATION OF SUBSOIL ACIDITY BY CALCIUM SOURCES IN LATERITE SOILS OF BLACK PEPPER GARDEN

By

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ABSTRACT OF THESIS

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COLLEGE OF HORTICULTURE

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ABSTRACT

Soil acidity is a major problem in humid tropical regions due to high rainfall and temperature. Hydrogen and aluminium are the major ions responsible for soil acidity. Historically, soil scientists and agronomists have addressed the problem of soil acidity and recommend amelioration by conventional liming and ploughing. Black pepper, an important and widely used spice around the globe, is cultivated widely in our state. In Kerala, this crop is grown in laterite soils, which poses many soil related stress of which soil acidity is a major one. The productivity of pepper is very low in these tracts, and lower compared to other places. High exchangeable Al and low Ca content in subsurface horizons act as barriers for the root growth of black pepper towards lower layers. The effect of conventionally surface applied liming materials like $CaCO_3$, $Ca(OH)_2$ will be confined to the top layer alone. While in materials like Phosphogypsum, Ca is soluble and can move to lower depths and offer possibility of ameliorating subsoil layers. Isotopic techniques are useful for a quick and reliable means of studying the movement of ameliorants through the soil and also to examine the distribution of active roots at lower depth of soil column without destroying the plant.

With this background, an investigation was carried out at College Of Horticulture, Vellanikkara about the subsoil acidity amelioration in laterite soil of black pepper garden using three calcium sources- $CaCO_3$, $Ca(OH)_2$ and Phosphogypsum. The whole study was conducted as 5 experiments using the soil collected from the pepper garden, College of Horticulture, Vellanikkara. Analysis of soil sample revealed that the exchangeable aluminium content was 69 ppm at the subsoil layer is in significantly higher concentration than the surface. On the basis of this an incubation experiment using three calcium sources, lime, slaked lime and Phosphogypsum was done and the results revealed that lime is more effective in increasing the pH while Phosphogypsum is effective for reducing the exchangeable Al in soils. In continuation to this soil column study using PVC columns filled with soil layers simulating field condition revealed that liming at 1

LR level was better for good plant growth. The effect of three sources on ameliorating subsoil acidity was evaluated by measuring the root activity of pepper plants grown in the columns by isotopic method. For this ^{32}P was applied at a depth of 50 cm depth and the counts on leaf after a period of 8 days were taken as an indication of presence of active roots at 50 cm depth. The counts obtained from the leaf sample of black pepper revealed that count rates increased with increase in level of application of liming materials. In soil columns treated with phosphogypsum, significantly higher counts were noticed which indicates better root growth at subsurface layer of the PG treated columns.

This result was confirmed by performing a leaching experiment in PVC columns using ^{45}Ca labelled ameliorants. Radio assay and autoradiography done on this experiment also proved that, in Phosphogypsum, Ca is highly mobile compared to $CaCO_3$ and $Ca(OH)_2$. In order to understand the response and tolerance level of Al on pepper plants specifically on roots a solution culture experiment was also done by growing rooted plants in Hoagland solution containing different levels of Al. Solution culture experiment proved that the pepper root tolerates an Al concentration of 5 and 10 ppm and beyond this level plants die off and roots decay. How ever at 5 ppm level of Al profuse root growth was noticed. The anatomical observation of the roots were also done and some modification in the tissue orientation is noticed.

On the basis of this investigation it can be concluded that

1. A sub surface zone with high concentration of exchangeable Al exists in laterite soil of the pepper garden of College of Horticulture.
2. Phosphogysum offers a potential option for ameliorating the subsoil layers and to promote root growth of black pepper to deeper soil layers.
3. Some promoting effect on black pepper root growth is noticed at 5 ppm Al, in solution culture.

On the basis of these observations it is suggested that further investigations are needed on other soil types and also to validate by field trials. The acidic nature of PG at the zone of its application has to be contained by blending this material with $CaCO_3$ or $Ca(OH)_2$. The biochemical responses of the black pepper plant to exposure to Al, needs to be studied in detail by elaborate experiments.