MANAGEMENT OF ACIDITY BY COMBINED APPLICATION OF LIME AND GYPSUM IN A LOW ACTIVITY CLAY SOIL OF KERALA

By

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THESIS
Submitted in partial fulfilment of the
requirement for the degree

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Dedicated to

My Beloved Friend

Magimma Zacharias

DECLARATION

I hereby declare that this thesis entitled **"Management of acidity by combined application of lime and gypsum in a low activity clay soil of Kerala"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

K. TESSY JACOB

Vellanikkara,
24.06.1992.

CERTIFICATE

Certified that this thesis entitled **"Management of acidity by combined application of lime and gypsum in a low activity clay soil of Kerala"** is a record of research work done independently by **Smt. K. Tessy Jacob** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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(Chairman Advisory Committee)

Vellanikkara,
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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Smt. K. Tessy Jacob**, a candidate for the degree of Master of Science in Agriculture, agree that the thesis entitled **"Management of acidity by combined application of lime and gypsum in a low activity clay soil of Kerala"** may be submitted by Smt. K. Tessy Jacob in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

In humid tropical and subtropical regions high temperature and heavy precipitation promote deeply weathered, heavily leached soils. These soils are inherently acid and contain very small amounts of exchangeable calcium and magnesium, high levels of exchangeable aluminium and possess low cation exchange capacity (Smyth, 1976). Available data indicate that generally, higher concentrations of solution Al^{3+} occur in the tropics, and so ameliorating these acid soils can be particularly difficult. The lower levels of solution aluminium found in regions of less intense weathering can also be very important, since small amounts of Al^{3+} are toxic. The adverse effect of acid soils on plant growth is mainly related to the presence of exchangeable Al, Mn and Fe in toxic concentrations, low availability of bases and imbalances of soil and plant nutrients.

Laterite soils covering nearly 60 per cent of soils of Kerala are predominant in low activity kaolinite and hydrous oxide clays. These soils though acid and infertile, can be very productive, when limed and fertilized. Conventional liming practices to achieve near neutral pH values often require very high lime doses. Moreover the practice of surface incorporation of lime on the upper 15 cm of the soil often neutralizes only the surface acidity and toxic factors.

Thus subsoil acidity and low Ca concentration continue to exist as a problem below the normal plough depth. The inability of surface-incorporated lime to ameliorate deeper soil horizons has been demonstrated in various studies (Khalid and Silva, 1980; Pavan et al., 1982; Reeve and Sumner, 1972; Ritchey et al., 1980).

The slow movement of lime through the soil, the cost factor and difficulty of mixing lime into the subsoil have led researchers to examine surface applied amendments, such as gypsum, in the amelioration of subsoil acidity. Since gypsum ($CaSO_4.2H_2O$) does not alter soil pH appreciably, pH dependent charge remains unchanged, enabling the gypsum to move through the soil much more readily than lime. Sumner (1970) and Reeve and Sumner (1972) were the first to demonstrate the beneficial effects of gypsum on subsoil acidity. Pavan et al. (1984) suggested combination of dolomitic lime stone and gypsum for reducing exchangeable aluminium and supplying calcium and magnesium throughout the entire profile.

Though there have been attempts to study the effect of liming on crops in the upland laterite soils of Kerala, there is very little information on the comparative suitability of various liming methods suggested in general for these soils. Further, data are scanty with regard to impact of liming on subsoil acidity, Ca and Al saturation, pH and yield of crops.

The present study was therefore undertaken in the College of Horticulture, Vellanikkara with the following prime objectives.

1. To characterize the low activity clay soils of Kerala in respect of acidity contributing factors.

2. To study the effect of different combinations of lime and gypsum on the mobility of Ca and Mg to the subsoil and consequent changes in pH.

3. To study the effect of combined application of lime and gypsum on the growth and uptake of nutrients by an Al sensitive test crop - soybean.

The results of the present investigation will throw open new avenues in the management of annuals and perennials which form the major crops in the acidic upland regions of the state.

Review of Literature

REVIEW OF LITERATURE

Soil acidity is a major problem in many parts of the world, particularly on highly weathered soils. These soils have developed under humid conditions where weathering processes have resulted in Al^{3+} occupying a large proportion of the exchange sites. Historically, however, soil scientists and agronomists have addressed the problem of soil acidity in the context of the plough layer, the zone readily accessible to amelioration by conventional liming and ploughing procedures. Until a decade ago, the effects of soil acidity in the subsoil horizons had received little attention. Haynes (1984) has stressed the need to develop practical methods of ameliorating acid subsoils, which occur most widely in those parts of the world struggling to achieve self-sufficiency in food production.

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

Nature of soil acidity

An appreciable fraction of the permanent negative charge of acid soils is encountered by aluminium and hydrogen ions generally known as exchangeable acidity. At first 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 dissolved hydrated alumina 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 _N_ KCl exchangeable acidity was caused predominantly by aluminium ions and to a negligible extent by exchangeable hydrogen ions.

Exchangeable aluminium and organic matter levels showed the greatest effect on soil acidity (Kaminiski _et_ _al_., 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 IM KCl for Ultisols. For Oxisols, soil acidity was better expressed in terms of exchangeable Al which correlated best with pH in KCl.

Reclamation of acid soils

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

Varghese and Money (1965) showed that the pH of Vellayani soil can be raised by calcium and magnesium compounds. Fassbender et al. (1971) concluded that liming with 1-32 me/100 g of Ca + Mg using pure carbonates with Ca:Mg ratio of 4:1 increased pH by 2 units in alluvial soils and latosols. Bolton (1977) and Fiskell et al. (1964) reported that the soil CEC increased linearly with increase in pH from 2.3 to 9.0. 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, B. Van (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 (Datta et al., 1983). Datta et al. (1984) suggested that application of pressmud and lime to ameliorate soil acidity resulted in significant reduction in the availability of Zn and Fe in soil but not to the level of deficiency. Maria et al. (1985) reported that liming raised the pH values significantly. Samonte (1985) obtained optimum yields when the pH was raised above 6. The N status of plants were improved by lime application.

Exchangeable aluminium as a criterion of lime requirement

Pavar and Marshall (1934) considered exchangeable Al as the criterion of soil acidity rather than hydrogen ion concentration.

Ragland and Coleman (1959) reported that in Norfolk soils, root growth into the subsoils increased substantially when lime sufficient to cause hydrolysis of the exchangeable Al was added.

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.

Kamprath (1970) has reported that lime application based on exchangeable Al appeared to be a realistic approach for leached mineral soils.

Reeve and Sumner (1970) in a glass house study of crop growth on Natal Oxisols showed that growth response to lime took place when exchangeable Al was reduced to a critical level and addition of considerably higher amounts of lime in order to raise the pH to near neutrality, were harmful to plant growth. The amount of lime calculated was only approximately 1/6th of the amount required to raise the soil pH to 6.5.

Hoyt and Nyborg (1971) have suggested that extractable Al could be a valuable supplement to soil pH in assessing the need for lime application for growing Al tolerant varieties.

Sartain and Kamprath (1975) reported that the dry weight of soybean tops increased as the Al saturation was decreased by liming.

Amedee and Peech (1976) have pointed out that lime requirement based on exchangeable aluminium concentration was less than the estimate of lime based on neutralisation value.

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 g soil as a more effective means of increasing yield than the raising of soil pH to neutrality.

Mendez and Kamprath (1978) have demonstrated that lime rates equivalent to 1.5 times of the exchangeable aluminium content of a soil can neutralise most of the exchangeable Al and adjust the pH satisfactorily for plant growth. Such liming rates were considerably lesser than those required to raise the pH to 7.0.

Fox (1979) reported that the relative yield of corn on three Ultisols was a function of the Al saturation of the effective CEC. Grain yield was greater than 90 per cent of maximum when Al saturation were less than 20 per cent. Liming to raise the pH beyond that at which Al saturation was reduced to zero did not give further increases in grain yield.

Cochrane _et al_. (1980) have proposed the use of minimum amount of lime on acid soils so as to decrease the per cent Al saturation to levels that do not affect production and compensate crop Al tolerance.

An equation for calculating the lime requirement of acid mineral soils based on neutralisation of exchangeable aluminium was developed by Kamprath (1984). $CaCO_3$ required to neutralise a specific quantity of KCl exchangeable Al is given by the equation.

$CaCO_3$ tons ha^{-1} = cmol (1/3 Al^{-3}) kg^{-1} x factor. The factor for most Ultisols and Oxisols is in the range of 1.5 to 2.0. The factor takes into account that as the pH of the soils increases, pH dependent acidity ionises and reacts with lime.

Patiram et al. (1989) found that liming at a dose equivalent to exchangeable Al^{3+} produced 90 per cent of the maximum maize yield. However, maximum yield of maize and soybean were obtained when lime rates were 1-2 times and 1-1.5 times the equivalent of exchangeable Al respectively. Shoemaker's buffer method and Woodruff's buffer method over estimated the lime requirement and depressed the yield.

Effect of liming on growth and yield of legumes

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/100 g soil and by decreasing exchangeable Al to 2 me/100 g soil.

Awan (1964) reported highly significant yield increases for sorghum, corn, beans, cowpea and green manure, when the acid soil (pH 5.5) was limed to raise the pH to 6.5.

Evans and Kamprath (1970) noted that liming increased the growth of corn on mineral soils when the Al saturation was greater than 70 per cent.

Martini et al. (1974) demonstrated the effects of soybean to liming in five Oxisols of southern Brazil. Optimum yields were obtained when liming adjusted Al from 0.1 to 0.5 me/100 g (1-5 per acent Al saturation), soil pH from 5.2 to 5.7 and Ca + Mg from 5.7 to 8.5 me/100 g. Liming significantly increased soybean nodulation and total N content of plant tissue, reduced P fixation and Mn levels in the soil.

Sartain and Kamprath (1975) explained that soybean yields on Oxisols were sharply reduced at Al saturations greater than 10 per cent. Soybean, a legume and dependent upon N fixation is more sensitive to Al than corn, a nonlegume. Nodule numbers per soybean increased from 12 per plant at 81 per cent Al saturation to 38 per plant at four per cent Al saturation.

Munns and Fox (1976) reported depression of early growth or nodulation of certain species of legume when a Hawaiian Oxisol was limed at rates above 6 t ha^{-1} (pH 6.0).

Alley (1981) noted an increase in initial crop yields with lime application.

Samson et al. (1986) found that coating inoculated seeds of soybeans with dolomite favoured nodulation by Rhizobium japonicum and increased yields compared with uncoated seeds.

Fornasieri et al. (1987) reported that in a dystrophic red latosol, lime and gympsum alone or in combination were applied to groundnuts. All the treatments increased number of pods and potential and actual number of nuts resulting in higher yield.

Bruce (1988) observed that when soybean was grown in four topsoil and 17 subsoil samples amended with liming materials (calcium carbonate and magnesium carbonate) and soluble calcium salts ($CaSO_4.2H_2O$ and $CaCl_2.2H_2O$), in most soils the soluble salts increased concentration and activities of Al in solution to levels that restricted root growth and $MgCO_3$ induced a calcium limitation to root growth.

Gupta et al. (1989) proposed a significant increase in yield of wheat and to a lesser extent of soybean, barley and maize by liming.

Alva and Sumner (1990) explained that top and root growth of lucerne (Medicago sativa) and soybean (Glycine max) were significantly greater in phosphogypsum amended soils.

Effect of liming on chemical properties of soil

Abruna et al. (1964) reported that exchangeable Al and Mn content of humid tropical soils was 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.

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.

The studies of Padmaja et al. (1972) revealed that liming red loam soils of Kerala at the rate of 2.5 t ha^{-1} of calcium oxide raised the soil pH by 1.0 to 1.5 units. White (1970) observed that dolomitic limestone applied to an acid podzol (pH 4.7) increased soil pH and decreased extractable Mn in soils.

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 and Ca + Mg + K 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.

Anjos and Rowell (1983) demonstrated that the losses of Ca by leaching increased with calcium oxide application. The initial contents of nitrate and chloride in the soil caused significant calcium losses. The changes in the content of exchangeable calcium and aluminium and pH occurred mainly in the top two centimetres of soil.

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 Mg was best correlated with exchangeable aluminium, supporting the hypothesis that Mg fixation is due to the occlusion or con precipitation of Mg with Al upon liming.

Blaszcyk et al. (1986) proposed that liming at the rate of 18.4 t ha^{-1} significantly increased calcium, magnesium and potassium concentration in the topsoil.

Bishnoi et al. (1987) proposed that liming reduced extractable and exchangeable Fe, Al and Mn in acid soils.

Gama (1987) reported that application of calcium carbonate resulted in the release of non-exchangeable potassium and slight magnesium fixation in acid soils. Exchangeable aluminium was reduced to very low levels. It is suggested that this reduction may improve adsorption of Mg solubilised by weathering.

Nakayama (1987) found that liming increased nitrogen, phosphorus, potassium, calcium and magnesium contents of the soil.

Studies conducted by Bertic (1988) revealed that by the application of hydrated lime at the rate of 20 t ha^{-1}, the Fe content in soil decreased from 34.1 ppm to 14.1 ppm, titrable acidity from 16.0 to 1.6 me/100 g soil and exchangeable acidity from 3.0 to 0.1 me/100 g 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 other 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 ratio 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.

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*), barely (*Hoardeum vulgare*) and peas (*Pisum sativum* L.).

Kuruvila (1974) proposed that the application of lime alone or in combination with MnO_2 or nitrate resulted in decrease in the nitrogen and phosphorus content of straw. Similar result was obtained by Baumgartner *et al*. (1974) in soybean.

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 cowpea.

Gupta *et al*. (1989) explained that liming increased the uptake of phosphorus, calcium and potassium in plants.

Gypsum as an ameliorant for acid subsoils

Hourigan *et al*. (1961) demonstrated that plant yields, root proliferation and consequent uptake of calcium depend largely on adequate level of lime in both topsoil and subsoil. The slow movement of lime through the soil and the expense and difficulty of mixing lime into the subsoil have led researchers to examine, surface-applied amendments, such as gypsum, in the amelioration of subsoil acidity. Since gypsum ($CaSO_4.2H_2O$) does not alter soil pH appreciably, pH dependent charge remains unchanged, enabling the gypsum to move through the soil much more readily than lime.

Reeve and Sumner (1972) were the first to demonstrate the feasibility of ameliorating subsoil acidity in Natal Oxisols by leaching various combinations of chemical amendments. They recommended surface applications of gypsum and dolomite (combined) to neutralise exchangeable Al while increasing the level of available Ca and Mg in the subsoil.

Depth of liming is an important factor in increasing the utilization of subsoil moisture. Root growth of corn in the 15-30 cm depth of an Oxisol was doubled when the Al saturation was decreased from 75 per cent to 5 per cent (Gonzalez - Erico *et al*., 1979).

Ritchey *et al*. (1980) reported that the calcium content in the subsoil of an Oxisol was increased and exchangeable Al was decreased with the application of 9700 kg ha^{-1} of ordinary superphosphate. The $CaSO_4.2H_2O$ present in the ordinary superphosphate moved with sulfate ions to the lower soil depths. Thus, in soils with primary kaolinite - iron oxide minerology, the addition of $CaSO_4.2H_2O$ and subsequent leaching of Ca improves the base status of the subsoil.

Ritchey *et al*. (1982) observed a nutritional response by supplementing the Ca level of an acid subsoil of a Brazilian Oxisol.

Deep rooting of annual crops planted in newly cleared, very highly weathered soils of the Brazilian Cerrado may be limited by Al toxicity or lack of calcium in the subsoil. In two adjacent soybean experiments on a clayey red yellow Latosol, calcium deficiency was observed below 60 cm in the first year. The Ca levels, more than 0.05 me/100 g down to atleast 105-120 cm was encountered in the fourth year suggesting that managing fertilizer to encourage calcium leaching can efficiently correct deficiency of this element in the subsoil (Ritchey *et al.*, 1983).

Pavan *et al.* (1984) in a green house experiment found that $CaCO_3$ treatments increased soil pH, CEC and exchangeable Ca, decreased exchangeable Mg and Al in the upper 20 cm of the soil profile. $CaSO_4.2H_2O$ treatments reduced the level of exchangeable Al and Mg throughout the 100 cm depth of the profile while exchangeable Ca increased. Soil pH and CEC were unaffected by this treatment.

Buyeye *et al.* (1985) obtained improved rooting following leaching of gypsum into the subsoil and this was ascribed to increased subsoil Ca status or partial detoxification of Al through sulfate complexing or both.

Mallet *et al.* (1985) reported that low soil pH and consequent Al toxicity is a major factor limiting root proliferation and grain yields of maize in many parts of South

Africa. Incorporating lime to a minimum depth of 55 cm allowed access to enough moisture in maize to avoid dry spells.

Dal Bo *et al*. (1986) conducted a leaching trial with $CaCO_3$, $CaSO_4$ and $CaCl_2$ and found that movement of Ca do not occur when the source was $CaCO_3$ only. However $CaCl_2$ promoted intense base leaching. When the source was $CaSO_4$, Ca movement was intermediate and under higher rates, the Al saturation was greatly reduced in the deeper soil layers. However there were increases in the Ca/Mg ratio in the soil surface layers.

Ellington (1986) reported that a combination of lime, deep ripping and gypsum gave the highest yields.

Soil samples collected at 0-10 cm and 10-20 cm revealed that gypsum application up to 16 t ha^{-1} did not affect the values of pH, K, Mg and Al^{3+} at either depth, but the application of 32 t ha^{-1} reduced Mg values at both soil depths and the Al values only at 0-10 cm depth. Surface application of limestone did not affect soil pH, but decreased Al^{3+} at the 0-10 cm depth and increased Mg at both depths (Ernai, 1986).

Hoyt *et al*. (1986) used soil columns to study downward movement of calcite and dolomite applied at two rates on the soil suface or incorporated 0-5 cm deep in combinations with gypsum and irrigated with 800 mm of deionised water for three weeks. Calcite and dolomite were equally effective in raising soil pH at the lower depths. Neither gypsum nor doubling the liming rate had much effect on lime movement.

A problem often encountered with gypsum application on highly weathered soils is the removal of K and Mg from the surface soil (Dal Bo et al., 1986; Ernai, 1986; Ritchey et al., 1980; Sumner et al., 1986 and Syed, 1987).

Syed (1987) reported that exchangeable calcium is increased uniformly down the profile by gypsum application and move in the percolating rain water.

Increased yields of crops grown on acid soils with surface incorporated gypsum have been attributed to increased exchangeable Ca, decreased exchangeable Al, and increased root length density in the subsoil (Farina and Channon, 1988b; Hammel et al., 1985; Sumner et al., 1986).

Hern et al. (1988) reported that soil columns treated with ethylene diamine tetra acetic acid (EDTA) and lime ($CaCO_3$) when leached with water, significant levels of exchangeable Al were removed to a depth of 60 cm whereas topsoil treatments of lime alone had little effect on subsoil exchangeable Al below 30 cm.

Gillman et al. (1989) studied the downward movement of Ca applied to a north Queensland Oxisol when irrigated with

225 mm of aritificial rainfall. Soil cores taken to 1 m depth revealed that most of the calcium from the lime treatment remained in the top 10 cm but in the gypsum treatment calcium moved to about 30 cm.

The amelioration of acid-soil infertility by gypsum or phosphogypsum was due to a combination of SO_4^- induced surface charge development, increased cation retention, and a decrease in exchangeable Al (Alva et al., 1990). The reduction in exchangeable Al after gypsum or phosphogypsum application was the result of a "self-liming" effect resulting from SO_4^{2-} induced Al polymerization by ligand exchange for OH^- groups (Alva and Sumner, 1990; Chang and Thomas, 1963).

The effect of lime and gypsum on the chemical properties of subsurface layers of a red latosol (pH 4.4-4.6) and the effect of subsurface acidity on the nutrition and development of coffee seedlings were investigated by Chaves et al. (1990), in soil columns (60 cm deep). Both vegetative and root growth were restricted by subsoil acidity. Incorporating lime to the whole column (0-60 cm) increased vegetative and root growth compared to the control (0-60 cm). Surface application of gypsum increased calcium and decreased exchangeable Al contents throughout the whole column and enhanced root growth in the deeper soil layer.

Patel and Bhajan Singh (1991) reported that gypsum treatments were effective in increasing exchangeable Ca and Mg in the soil.

Results of the liming trials by Shamshuddin *et al.* (1991) showed that soil solution Ca in the lime treatment remained mainly in the zone of incorporation, but in the gypsum treatment some calcium moved into the 15-30 cm zone and liming decreased Al^{3+} activity.

Materials and Methods

MATERIALS AND METHODS

1 Characterisation of soils

1.1 Collection of soil samples

Twenty five surface samples representing the major laterite soil series in Trichur viz., Vellanikkara series were collected from widely distributed locations in the Instructional Farm of the College of Horticulture.

The soil samples were collected from a depth of 15 cm after making a 'V' shaped cut with a sharp spade. The fresh soil was packed in polythene bags labelled and transported to the laboratory. The air dried samples were powdered with a wooden mallet and pressed through 2 mm sieve. The sieved samples were stored in air tight containers and used for the analysis.

1.2 Analysis of soil samples

Particle size distribution of the soil was determined by the hydrometer method (Piper, 1942). Organic carbon was estimated by Walkley and Blacks' rapid titration method (Jackson, 1958).

For the determination of total nutrients 1 g of the air dried soil sample was digested with diacid mixture

(1:2 perchloric acid - nitric acid mixture) and this extract was used for the analysis. Total calcium and magnesium in the extract were determined using EDTA titration method and expressed as the oxide form. Total iron was determined by the orthophenanthroline method (Hesse, 1971). Sesquioxides were precipitated by ammonia and determined gravimetrically. Total Al_2O_3 was computed by deducting total Fe_2O_3 from sesquioxides (Piper, 1942).

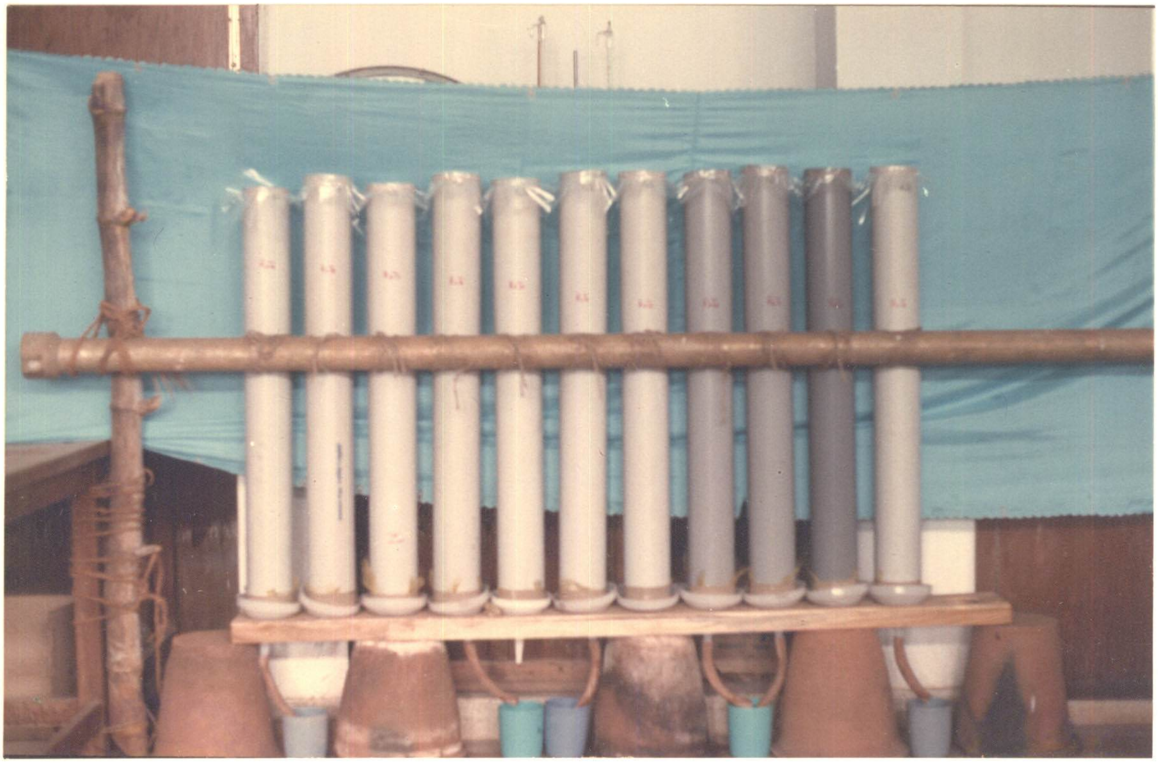
Cation exchange capacity was determined using neutral N ammonium acetate. Exchangeable cations - calcium, magnesium, sodium and potassium were estimated in the ammonium acetate extract (Jackson, 1958).

Exchangeable aluminium was extracted using 1N KCl and estimated by titration method (Thomas, 1982). Lime requirement was computed based on rates equivalent to neutralise 1.5 times exchangeable aluminium (Kamprath, 1970).

2. Leaching and mobility of Ca and Mg using different liming materials in combination with gypsum

A laboratory experiment to study the mobility of calcium and magnesium was taken up using PVC columns of 10 cm diameter and length 100 cm. Soil samples from a profile of Vellanikkara series were collected at five depths viz., 0-20, 20-40, 40-60, 60-80 and 80-100 cm. The bulk samples from each layer were collected separately, air dried and ground with a

Plate 1 An overall view of the leaching experiment



wooden mallet. These samples were filled up in the PVC column, depthwise maintaining a bulk density of 1.5 $g cm^{-3}$ to simulate a soil profile.

The filled up PVC columns were fixed vertically in the green house using wooden stands and support. Drainage was provided by a funnel and tube arrangement at the bottom of each column. The experiment was conducted for a period of 45 days during February to April, 1991.

The physico-chemical properties of the soil are presented in Table 1.

Table 1. Physical and chemical properties of the soil used for the column study

Location - Vellanikkara

Type - Laterite

Dimension, cm		Surface area	Volume	Bulk density	Moisture
Length	Diameter	cm^2	cm^3	$g\ cm^{-3}$	%
100	10	78.5	7850	1.5	2.5

Horizon cm	pH	Exchangeable, cmol (+) kg^{-1}						Al saturation %
		Al	Ca	Mg	K	Na	Cations	
0-20	5.31	1.30	1.76	0.66	0.11	0.17	4.00	32.50
20-40	5.10	1.43	1.54	0.66	0.12	0.16	3.91	36.57
40-60	5.07	1.69	1.54	0.66	0.13	0.11	4.13	40.92
60-80	5.03	1.82	1.76	1.10	0.12	0.22	5.02	36.25
80-100	5.16	1.30	2.64	1.32	0.14	0.18	5.58	23.30

2.1 Layout of the experiment

Design : CRD

Number of replication : 2

Treatments

T_0 : No lime

T_1 : $CaCO_3$ at the rate of 1.5 times exchangeable Al content

T_2 : $CaCO_3$ + $CaSO_4.2H_2O$ (25 per cent of total lime requirement)

T_3 : $CaCO_3$ + $CaSO_4.2H_2O$ (50 per cent of total lime requirement)

T_4 : $CaCO_3$ + $CaSO_4.2H_2O$ (75 per cent of total lime requirement)

T_5 : $MgCO_3$ at the rate of 1.5 times exchangeable Al content

T_6 : $MgCO_3$ + $CaSO_4.2H_2O$ (25 per cent of the total lime requirement

T_7 : $MgCO_3$ + $CaSO_4.2H_2O$ (50 per cent of the total lime requirement)

T_8 : $MgCO_3$ + $CaSO_4.2H_2O$ (75 per cent of the total lime requirement)

T_9 : $CaSO_4.2H_2O$ at the rate of 1.5 times exchangeable Al content

The rates of application of the chemical amendments were based on the content of exchangeable Al (KCl extraction) throughout the soil column. The mean exchangeable Al value for the 0-100 cm soil depth was found to be 1.51 cmol (+) kg^{-1} (Table 1). Lime application was done at the rate to neutralise 1.5 times exchangeable Al content of the soil (Kamprath, 1970). The amendments were mixed with the soil to a depth of 2 cm. Summary of treatments and quantity applied are presented in Table 2.

Table 2. Calcium carbonate, magnesium carbonate and gypsum treatments of soil columns

Treatment notation	Amendment, g $column^{-1}$		
	$CaCO_3$	$MgCO_3$	$CaSO_4.2H_2O$
T_0	0.0	0.0	0.0
T_1	13.6	0.0	0.0
T_2	10.2	0.0	3.4
T_3	6.8	0.0	6.8
T_4	3.4	0.0	10.2
T_5	0.0	11.4	0.0
T_6	0.0	8.6	2.9
T_7	0.0	5.7	5.7
T_8	0.0	2.9	8.5
T_9	0.0	0.0	23.4

2.2 Irrigation management

Vellanikkara receives an annual precipitation of 2600 mm (Meteorological data, College of Horticulture, Vellanikkara) with the greatest amount in June, followed by July and August. The monthly average rainfall for these months for the year 1990 was 560 mm with a mean daily precipitation of 20 mm per day. To simulate the rainfall, all the soil columns were irrigated daily with the mean daily precipitation (150 ml) for a period of 45 days. Irrigations were carried out by adding the required amount of water on to a filter paper covering the surface of the soil column using a rose can. After irrigation the top of the PVC columns were covered with polythene sheets to avoid evaporation losses. Prior to application of treatments the soils in the columns were brought to field capacity.

Irrigation was continued for 45 days after the application of treatments, the soil columns were then cut horizontally at different depths by means of a hack-saw. The soil cores were cut at the following depths: 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90 and 90-100 cm. The soil samples were air dried, sieved and stored in containers for chemical analysis.

2.3 Soil chemical analysis

The soil samples at various depths were analysed for pH, exchangeable calcium, magnesium and aluminium. The Ca and Al saturation and effective CEC were also found out.

The pH, exchangeable aluminium, sodium and potassium were determined as per the method explained earlier. Neutral 1 N KCl solution was used to extract exchangeable Ca and Mg.

Exchangeable calcium and magnesium in the KCl extract were determined by titration with Na_2 EDTA (Hesse, 1971).

3. Potculture experiment

The potculture experiment was carried out using an aluminium sensitive test crop (Soybean - Glycine max L.) to study the effect of liming in combination with gypsum on 50:50 basis on the growth, yield and uptake of various nutrients.

3.1 Collection of soil

Bulk surface samples from 20 cm depth representing Vellanikkara series were collected and used for the potculture experiment. The soil was dried in shade, the larger clods were broken and the stones and pebbles removed. The soil was filled in earthern pots of 25 cm diameter. The data on chemical properties of the soil used for the potculture experiment are given below:

pH in water (1:2.5soil water suspension)	4.7
Available N, kg ha^{-1}	197.57
Available P, kg ha^{-1}	8.62
Available K, kg ha^{-1}	207.2
Exchangeable Ca, cmol (+) kg^{-1}	1.8
Exchangeable Mg, cmol (+) kg^{-1}	0.4
Exchangeable Na, cmol (+) kg^{-1}	0.13
Exchangeable K, cmol (+) kg^{-1}	0.21
Exchangeable Al, cmol (+) kg^{-1}	1.00

3.2 Layout of the experiment

Design : CRD

Replication : 4

T_0 : No lime

T_1 : $CaCO_3$ at rate equivalent to neutralise 1.5 times exchangeable Al (1680 kg ha^{-1})

T_2 : $CaCO_3$ at rate equivalent to neutralise 3.0 times exchangeable Al (3360 kg ha^{-1})

T_3 : $CaCO_3$ + $CaSO_4.2H_2O$ (50:50) at rate equivalent to neutralise exchangeable Al (560 kg ha^{-1} each)

T_4 : $CaCO_3$ + $CaSO_4.2H_2O$ (50:50) at rate equivalent to neutralise 3.0 times exchangeable Al (1680 kg ha^{-1} each)

Table 3. Lime and gypsum treatments in potculture experiment

Treatment notation	$CaCO_3$, g pot^{-1}	$CaSO_4.2H_2O$, g pot^{-1}
T_0	0.0	0.0
T_1	7.5	0.0
T_2	15.0	0.0
T_3	2.5	2.5
T_4	7.5	7.5

Earthern pots of uniform size were filled with 10 kg of the soil selected for this study. The treatments were applied on the surface 5 cm layer and mixed well with the top soil. Then water was sprinkled just to moisten the soil. Table 3 gives a summary of the treatments applied.

3.3 Sowing of seeds

Ten days after the application of treatments soybean (variety, Improved Pelicon) seeds were sown. Only one healthy plant was maintained in each pot.

3.4 Irrigation

The crop was irrigated once in 3 days with 2 litres of water. No water was allowed to drain.

3.5 Fertilizer application

NPK fertilizers, as urea, superphosphate and muriate of potash were applied at the rate of 20:30:10 kg ha^{-1} as per the Package of Practice Recommendation (KAU, 1989).

3.6 Plant protection

Dimethoate at the rate of 0.03 per cent was applied to the crop for the control of mites.

3.7 Harvest

The crop was harvested four months after sowing. Harvesting was done by pulling out the plants without disturbing the root system.

3.8 Biometric observations

The following biometric observations were taken at the time of harvest.

3.8.1 Height of plants

Plant height was measured from the base of the stem to the tip of the youngest leaf using a metre scale and expressed in centimetres.

3.8.2 Root length

The length of root was measured in centimetres, from the base of the stem to the tip of the longest root.

3.8.3 Nodule count

The roots of the uprooted plants were washed carefully in running water and all the soil particles adhering to the root systems were removed using a jet of water. The root nodules were separated and the number noted.

3.8.4 Fresh weight of pod

Fresh weight of pod was recorded at the time of harvest and expressed in gram.

3.8.5 Dry weight of pod

The pods were dried in shade and again dried in an air oven at 80 ± 5°C, until constant weight. The weight in gram was recorded.

3.8.6 Dry weight of shoot

The air dried shoots were again dried in an air oven at 80 ± 5°C until constant weight. The weight was recorded in gram.

3.8.7 Dry weight of root

The air dried roots were again dried in an air oven at 80 ± 5°C until constant weight and the weight was recorded in gram.

3.8.8 Yield

The dried pods were separated into grain and husk and the weight of grains recorded in gram.

3.9 Analytical procedure

3.9.1 Soil samples

The soil from each pot was mixed thoroughly and a representative sample was collected. It was air dried and sieved and stored in plastic containers for chemical analysis.

The soil samples before and after the application of treatments were tested for pH, total calcium and magnesium, exchangeable calcium, magnesium and aluminium, available nitrogen, phosphorus, potassium and the micronutrients iron, manganese, zinc and copper. Effective CEC, and aluminium saturation were also found out.

pH, total calcium and magnesium, exchangeable calcium, magnesium, and aluminium were determined as per standard analytical procedures. Available nitrogen was determined by alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus was extracted with Bray No.1 extractant and determined by chlorostannous reduced molybdo-phosphoric blue colour method in HCl system and available potassium was extracted by neutral normal ammonium acetate and estimated by using EEL flame photometer. For the determination of extractable micro-nutrients the soil samples were extracted with diacid ($0.05 \underline{N}$ HCl + $0.025 \underline{N}$ H_2SO_4) extract (Perkins, 1970) and estimated using Perkin Elmer atomic absorption spectrophotometer.

3.9.2 Plant sample

The plant parts (tops) collected at the time of harvest were analysed separately viz., shoot and pod for total N, P, K, Ca, Mg, Fe, Mn, Zn and Cu.

Total N was determined by the microkjeldal digestion distillation method (Jackson, 1958). For the determination of other nutrients a triacid mixture was used. The P content in this extract was determined colorimetrically by the vanado molybdo phosphoric yellow colour method in nitric acid system. In the acid extract, K was determined using an EEL flame photometer. Calcium and magnesium were estimated using EDTA titration method. The micronutrients viz., Fe, Fn, Zn and Cu in the triacid extract were determined using atomic absorption spectrophotometer (Jackson, 1958).

3.10 Uptake of nutrients

The total uptakes of N, P, K, Ca, Mg and micronutrients were calculated by multiplying the drymatter of the crops with the respective nutrient content and expressed in mg pot^{-1} and μg pot^{-1} for major nutrients and micronutrients respectively.

3.11 Statistical analysis

The data recorded for different characters were compiled and tabulated in proper form and were subjected to analysis of variance (Panse and Sukhatme, 1967).

Results

RESULTS

1. Characterisation of soils used for the study

The soils selected for the study come under the Vellanikkara series. They are deep dark laterite soils having silty loam to silty clay loam surface texture. They occur gently to steep sloping areas.

1.1 Textural analysis

Surface samples collected at random from widely distributed areas were used for the study.

Table 4 gives the particle size distribution of surface samples.

The soils in general show a textural class ranging from silty loam to silty clay loam. The soils are predominantly sandy with the sand content ranging from 62.0 to 72.0 per cent. The clay content of the soils do not show much variation and ranges from 23.8 to 32.6 per cent. As is characteristic of the tropical soils the silt, forms the lowest among the size fraction, with values ranging from 4.0 to 10.0 per cent.

Table 4. Particle size distribution of surface soil samples

Sl.No.	% sand	% silt	% clay	Textural class
1.	64.0	4.0	32.0	Silty clay loam
2.	64.0	4.0	32.0	Silty clay loam
3.	62.0	6.0	32.0	Silty clay loam
4.	70.0	5.2	24.8	Silty loam
5.	70.0	4.0	26.0	Silty loam
6.	62.0	6.0	32.0	Silty clay loam
7.	64.0	10.0	26.0	Silty loam
8.	68.0	4.0	28.0	Silty loam
9.	65.2	4.8	32.0	Silty clay loam
10.	64.8	7.2	28.0	Silty loam
11.	66.6	4.4	29.0	Silty clay loam
12.	64.8	5.2	30.0	Silty clay loam
13.	64.0	8.0	28.0	Silty clay loam
14.	68.2	5.0	26.8	Silty loam
15.	69.0	5.6	25.4	Silty loam
16.	62.0	5.4	32.6	Silty clay loam
17.	64.0	8.0	28.0	Silty clay loam
18.	72.0	4.2	23.8	Silty loam
19.	66.2	4.4	29.4	Silty clay loam
20.	66.0	6.0	28.0	Silty clay loam
21.	66.0	4.0	30.0	Silty clay loam
22.	67.6	5.6	26.8	Silty loam
23.	66.0	4.0	32.0	Silty clay loam
24.	64.0	6.0	32.0	Silty clay loam
25.	64.6	4.4	31.0	Silty clay loam

1.2 Chemical characteristics

The chemical characteristics are presented in Table 5a and 5b.

Soils are in general low in organic carbon as is characteristic of tropical soil. The organic carbon content recorded a maximum of 1.5 per cent and minimum value of 0.75 per cent.

The soils being ferralitic the sesquioxide content was high varying from 19.0 to 32.8 per cent.

The total Fe_2O_3 content of the soils ranged from 6.95 per cent to 10.22 per cent. The Al_2O_3 content recorded a maximum value of 23.02 per cent and a minimum value of 23.02 per cent and a minimum value of 10.39 per cent.

The CEC as expected was low with values ranging from 7.36 to 10.25 cmol (+) kg^{-1}.

The base saturation of the soil decide the extent of lime required. Being surface soils the base saturation was fairly high. The value varied from 37.07 to 55.11 per cent.

pH showed very little variation and the range observed was from 5.26 to 5.68.

Table 5a. Chemical characteristics of surface soil samples

Sl. No.	Organic carbon %	Total Fe_2O_3 %	Total Al_2O_3 % on deduction	Sesqui-oxides %	pH	Total CaO %	Total MgO %
1.	1.02	9.81	22.99	32.80	5.68	0.50	0.15
2.	0.75	9.81	19.19	29.90	5.39	0.70	0.22
3.	0.96	9.41	10.59	20.00	5.43	0.29	0.35
4.	1.20	8.18	10.82	19.00	5.61	0.20	0.22
5.	1.41	6.95	13.05	20.00	5.45	0.80	0.15
6.	0.87	10.22	21.18	31.40	5.65	0.99	0.35
7.	0.84	8.18	23.02	31.20	5.49	0.80	0.28
8.	0.84	8.99	15.01	24.00	5.26	0.60	0.15
9.	0.99	8.99	16.21	25.20	5.31	0.90	0.15
10.	1.50	8.99	15.81	24.80	5.59	1.40	0.43
11.	1.08	8.18	17.42	25.60	5.41	0.59	0.17
12.	1.23	7.36	19.04	26.40	5.38	0.55	0.15
13.	0.96	6.95	12.45	19.40	5.45	0.66	0.15
14.	0.87	9.41	10.39	19.80	5.60	0.76	0.13
15.	1.02	8.59	12.41	21.00	5.33	0.87	0.15
16.	0.99	8.59	13.41	22.00	5.40	0.98	0.35
17.	0.84	9.81	12.19	22.00	5.51	0.94	0.25
18.	0.84	9.41	13.59	23.00	5.55	0.81	0.18
19.	1.05	9.41	14.59	24.00	5.39	0.88	0.17
20.	1.41	8.99	15.81	24.80	5.41	0.83	0.28
21.	1.29	9.81	15.19	25.00	5.65	0.69	0.30
22.	1.17	10.22	15.38	25.60	5.43	0.70	0.25
23.	1.17	7.76	17.44	25.20	5.26	0.78	0.20
24.	1.05	7.76	22.24	30.00	5.29	0.99	0.33
25.	0.99	8.99	20.01	29.00	5.36	0.87	0.32

Table 5b. Chemical characteristics of surface soil samples

CEC cmol (+) kg^{-1}	Base saturation %	Exchangeable Al cmol (+) kg^{-1}	Al saturation of total CEC %	Al saturation of effective CEC %	Lime requirement t ha^{-1}
10.25	37.07	1.08	10.54	22.13	1.8144
10.25	37.66	1.08	10.54	21.86	1.8144
9.75	38.67	0.90	9.23	19.27	1.5120
9.60	47.50	0.45	4.69	8.98	0.7560
9.60	50.63	0.81	8.44	14.29	1.3608
8.30	41.45	0.81	9.76	19.06	1.3608
7.50	51.87	0.90	12.00	18.79	1.5120
7.80	59.10	0.90	11.54	16.33	1.5120
8.88	42.23	0.99	11.15	20.89	1.6632
8.50	52.59	0.99	11.65	18.13	1.6632
9.50	50.95	0.90	9.47	15.68	1.5120
9.26	48.38	0.90	9.72	16.73	1.5120
9.18	45.10	0.81	8.82	16.36	1.3608
8.64	39.58	1.08	12.50	24.00	1.8144
7.92	48.23	1.08	13.64	22.04	1.8144
8.00	48.13	0.99	12.38	20.45	1.6632
8.20	47.20	0.81	9.88	17.31	1.3608
9.80	46.33	0.81	8.27	15.14	1.3608
9.88	38.87	0.99	10.02	20.50	1.6632
7.54	49.60	0.99	13.13	20.93	1.6632
8.10	51.48	0.54	6.67	11.46	0.9072
7.36	51.09	0.81	11.01	17.72	1.3608
7.45	51.14	0.99	13.29	20.63	1.6632
8.00	47.38	1.08	13.50	22.18	1.8144
8.22	55.11	0.90	10.95	16.57	1.5120

In the case of exchangeable Al, the minimum value obtained was 0.45 cmol (+) kg^{-1} and the maximum value 1.08 cmol (+) kg^{-1}. However, for most of the samples the value recorded was around 1.0 cmol (+) kg^{-1}.

The Al saturation of total CEC showed a minimum value of 4.69 per cent and a maximum value of 13.64 per cent. Whereas the Al saturation of effective CEC which is considered more realistic for leached mineral soils, varied from 8.98 to 24.00 per cent.

Lime requirement based on 1.5 times exchangeable Al content varied from 0.756 t ha^{-1} to 1.814 t ha^{-1}.

The CaO content of the soil ranged from 0.20 to 0.99 per cent and MgO from 0.13 to 0.35 per cent.

2. Leaching and mobility of Ca and Mg using different liming materials in combination with gypsum

2.1 Depth-wise distribution of pH as influenced by treatments

Table 6 and Fig.1, 2 and 3 indicate the change in pH resulting from the treatment.

The $CaCO_3$ treatment raised the pH of the 0 to 5 cm horizon from 5.7 to 7.4, however little or no change in pH occurred below 15 cm depth. The pH of the 0-5 cm horizon was

Table 6. pH profile of the soil columns as influenced by various treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ +75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
0-5	5.7	7.4	7.4	7.0	6.6	8.5	8.0	7.6	6.9	4.9
5-10	5.4	5.6	5.3	5.2	5.0	5.9	5.7	6.0	5.2	4.9
10-15	5.5	5.4	5.1	5.1	5.0	5.5	5.3	5.3	5.0	4.9
15-20	5.4	5.4	5.2	5.1	5.0	5.4	5.1	5.3	5.1	4.9
20-25	5.3	5.3	5.2	5.2	4.9	5.3	5.2	5.4	5.0	4.9
25-30	5.3	5.2	5.3	5.1	5.0	5.1	5.1	5.2	4.9	4.9
30-40	5.2	5.2	5.2	5.2	5.0	5.1	5.1	5.2	4.9	4.9
40-50	5.0	5.0	5.0	5.0	4.8	4.9	4.9	5.0	5.0	5.0
50-60	5.0	5.0	5.1	5.0	4.8	5.0	4.8	4.9	4.8	5.0
60-70	5.0	4.9	5.0	4.5	4.8	4.8	4.9	4.9	4.7	4.7
70-80	5.3	5.0	5.2	5.0	4.8	4.9	5.2	5.0	4.9	4.8
80-90	5.6	5.3	5.6	5.4	5.4	5.3	5.7	5.3	5.2	5.3
90-100	5.9	5.4	5.8	5.6	6.0	5.9	5.9	5.8	5.3	5.7

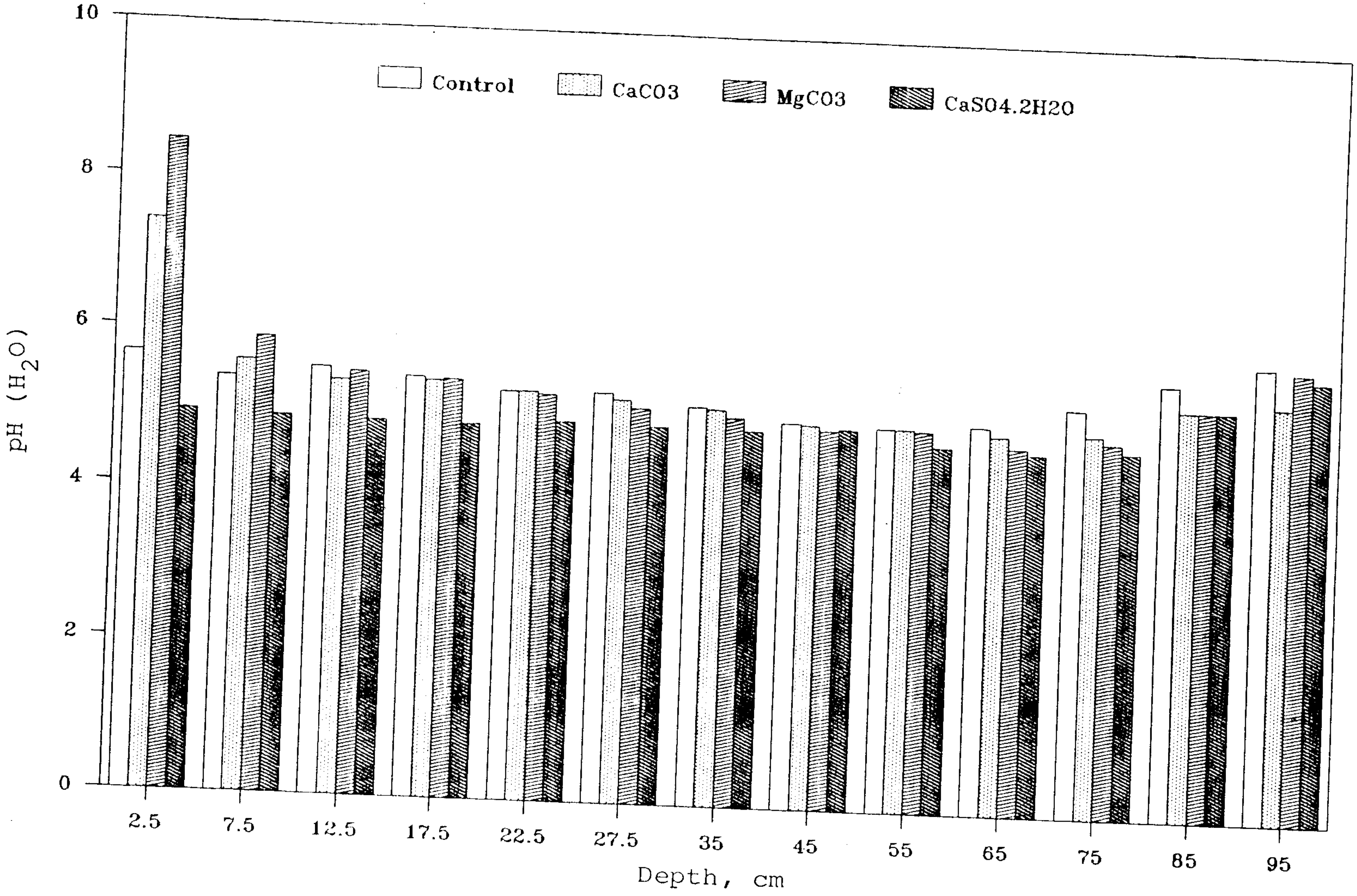


Fig.1 Depthwise distribution of pH as influenced by various treatments

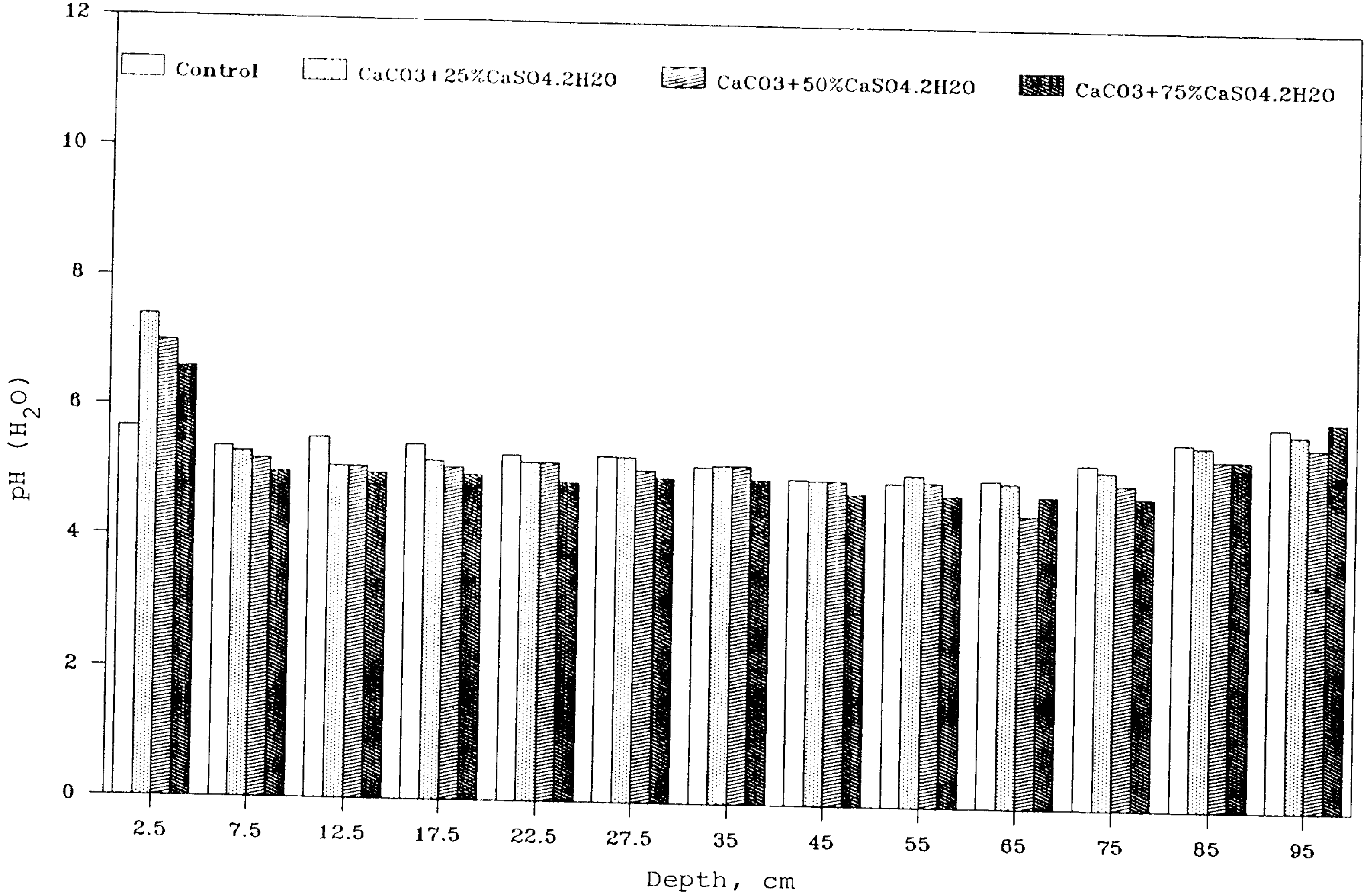


Fig.2 Depthwise distribution of pH as influenced by various treatments

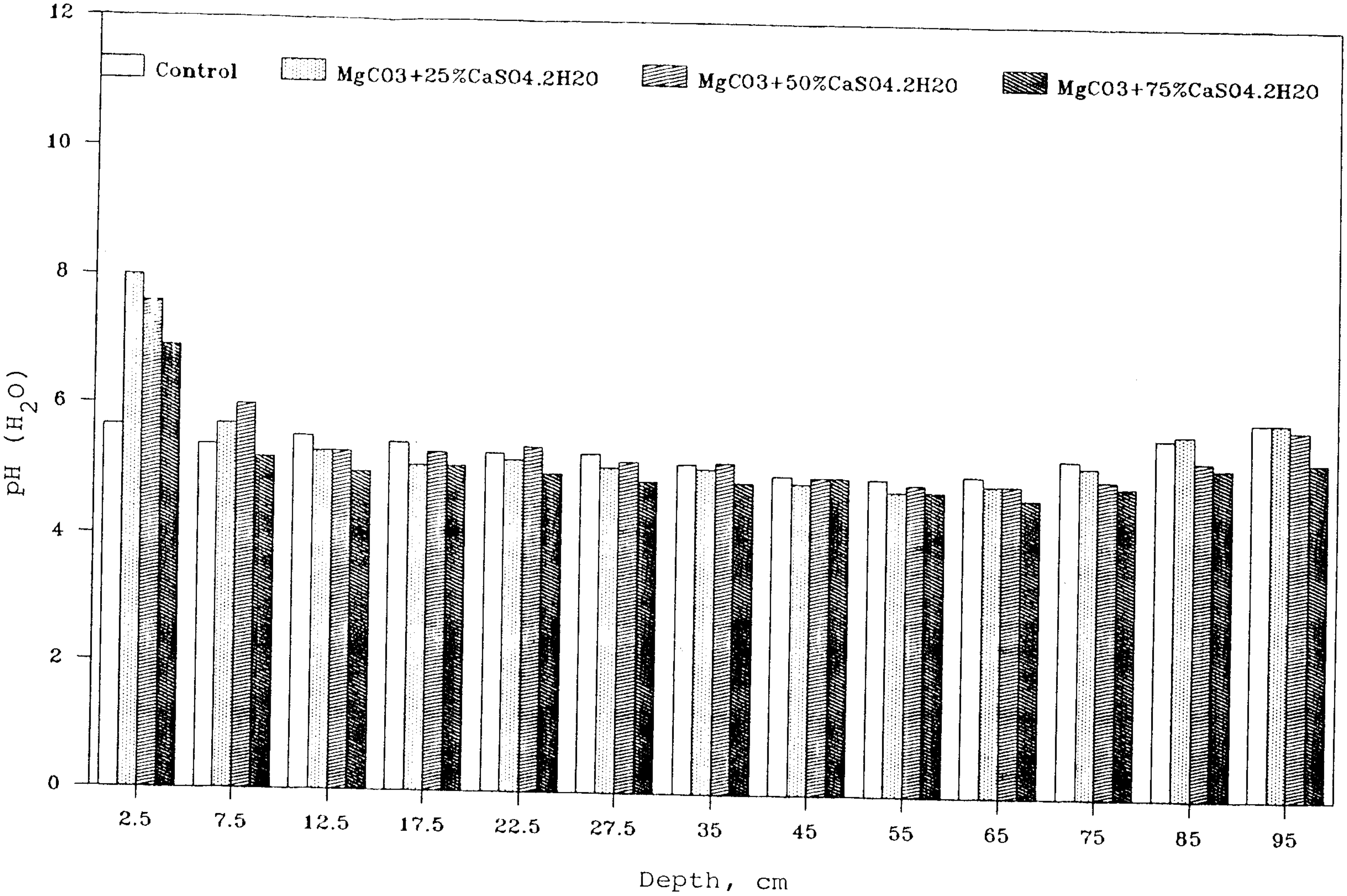


Fig.3 Depthwise distribution of pH as influenced by various treatments

raised to 8.5 from 5.7, by $MgCO_3$ treatment. But no change in pH occurred below 10 cm depth. In contrast to $CaCO_3$ and $MgCO_3$ treatments, the $CaSO_4.2H_2O$ treatment caused a reduction in pH throughout the length of the soil column (Fig.1).

In general, the combination of $CaCO_3$ + $CaSO_4.2H_2O$ increased the pH of the surface 0-5 cm layer of the soil column only and the combination of $CaCO_3$ with 25, 50 and 75 per cent $CaSO_4.2H_2O$, resulted in a slight reduction in pH up to 25, 30 and 90 cm depth respectively (Fig.2).

The combination treatment with $MgCO_3$ + 25 per cent $CaSO_4.2H_2O$ increased the pH in the 0-10 cm layer and a reduction in pH was noted up to 80 cm depth of the profile. Similarly, raising the $CaSO_4.2H_2O$ level of 50 per cent also raised the pH of the surface 0-10 cm horizon and caused a slight reduction in pH throughout the length of the column. The pH of the surface 0-5 cm layer was increased from 5.7 to 6.9 and a considerable lowering of pH in the remaining part of the column resulted due to the treatment with $MgCO_3$ and 75 per cent $CaSO_4.2H_2O$ (Fig.3).

2.2 Downward movement of applied Ca as influenced by various treatments

Downward movement of applied Ca resulting from the treatments is presented in Table 7 and Fig.4, 5 and 6.

Table 7. Downward movement of applied Ca [cmol (+) kg^{-1}] as influenced by various treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ +75% $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
0-5	1.98	11.77	12.10	13.09	16.72	1.21	2.31	6.49	9.02	17.71
5-10	1.65	1.76	2.75	3.96	4.29	1.65	1.43	1.21	2.75	5.39
10-15	1.54	1.43	2.64	3.85	4.07	1.54	1.54	1.32	2.64	5.17
15-20	1.54	1.54	2.64	3.63	3.85	1.54	1.76	1.65	2.64	5.06
20-25	1.54	1.43	2.09	3.52	3.74	1.54	1.87	1.87	2.42	4.73
25-30	1.54	1.54	1.76	2.75	3.08	1.65	1.76	2.31	2.42	4.62
30-40	1.42	1.65	1.43	2.09	2.20	1.65	1.54	1.98	2.42	3.63
40-50	1.54	1.76	1.54	1.87	1.87	1.54	1.65	1.65	2.42	1.87
50-60	1.54	1.54	1.32	1.76	1.87	1.65	1.54	1.65	2.09	1.98
60-70	1.65	1.54	1.54	1.76	1.76	1.87	1.76	1.54	1.98	1.98
70-80	1.87	1.76	2.09	2.09	2.20	1.87	2.20	2.20	2.09	1.98
80-90	2.42	2.09	2.20	2.20	2.53	2.20	2.64	2.53	2.75	2.42
90-100	2.64	2.53	2.64	2.64	2.64	2.53	2.86	2.75	2.86	2.75

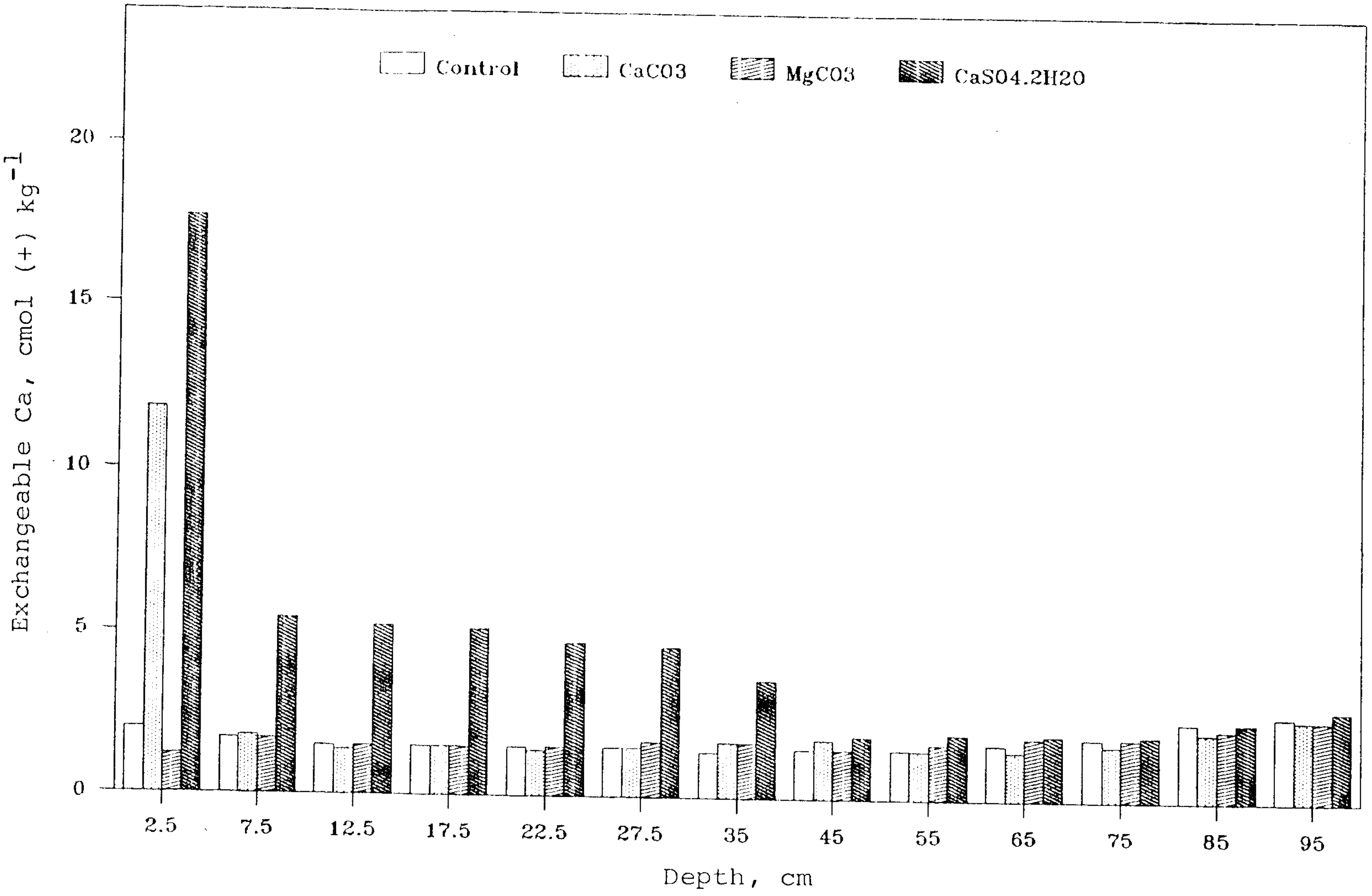


Fig.4 Downward movement of applied Ca as influenced by various treatments

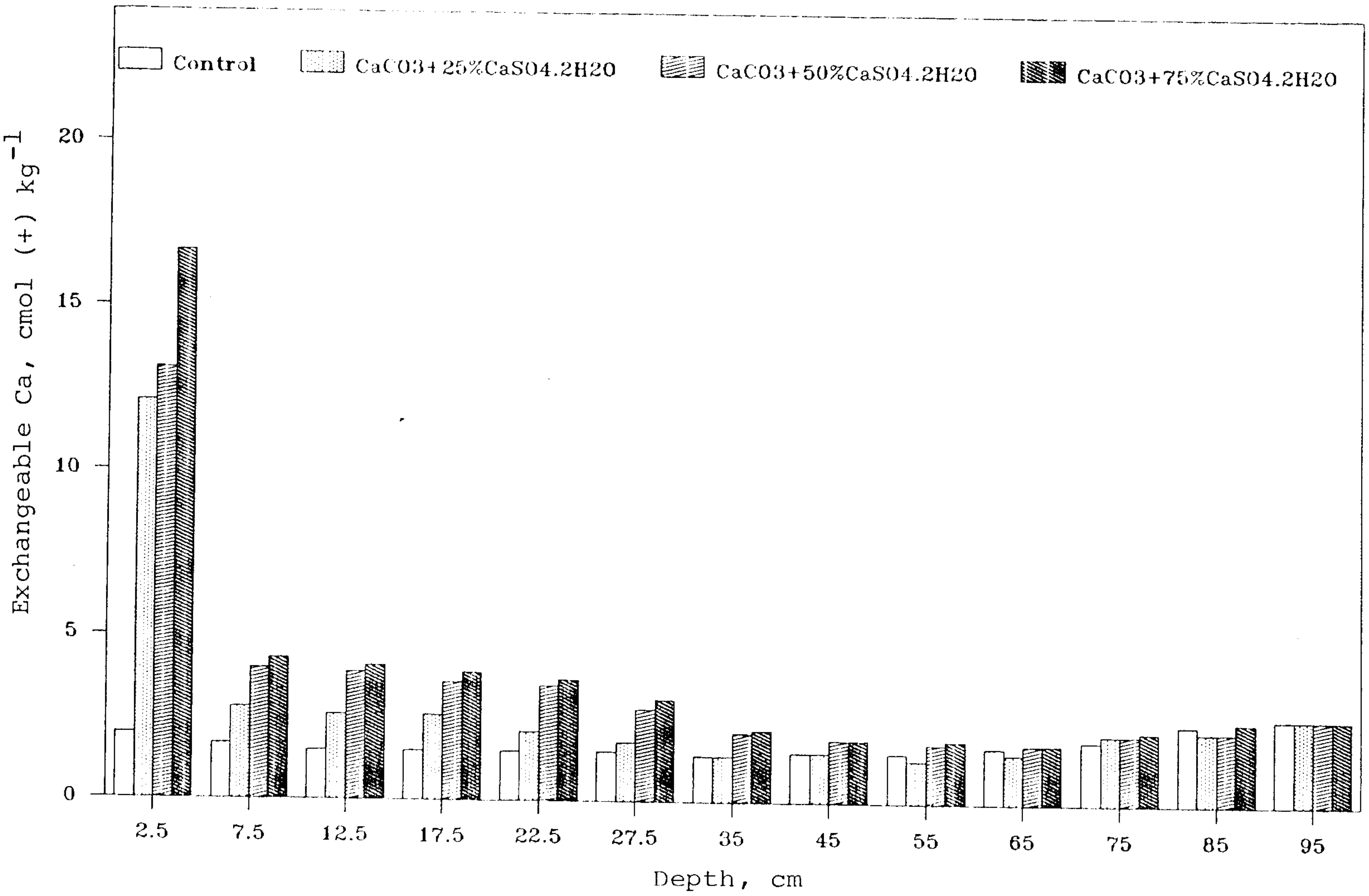


Fig.5 Downward movement of applied Ca as influenced by various treatments

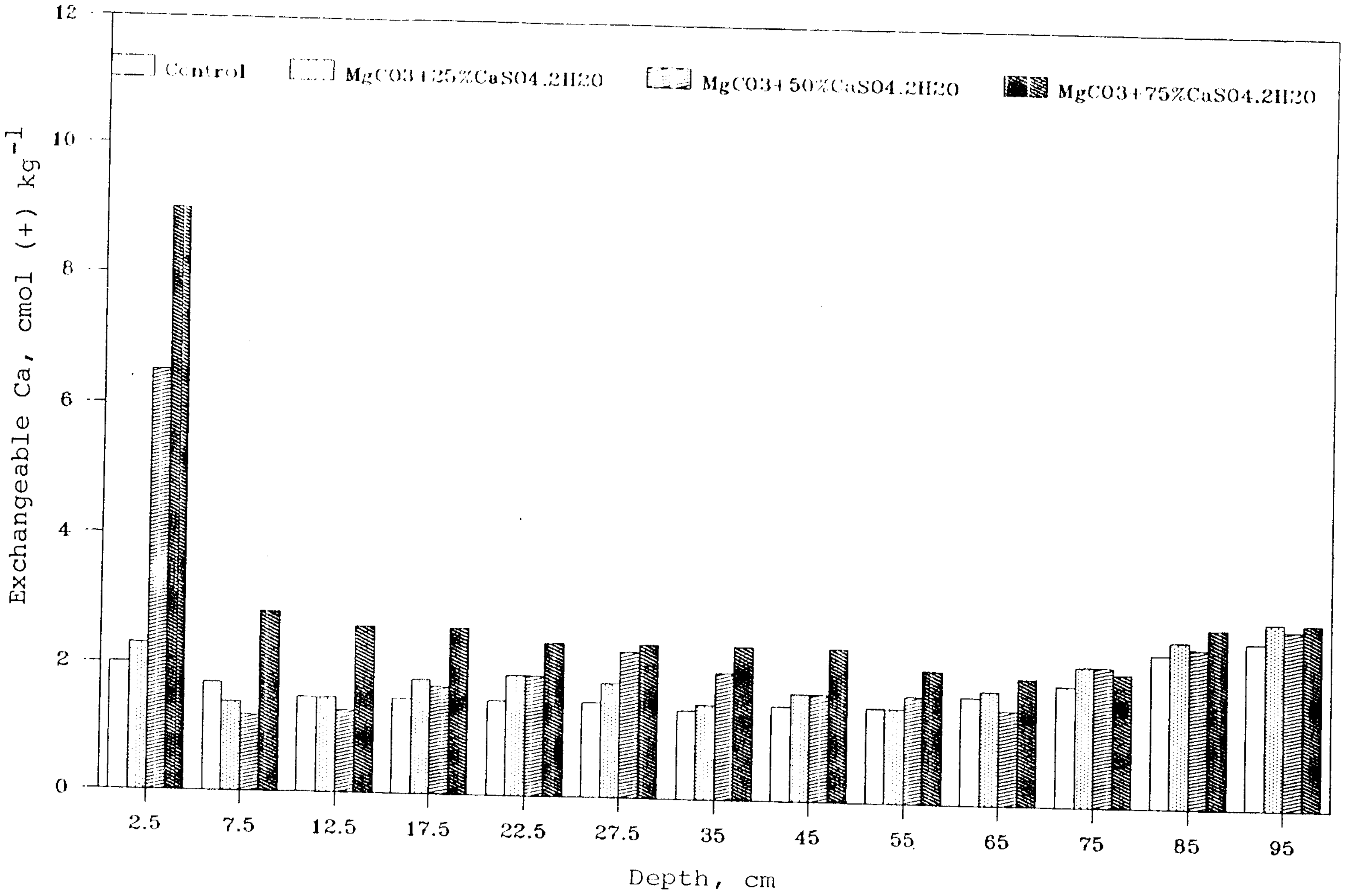


Fig.6 Downward movement of applied Ca as influenced by various treatments

The mobility of applied Ca resulting from the $CaCO_3$ treatment was restricted to the surface 10 cm of the profile, whereas the $MgCO_3$ treatment resulted in a little reduction in the exchangeable Ca in the 0-5 cm layer. In marked contrast to $CaCO_3$ and $MgCO_3$ treatments, the $CaSO_4.2H_2O$ treatment resulted in substantial accumulation of exchangeable Ca in 0-40 cm depth and a general increase in exchangeable Ca throughout the 100 cm length of the profile (Fig.4).

The combination treatment with $CaCO_3$ + 25 per cent $CaSO_4.2H_2O$ resulted in an increased mobility of Ca up to 30 cm. Increasing the $CaSO_4.2H_2O$ level to 50 per cent of the total lime requirement produced a greater mobility of Ca to 90 cm depth and a greater accumulation of calcium in the 0-40 cm depth was observed by raising the $CaSO_4.2H_2O$ level to 75 per cent (Fig.5).

The exchangeable Ca was increased in the 0-5 cm layer and decreased slightly in the 5-10 cm layer when $CaSO_4.2H_2O$ was added along with $MgCO_3$ at rates equivalent to 25 per cent of the total lime requirement. Towards the lower layers only a small increase in exchangeable Ca was observed. When $CaSO_4.2H_2O$ level was increased to 50 per cent, exchangeable Ca increased considerably in the 0-5 cm layer, but decreased up to 15 cm depth and showed a tendency to accumulate in the lower depths. But beyond 40 cm depth, the amount of exchangeable Ca accumulated was very small. The treatment with $MgCO_3$ + 75 per cent $CaSO_4.2H_2O$ resulted in a relatively uniform distribution of exchangeable Ca throughout the 100 cm length of the profile (Fig.6).

2.3 Downward movement of applied Mg as influenced by various treatments

Table 8 and Fig.7, 8 and 9 represent the changes in exchangeable Mg resulting from the various treatments.

Exchangeable Mg decreased in the surface 0-5 cm and 0-30 cm of the soil columns treated with $CaCO_3$ and $CaSO_4.2H_2O$ respectively though it increased slightly in the 10-15 cm and 30-50 cm layer of the soil columns given the treatments mentioned above. The remaining part of the profile contained more or less same exchangeable magnesium as that of the untreated soil column. The increase in exchangeable Mg resulting from the $MgCO_3$ treatment was restricted to the surface 10 cm of the profile (Fig.7).

The combination of $CaCO_3$ + 25 per cent $CaSO_4.2H_2O$ reduced exchangeable Mg in the 0-5 cm horizon from 0.66 to traces and in the 5-10 cm horizon from 0.66 to 0.22. But the exchangeable Mg level in the 20-30 cm horizon increased considerably. Though raising the $CaSO_4.2H_2O$ level to 50 per cent in T_3 caused an increase in exchangeable Mg in the

Table 8. Downward movement of applied Mg [cmol (+) kg^{-1}] as influenced by various treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4.2H_2O$	$CaCO_3$ + 50% $CaSO_4.2H_2O$	$CaCO_3$ +75% $CaSO_4.2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4.2H_2O$	$MgCO_3$ +50% $CaSO_4.2H_2O$	$MgCO_3$ + 75% $CaSO_4.2H_2O$	$CaSO_4$ $2H_2O$
0-5	0.66	Traces	Traces	Traces	Traces	13.97	11.66	5.64	1.65	Trace
5-10	0.66	0.66	0.22	Traces	Traces	2.75	2.53	2.09	1.10	Trace
10-15	0.77	1.10	0.66	0.33	Traces	0.99	1.87	1.98	1.10	Trace
15-20	0.88	0.88	0.88	0.44	1.10	0.77	1.65	2.20	1.43	Trace
20-25	0.88	0.99	1.54	1.65	1.10	0.99	1.54	2.20	1.76	0.44
25-30	0.77	0.88	1.21	2.09	1.87	0.77	1.54	1.54	1.98	0.66
30-40	0.66	0.66	0.88	0.55	1.54	0.77	0.99	1.32	1.98	1.21
40-50	0.77	0.55	0.99	0.77	1.32	0.88	0.88	1.32	1.21	1.10
50-60	0.66	0.88	1.10	0.99	0.99	1.10	0.88	0.99	0.77	0.88
60-70	0.99	0.88	1.10	1.10	0.99	1.21	1.10	1.21	0.66	0.88
70-80	1.10	1.21	1.32	1.10	1.21	1.32	1.10	1.32	1.32	0.88
80-90	1.32	1.43	1.54	1.54	1.32	1.32	1.21	1.21	1.32	1.21
90-100	1.32	1.43	1.32	1.32	1.32	1.76	1.32	1.54	1.32	1.54

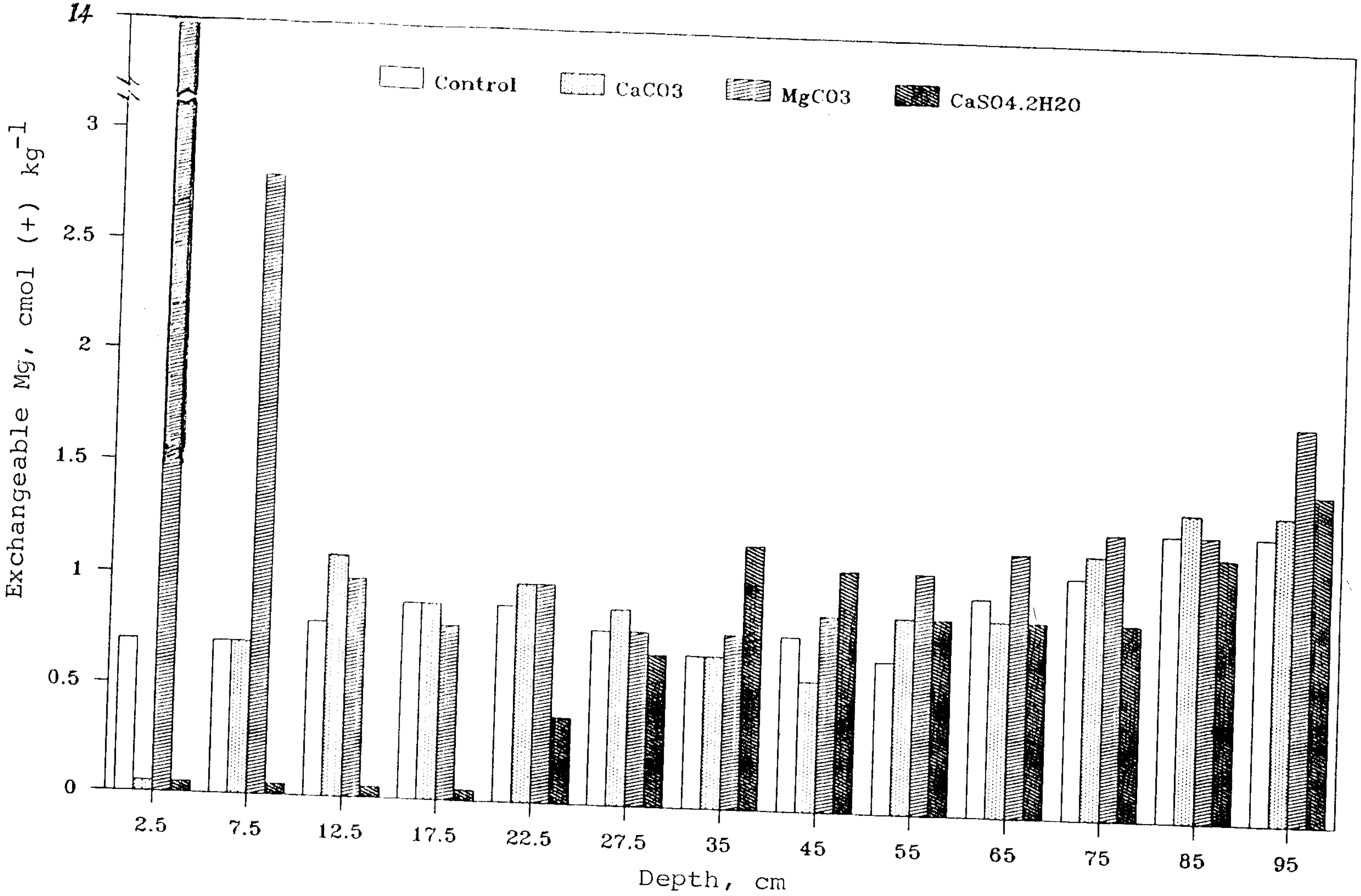


Fig.7. Downward movement of applied Mg as influenced by various treatments

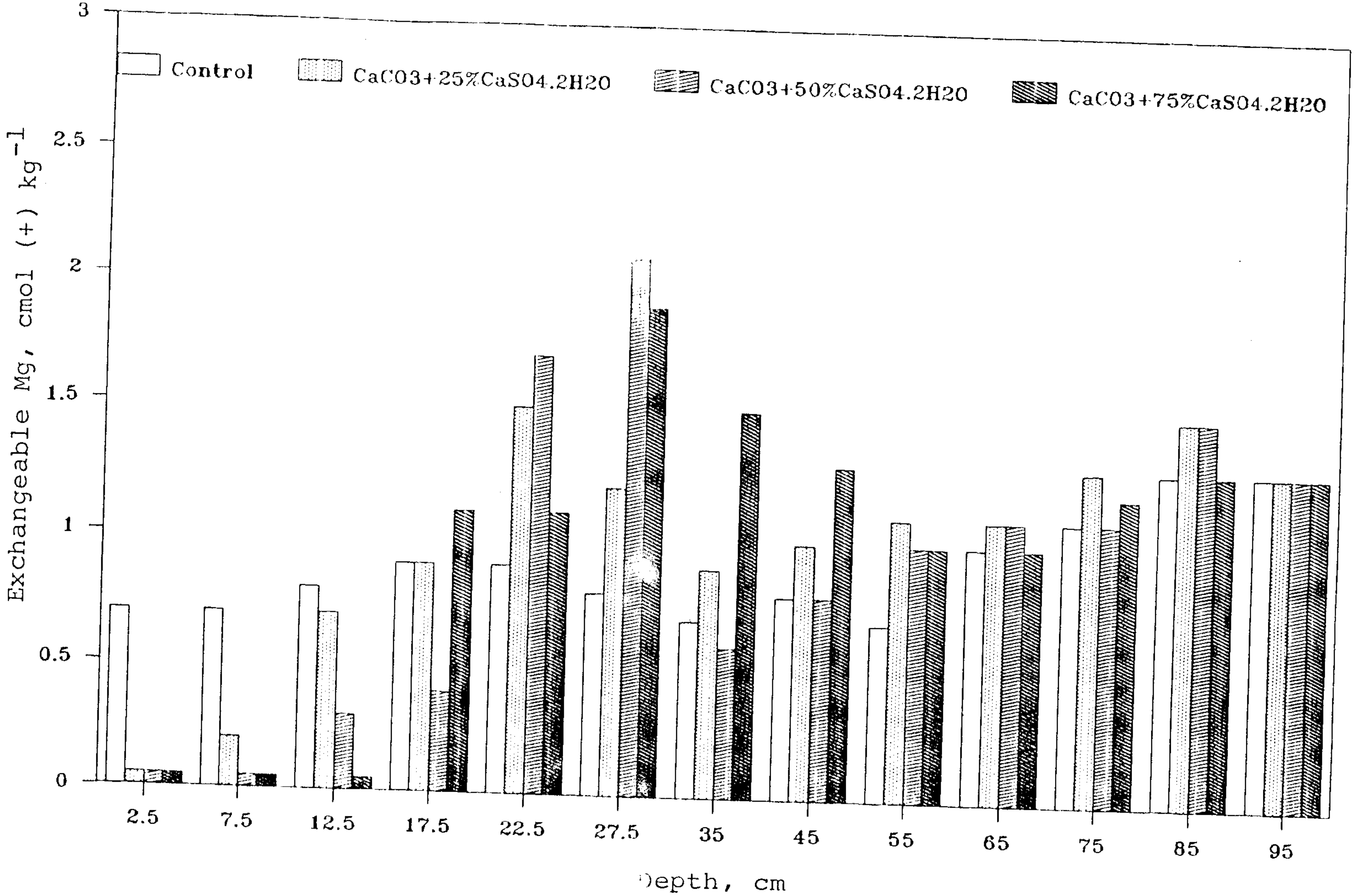


Fig.8 Downward movement of applied Mg as influenced by various treatments

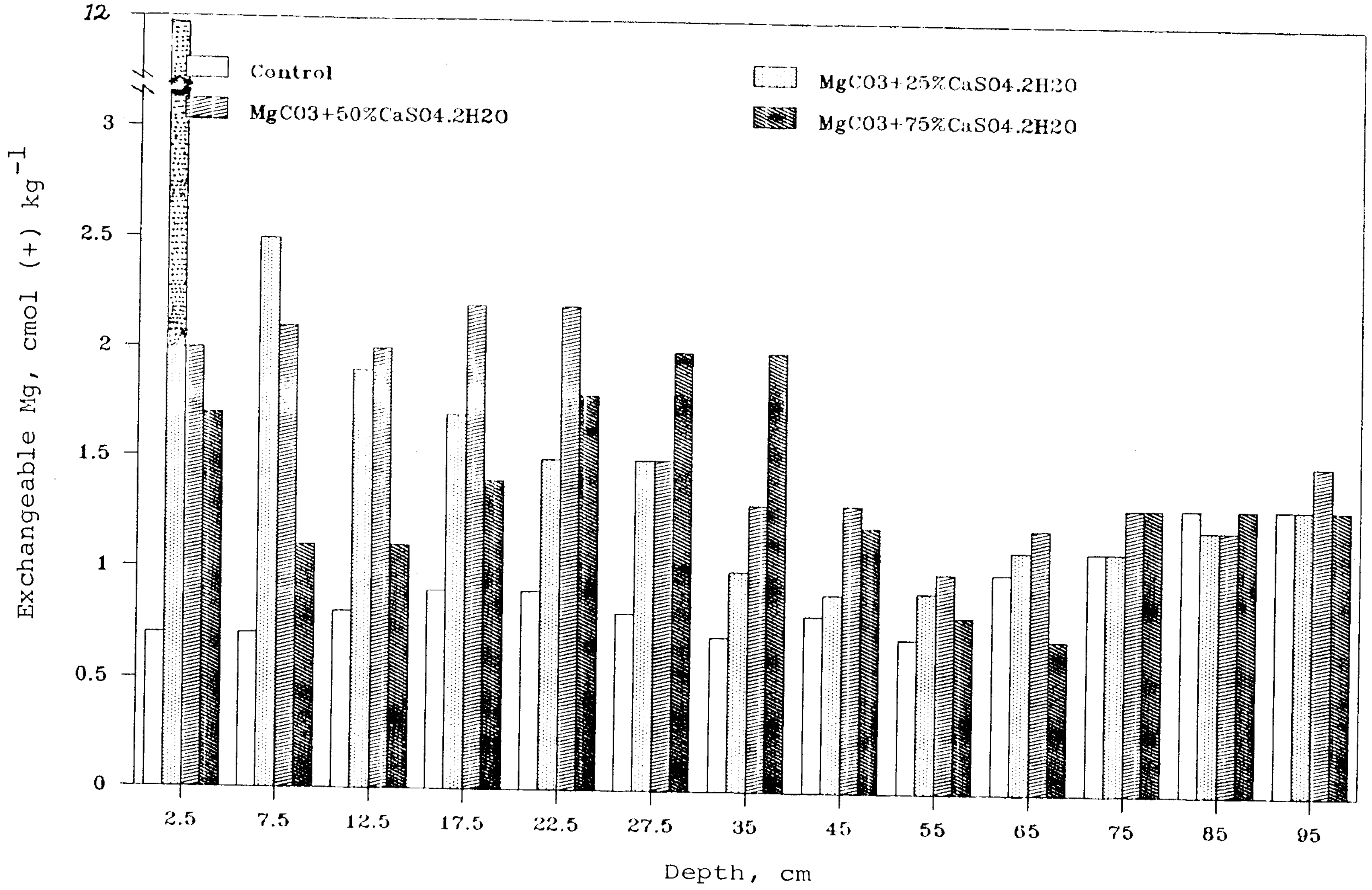


Fig.9 Downward movement of applied Mg as influenced by various treatments

20-30 cm layer, it reduced the Mg level in the surface 0-20 cm layer. Though the treatment with $CaCO_3$ + 75 per cent $CaSO_4.2H_2O$ reduced exchangeable Mg level from 0.66 cmol (+) kg^{-1} to traces in 0-15 cm horizon, exchangeable Mg increased considerably in the 15-50 cm horizon (Fig.8).

In marked contrast to the combination treatments with $CaCO_3$ and $CaSO_4.2H_2O$ effects, the $MgCO_3 + CaSO_4.2H_2O$ treatments resulted in relatively high exchangeable Mg in the surface horizons. Figure 9 indicates the mobility of Mg resulting from the combination of $MgCO_3$ + $CaSO_4.2H_2O$ treatments. There was marked mobility in exchangeable Mg up to 30 cm horizon and a slight increase in exchangeable Mg up to 30-70 cm depth, when the $CaSO_4.2H_2O$ level was 25 per cent. But increasing $CaSO_4.2H_2O$ level to 50 per cent resulted in an increased mobility of exchangeable Mg throughout the whole length of the 100 cm profile, whereas the combination treatment with 75 per cent $CaSO_4.2H_2O$ through increased the exchangeable Mg levels up to 50 cm length of the profile, the increase was relatively low in the surface horizons, when compared to the treatments with 25 and 50 per cent $CaSO_4.2H_2O$ (Fig.9).

2.4 Depth-wise distribution of exchangeable Al as influenced by the various treatments

Table 9 and Fig.10, 11 and 12 present the relationship between treatments and the distribution of exchangeable Al throughout the soil columns.

Table 9. Depth-wise distribution of exchangeable Al, [cmol (+) kg^{-1}] as influenced by variou treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$CaSO_4$ $2H_2O$
0-5	1.00	0.20	0.10	0.15	0.10	0.55	0.30	0.15	0.10	0.40
5-10	1.60	1.15	1.00	1.10	1.20	0.60	0.65	0.45	0.75	0.95
10-15	1.60	1.20	1.15	1.25	1.15	1.25	1.15	1.15	0.95	1.10
15-20	1.55	1.20	1.10	1.25	1.15	1.10	0.80	0.95	0.85	1.35
20-25	1.60	1.45	1.60	1.15	1.25	1.20	1.05	1.15	1.05	1.00
25-30	1.55	1.55	1.55	1.10	1.25	1.35	1.15	0.90	1.10	1.10
30-40	1.40	1.45	1.45	1.30	1.35	1.45	1.35	1.15	1.10	1.25
40-50	1.35	1.45	1.35	1.50	1.35	1.50	1.15	1.25	1.20	1.10
50-60	1.35	1.25	1.30	1.45	1.30	1.40	1.15	1.00	1.10	1.45
60-70	1.30	1.40	1.20	1.50	1.35	1.55	0.85	1.20	0.95	1.40
70-80	1.25	1.05	1.30	1.30	1.25	1.15	0.60	0.75	0.35	1.00
80-90	0.35	0.75	0.80	0.60	0.80	0.40	0.20	0.60	0.25	0.35
90-100	0.40	0.50	0.70	0.65	0.35	0.25	0.20	0.35	0.25	0.35

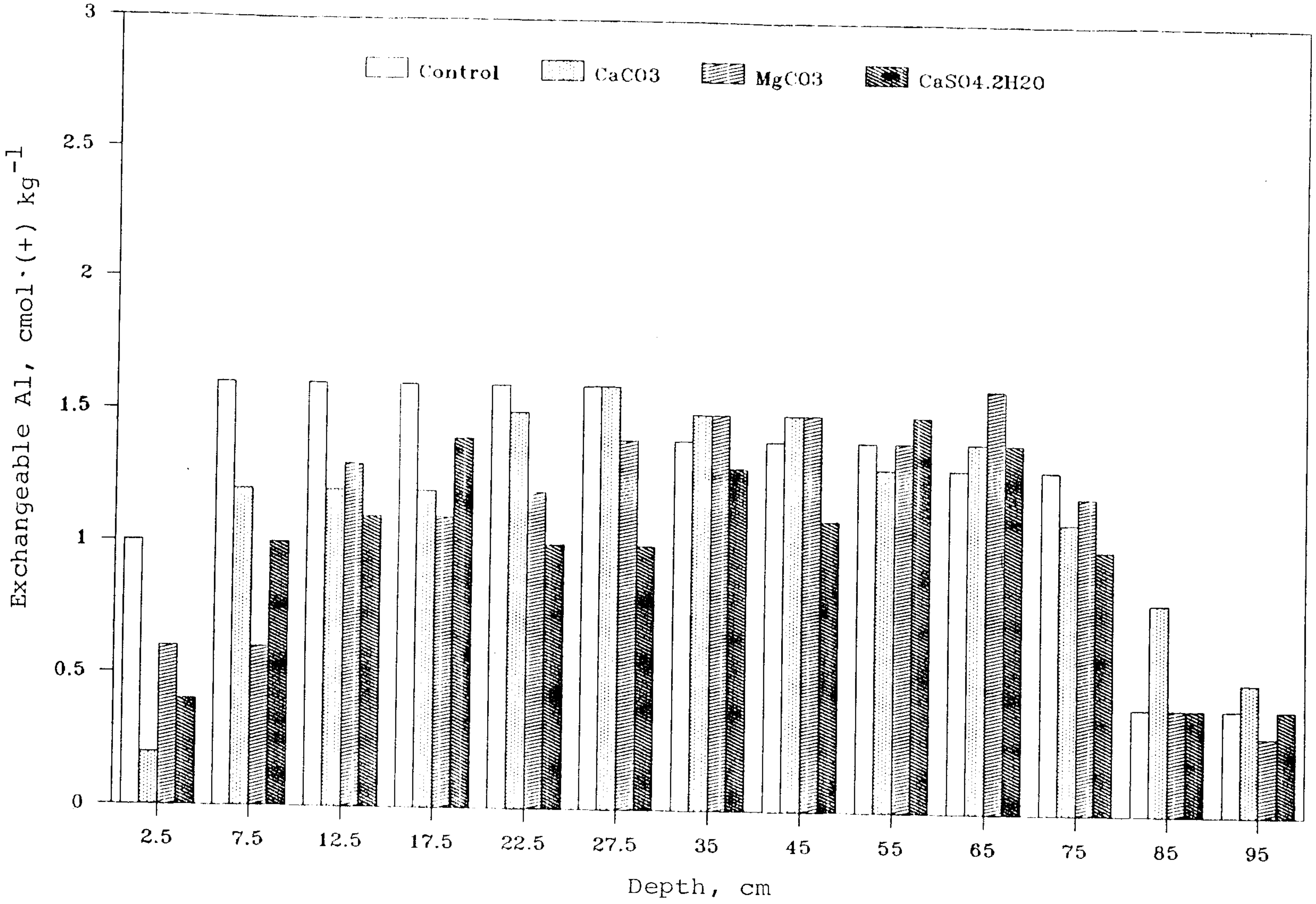


Fig.10 Depthwise distribution of exchangeable Al as influenced by various treatments

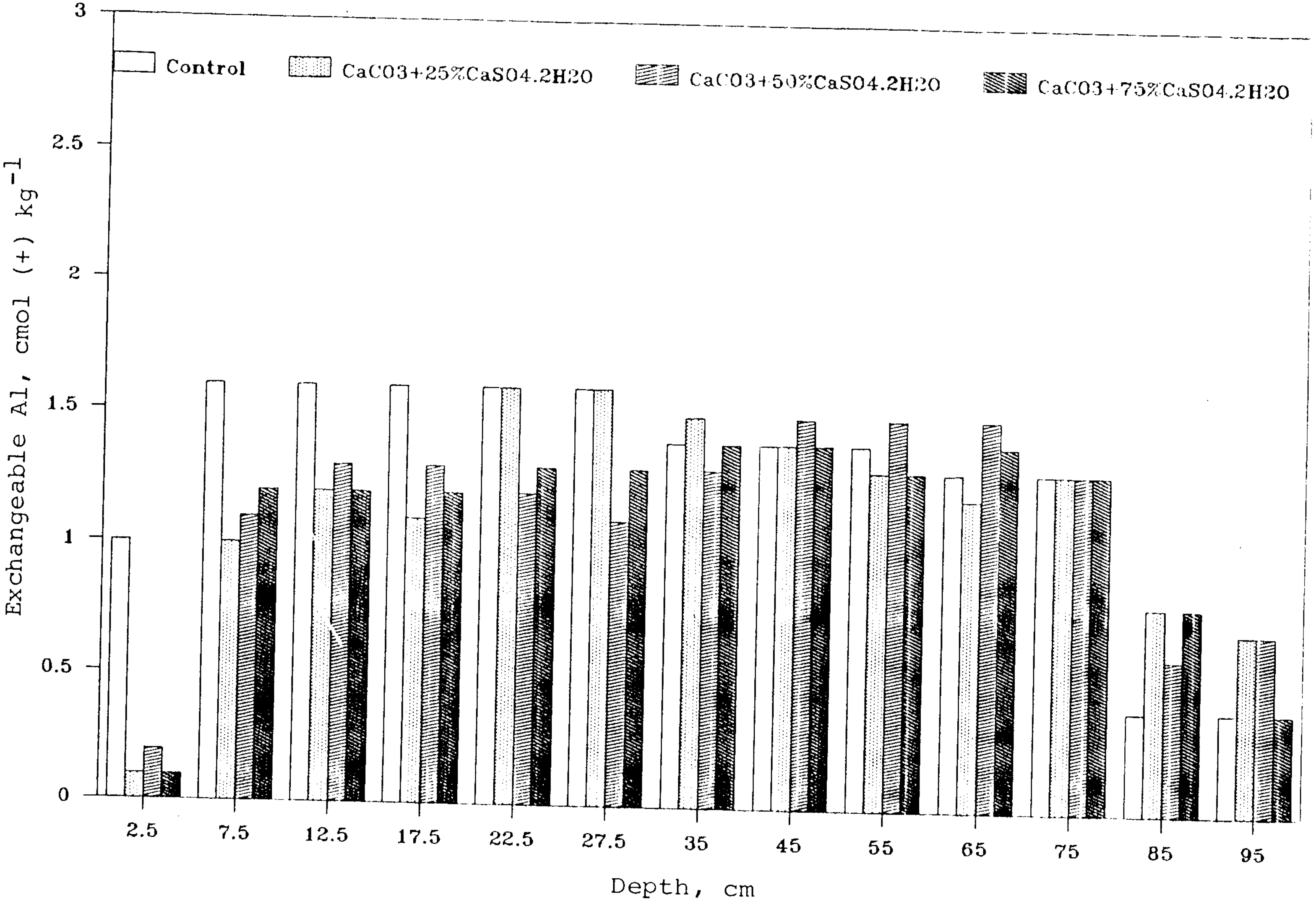


Fig.11 Depthwise distribution of exchangeable Al as influenced by various treatments

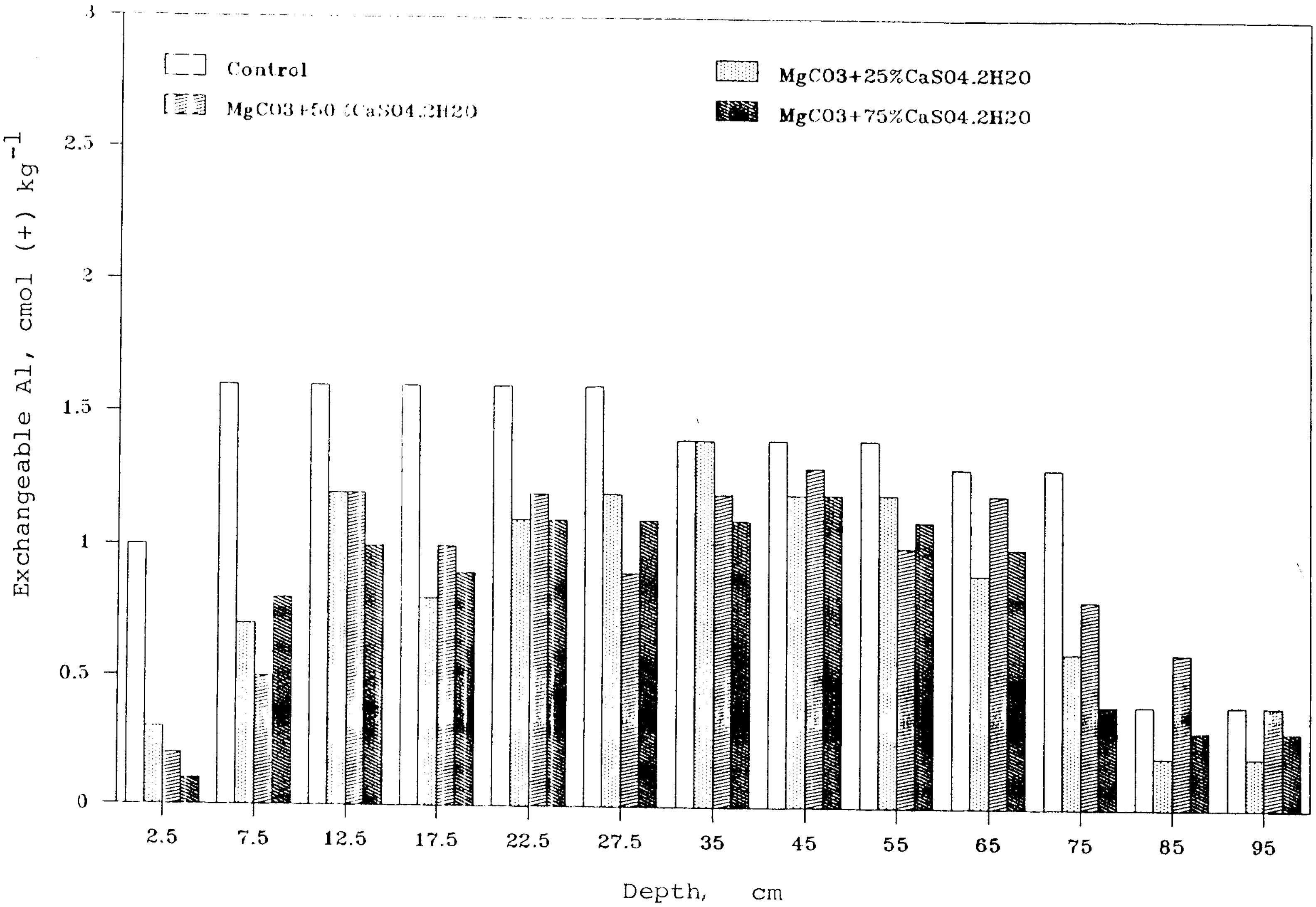


Fig.12 Depthwise distribution of exchangeable Al as influenced by various treatments

The $CaCO_3$ treatment neutralised exchangeable Al in the surface 5 cm of the soil column from 1.00 to 0.20 cmol (+) kg^{-1}. In general, the treatment resulted in a reduction in exchangeable Al to about 25 cm depth. In contrast to $CaCO_3$ treatment, the $MgCO_3$ treatment neutralised exchangeable Al in the surface 0-5 cm layer of the soil column from 1.00 to 0.6 cmol (+) kg^{-1}, in the 5-10 cm layer from 1.6 to 0.6 cmol (+) kg^{-1} and it caused a general reduction in exchangeable Al up to 30 cm depth of the profile. In contrast to $CaCO_3$ and $MgCO_3$ treatments, the $CaSO_4.2H_2O$ treatment reduced the exchangeable Al up to 50 cm depth of the profile (Fig.10).

The effect of combinations of $CaCO_3$ + $CaSO_4.2H_2O$ in neutralising exchangeable Al to very low levels was restricted to the 0-5 cm layer only (Fig.11). The lower level of $CaSO_4.2H_2O$ (25 per cent) reduced the exchangeable Al in the 0-20 cm horizon and the higher levels of $CaSO_4.2H_2O$ (50 and 75 per cent) were effective in neutralising exchangeable Al up to 40 cm depth.

In contrast to the limited effect of $CaCO_3$, $MgCO_3$, $CaSO_4.2H_2O$ and $CaCO_3$ + $CaSO_4.2H_2O$ treatments, the $MgCO_3$ + $CaSO_4.2H_2O$ treatments resulted in a general reduction in exchangeable Al throughout the length of the profile and considerable reduction in exchangeable Al in the 0-20 cm surface horizon (Fig.12).

2.5 Depth-wise distribution pattern of effective CEC as influenced by various treatments

The change in effective CEC resulting from the treatments are presented in Table 10 and Fig.13, 14 and 15.

The increase in effective CEC due to $CaCO_3$ treatment was restricted to the surface 0-5 cm of the profile. The remaining part of the profile showed a general reduction in effective CEC. Under the $MgCO_3$ treatment the effective CEC was increased in the surface 10 cm of the profile, then showed a slight reduction up to 30 cm depth and again it increased considerably in the rest of the profile. In contrast to the limited effect of $CaCO_3$ and $MgCO_3$ treatments, the $CaSO_4.2H_2O$ treatment caused a general increase in the effective CEC throughout the 100 cm length of the profile (Fig.13).

The effective CEC showed a general increase in the 100 cm length of the profile in the combination treatments both in the $CaCO_3$ + $CaSO_4.2H_2O$ and $MgCO_3$ + $CaSO_4.2H_2O$ except in the treatment with $MgCO_3$ + 50 per cent $CaSO_4.2H_2O$, where a small reduction in effective CEC was noted in the 70-100 cm length of the profile (Fig.14 and 15).

2.6 Depth-wise distribution pattern of Ca and Al saturation as influenced by various treatments

The relationship between various treatments and the distribution of Ca and Al saturation in the soil columns are presented in Tables 11 and 12.

Table 10. Effective cation exchange capacity, [cmol (+) kg^{-1}] of soil columns at different depth as influenced by various treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
0-5	4.03	12.33	12.65	13.64	17.24	16.07	14.86	12.70	11.15	18.44
5-10	4.21	3.90	4.24	5.40	5.81	5.32	4.92	4.06	4.92	6.63
10-15	4.11	4.07	4.78	5.76	5.57	4.09	4.85	4.77	5.01	6.82
15-20	4.29	3.92	4.88	5.66	6.47	3.74	4.50	5.11	5.24	6.76
20-25	4.31	4.17	5.52	6.64	6.44	4.04	4.72	5.54	5.58	7.19
25-30	4.15	4.25	4.86	6.28	6.53	4.08	4.76	5.09	5.81	6.69
30-40	3.79	4.07	4.09	4.22	5.45	4.18	4.17	4.76	5.84	6.42
40-50	3.95	4.05	4.17	4.41	4.86	4.24	4.02	4.51	5.15	4.42
50-60	3.84	3.96	4.08	4.52	4.52	4.45	3.91	2.98	4.31	4.64
60-70	4.28	4.12	4.19	4.75	4.50	4.45	4.11	4.27	3.94	4.63
70-80	4.56	4.33	5.10	4.83	5.02	4.70	4.28	4.63	4.12	4.25
80-90	4.46	4.67	4.88	4.75	5.06	4.30	4.41	4.76	4.73	4.36
90-100	4.76	4.84	5.11	5.05	4.71	4.99	4.78	5.07	4.86	5.06

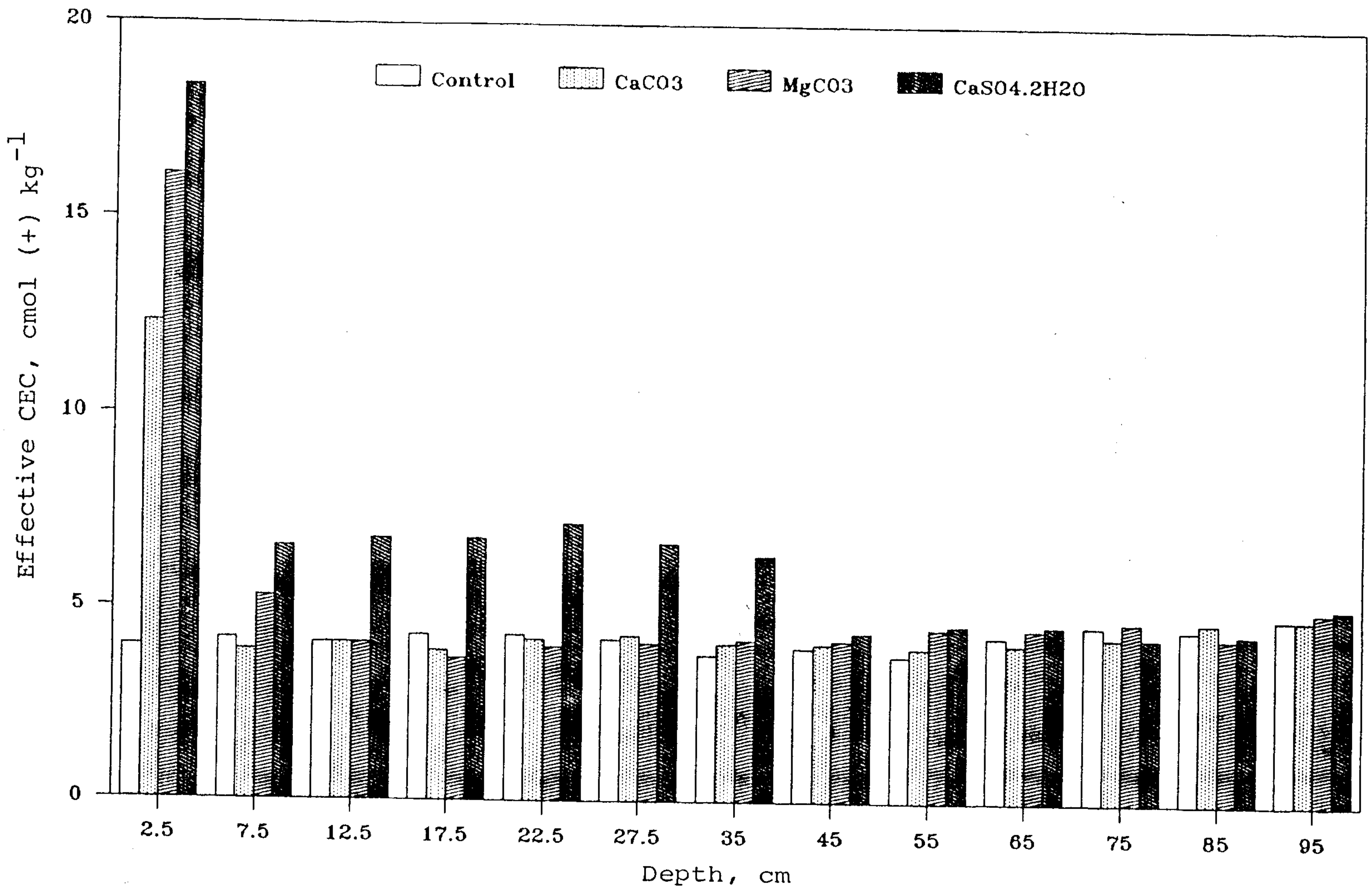


Fig.13 Effective CEC of soil columns at different depths as influenced by various treatments

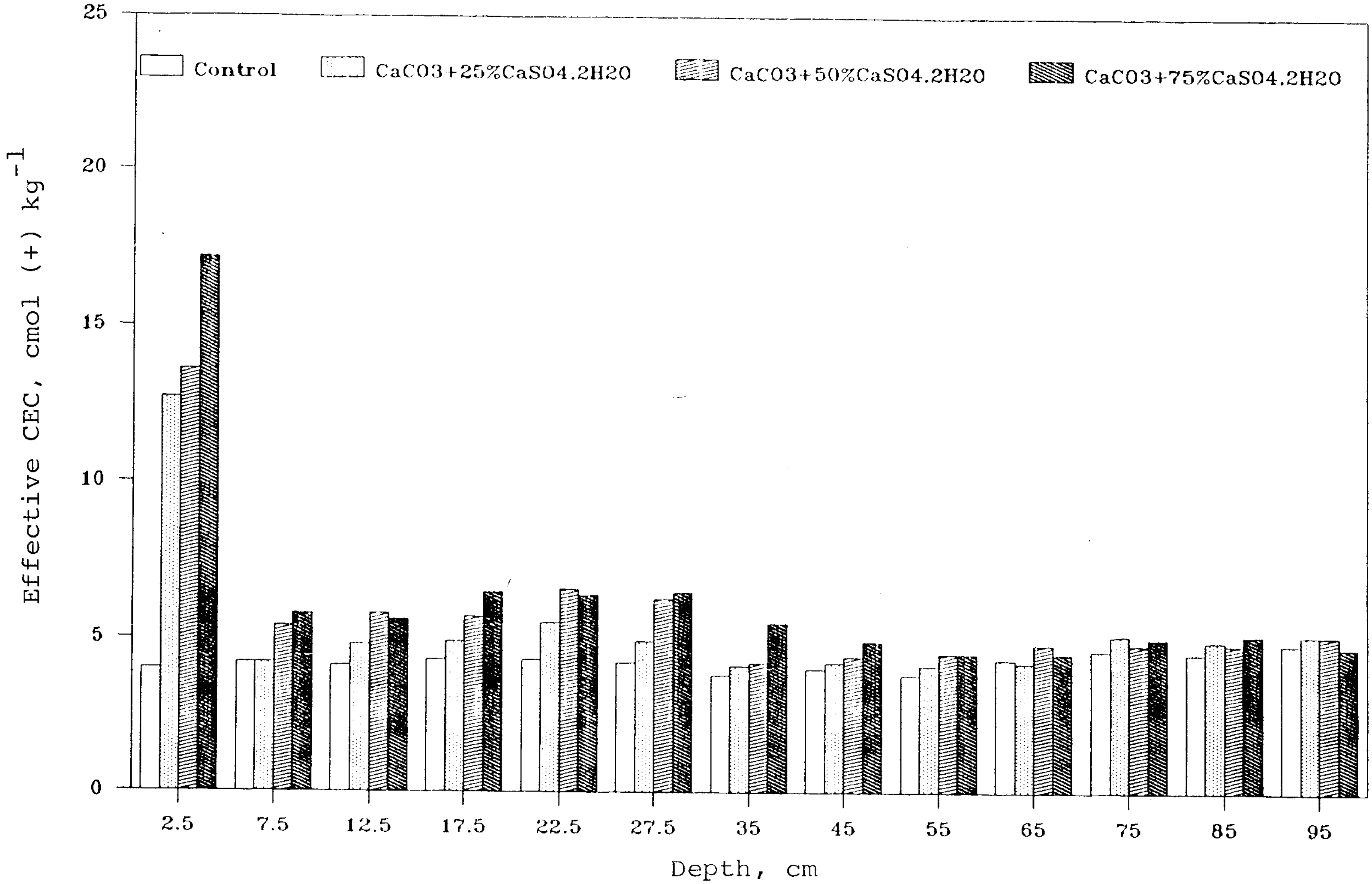


Fig.14 Effective CEC of soil columns at different depths as influenced by various treatments

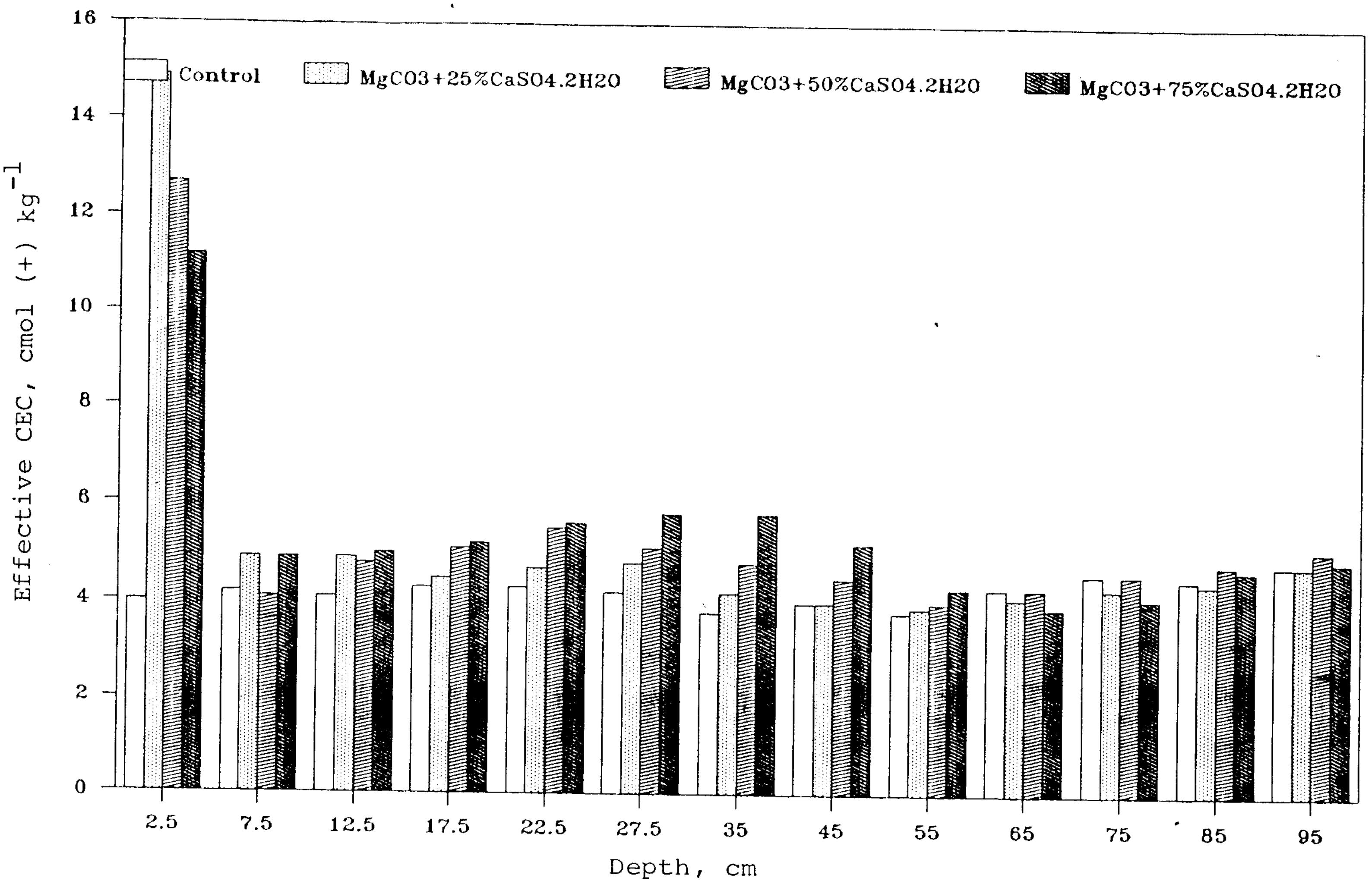


Fig.15 Effective CEC of soil columns at different depths as influenced by various treatments

The effect of $CaCO_3$ treatment in increasing Ca saturation was restricted to the 0-20 cm layer and in decreasing Al saturation up to 40 cm depth. In contrast to $CaCO_3$ treatment which increased Ca saturation from 49.13 to 95.4 per cent, the $MgCO_3$ treatment reduced the Ca saturation to 7.53 per cent in the 0-5 cm layer. Though it also reduced the Ca saturation in the 5-10 cm layer, the Ca saturation was increased up to 40 cm depth by $MgCO_3$ treatment. Al saturation was also reduced up to 60 cm depth. In contrast to the $CaCO_3$ and $MgCO_3$ treatments, the $CaSO_4.2H_2O$ treatments increased markedly the Ca Saturation up to 90 cm depth and caused a general reduction in Al saturation throughout the length of the profile. Al saturation was reduced markedly up to 60 cm depth by $CaSO_4.2H_2O$ treatment.

In general the combination of $CaCO_3$ + $CaSO_4.2H_2O$ in increasing Ca saturation and decreasing Al saturation showed an increasing trend with increasing level of $CaSO_4.2H_2O$. Thus the treatment with $CaCO_3$ + 25 per cent $CaSO_4.2H_2O$ increased the Ca saturation up to 25 cm depth and decreased the Al saturation upto 80 cm depth. The Ca saturation showed an increasing trend up to 50 cm depth and Al saturation showed a decreasing trend up to 80 cm depth by

Table 11. Percentage Ca saturation of soil columns at different depths as influenced by variou treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
0-5	49.13	95.46	95.65	95.97	96.98	7.53	15.55	51.10	80.90	96.04
5-10	39.19	45.13	64.86	73.33	73.84	31.05	29.07	29.80	55.90	81.30
10-15	37.47	35.14	55.23	66.84	73.07	37.65	31.75	27.67	52.69	75.81
15-20	35.90	39.29	54.10	64.13	59.51	41.18	39.11	32.29	50.38	74.85
20-25	35.73	34.29	37.86	53.01	58.07	38.12	39.62	33.75	44.98	65.79
25-30	37.11	36.25	36.21	43.79	47.17	40.44	36.97	45.38	41.65	69.06
30-40	37.73	40.54	34.96	49.53	40.37	39.47	36.93	41.60	41.44	56.54
40-50	38.99	43.46	36.93	48.40	38.48	36.32	41.04	36.59	46.99	42.31
50-60	40.10	38.89	32.35	38.85	41.37	37.08	39.39	41.46	48.49	42.67
60-70	38.55	37.38	36.75	37.05	39.00	42.02	42.82	36.07	50.25	42.76
70-80	41.01	40.65	40.98	43.27	43.82	39.79	51.40	47.52	50.73	46.59
80-90	54.26	44.75	45.08	46.32	50.00	51.16	59.86	53.15	58.14	55.50
90-100	55.46	52.27	51.66	52.28	56.05	50.70	59.83	54.24	58.85	54.35

Table 12. Percentage Al saturation of soil columns at different depths as influenced by various treatments

Depth cm	Treatments									
	Control	$CaCO_3$	$CaCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$CaCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$MgCO_3$	$MgCO_3$ + 25% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 50% $CaSO_4 \cdot 2H_2O$	$MgCO_3$ + 75% $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
0-5	24.81	1.62	0.01	0.01	0.01	3.42	2.02	1.18	0.01	2.17
5-10	38.00	29.49	23.58	20.37	20.61	11.28	13.21	11.08	6.56	14.33
10-15	38.93	29.48	24.06	21.70	20.65	30.56	23.71	24.11	18.96	16.13
15-20	36.13	30.61	22.54	22.08	17.00	29.41	17.78	18.59	16.22	19.97
20-25	37.12	34.77	28.99	17.32	19.41	29.70	22.24	20.76	18.82	13.91
25-30	37.35	36.47	31.89	17.52	19.14	33.09	24.16	17.68	18.93	16.44
30-40	36.94	35.63	35.45	30.81	24.77	34.69	32.37	24.16	18.84	19.47
40-50	34.18	35.80	32.37	34.01	27.78	35.38	28.61	27.72	23.30	24.89
50-60	35.16	31.57	31.86	32.01	28.76	31.46	29.41	25.13	25.52	31.25
60-70	30.37	33.98	28.64	31.58	30.00	34.83	20.68	28.10	22.04	30.24
70-80	27.41	24.26	25.49	26.92	24.90	24.47	14.02	16.20	8.50	23.53
80-90	7.85	16.06	16.39	12.63	15.81	9.30	4.54	12.61	5.29	8.03
90-100	8.40	10.33	13.70	12.87	7.43	5.01	4.18	6.90	5.14	6.92

raising the $CaSO_4.2H_2O$ level to 50 per cent. A marked increase in Ca saturation and decrease in Al saturation was observed in the whole length of the soil column when the $CaSO_4.2H_2O$ level was raised to 75 per cent, except in the 80-90 cm layer.

The combination of $MgCO_3$ + 25 per cent $CaSO_4.2H_2O$ reduced the Ca saturation in the surface 0-15 cm layer, but did not show any definite trend in the remaining part of the profile, whereas the Al saturation was generally reduced in the whole length of the profile.

The treatment with $MgCO_3$ + 50 per cent $CaSO_4.2H_2O$ resulted in a slight increase in Ca saturation in the surface 0-5 cm layer, but decreased considerably up to 25 cm depth. No regular trend was observed in the remainder of the profile. But the Al saturation showed a general reduction throughout the 100 cm length of the soil column. Under the combination treatment with $MgCO_3$ + 75 per cent $CaSO_4.2H_2O$, the Ca saturation increased considerably and Al saturation decreased to very low levels in the 100 cm profile.

3. Potculture experiment

3.1 Biometric characters

Data on biometric characters of soybean as influenced by the various treatments are presented in Table 13.

Table 13. Effect of liming in combination with gypsum on biometric characters

Treatment	Plant height (cm)	Root length (cm)	Nodule count
T_0	41.63	49.50	4.00
T_1	58.00	68.00	28.50
T_2	53.50	64.50	17.50
T_3	52.00	53.00	17.25
T_4	57.75	65.00	21.75
SEm ±	3.22	10.11	3.90
CD (0.05)	9.71	NS	11.75

T_0 : No lime

T_1 : $CaCO_3$ equivalent to 1.5 times exchangeable Al

T_2 : $CaCO_3$ equivalent to 3.0 times exchangeable Al

T_3 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to exchangeable Al

T_4 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to 3.0 times exchangeable Al

3.1.1 Plant height

Plant height recorded a maximum value of 58.0 cm in the treatment with $CaCO_3$ at 1.5 times exchangeable Al content which though on par with the other treatments, was significantly superior to the control (41.63 cm).

3.1.2 Root length

No significant variation was observed in the root length of soybean due to treatments. The range in root length varied from 49.5 to 68.0 cm.

3.1.3 Nodule count

Liming significantly increased the nodule count. The treatment with $CaCO_3$ at the rate of 1.5 times exchangeable Al produced the maximum number of nodules and was on par with all the other treatments. The minimum value was recorded by the control and was significantly inferior to the other treatments. The range in the nodule number varied from 4.0 to 28.5.

3.2 Effect of lime in combination with gypsum on yield parameters of soybean

The yield parameters as influenced by the treatments are presented in Table 14.

Table 14. Effect of lime in combination with gypsum on yield parameters, g $plant^{-1}$

Treatment	Fresh weight of pod	Dry weight of pod	Grain yield	Haulm yield	Dry weight of root	Total dry weight
T_0	3.80	1.55	0.60	1.38	0.500	3.03
T_1	7.38	4.23	2.40	2.40	0.825	7.45
T_2	7.33	3.78	2.08	2.53	0.900	7.20
T_3	5.71	2.68	1.53	2.60	0.625	5.93
T_4	7.60	3.88	2.18	3.45	0.800	8.13
SEm ±	1.32	0.55	0.34	0.36	0.100	0.96
CD (0.05)	NS	1.66	1.03	1.09	NS	2.88

T_0 : No lime

T_1 : $CaCO_3$ at the rate of 1.5 times exchangeable Al content

T_2 : $CaCO_3$ at the rate of 3.0 times exchangeable Al content

T_3 : $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al content

T_4 : $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of 3.0 times exchangeable Al content

3.2.1 Fresh weight of pod

The fresh weight of pod showed a variation of 3.8 to 7.6 g plant^{-1}. Fresh weight of pod was not influenced significantly by treatments.

3.2.2 Dry weight of pod

Significant variation was observed in the dry weight of pod due to treatments. The treatment with $CaCO_3$ at 1.5 times exchangeable Al, though on par with the other treatments was significantly superior to the control. The maximum and minimum values recorded were 4.23 g plant^{-1} and 1.55 g plant^{-1} respectively.

3.2.3 Grain yield

Grain yield in soybean was significantly influenced by treatments. Maximum and minimum values were recorded by the treatment with $CaCO_3$ at 1.5 times exchangeable Al (T_1) and control respectively. T_1, though on par with the other treatments was significantly superior to the control.

3.2.4 Dry weight of shoot

Liming significantly increased the dry weight of shoot in soybean. The treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, though on par with the other treatments was significantly superior to the control, which was on par with the treatment with $CaCO_3$ at 1.5 times exchangeable Al. The range in the values varied from 1.375 to 3.450 g $plant^{-1}$.

3.2.5 Dry weight of root

No significant variation was observed in the dry weight of root due to treatments. The range in dry weight of root showed a variation from 0.5 to 0.9 g $plant^{-1}$.

3.2.6 Total dry weight

The total dry weight of soybean was increased significantly due to liming. The treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, though on par with other treatments was significantly superior to the control. The maximum and minimum values recorded were 8.13 and 3.03 g $plant^{-1}$ respectively.

3.3 Effect of lime in combination with gypsum on nutrient composition and total uptake of soybean

Data relating to major and micronutrient composition and their uptake are given in Tables 15a and 15b respectively.

3.3.1 Nitrogen

No significant variation was observed in the nitrogen content of shoot due to treatments. But liming at the rate of

Table 15a. Major nutrient composition of soybean and total nutrient uptake as influenced by various treatments

Treatment	Nutrient composition, %										Total uptake, mg pot^{-1}				
	N		P		K		Ca		Mg		N	P	K	Ca	Mg
	Shoot	Pod	Shoot	Pod	Shoot	Pod	Shoot	Pod	Shoot	Pod					
T_0	0.675	3.00	0.250	0.600	0.800	1.68	2.03	1.18	0.725	1.23	51.18	12.19	36.26	44.71	27.92
T_1	0.775	3.28	0.275	0.675	0.850	1.65	1.90	1.48	0.060	0.925	152.23	34.63	72.12	105.12	37.07
T_2	0.675	3.20	0.300	0.500	1.10	1.55	1.85	1.50	0.725	1.13	135.37	26.08	85.76	111.98	55.74
T_3	0.775	3.43	0.275	0.600	1.05	1.73	1.75	1.63	0.575	1.01	114.60	24.53	73.64	88.36	42.61
T_4	0.625	3.35	0.350	0.725	1.20	1.68	2.58	1.43	0.375	1.03	149.51	39.68	106.45	114.73	53.17
SEm +	0.06	0.27	0.04	0.04	0.13	0.05	0.30	0.17	0.14	0.12	19.79	4.61	13.72	19.30	7.07
CD (0.05)	NS	NS	NS	0.117	NS	NS	NS	NS	0.42	NS	59.65	13.88	41.35	NS	NS

T_0 : No lime

T_1 : $CaCO_3$ equivalent to 1.5 times exchangeable Al

T_2 : $CaCO_3$ equivalent to 3.0 times exchangeable Al

T_3 : $CaCO_3$ + $CaSO_4.2H_2O$ equivalent to exchangeable Al

T_4 : $CaCO_3$ + $CaSO_4.2H_2O$ equivalent to 3.0 times exchangeable Al

1.5 times exchangeable Al slightly increased the N content. The range in the nitrogen content of shoot varied from 0.63 to 0.78 per cent (Table 15a).

Though the N content of pod did not show statistically significant difference due to treatments, it showed a general increase with liming. But when higher rates of lime are applied, the N content showed a decreasing trend as observed in treatments with 3.0 times exchangeable Al (T_2 and T_4). Maximum N content of pod was recorded by the treatment which received a combination of lime and gypsum at the rate equivalent to neutralise exchangeable Al content.

In contrast to the nitrogen content, the nitrogen uptake by soybean was significantly influenced by liming. The maximum nitrogen uptake was recorded by the treatment which received $CaCO_3$ at the rate of 1.5 times exchangeable Al, which though on par with the other treatments, was significantly superior to the control. The range in the N uptake varied from 51.18 mg pot^{-1} to 152.22 mg pot^{-1}.

3.3.2 Phosphorus

Phosphorus content of shoot did not show significant variation between treatments. However it showed a tendency to increase with increasing lime rate (Table 15a).

The analytical data on P content of pod revealed that there was significant difference in phosphorus content of pod due to treatments. The maximum P content of pod was recorded by the treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, which though on par with the treatment with $CaCO_3$ at 1.5 times exchangeable Al, was significantly superior to the other treatments. The lowest P content was recorded by the treatment which received $CaCO_3$ at three times exchangeable Al content.

Similarly, the phosphorus uptake by soybean also showed significant difference due to treatments. Maximum P uptake of 39.68 mg pot^{-1} was recorded by the treatment which received $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of 3.0 times exchangeable Al content, though on par with the treatments which received lime at the rate of 3.0 and 1.5 times exchangeable Al content minimum P uptake (12.19 mg pot^{-1}) was recorded by the control and was on par with the treatment which received the lowest level of lime + gypsum.

3.3.3 Potassium

The potassium content of shoot was not influenced significantly due to treatments and the values varied from 0.80 to 1.20 per cent. As in the case of phosphorus content of shoot, the potassium content also increased with increasing levels of lime (Table 15a).

The potassium content of pod did not show statistically significant difference due to treatments. The potassium content of pod recorded by the different treatments are 1.73, 1.68, 1.68, 1.65 and 1.55 per cent in the treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al (T_3), $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al (T_4) control (T_0), $CaCO_3$ at 1.5 times exchangeable Al (T_1), $CaCO_3$ at 3.0 times exchangeable Al (T_2) respectively.

In contrast to potassium content, the potassium uptake by soybean showed significant variation due to treatments. The treatment which received lime and gypsum at the rate of 3.0 times exchangeable Al, recorded a maximum potassium uptake of 106.45 mg pot^{-1}, though on par with the other treatments which received lime. The minimum K uptake was recorded by the control and was on par with the treatments with $CaCO_3$ at 1.5 times exchangeable Al, and $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al.

3.3.4 Calcium

With increase in lime rate, the calcium content of shoot showed a decreasing trend except for T_4, the treatment with combination of lime and gypsum at rates equivalent to 3.0 times exchangeable Al. However the variation due to treatments was not significant. The calcium content of pod ranged from 1.85 to 2.58 per cent (Table 15a).

An increasing tendency, though not regular was observed in the calcium content of pod due to liming. The maximum and minimum values were recorded by the treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al and control respectively. The range in the values varied from 1.18 to 1.63 per cent and the variation due to treatments was not statistically significant.

Though the calcium uptake showed no significant variation due to treatments, it showed an increasing tendency with increasing lime rate. The range in calcium uptake varied from 44.71 to 114.73 mg pot^{-1}. The maximum and minimum values were recorded by the treatment which received lime and gypsum at the rate of 3.0 times exchangeable Al and control respectively.

3.3.5 Magnesium

The magnesium content of shoot was minimum and significantly lower under the treatment with $CaCO_3$ at 1.5 times exchangeable Al than all the other treatments. In general, a reduction in magnesium content of shoot was observed due to liming (Table 15a).

In the case of pod the magnesium content did not show significant difference due to treatments. The maximum and minimum content were recorded by the control and the treatment with $CaCO_3$ at 1.5 times exchangeable Al. General trend was a decrease in magnesium content, though not regular, with liming. The range in the values varied from 0.93 to 1.23 per cent.

A general increase in magnesium uptake, though not significant was observed due to liming. The magnesium uptake showed a variation of 27.92 to 55.74 mg pot^{-1}.

3.3.6 Iron

The iron content of shoot was not significant due to treatments. It showed a variation of 11.55 ppm to 33.34 ppm among treatments. No definite trend was observed in iron content due to treatments (Table 15b).

Significant variation was observed in the iron content of pod due to treatments. The range in the values varied from 2.20 to 6.35 ppm. The treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, though on par with the treatment with $CaCO_3$ at 3.0 times exchangeable Al, was significantly superior to the treatments with $CaCO_3$ at 1.5 times exchangeable Al, $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al and control.

A general increase in the iron uptake by soybean was observed due to liming. But no particular trend was observed.

Table 15b. Micronutrients composition of soybean and total nutrient uptake as influenced by variou treatments

Treatment	Nutrient composition, ppm								Total uptake, µg pot^{-1}			
	Fe		Mn		Zn		Cu		Fe	Mn	Zn	Cu
	Shoot	Pod	Shoot	Pod	Shoot	Pod	Shoot	Pod				
T_0	15.10	3.90	3.33	1.18	4.03	3.70	0.350	0.418	27.88	6.83	13.35	1.2
T_1	33.38	2.20	1.58	0.85	3.60	1.72	0.208	0.328	85.48	7.27	16.56	1.9
T_2	11.55	5.40	1.75	0.90	2.20	4.70	0.425	0.150	52.98	7.55	25.01	1.1
T_3	23.63	3.18	1.90	0.95	1.98	1.95	0.225	0.218	72.34	7.25	12.22	1.1
T_4	28.58	6.35	1.98	1.00	2.38	0.930	0.175	0.235	127.12	10.80	11.55	1.9
SEm ±	7.96	0.72	0.58	0.07	0.97	1.05	0.14	0.04	24.34	1.64	6.35	0.2
CD (0.05)	NS	2.17	NS	NS	NS	NS	NS	0.135	NS	NS	NS	NS

T_0 : No lime

T_1 : $CaCO_3$ equivalent to 1.5 times exchangeable Al

T_2 : $CaCO_3$ equivalent to 3.0 times exchangeable Al

T_3 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to exchangeable Al

T_3 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to 3.0 times exchangeable Al

The range in the values varied from 27.88 to 127.12 $\mu g\ pot^{-1}$ and the variation was not statistically significant.

3.3.7 Manganese

Manganese content of shoot showed no significant variation between treatments. But it showed a decreasing trend due to liming (Table 15b).

Similar to the manganese content of shoot, the manganese content of pod also showed no significant difference due to treatment and it decreased with liming. The maximum and minimum values recorded were 1.18 and 0.85 ppm.

In contrast to the manganese content of shoot and pod, the manganese uptake by soybean showed an increasing trend with liming. The range in the values observed varied from 6.83 to 10.80 $\mu g\ pot^{-1}$ and the variation was not significant.

3.3.8 Zinc

Zinc content of shoot recorded a maximum value of 4.03 ppm in the control and a minimum value of 1.98 ppm in the treatment with $CaCO_3 + CaSO_4.2H_2O$ at the rate of exchangeable Al. Though no significant variation was observed between treatments, the zinc content of shoot decreased by liming (Table 15b).

The results indicated that the zinc content of pod did not differ significantly due to treatments. The maximum and minimum values were recorded by the treatments with $CaCO_3$ at 3.0 times exchangeable Al and $CaCO_3 + CaSO_4.2H_2O$ at 3.0 times exchangeable Al respectively. No regular trend was observed in the zinc content of pod due to treatments.

Similar to the zinc content of shoot and pod the zinc uptake showed no significant variation due to treatments. The $CaCO_3$ treatment showed an increasing tendency in zinc uptake with increasing lime rate whereas the combination treatments showed a decreasing tendency with increasing rates of lime and gypsum. The range in the values recorded were 11.55 to 25.01 $\mu g\ pot^{-1}$.

3.3.9 Copper

No significant variation was observed in the copper content of shoot due to treatments. The range in the copper content recorded a variation from 0.18 to 0.43 ppm (Table 15b).

A general reduction in the copper content of pod was observed due to treatments. The range in the values varied from 0.150 to 0.418 ppm.

The results indicated that the copper uptake by soybean did not differ significantly due to treatments. No particular trend was observed in the copper uptake and the range in copper uptake varied from 1.17 to 1.96 μg pot^{-1}.

3.4 Effect of lime in combination with gypsum on acidity parameters

Data on pH, effective CEC exchangeable Al and Al saturation as influenced by the various treatments are presented in Table 16.

3.4.1 pH

The pH of soil varied significantly among treatments. The treatment with $CaCO_3$ at 3.0 times exchangeable Al recorded a maximum pH of 5.9 and was superior to the other treatments which were on par.

3.4.2 Effective CEC

Significant variation was observed in the effective CEC of soil due to treatments. A regular trend was observed in effective CEC with increase in lime rate. The treatment with $CaCO_3$ at 3.0 times exchangeable Al recorded the maximum value and was superior to the other treatments. The range in effective CEC varied from 5.20 to 8.53 cmol (+) kg^{-1} soil.

3.4.3 Exchangeable aluminium

Significant reduction in exchangeable aluminium was

Table 16. Effect of lime in combination with gypsum on acidity parameters

Treatment	pH	Effective CEC cmol (+) kg^{-1}	Exchangeable Al cmol (+) kg^{-1}	Al saturation %
T_0	5.40	5.20	0.975	17.68
T_1	5.68	6.95	0.475	6.98
T_2	5.90	8.53	0.175	2.05
T_3	5.40	6.23	0.775	12.08
T_4	5.45	7.58	0.400	5.20
SEm ±	0.02	0.22	0.13	2.07
CD (0.05)	0.07	0.66	0.387	6.22

T_0 : No lime

T_1 : $CaCO_3$ alone equivalent to 1.5 times times exchangeable Al 1680 kg/ha

T_2 : $CaCO_3$ alone equivalent to 3.0 times exchangeable Al 3472 kg/ha

T_3 : $CaCO_3$ + $CaSO_4$ equivalent to exchangeable Al 560 kg/ha each

T_4 : $CaCO_3$ + $CaSO_4$ equivalent to 3.0 times exchangeable Al 1736 kg/ha each observed due to liming. The treatment with $CaCO_3$ at 3.0 times exchangeable Al, though on par with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al and $CaCO_3$ at 1.5 times exchangeable Al, was significantly superior to the treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al. The maximum and minimum values were recorded by the control (0.98 cmol (+) kg^{-1}) and the treatment with $CaCO_3$ at 3.0 times exchangeable Al (0.18 cmol (+) kg^{-1}).

3.4.4 Aluminium saturation

The per cent Al saturation was significantly reduced by treatments. The per cent Al saturation was reduced to 2.05, 5.20, 6.98 and 12.08 per cent in treatment with $CaCO_3$ at 3.0 times exchangeable Al, $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, $CaCO_3$ at 1.5 times exchangeable Al, and $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al respectively.

3.5 Effect of lime in combination with gypsum on nutrient content of soil

The results on nutrient content of soil as influenced by the treatments are presented in Table 17.

3.5.1 Total calcium

The total calcium content of soil was significantly influenced by liming. The treatment with $CaCO_3$ at 3.0 times

Table 17. Effect of lime in combination with gypsum on nutrient content of soil

Treatments	Total		Available			Exchangeable		Extractable			
	Ca	Mg	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%		kg ha^{-1}			cmol (+) kg^{-1}		ppm			
T_0	0.425	0.400	88.23	9.80	225.40	2.80	0.98	6.85	23.83	4.48	2.00
T_1	0.425	0.300	181.20	8.03	212.80	4.33	1.75	6.83	24.13	3.03	2.03
T_2	0.575	0.225	127.20	6.88	194.60	6.63	1.26	5.83	24.55	3.95	1.93
T_3	0.400	0.300	151.73	6.85	219.80	4.13	0.95	6.35	24.33	4.55	2.08
T_4	0.350	0.300	162.28	7.08	210.00	5.00	1.70	6.60	24.08	2.98	2.00
SEm ±	0.05	0.02	14.06	0.65	5.28	0.36	0.38	0.27	6.62	1.10	0.05
CD (0.05)	0.143	0.067	42.37	1.95	15.90	1.08	NS	NS	NS	NS	NS

T_0 : No lime

T_1 : $CaCO_3$ equivalent to 1.5 times exchangeable Al

T_2 : $CaCO_3$ equivalent to 3.0 times exchangeable Al

T_3 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to exchangeable Al

T_4 : $CaCO_3 + CaSO_4.2H_2O$ equivalent to 3.0 times exchangeable Al

exchangeable Al recorded the maximum Ca content and was superior to the other treatments, which were on par. Total Ca values recorded by other treatments were less than or equal to that of the control.

3.5.2 Total magnesium

Liming significantly reduced the total magnesium content of soils. Maximum value of 0.40 per cent was recorded in the control and with increasing lime rate total magnesium in soil decreased.

3.5.3 Available nitrogen

The available nitrogen content of soil was significantly influenced by liming. The maximum available N content was recorded by the treatment with $CaCO_3$ at 1.5 times exchangeable Al and was on par with the two combination treatments, but significantly superior to the treatment with $CaCO_3$ at 3.0 times exchangeable Al and control. The range in the values varied from 88.23 to 181.20 kg ha^{-1}.

3.5.4 Available phosphorus

A general reduction in the available P content was observed by liming. The available P content in soil showed a reduction from 9.80 to 6.85 kg ha^{-1} due to liming. Highest available P content was recorded by control and was on par with the treatment with $CaCO_3$ at 1.5 times exchangeable Al. The treatments with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al, $CaCO_3$ at 3.0 times exchangeable Al, and $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al were on par with $CaCO_3$ at 1.5 times exchangeable Al and significantly inferior to the control.

3.5.5 Available potassium

The available potassium in soil showed a decreasing trend with increasing lime rate. The range in the values varied from 194.60 to 225.40 kg ha^{-1}. The treatment with $CaCO_3$ at 3.0 times exchangeable Al, though on par with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al, was significantly inferior to the treatments with $CaCO_3$ at 1.5 times exchangeable Al, $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al and the control.

3.5.6 Exchangeable calcium

The exchangeable calcium in soil was significantly increased by liming. Maximum value was recorded by the treatment with $CaCO_3$ at 3.0 times exchangeable Al (6.63 cmol (+) kg^{-1} and was statistically superior to the other treatments. The treatments with $CaCO_3$ at 1.5 times exchangeable Al, $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al, and $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al though on par among themselves, differed significantly from the control (2.8 cmol (+) kg^{-1}). In general, the exchangeable calcium showed an increasing trend with increase in lime rate.

3.5.7 Exchangeable magnesium

No significant variation was observed in the exchangeable magnesium content of soil due to treatments. The range in exchangeable magnesium varied from 0.98 to 1.75 cmol (+) kg^{-1}.

3.5.8 Extractable iron

A general reduction in extractable iron in soil was observed due to treatments. The range in the values varied from 5.83 to 8.85 ppm and the variation was not significant.

3.5.9 Extractable manganese

There was no significant difference in the manganese content of soil due to treatments and the values differed from 23.83 ppm to 24.55 ppm.

3.5.10 Extractable zinc

The zinc content of soil did not show statistically significant difference due to treatments. The zinc content was slightly decreased from the control in all the treatments except in the combination treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al.

3.5.11 Extractable copper

No significant variation was observed in the extractable copper content of soil due to treatments. The range in the copper content varied from 1.93 to 2.08 ppm.

Discussion

DISCUSSION

1 Characterisation of soils used for the study

1.1 Textural analysis

The soils selected for the study were ferralitic with silty loam to silty clay loam texture. Sand was the predominant size fraction and silt recorded the lowest values.

1.2 Chemical characteristics

Organic carbon content was low as is characteristic of tropical soils, being depleted because of higher mineralisation rates.

The sesquioxide content was high and can be attributed to the kaolinitic clay which retain the oxides on the clay surfaces.

The total CaO and MgO contents recorded low values. The total reserve of plant nutrients is mainly a function of the mineralogy of the sand fraction (Hughes, 1981). The fine sand fraction of the red and laterite soils of Kerala has a dominance of quartz. The soils are mainly derived from acid crystalline rock which again is poor in weatherable minerals. These factors have contributed to the low nutrient reserves (Bastin, 1985).

The cation exchange capacity of soils was low and confirm earlier reports of Coleman and Thomas (1967), on low activity clay soils.

The soils are highly weathered and leached with consequent low base saturation values. The samples under investigation were mainly from the surface horizons and hence have high base saturation values suggestive of the influence of the organic fraction.

The exchangeable Al content and the Al saturation based on effective CEC was calculated since this was considered as a useful measure of soil acidity as compared to exchangeable hydrogen (Sanchez, 1976).

In acid soil reclamation, exchangeable Al rather than exchangeable H has been found to be critical. Hence lime requirement based on 1.5 times exchangeable Al was used as criterion for reducing hazards of Al in soil solution and supplying sufficient Ca and Mg (Evans and Kamprath, 1970). This approach has considerably reduced the conventional lime recommendation required to raise the pH of soil to neutrality.

2. Leaching and mobility of Ca and Mg using different liming materials in combination with gypsum

2.1 Depth-wise distribution of pH as influenced by various treatments

The $CaCO_3$ and $MgCO_3$ treatments raised the pH of only the surface 10 cm layer of soil. No change in pH occurred beyond 10 cm depth. But the $CaSO_4.2H_2O$ treatment caused considerable reduction in pH (0.2 to 0.8 units) throughout the length of the soil column. The combination treatment with $CaSO_4.2H_2O$ also brought about reduction in pH. Under field and laboratory conditions, gypsum application has been found to increase/decrease or have little effect on soil pH down the profile (Couto et al., 1979; Farina and Channon, 1988b; Hue et al., 1985; Ritchey et al., 1980; Pavan et al., 1982, 1984).The pH change may arise as a result of the conflicting reactions between gypsum and soil surfaces, in which Ca replaces H and Al, and SO_4 replaces OH by ligand exchange. Pavan et al. (1984) showed that, in soils high in exchangeable Al, H^+ release by hydrolysis was likely to exceed OH^- release, causing soil pH to decrease, whereas in soils that are highly weathered but low in exchangeable Al, the reverse was likely to occur (Ritchey et al., 1980).

2.2 Downward movement of applied Ca as influenced by various treatments

The mobility of applied Ca resulting from the $CaCO_3$ treatment was restricted to the surface 10 cm of the profile. The products of $CaCO_3$ neutralization by acid soil, release exchangeable Ca and HCO_3 with the latter decomposing into CO_2 and OH^-. Downward mobility of cations in soil is often accelerated by the presence of an associated anion. In the above reaction the absence of a stable anion has retarded the movement of Ca beyond 10 cm.

The $MgCO_3$ treatment has brought-about a little reduction in exchangeable Ca in the surface 0-5 cm layer though the remaining part of the profile contained more or less same amount of exchangeable Ca as that of the control.

In marked contrast to the $CaCO_3$ and $MgCO_3$ treatments, application of $CaSO_4.2H_2O$ has resulted in a relatively higher accumulation of exchangeable Ca in 0-40 cm horizon and a general increase in the remaining part of the profile. Under this treatment there was a greater solubility of Ca which enhanced the distribution of Ca throughout the profile.

Similarly application of $CaCO_3$ in combination with $CaSO_4.2H_2O$ has also brought about substantial movement of Ca to the lower depths. The movement of Ca was found to increase as the proportion of $CaSO_4.2H_2O$ was increased. This further strengthens the role of a soluble stable anion (SO_4^{--}) present in gypsum, in the downward mobility of calcium. The same trend holds good in the combination treatments of $MgCO_3$ and $CaSO_4.2H_2O$.

Reeve and Sumner (1972) and Ritchey _et_ _al_. (1980, 1982) observed a greater amelioration of subsoil acidity in

Oxisols treated with $CaSO_4.2H_2O$ compared to $CaCO_3$, resulting from the greater downward mobility of calcium.

2.3 Downward movement of applied Mg as influenced by various treatments

Exchangeable Mg was reduced to traces in the surface 0-5 cm layer in the $CaCO_3$ and 0-20 cm layer in the $CaSO_4.2H_2O$ applied treatments. Reduction in exchangeable Mg levels in lime treated plots have been observed by Edmeades <u>et</u> <u>al</u>. (1985), Grove <u>et</u> <u>al</u>. (1981) and Myers <u>et</u> <u>al</u>. (1988). The mechanism involved is the release of exchangeable Mg into soil solution by added Ca and subsequent leaching to lower layers. The above mechanism is probably responsible for the reduced exchangeable Mg levels in the surface layers.

The combination treatments of $CaCO_3$ + $CaSO_4.2H_2O$ brought about distinct increase in exchangeable Mg levels in the 0-30 and 30-50 cm levels. The increase was more when the proportion of $CaSO_4.2H_2O$ was increased. The greater exchanging capacity of Ca for Mg and the presence of a stable associated anion have been conducive for the mobility of Mg to the lower depths as observed by earlier workers in the case of Ca mobility.

As observed in the case of Ca, application of $MgCO_3$ in combination with $CaSO_4.2H_2O$ increased the mobility of exchangeable Mg to lower levels. This again can be attributed to the presence of the associated stable anion, SO_4^{--} (Shainberg et al., 1989; Syed, 1987).

2.4 Depth-wise distribution of exchangeable Al as influenced by the various treatments

The $CaCO_3$ treatment neutralised exchangeable Al to a depth of 25 cm, $MgCO_3$ treatment to 30 cm and $CaSO_4.2H_2O$ treatment to a depth of 50 cm. Combination of $CaCO_3$ and different levels of $CaSO_4.2H_2O$ was effective in neutralizing exchangeable Al to a depth of 40 cm only. But the combination of $MgCO_3$ and different levels of gypsum reduced exchangeable Al throughout the length of the profile. This decrease in exchangeable Al was not due to leaching losses, but rather to polymerisation of Al into insoluble form(s) (Pavan et al., 1984).

A similar reduction in exchangeable Al by $CaSO_4.2H_2O$ has been reported by earlier workers. Reeve and Sumner (1970, 1972) and Ritchey et al. (1980) have reported decreases in exchangeable Al on treating Oxisols with $CaSO_4.2H_2O$. Reeve and Sumner (1970) ascribed the reduction in exchangeable Al to a sulfate induced polymerisation of Al^{3+} as proposed by Chang and Thomas (1963). The latter also suggested that the OH^- replaced by SO_4^{2-} neutralised H^+ released through hydrolysis of Al.

2.5 Depth-wise distribution pattern of effective CEC as influenced by various treatments

A general increase in effective CEC in the 100 cm length of the profile caused by the $CaSO_4.2H_2O$ treatment might have been due to increased mobility of Ca throughout the 100 cm length of the profile in this treatment. Similarly the combination of $CaCO_3$ + $CaSO_4.2H_2O$ resulted in a greater accumulation of applied Ca in 100 cm length of the profile and combination of $MgCO_3$ + $CaSO_4.2H_2O$ resulted in greater accumulation of Mg and Ca in the 100 cm length of the profile. This might be the probable reason for increased effective CEC in the combination treatment.

2.6 Depth-wise distribution pattern of Ca and Al saturation as influenced by the various treatments

The effect of $CaCO_3$ treatment in increasing Ca saturation was limited to the surface 20 cm of the profile and in decreasing Al saturation to 40 cm depth. This may be due to the limited solubility of $CaCO_3$ and mobility of exchangeable Ca which restricted downward movement of Ca. $MgCO_3$ treatment though reduced Ca saturation in surface 10 cm layer, increased the same upto 40 cm depth and reduced Al saturation to 60 cm depth.

As mentioned earlier the $CaSO_4.2H_2O$ treatment has a marked effect in increasing the mobility of Ca to the lower depths. This has brought about an increase in the Ca saturation with a concomitant decrease in the Al saturation throughout the length of the profile. The effect was more pronounced in the treatment where the proportion of $CaSO_4$ was 75 per cent in the combination treatments.

3. Potculture experiment

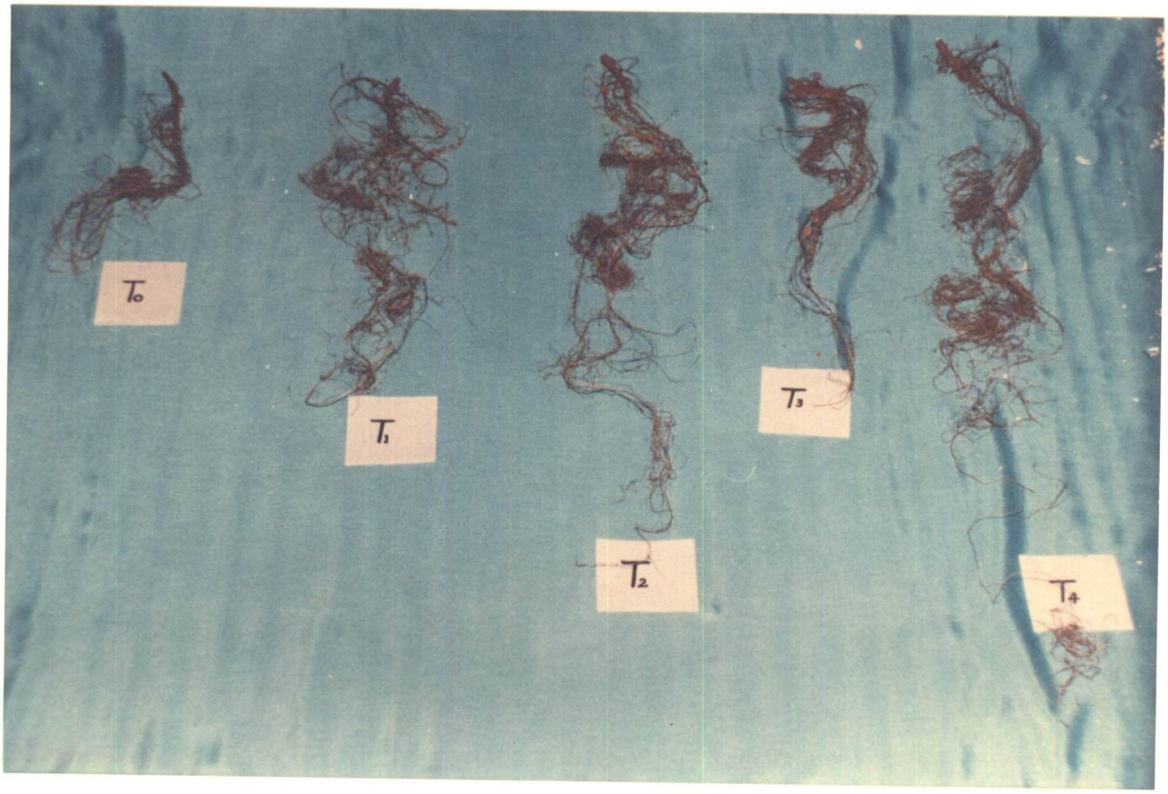
3.1 Biometric characters

The height of soybean plants showed a tendency to increase with liming. Soybean being an Al sensitive crop the reduction in exchangeable Al due to liming, can be a probable reason for the increased growth of the plant. Similar results were obtained by Meena (1987) in cowpea and fodder maize.

The length of roots in soybean also exhibited a negative relation with exchangeable Al content of the soil as evidenced from Table 13 and Plate 2. The treatment with $CaCO_3$ at 1.5 times exchangeable Al produced the maximum root length. Al is observed to be more harmful to roots than tops and an inhibition of root development has been identified as one of the first observable symptoms of Al toxicity in plants (Alva and Sumner (1990), Brenes and Pearson (1973) and Gonsalez-Erico et al. (1979).

A reduction in exchangeable Al and per cent Al saturation brought about by liming has resulted in an increase

Plate 2 Effect of lime in combination with gypsum on root growth


T0
T1
T2
T3
T4

in the number of nodules indicating the specific effect of Al on suppression of root nodule formation in soybean. A similar reduction in nodule formation due to high Al saturation has been reported earlier (Martini, 1974; Sartain and Kamprath, 1975). Samson (1986) has reported increased nodulation by coating soybean seeds with dolomite.

3.2 Yield parameters

Liming resulted in a general increase in the fresh weight of pod in soybean. Maximum dry weight of pod was observed in the treatment with $CaCO_3$ at 1.5 times exchangeable Al and corresponding Al saturation of 6.98 per cent. In the other treatments where the per cent Al saturation was less than 6.98, the dry weight of pod was comparatively lower when compared to the treatment where the exchangeable Al content was 0.48 cmol (+) kg^{-1}.

Grain yield was also maximum in the treatment with $CaCO_3$ at 1.5 times exchangeable Al. The attainment of maximum grain yield at 6.98 per cent Al saturation of the soil is significant and clearly indicates the possibility of getting a higher yield at this level of exchangeable Al. The observation points to the fact that it is sufficient to reduce the per cent Al saturation to values around 7 per cent to obtain a better yield in soybean. Martini _et al_. (1974) pointed out that soybean yields on Oxisols were sharply reduced at Al saturations greater than 10 per cent. Though not significant, liming at the rate of one equivalent of exchangeable Al, and at 3.0 times exchangeable Al gave low yields.

The combination of $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al produced maximum haulm yield and was significant over check. This was followed by the combination treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at the rate of exchangeable Al.

Increased yields of crops grown on acid soils with surface incorporated gypsum may be due to the increased exchangeable Ca, decreased exchangeable Al and increased root length density (Farina and Channon, 1988b; Hammel _et_ _al_., 1985; Sumner _et_ _al_., 1986).

Though not significant the treatment with $CaCO_3$ at 3.0 times exchangeable Al produced maximum root dry weight. Increased root growth as a result of liming has also been reported earlier (Munns and Fox, 1976), Alva and Sumner, 1990).

Significant increase in total dry weight was observed in all the treatments over the check. But between the different lime treatments no significant variation existed. The increased total dry weight due to liming may be because of the increased growth and uptake of nutrients as a result of neutralization of exchangeable Al and effective water utilization with increased root proliferation. The reduction of dry matter in the treatment with no lime may be attributed to the adverse effect of exchangeable Al in root growth and nutrient absorption which is essential for maintaining a higher rate of carbohydrate synthesis (Lee, 1971; Sanchez, 1976).

3.3 Nutrient composition and uptake

From the results it is clear that the nitrogen content of shoot and pod in soybean do not differ significantly due to treatments. However N uptake in soybean was significantly influenced by treatments. Similar results were obtained for available N also (Table 17). Therefore, the increased uptake of N may be due to the increased availability of N as a result of liming.

Though not significant, the P content of shoot was slightly increased and the P content of pod showed significant increase by liming. Liming resulted in significant increase in P uptake also (Table 15a). The maximum P content and P uptake was recorded by the treatment $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al. The supply of Ca to the soil neutralized exchangeable Al and the combined application of lime and gypsum resulted in neutralization of Al to lower depth also. Ritchey et al. (1980) noted that with surface application of chemical amendments to an Oxisol, Ca from $CaSO_4.2H_2O$ moved substantially further than Ca from $CaCO_3$ into the subsoil. Neutralization of exchangeable Al in subsoil resulted in increased root proliferation. Kehoe and Curnow (1963) pointed out that improved uptake of P from limed soil may be due to improved ability of plants to take up P rather than to an improved rate of supply by the soil.

Reduction of exchangeable Al in soils by liming has not produced any marked increase in the K content of shoot and pod in soybean. However, the K uptake was significantly influenced by liming and maximum K uptake was recorded by the combination treatment of $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al content, though the available K was decreased by liming. A high level of Al in the soil or in the plant is not likely to reduce K absorption and translocation in cowpea (Meena, 1987). In fact, low levels of Al have been reported to act as a stimulant for K absorption (Andrew et al., 1973; Fageria and Carvalho, 1982).

The content of Ca in the shoot and pod of soybean and the uptake of Ca were not influenced significantly by treatments. But the Ca uptake showed an increasing trend with increase in the rate of liming. This indicates a lesser uptake of Ca in the presence of Al.

The Mg content of pod did not show much variation due to liming whereas Mg uptake showed an increasing trend with liming. A higher uptake of Mg may be due to the neutralization of Al by liming.

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), Kunishi (1982) and Marykutty (1986). Meena (1987) proposed an increased uptake of N, P, Ca and Mg by a reduction in exchangeable Al and PAS.

The Fe content of shoot was not affected much by liming, however, the Fe content of pod was significantly increased by liming with maximum value recorded by the combination treatment of $CaCO_3 + CaSO_4.2H_2O$ at 3.0 times exchangeable Al content. Fe uptake showed an increasing trend with liming.

The manganese content of shoot and pod showed a reduction, though not significant, due to liming. However, the Mn uptake in general showed an increasing trend due to liming.

The zinc content of shoot and pod was not affected much by liming and no regular trend was observed in the Zn uptake due to liming.

The copper content of pod was significantly decreased by liming, eventhough the content in shoot and Cu uptake seemed to be not affected much by reduction in exchangeable Al content of soil.

3.4 Effect of lime in combination with gypsum on acidity parameters

An increase in pH and a reduction in exchangeable Al and Al saturation have been observed as the most important and immediate effects consequent to liming. Thus soils treated with lime at the rate of 1.5, 3.0 times exchangeable Al and lime + gypsum at the rate of one equivalent of exchangeable Al and 3.0 times exchangeable Al, recorded an increase of 0.28, 0.50, 0.00, 0.05 units of pH respectively. In the case of exchangeable Al the same treatments recorded a decrease of 0.50, 0.70, 0.20 and 0.58 cmol (+) kg^{-1} respectively. In the case of per cent Al saturation the same treatments reduced the values from 17.68 to 6.98, 2.05, 12.08 and 5.20 and the effective CEC was increased from 5.20 to 6.95, 8.53, 6.23 and 7.58 respectively.

The effect of liming to reduce exchangeable Al levels is an established fact. The present study has further strengthened the fact that complete neutralization of exchangeable Al is not a must in management of acid soils for achieving high yields.

3.5 Effect of lime in combination with gypsum on nutrient content of soil

1. Total Ca and Mg

The significant increase in total Ca by $CaCO_3$ at 3.0 times exchangeable Al may be due to an increased supply of Ca and neutralization of exchangeable Al to very low levels. However total Mg was significantly decreased by liming. Reduction in soil Mg consequent to liming has been reported earlier (Edmeades *et al.*, 1985; Grove *et al.*, 1981 and Myers *et al.*, 1988).

2. Available N, P and K

The higher content of available N in the limed soil may be provided by a better association between the macro and micro symbionts. This is evidenced by the higher nodulation of soybean in these treatments giving a low level of exchangeable Al. Nakayama (1987) reported an increased N content of soil with liming.

It is seen that liming of soil enhanced the uptake of P by the plant (Table 15a). It is also generally expected that the treatment should increase the available P content of soil. However, the results of the study point to the contrary (Table 17). It may be noted in this context that although the difference in available P content of limed and non-limed (control) soils is significant, the decrease in soil available P following liming is marginal. This decrease in soil available P in limed soil could be probably due to the increased uptake of P by the plant (Table 15a).

Similar to available phosphorus, the available potassium in soil also showed a definite decreasing trend with increase in the rate of liming. Decreased K availability as a result of liming has been reported by Rojas and Adams (1980) and Gupta (1989).

3. Exchangeable Ca and Mg

An increase in exchangeable Ca is due to the increased supply by the added materials $CaCO_3$ and gypsum. Increased exchangeable Ca due to liming has been reported by Alley (1981), Blaszcyk (1986), Gupta (1989), Haynes and Ludecke (1981), Helyar and Anderson (1974) and Nakayama (1987).

In contrast to exchangeable Ca, the exchangeable Mg in soil was not much affected by liming. Similar observations were obtained by Ross _et_ _al_. (1964). But Edmeades _et_ _al_. (1985), Grove _et_ _al_. (1981) and Myers _et_ _al_. (1988) reported reduction in exchangeable Mg and Alley (1981 and Blaszcyk _et_ _al_. (1986) reported increase in exchangeable Mg due to liming, clearly outlining the wide ranging effects of liming on exchangeable Mg content of the soil.

4. Extractable Fe, Mn, Zn and Cu

Extractable Fe, Mn, Zn and Cu were not influenced significantly by liming.

Summary

SUMMARY

An investigation was conducted at the College of Horticulture, Vellanikkara, during the period 1989-'91, with a view to identify the most appropriate and economic lime recommendation method and the most suitable combination of lime and gypsum for profitable management of upland laterite soils. The first study was to characterize the low activity clay soils (laterite) of Kerala in respect of acidity contribution factors. Another laboratory experiment was conducted with PVC columns to study the mobility of Ca and Mg using different liming materials in combination with gypsum. A potculture experiment was also carried out using soybean, to study the effect of liming in combination with gypsum on the growth, yield and uptake of various nutrients. The results of the investigation are summarised below.

1. The soils in general come under the textural class ranging from silty loam to silty clay loam.

2. Regarding the chemical characteristics, the soils in general were low in organic carbon, and high in sesquioxide. The CaO and MgO contents were low. The CEC as expected was low whereas base saturation recorded fairly high values. The soils in general were acidic in reaction

and the exchangeable Al content was fairly high. Lime requirement based on exchangeable Al content varied from 0.75 to 1.80 t ha^{-1}.

3. The distribution and mobility of Ca and Mg using lime in combination with gypsum was studied. $CaCO_3$ treatment resulted in increase in pH, exchangeable Ca, Ca saturation and effective CEC and reduction in exchangeable Mg and Al in the surface layers only. Whereas the $CaSO_4.2H_2O$ treatment increased exchangeable Ca, effective CEC and Ca saturation throughout the length of the profile and caused substantial accumulation of Ca in the 0-40 cm layer. It also resulted in a general reduction in pH and Al saturation throughout 100 cm length of the column and in exchangeable Mg and Al up to 0-30 and 0-50 cm length of the profile respectively.

4. The $MgCO_3$ treatment was effective in increasing pH, exchangeable Mg and effective CEC in the surface layers but it reduced exchangeable Ca in the 0-5 cm layer and exchangeable Al up to 30 cm depth. It also reduced Ca saturation in the surface layers and Al saturation up to 60 cm depth.

5. The combination treatments in general increased the pH of the surface layers and as the level of gypsum increased, the depth to which reduction in pH occurred also increased.

6. The combination of $CaCO_3$ + 75 per cent $CaSO_4.2H_2O$ resulted in a marked increase in exchangeable Ca, Ca saturation and effective CEC throughout the length of the column, though it reduced exchangeable Mg in the surface layers. It also reduced effectively the exchangeable Al up to 40 cm depth and Al saturation in the whole length of the profile.

7. Combination of $CaCO_3$ + 50 per cent $CaSO_4.2H_2O$, though increased exchangeable Ca to 90 cm depth and effective CEC throughout the length of the profile, Ca saturation was increased up to 50 cm only. It also neutralised exchangeable Al to 40 cm depth and reduced Al saturation to 80 cm depth.

8. The combination treatment with $MgCO_3$ + 75 per cent $CaSO_4.2H_2O$ resulted in a relatively uniform distribution of exchangeable Ca, Mg, effective CEC and Ca saturation throughout the length of the profile and a general reduction in exchangeable Al and a considerable reduction in Al saturation throughout the column.

9. Plant height and nodule number were significantly increased by liming and maximum value was recorded by the treatment with $CaCO_3$ at 1.5 times exchangeable Al.

10. Dry weight of pod, grain yield, haulm yield and total dry weight increased significantly by liming with maximum value recorded by the treatment with $CaCO_3$ at 1.5 times

exchangeable Al in dry weight of pod and grain yield. The combination treatment with $CaCO_3$ + $CaSO_4.2H_2O$ at 3.0 times exchangeable Al recorded maximum haulm yield and total dry weight.

11. No significant variation due to liming was observed in the case of root length, fresh weight of pod and dry weight of root.

12. Liming significantly increased N, P, and K uptake by soybean. However, Ca, Mg, Fe, Mn, Zn and Cu uptake did not show statistically significant difference due to treatments.

13. The pH, effective CEC, exchangeable Al and Al saturation of soil varied significantly due to treatments.

14. Total Ca in soil was significantly increased and total Mg was significantly reduced by liming. Maximum value for total Ca and minimum value for total Mg was recorded by the treatment with $CaCO_3$ at 3.0 times exchangeable Al.

15. The available N in soil showed significant increase due to liming with the maximum value recorded by the treatment with $CaCO_3$ at 1.5 times exchangeable Al.

16. Significant reduction in available P and K content of soil was observed due to liming.

17. Maximum value for exchangeable Ca was recorded by the treatment with $CaCO_3$ at 3.0 times exchangeable Al and was statistically superior to all other treatments.

18. No significant variation was observed in exchangeable Mg diacid extractable Fe, Mn, Zn and Cu due to various treatments.

19. Though the treatment with $CaCO_3$ at 3.0 times exchangeable Al recorded the highest values for pH, effective CEC, total Ca, exchangeable Ca and lowest values for exchangeable Al and Al saturation, maximum values for plant height, nodule number, dry weight of pod, grain yield, available N, and N uptake were recorded by the treatment with $CaCO_3$ at 1.5 times exchangeable Al. This indicates liming at 1.5 times exchangeable Al content of soil was found to be the most appropriate and economic lime recommendation method for the highly weathered and leached acid soils of Kerala.

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* Originals not seen

Appendix

APPENDIX

Abstract of analysis of variance for the effect of different treatments

Sl. No.	Treatment/character	Mean square	
		Treatment	Error
1.	Plant height, cm	177.300*	41.496
2.	Nodule count	320.925**	60.767
3.	Dry weight of pod, g plant^{-1}	4.850*	1.210
4.	Grain yield, g plant^{-1}	2.082*	0.467
5.	Haulm yield, g plant^{-1}	2.184*	0.523
6.	Total dry weight, g plant^{-1}	13.319*	3.665
7.	Total N uptake, mg pot^{-1}	6501.280*	1566.840
8.	Total P content of pod, per cent	0.029*	0.006
9.	Total P uptake, mg pot^{-1}	444.560**	84.840
10.	Total K uptake, mg pot^{-1}	2615.450*	753.170
11.	Total Fe content of pod, ppm	11.203**	2.081
12.	pH (H_2O)	0.192**	0.002
13.	Effective CEC, cmol (+) kg^{-1}	6.444**	0.191
14.	Exchangeable Al, cmol (+) kg^{-1}	0.399**	0.066
15.	Percentage Al saturation	151.44**	17.058
16.	Available N, kg ha^{-1}	5159.006**	790.563
17.	Available P, kg ha^{-1}	6.306*	1.666
18.	Available K, kg ha^{-1}	546.448**	111.328
19.	Total Ca, per cent	0.028*	0.009
20.	Total Mg, per cent	0.015**	0.002
21.	Exchangeable Ca, cmol (+) kg^{-1}	7.799**	0.511

* Significant at 5 per cent level

** Significant at 1 per cent level

MANAGEMENT OF ACIDITY BY COMBINED APPLICATION OF LIME AND GYPSUM IN A LOW ACTIVITY CLAY SOIL OF KERALA

By

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ABSTRACT OF A THESIS
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ABSTRACT

An investigation was conducted at the College of Horticulture, Vellanikkara in the period 1989-'91, with a view to identify the most appropriate and economic lime recommendation method and the most suitable combination of lime and gypsum for profitable management of upland laterite (LAC) soils. The first study was to characterise the low activity clay soils of Kerala in respect of acidity contribution factors. Another laboratory experiment was also conducted with PVC columns to study the mobility of Ca and Mg using different liming materials in combination with gypsum. A potculture experiment was also carried out using soybean to study the effect of liming in combination with gypsum on the growth, yield and uptake of various nutrients.

The characterisation study revealed that the soils in the Vellanikkara series come under the textural class ranging from silty loam to silty clay loam. The soils in general were acidic in reaction with fairly high content of exchangeable Al and low CaO and MgO contents. Sesquioxide, Fe_2O_3 and Al_2O_3 contents were high. The soils were low in organic carbon and CEC.

The leaching experiment revealed that $CaCO_3$ and $MgCO_3$ can be used as an ameliorant for acid surface soils as it

neutralised exchangeable Al and increased pH in the surface layer only. $CaSO_4.2H_2O$, however can be used as an ameliorant for acid subsoils as it neutralised exchangeable Al and supplied Ca throughout the length of the profile. The combination treatment with $MgCO_3$ + 75 per cent $CaSO_4.2H_2O$ can be suggested as an ameliorant for acid surface as well as subsoils as it resulted in uniform distribution of exchangeable Ca and Mg throughout the length of the column and neutralised exchangeable Al in the whole length of the profile.

Liming resulted in significant increase in plant height, nodule number, dry weight of pod, grain yield, haulm yield, total dry weight and N, P, K uptake. Soil pH, effective CEC, total Ca, exchangeable Ca and available N were increased significantly due to liming. However significant reduction in total Mg, exchangeable Al, Al saturation and available P and K resulted due to liming.

Liming at the rate of 1.5 times exchangeable Al content of soil was found to be the most appropriate and economic lime recommendation method for the highly weathered and leached acid soils of Kerala.