EXCHANGEABLE ALUMINIUM AS AN INDEX OF THE LIME REQUIREMENT OF THE LATERITE SOILS OF KERALA

By

N. M. MUHAMED SAKEER.

THESIS

Submitted in partial fulfilment of the requirements for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science & Agricultural Chemistry

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 654

KERALA, INDIA

1997

DECLARATION

I here by declare that the thesis entitled **"Exchangeable aluminium as an index of the lime requirement of the laterite soils 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, fellowship, associateship or other similar title, of any other university or society.

Vellanikkara
9-10-1997

N.M. MUHAMED SAKEER

Dr.K.C.Marykutty
Associate Professor
Department of Soil Science and
Agricultural Chemistry
College of Horticulture

Vellanikkara
9-10-1997

CERTIFICATE

Certified that the thesis entitled "**Exchangeable aluminium as an index of the lime requirement of the laterite soils of Kerala**" is a record of the research work done independently by **Mr.N.M.Muhamed Sakeer**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Marykutty K.C.
K.C. Marykutty
Chairperson, Advisory Committee

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr.N.M.Muhamed Sakeer**, a candidate for the degree of **Master of Science in Agriculture**, with major in **Soil Science and Agricultural Chemistry** agree that the thesis entitled **"Exchangeable aluminium as an index of the lime requirement of the laterite soils of Kerala"** may be submitted by Mr.N.M.Muhamed Sakeer, in partial fulfilment of the requirement for the degree.

Chairperson

Dr.K.C.Marykutty

Members

Dr.A.I.Jose

Sri.C.S.Gopi

Dr.V.K.G.Unnithan

EXTERNAL EXAMINER

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

*I express my deep sense of gratitude and indebtedness to **Dr.K.C.Marykutty**, Associate Professor, Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara and the Chairperson of my Advisory Committee for her valuable guidance constant encouragement, inspiration and patience throughout the course of study and research work.*

*I am thankful to **Dr.A.I.Jose**, Associate Dean, College of Horticulture, Vellanikkara for his valuable suggestions, encouragement and advice rendered during the course of study.*

*My sincere thanks to **Sri.C.S.Gopi**, Associate Professor, Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara for his help and guidance during the study.*

*I extend my sincere thanks to **Dr.V.K.G.Unnithan**, Associate Professor, Department of Agricultural Statistics, College of Horticulture, Vellanikkara for his valuable advice and help rendered in the statistical analysis of the data and subsequent interpretation.*

I wish to extend my heartful thanks to all the teaching and non-teaching staff of the Department of Soil Science and Agricultural Chemistry for their immense help and support during the course of the study.

My profound sense of gratitude is due to all my friends and in particular Rajesh, Santhosh, Nimba, Anila, Mullakoya, Jidesh, Ajith, Binu, Dhanesh, Jayasankar, Manoj, Bavrah etc. for their help and encouragement in this work.

I thank Mr.Joy for the neat and prompt typing of the manuscript.

I thank my parents, wife, child, brothers, sisters and in laws for all the mental and physical support rendered during the course of my study.

Above all, I bow my head before God Almighty whose blessings enabled me to undertake this venture successfully.

N.M.Muhamed Sakeer

To my parents

Introduction

INTRODUCTION

The vast majority of the soils of the humid tropics are acidic. The high rainfall, mean annual temperature, type of vegetation, parent material, hydrologic conditions etc. govern the extent and intensity of acid soils. Acid soils contain very small amounts of exchangeable calcium and magnesium, high levels of exchangeable aluminium and hydrogen, and possess low cation exchange capacity. 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.

Breakdown of clay colloids during weathering releases aluminium from the aluminosilicate layers. The aluminium ions so released remain either attached to the colloidal particles by replacing hydrogen ions or are released into the soil solution. In the soil solution each trivalent aluminium ion reacts with water to form hydroxy aluminium compounds, yielding three hydrogen ions which further increases soil acidity. In addition to this, the free aluminium ions present in highly acidic soil solutions act as a direct toxicant for several crops. Although aluminium is not an essential element, an appreciable amount of this element is often present in most plants. High aluminium levels in soil solution is known to cause direct harm to roots and decrease root growth and translocation of minerals especially Ca and P to the top.

Laterite soils covering 60 per cent of soils of Kerala are predominant in low activity kaolinite and hydrous oxide clays. These soils though acidic 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. The purpose of liming is primarily to neutralise the exchangeable aluminium and it usually achieved when the soil pH is raised to about 5.5. Many workers have proved in recent years that the aluminium removed from the soil by N KCl, designated as exchangeable aluminium gives a more reliable and realistic estimate of lime needed to neutralise reactive aluminium and to make a favourable soil condition for plant growth.

Cochrane *et al.* (1980) have proposed the use of minimum amount of lime on acid soils so as to decrease the percentage aluminium saturation to levels that do not affect production and compensate crop aluminium tolerance. The work of Marykutty and Aiyer (1992) showed that the maximum yield of rice was obtained when lime dose well below 0.25 LR, which was the lowest level tried for laterite soils of Kerala. Singh *et al.* (1993) reported that high values of lime requirement based on pH and texture of the soil cannot be considered economical and recommended KCl-Al x 1.5 or NH_4Cl-Al x 0.75 values of lime requirement for significant and economical reclamation of acid soils.

The concept of use of lime levels only up to the point of elimination of aluminium toxicity has been developed in the light of these. The use of lime based on exchangeable aluminium ensures the maintenance of a slightly acidic soil condition where the aluminium may not be toxic to crop plants and at the same time permit a better utilization of unavailable plant nutrients from the soil.

Toxicity of aluminium is one of the main constraints of crop production in acid soils. In cereal crops, the symptoms of aluminium injury are first apparent on the roots. Injured roots are slower to elongate. Later they thicken and do not branch normally. The root tip disintegrates and turns brown and the adventitious roots proliferate as long as the crown is alive.

Though there have been attempts to study the effect of liming on low land laterite soils of Kerala, there is very little information on the comparative suitability of various liming methods suggested in general for these soils.

The present study was therefore undertaken with the following objectives.

1. To assess the lime requirement in terms of exchangeable aluminium,
2. To correlate the pH and lime requirement values with the exchangeable aluminium content of soil, and
3. To study the effect of liming on crop performance with special reference to exchangeable aluminium content of soil.

REVIEW OF LITERATURE

The vast majority of the humid tropical soils of the world are acidic due to the direct and indirect influence of high temperature and rainfall. The acidity of soils results from base unsaturation caused by leaching out of bases through high rainfall and through genesis from base-poor acidic rocks and acidic parent materials.

Many of the problems associated with growing crops in acid soils were assumed originally as due to the confrontation of H^+ ions with the plant roots. Now it is clear that aluminium ions have an equal role in the problems of acid soils. Exchangeable aluminium is identified as the chief factor limiting the growth and productivity of crop plants in acid soils.

Ever since the recognition of aluminium as a potential source of soil acidity and the associated toxicity problems, considerable research has been undertaken for a better understanding of the various facts of this important problem. Some of the important work in this direction is reviewed and summerised below.

1 Nature of soil acidity

The permanent negative charge of acid soils is mainly 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 suspensions 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.

Schofield (1949) believed that aluminium was the main constituent of soil acidity. Results obtained by Gilly (1958) on two soils of high exchange acidity. pH (KCl) 4-3.5 as compared with pH (H_2O) 5.3-4.8 indicated that the later was entirely due to aluminium ions. A difference greater than one between pH measured in water and in 1N KCl is attributed to high exchangeable aluminium. Coleman *et al.* (1959) measured the CEC and exchangeable cations in 13 soils from North California and found that N KCl exchangeable acidity was caused by aluminium ions and negligible amount of exchangeable hydrogen ions.

Yuan (1963) used titration curves of 1N KCl extracts of soils to determine echangeable hydrogen and aliminium and found that very acid soils (< 4.8 pH) had more hydrogen than aliminium ions. At high pH values, there were more aluminium than hydrogen ions, both becoming negligible above pH 5.8. Coulter (1969) reported that acid soils were Al saturated materials with apparent weak acid characteristics due to the hydrolysis of adsorbed Al^{3+}.

Zelazny and Fiskell (1971) reported that the acidity exchangeable with neutral KCl was primarily Al. Kaminski and Bohnen (1976) had observed that exchangeable aluminium and organic matter levels showed the greatest effect on soil acidity. Sanchez (1976) studied the inter-relationship between the nature of soil acidity, exchangeable aluminium and per cent aluminium saturation and considered soil acidity as a poor defined parameter and reported that per cent aluminium saturation calculated on the basis of ECEC should be taken as a useful measure of soil acidity. He suggested that lime recommendations should be based on the amount of exchangeable aluminium in the top soil.

Hoyt (1977) studied 29 soil samples with in a field with similar pH (4.6-4.72) but widely varying organic matter content (3.5-20.5%) and reported that exchangeable aluminium decreased while pH dependent acidity increased with increasing organic matter content. Singh and Aleushin (1983) had reported that exchangeable acidity determined with neutral N KCl is attributed to Al^{3+} ions and hydrolytic acidity (sodium acetate extractable) is attributed to hydrogen ions. Halder and Mandal (1985) studied pH, exchangeable acidity, extractable acidity and exchangeable aluminium to determine lime requirement (LR) of 0.64 soil samples in Assam and have observed negative correlation between pH and LR values and positive correlation with exchangeable acidity, extractable acidity and exchangeable aluminium.

Sharma *et al.* (1990) have studied exchangeable, pH dependent and total acidity and reported that electrostatically bonded Al^{3+} and H^{+} contributed 79 per cent and 21 per cent respectively to exchangeable acidity while total acidity comprised of 71 per cent pH dependent and 29 per cent exchangeable acidity. Soil factors affecting the different forms of acidity were pH, organic matter exchangeable and extractable Al. Das *et al.* (1991) studied fourteen acid soils to assess the relation between different types of soil acidity and physicochemical parameters and observed significant correlation of organic carbon and exchangeable Al with hydrolytic acidity and exchange acidity with exchangeable Al^{3+}.

Das *et al.* (1992) concluded that more than half of the permanent charge is satisfied by H^{+} and Al^{3+} below pH 4.7 and decreased < 2.3 per cent above pH 5.8. Liming and K fertilization decreased exchangeable, pH dependent, total acidity, exchangeable, extractable, amorphous, crystalline and total Al and Fe (Dixit and

Sharma, 1993). While studying the nature of acidity in soils developed on granite gnesis Singh *et al.* (1993) concluded that the form of acidity was mainly contributed by aluminium. According to Ananthanarayana and Hanumantharaju (1994) aluminium saturation increased with increasing total potential acidity whereas calcium saturation decreases. pH dependent acidity contributed to more than 90 per cent of the potential acidity.

Prabhuraj and Murthy (1994) reported that the major contributing factors for different kinds of acidities are exchangeable Al^{3+}, exchangeable H^{+} and functional groups of soil humus. Kailashkumar *et al.* (1995) reported that electrostatically bonded H^{+} and Al^{3+} acidities constituted 39.3 and 60.7 per cent of exchangeable acidity while pH dependent and exchange acidities comprised 92.2 and 7.8 per cent of total acidity.

Dipak *et al.* (1997) reported that the potential acidity showed significant positive correlations with Fe oxides, clay and organic matter and the pH dependent acidity contributes towards the potential acidity. Bandyopadhyay and Chattopadhyay (1997) observed that pH_w and pH (KCl) showed negative relationships with all types of acidities.

1.1 Aluminium as a potential source of acidity in acid soils

According to Dewan (1966) exchangeable aluminium is the predominant source of acidity in soils containing Kaolinite and Vermiculite clay minerals. Kamprath (1970) has pointed out that at a pH below 5.4, the buffer capacity of the soils was primarily due to exchangeable aluminium and that soils with high exchangeable aluminium possessed only a comparatively lower CEC.

Breakdown of clay colloids during weathering releases aluminium from the alumino silicate layers. The aluminium ions so relased remain either attached to the colloidal particles by replacing hydrogen ions or are released into the soil solution. In the soil solution trivalent aluminium ion reacts with water to form hydroxy aluminium compounds, yielding three hydrogen ions which further increases soil acidity (Black, 1973).

Bloom *et al.* (1979) considered the activity of Al^{3+} in soil solution as a function of soil pH and stated that this relationship dependend on the exchange of aluminium ions from the organic matter to the exchange sites on the clay surface. Saigura *et al.* (1980), Franco and Munns (1982) and Adams and Hatchcock (1984) have proposed exchange acidity as a realistic measure of the aluminium toxicity potential of a soil.

Shamshuddin and Tessens (1983) have indicated the significance of aluminium in controlling the acidity of acid soils. They considered that the buffering action of soils is dominated by aluminium below pH 5.5. An increase in the solubility of aluminium consequent to increase in soil acidity has been reported by Bache (1985).

1.2 Influence of aluminium on plant growth and its toxic effects in rice plants

Acid soils having high concentration of aluminium and pH below 5.5 adversely affect the production of most field crops. The excess aluminium content in soil results in the inhibition of root growth which will in turn decrease water and nutrient uptake. Reduction in water uptake makes the crop more susceptible to water stress under drought conditions and decreased nutrient uptake leads to growth reduction.

The aluminium concentration of soil solution has been considered to be a real measure of aluminium toxicity potential. Lockard and McWalter (1956) showed that aluminium toxicity occurs at concentrations between 6.7 and 40.5 ppm in rice plants. Tomlinson (1957) had reported an aluminium level higher than 250 ppm might be harmful to plants.

Nye *et al.* (1961) and Evans and Kamprath (1970) have reported that the aluminium concentration in the soil solution was generally less than 1 ppm. When the aluminium saturation increased beyond 60 per cent, aluminium in the soil solution also recorded a correspondingly sharp increase. Presence of organic matter however was found to reduce aluminium concentration in soil solution.

Cate and Sukhai (1964) have shown that water soluble aluminium concentration as low as 1 to 2 ppm markedly inhibited the growth of roots while leaf symptoms occurred only at a concentration of 25 ppm. Higher concentrations inhibited root growth and produced green and yellow spots on the leaves. Adams and Lund (1966) reported that critical levels of aluminium vary for different crops and soils.

Tanaka and Navasero (1966) reported that critical concentrations of aluminium in culture solution was 25 ppm for the rice plant. Foy *et al.* (1967) have shown that aluminium sensitive varieties of rice have higher root CEC values and can induce lower pH levels in nutrient solution than aluminium tolerant varieties.

Chenn (1968) in a study on the aluminium ions on the rice growth in nutrient culture showed that the plant growth was impaired when Al^{3+} concentration in the medium exceeded 2 ppm. The aluminium content in the roots was 2.7 to 4.6 and 3.7 to 9.9 times higher than that in the stems and leaves. In cultures with excised roots the pH of the medium significantly affected aluminium uptake. Aluminium uptake from the solution of higher concentration was greater in rice roots compared to barley roots. These findings were considered to be relevant to the greater adaptability of rice on acid soils. Ota (1968) reported that the rice disease 'bronzing' in Ceylon was found to be caused by aluminium toxicity in combination with calcium deficiency.

The toxic symptoms of aluminium in most acid soils show specific variation. Sufficiently high concentration of aluminium over a period of time will frequently damage even the most tolerant varieties. Symptoms will appear in the plant tops at a later seedling stage and high concentration between weight of roots and tops have been reported by Reid *et al.* (1969).

Thawornwong and Diest (1974) reported that the concentration of 2 ppm aluminium was lethal only to young rice seedlings and that plants has passed the seedling stage were not affected.

Frageria and Carvalho (1982) showed the differential behaviour of rice cultivars to aluminium levels and concluded that levels of aluminium in the top of a 21 day old rice plant varied from 100 to 417 ppm. Blamey *et al.* (1983) have reported that aluminium in solution markedly reduced root elongation as well as absorption and translocation of nutrients to the plants.

Abraham (1984) also showed that 20 ppm of aluminium in nutrient solution suppressed root elongation of rice, and more than 30 ppm of aluminium reduced the number of productive tillers as well as yield of grain and straw. Aluminium toxicity also caused a reduction in the uptake of all nutrients in rice. Frageria (1985) have also reported that increased aluminium concentration in nutrient solution inhibited the uptake of N, P, K, Ca, Mg, S, Fe, B, Cu, Zn and Mn in rice.

1.3 Effect of liming on aluminium content of soil

The solubility of aluminium and the severity of its toxicity to plants are affected by many soil factors such as pH, type of predominant clay mineral, concentration of other cations, total salt concentration, moisture level, organic matter etc. Very often aluminium toxicity is not the only factor limiting productivity in acid soils.

Liming is the oldest practice to overcome the adverse soil conditions affecting crop production. Use of lime as an ameliorant for reducing aluminium toxicity and reclamation of acid soils has been reported by Blair and Prince (1923), Coleman *et al.* (1958), Thomas (1960), Subramoney (1961), Nhung and Ponnamperuma (1966), Goswami *et al.* (1976) and many others.

Brauner and Catani (1967) in an incubation experiment with 11 acid soils using $CaCO_3$ at 100 and 300 mg 100 g^{-1} soil recorded a decrease in exchangeable aluminium and titrable acidity and an increase in the pH of aqueous suspensions and KCl extracts of soils. Evans and Kamprath (1970) reported that small increments of lime resulted in relatively rapid decrease in soil solution aluminium.

Reeve and Summer (1970) and Reid *et al.* (1971) have showed growth response to lime upto the point of elimination of exchangeable aluminium after which a significant reduction in yield occurred. Response to phosphorus in aluminium toxic soils by increased levels of lime was reported by Helyar and Anderson (1971). Kabeerathumma and Nair (1973) and Abraham (1984) have showed a reduction in exchangeable aluminium and hydrogen content of the acid soils of Kerala as a result of liming.

Serda and Gonzalez (1979) recommended the optimum level of lime to minimise aluminium toxicity as 1.5 to 3.0 times the lime required to neutralise the exchange acidity present in acid soils. Cochrane *et al.* (1980) suggested the use of minimum amount of lime in acid soils so as to decrease the aluminium saturation to levels that do not affect the economy of crop production.

Exchangeable and soluble aluminium in acid soils were reduced by liming (Bache and Crooke, 1981). A negative but linear relationship between exchangeable calcium and aluminium was observed by Haynes and Ludecke (1981). Jones *et al.* (1982) reported that eventhough there was no significant effect in increasing the yield, lime decreased the exchangeable aluminium from 0.12 to 0.01 me 100 g^{-1}.

Mukhopadhyay *et al.* (1984) have showed that increasing the rate of application of $CaCO_3$ decreased exchangeable aluminium content of soils. Curtain and Smillie (1986) observed that liming decreased the free aluminium concentration in the soil.

The studies of Marykutty (1986) revealed that application of lime reduced the H^{+} and Al^{3+} contents of the Kuttanad, Kole, Pokkali and laterite alluvium soils of Kerala.

Marykutty and Aiyer (1987) reported that washing the soil two or three times at an interval of two days with 10 cm water from the soil surface after the application of lime was more effective for increasing the pH and decreasing the exchangeable aluminium and hydrogen.

Meena (1987) conducted an experiment with treatments as lime based on conventional lime requirement (7.7 t ha^{-1}) lime to reduce percentage Al saturation to less than 30 (500 kg ha^{-1}) lime to reduce the percentage aluminium saturation to less than 40 (250 kg ha^{-1}) and no liming for the crops cowpea and fodder maize and concluded that cowpea can be cultivated profitably in presence of 500 kg lime ha^{-1} which permitted certain amount of exchangeable aluminium level in soil while maize was more sensitive and it needs complete elimination of exchangeable aluminium.

Based on the studies on liming of acid soils of Himachal Pradesh, Bishnoi *et al.* (1988) reported that lime application increased the ECEC, base saturation, while it decreased the exchangeable acidity and toxic levels of Al^{3+}, Fe^{3+} and Mn^{2+}. Gupta *et al.* (1989) reported that liming increased available contents of phosphorus and calcium, pH, ECEC and decreased available potassium, iron, aluminium and aluminium saturation.

Patiram *et al.* (1989) found out the lime requirement indices and reported that maximum yield was obtained when the lime rates were 1 to 2 times the equivalent of exchangeable aluminium.

By principal component analysis Marykutty and Aiyer (1990) clustered the acid soils of Kerala. Lateritic alluvium was placed in the sixth and seventh cluster with a range of aluminium saturation of ECEC 30-40 and below 30 per cent respectively. Marykutty and Aiyer (1992) further showed that maximum yield was obtained when lime dose well below 0.25 LR, that is the lowest level lime application tried for laterite soils.

Jacob and Venugopal (1993) reported that combination of $CaCO_3$ and different levels of $CaSO_4 . 2H_2O$ was effective in reducing the exchangeable Al to a depth of 40 cm.

1.4 Exchangeable aluminium as a criterion for lime requirement

Exchangeable aluminium was considered as the criterion of soil acidity rather than hydrogen ion concentration by Pavar and Marshall (1934).

Lime application based on exchangeable aluminium was a realistic approach for leached mineral soils (Kamprath, 1970). He observed that on addition of lime equivalent to the exchangeable aluminium content reduced the aluminium saturation of the effective CEC less than 30 per cent. Neutralisation of non-exchangeable acidity was resulted on application of lime, greater than this equivalent which is uneconomical.

Reeve and Summer (1970) considered exchangeable aluminium status as a suitable criterion for the measurement of lime requirement. The amount of lime thus calculated was only approximately 1/6th of the amount required to raise the soil pH to 6.5. Hoyt and Nyborg (1971) recommended that extractable aluminium could be a valuable supplement to soil pH in assessing the need for lime application.

Lime requirement based on exchangeable aluminium concentration was less than the estimate of lime based on the neutralization value (Amedee and Peech, 1976). Sanchez (1976) suggested that lime recommendations should be based on the amount of exchangeable aluminium in the top soil.

Martin *et al.* (1977) suggested that liming rates to bring soil pH from 4.8 to 5.7 and to reduce exchangeable aluminium to 1.5 mg 100 g^{-1} soil as a more valid means of increasing yield than the raising of soil pH to neutrality.

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

Use of minimum amount of lime on acid soils so as to decrease the percentage aluminium saturation to levels that do not affect production and compensate crop aluminium tolerence was suggested by Cochrane *et al.* (1980). Farina *et al.* (1980) concluded that because of considerable variation in the optimum pH requirements of the different soils, pH proved to be a poor measure of lime requirement. But both highly weathered and less weathered soils behaved similarly when assessed on the basis of aluminium saturation.

Saigura *et al.* (1980) showed exchange acidity as a useful realistic measure of aluminium toxicity potential.

Studies of Devi (1983) revealed that the quantity of lime required varied from 0.5 t ha^{-1} in uplands and 1.6 to 5.8 t ha^{-1} in rice fallows. The factors causing acidity in those soils were Al and Mn. Manrique (1986) observed that a pH value < 4 in 1M KCl should indicate an aluminium saturation less than 15 per cent.

Meena (1987) conducted experiment with lime treatment to reduce the percentage Al saturation to less than 30 (500 kg ha^{-1}) and concluded that cowpea can be cultivated profitably in presence of 500 kg lime ha^{-1} and also revealed that cowpea exhibited greater tolerance to aluminium at 1.26 milliequivalent of exchangeable calcium.

1.5 Effect of liming on the uptake of nutrients

Increase in the nitrogen content of the grain and straw in rice was observed by the application of lime by Varghese (1963) and Nair (1970). The potassium content of plant was decreased by the application of high levels of lime (Koshy, 1960 and Nair, 1970).

Kabeerathumma (1969) reported that the uptake of nitrogen, phosphorus, calcium and magnesium was increased with increased dose of lime in rice.

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. 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.

Mandal (1976) reported that liming had been found to depress the uptake of iron, manganese, copper and zinc in soybean. Butorac and Uscumlic (1978) suggested that liming increased the contents of N, P, Ca and decreased those of potassium and magnesium in the stem and leaf of lucerne.

According to Njos (1978), N, P and Ca contents of grain and Ca content of hay were increased with liming. Motowicka-Terelak (1978) had observed that liming increased the Ca content inplants and decreased Mn content, while the effect on N, P, K and Mg contents varied with the levels of lime and plant species.

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 rice and legumes and decreased the concentration of magnesium, potassium and zinc.

Anilakumar (1980), Maria *et al.* (1985) and Marykutty (1986) found that the total uptake of N, P, Ca and Mg by rice plant increased with lime application. Meena (1987) proposed that a reduction in exchangeable aluminium per cent, aluminium 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.

1.6 Different forms of iron and aluminium

A decrease in different forms of aluminium and iron due to liming was reported by Datta and Gupta (1983). Dixit and Sharma (1993) suggested that the application of lime up to 7.4 t ha^{-1} significantly decreased the exchangeable, extractable and amorphous forms of aluminium and iron after the harvest of wheat, soybean and linseed.

Verma and Singh (1996) reported that exchangeable, extractable and amorphous forms of aluminium significantly and positively correlated with all the forms of soil acidity while crystalline form does not showed significant positive correlation. They also reported that exchangeable and extractable forms of aluminium contributed much towards exchangeable acidity followed by pH dependent acidity and total acidity.

Materials and Methods

MATERIALS AND METHODS

The study was carried out at College of Horticulture, Vellanikkara, Kerala Agricultural University, Thrissur, Kerala, to assess the lime requirement in terms of exchangeable aluminium, to correlate the pH and lime requirement values with the exchangeable aluminium content of soil and to study the effect of liming on crop performance with special reference to exchangeable aluminium content of soil.

The study included the collection and analysis of 50 surface soil samples (0-15 cm) from the laterite zone, a pot culture experiment to compare the effectiveness of different levels of lime based on exchangeable aluminium content of soil and an incubation study to evaluate the soil characters under laboratory conditions.

1 Collection of surface soil samples

A total number of fifty surface soil samples representing rice growing tracts of laterite zone of Kerala were collected from Malappuram, Palakkad and Thrissur districts. The location from which the soils were collected are given in Table 1.

Soil samples were collected from a depth of 0-15 cm. The fresh soils were packed in polythene bags, labelled and transported to the laboratory. In the laboratory these samples were dried in shade, powdered with a wooden mallet and sieved through 2 mm sieve. The soil samples were stored in air tight containers for further analysis.

Table 1. Details of locations of the surface soil samples collected

Sl. No.	Location	Sl. No.	Location
A. Malappuram district (22 samples)			
1	Angadippuram	26	Unniyal
2	Perinthalmanna	27	Karkidakamkunnu
3	Aliparamba	28	Kanhirappuzha
4	Thazhekkode	29	Thachampara
5	Vettathur	30	Palakkazhi
6	Puthanazhi	31	Kattukulam
7	Iringatiri	32	Bheemanadu
8	Kuttathy	33	Kottopadam
9	Thuvvur	34	Ariyoor
10	Kalikavu	35	Kumaramputhur
11	Karuvarakundu	36	Thathengalam
12	Mampuzha	37	Mannarkkad
13	Pandikkad		
14	Vaniyambalam	C. Thrissur district (13 samples)	
15	Edayattur		
16	Melattur	38	Nadathara
17	Edappatta	39	Ollur
18	Wandoor	40	Nandikkara
19	Elamkulam	41	Puthukkad
20	Keezhattoor	42	Elamthuruthy
21	Manjeri	43	Mannuthy
22	Edavanna	44	Vazhukkampara
		45	Thanippara
B. Palakkad districts (15 samples)		46	Kannara
		47	Alpara
23	Edathanattukara	48	Pattikkad
24	Vattamannapuram	49	Chuvannamannu
25	Alanallur	50	Thottappadi

1.1 Analysis of the surface soil samples

Mechanical analysis of soils was carried out by the hydrometer method (Piper, 1942). Soil reaction was determined in a 1:2.5 soil water suspension as well as 1N KCl solution using a pH meter and electrical conductivity was estimated in the supernatent solution using the conductivity meter.

The lime requirement was determined by the method of Shoemaker *et al.* (1961) as described by Hesse (1971), based on total acidity by the method of triethanol-barium chloride titration (Black *et al.*, 1965) and based on exchangeable aluminium content of soil (Singh *et al.*, 1993).

Different forms of acidities such as exchangeable acidity and total acidity were determined as described by Reeuwijk (1992). The pH dependent acidity was calculated from the difference between potential acidity and exchangeable acidity. Different forms of iron and aluminium were determined by methods suggested by Ballard and Fiskell (1974).

The organic carbon content was determined by Walkley and Black method as described by Jackson (1958). Total elemental analysis of Al, Fe, P, K, Ca and Mg was done using diacid extract (HNO_3 and $HClO_4$ in 2:1 ratio). Total aluminium and iron were determined by aluminon and O-phenanthroline methods respectively (Black *et al.*, 1965). Total P was determined by Vanadomolybdate yellow colour method while total Ca and Mg were estimated by EDTA titration method as outlined by Hesse (1971). Total potassium was read using EEL flame photometer.

Exchangeable aluminium and hydrogen were estimated in the 1N KCl extract (Black *et al.*, 1965). Neutral 1N NH_4OAc was used for the extraction of exchangeable cations. Ca and Mg were determined by EDTA titration method as outlined by Hesse (1971). Exchangeable sodium and potassium were read using EEL flame photometer. Cation exchange capacity (CEC) was determined as the sum of exchangeable bases and total acidity whereas effective CEC (ECEC) was estimated as the sum of exchangeable bases and KCl extractable acidity as described by Reeuwijk (1992). Base saturation was calculated on the basis of the total CEC as suggested by Coleman *et al.* (1958).

In order to study increase of pH on submergence the fifty surface soil samples collected were kept under submergence for 40 days. For this 50 g of soil was taken in plastic containers and water was added to a soil solution ratio of 1:2.5. The pH was noted at periodical intervals upto 40 days. Water level was kept constant throughout the entire period.

1.2 Statistical analysis

Correlation coefficient between the various characteristics of the surface soil samples were calculated as suggested by Panse and Sukhatme (1978).

2 Pot culture experiment: Effect of graded level of lime on soil and plant characters

From the fifty surface soils studied, three soils were selected based on low, medium and high exchangeable aluminium content for conducting the pot culture experiment. These samples were located at Pattikkad in Thrissur district (low), Edathanattukara in Palakkad district (medium) and Iringatiri in Malappuram district (high), respectively. Bulk samples were collected from these locations and brought to the laboratory. The soil was dried in the shade, the larger clods were broken and filled 5 kg of soil in earthern pots. The data on the physico-chemical analysis of the soils used in the pot culture experiments were given in Table 2.

The experiment was laid out in a completely randomised design (CRD) with 5 treatments and 5 replication for each soil. The rice variety used was Triveni. The details of treatments were as follows:

Soils - 3

S_1 - Exchangeable aluminium low (Pattikkad, Thrissur district)

S_2 - Exchangeable aluminium medium (Edathanattukara, Palakkad, district)

S_3 - Exchangeable aluminium high (Iringatiri, Malappuram district)

Levels of lime - 5

L_0 - No lime (control)

L_1 - Ca at the rate of 0.5 times of exchangeable aluminium equivalent

L_2 - Ca at the rate of 1.0 times of exchangeable aluminium equivalent

L_3 - Ca at the rate of 1.5 times of exchangeable aluminium equivalent

L_4 - Ca at the rate of 2.0 times of exchangeable aluminium equivalent

Sufficient water was added to the pots to wet the soil and to bring about a puddled condition. The lime was added as per the treatments one week before the transplanting of the seedlings. The quantity of $CaCO_3$ calculated for 5 kg soil based on Ca at the rate of 0.5 times of exchangeable aluminium equivalent was 238 mg, 952 mg and 2.38 g for S_1, S_2 and S_3 respectively. Accordingly other levels of lime

Table 2. Physico-chemical characteristics of the soils used for pot culture experiment

Characters	Pattikkad (Thrissur district) S_1	Edathanattukara (Palakkad district) S_2	Iringatiri (Malappuram district) S_3
Soil type	Laterite	Laterite	Laterite
Soil classification	Oxisols	Oxisols	Oxisols
Sand (%)	54.96	49.56	59.92
Silt (%)	11.99	11.99	11.99
Clay (%)	31.96	35.96	23.77
Texture	Sandy clay loam	Sandy clay loam	Sandy clay loam
pH (H_2O)	5.40	5.60	4.30
pH (KCl)	4.30	3.90	3.80
EC (dS m^{-1})	0.08	0.12	0.11
Total phosphorus (%)	0.03	0.06	0.05
Total potassium (%)	0.30	0.16	0.11
Total aluminium (%)	0.10	0.11	0.17
Total iron (%)	0.11	0.11	0.14
Organic carbon (%)	1.11	1.45	2.39
Lime requirement ($CaCO_3$ t ha^{-1}) (based on Exch. Al)	0.32	2.26	4.85
Exchangeable aluminium (cmol(+) kg^{-1})	0.19	1.37	2.94
Exchangeable hydrogen („)	0.26	0.23	0.46
Exchangeable acidity („)	0.55	0.90	2.55
Total acidity („)	2.10	2.85	4.20
pH dependent acidity („)	1.55	1.95	1.65
Exchangeable cations („) (Ca + Mg + K + Na)	4.92	5.96	8.40
CEC („)	7.10	8.80	12.70
ECEC („)	5.47	6.90	10.85
Base saturation (%)	69.10	67.90	66.10

were calculated. Two seedlings were transplanted at the rate of three hills per pot on 01-11-1994. Cultural and manurial practices were done as per the package of practice recommendations of the KAU (Anon, 1993) for rice. Out of five replication, two replications were used for destructive sampling.

2.1 Soil analysis

Soil samples were collected before transplanting, tillering, flowering and harvesting stage of the crop. The notations given for the four stages were

P_0 - before transplanting the seedlings
P_1 - tillering stage
P_2 - flowering stage
P_3 - harvesting stage

The collected soil samples were air dried, ground and passed through 2 mm sieve and stored in polythene bags.

Soil samples collected at different stages of crop growth were analysed for pH, organic carbon, different forms of acidities, aluminium, iron, exchangeable cations, CEC, effective CEC (ECEC) and base saturation as described under 1.1. Available phosphorus was extracted using Bray I extractant (0.03N NH_4F in 0.025N HCl) and determined by the chlorostannous reduced molybdophosphoric blue colour method in HCl system as described by Jackson (1958).

2.2 Biometric observations

Biometric observations of the plants were recorded at three stages of growth. The notations given for three stages were

P_1 - tillering stage

P_2 - flowering stage

P_3 - harvesting stage

The following observations were taken from each pot.

2.2.1 Height of the plant

Height of the plant was measured from the base to the tip of the leaves using a metre scale and expressed in centimetres.

2.2.2 Number of leaves

2.2.3 Number of tillers

2.2.4 Dry matter yield in all the above three stages were recorded.

2.3 Plant analysis

Plant samples collected at three stages and grain collected at harvesting stage were dried, ground in mechanical grinder and preserved in separate containers to study the uptake pattern of the nutrients.

For the determination of P, K, Ca, Mg, Fe and Al, a diacid extract was prepared with HNO_3 and $HClO_4$ in 3:1 ratio (Hesse, 1971). The P content from this extract was determined colorimetrically by the vanadomolybdophosphoric yellow colour method in HNO_3 system (Jackson, 1958). For the determination of K, the extract was diluted and read in an EEL flame photometer. Ca and Mg were determined by EDTA titration method and Al and Fe were determined by aluminon and O-phenanthroline methods respectively as described by Hesse (1971). Nitrogen was estimated by microkjeldhal's method (Jackson, 1958). Uptake of nutrients were computed from the percentage of nutrients.

2.4 Statistical analysis

Analysis of variance for the soil and plant characters were done as described by Panse and Sukhatme (1978).

3 Incubation study

The incubation study was carried out to evaluate the soil characters under laboratory conditions without plants. The soils and treatments were the same as in the pot culture experiment and notations used were also same as described under section 2. In this study the soils were kept at two moisture regimes. The notations used were as follows:

M_1 - at field capacity level
M_2 - under submerged condition

The experiment was laid out in a completely randomised design with two replications. One kilogram of soil was taken in plastic containers and lime was applied as per treatments. The soils were kept for four months under field capacity level as well as under submerged conditions. The soil samples were taken at monthly intervals for analysis.

3.1 Soil analysis

The soil samples collected were dried and sieved through 2 mm sieve. The sieved samples were analysed for pH, organic carbon, available P, exchangeable cations, different form of acidity, aluminium, iron, CEC, effective CEC and base saturation by various methods as described under section 1.1.

3.2 Statistical analysis

Analysis of variance for the soil characters were done as described by Panse and Sukhatme (1978).

Results and Discussion

RESULTS AND DISCUSSION

1 Analysis of surface soil samples

A laboratory study with fifty surface soil samples to assess the exchangeable aluminium content (low, medium and high) and to study the nature of acidity from the rice growing tracts representing the laterite zone of Kerala was carried out. The samples were collected from Thrissur, Palakkad and Malappuram districts. The important parameters included in the study were wet pH(H_2O), dry pH(H_2O), pH(KCl) increase in pH on submergence, EC, exchangeable aluminium, exchangeable acidity, total acidity, pH dependent acidity, exchangeable Ca, Mg, K, Na and Fe, CEC, effective CEC, organic carbon, base saturation, lime requirement based on pH, exchangeable Al and total acidity, total elemental analysis of Fe, Al, P, K, Ca and Mg, different forms of Al and Fe and textural class determination. The results of various parameters are presented in Tables 3 and 4. The inter correlation between various parameters was worked out and given in Table 5.

1.1 Parameters for the measurement of soil acidity (Table 3)

1.1.1 Wet soil pH(H_2O), dry soil pH(H_2O) and pH(KCl)

The wet soil pH(H_2O) of the soils collected from Malappuram district varied from 4.65 to 5.75, soils from Palakkad district showed a range from 5.05 to 5.75 andThrissur soils exhibited values from 5.05 to 5.90.

Surface soil samples collected from Malappuram district showed a range in dry pH(H_2O) from 4.35 to 5.65, Palakkad district samples exhibited values ranging from 4.85 to 5.65 and those from Thrissur district showed a range from 4.85 to 5.80.

Table 3. Parameters for the measurement of soil acidity of surface soil samples

Sl. No.	Location	Wet pH (H_2O)	Dry pH (H_2O)	pH (KCl)	Increase in pH on submergence	Electrical conductivity dS m^{-1}	Exchangeable hydrogen	Exchangeable aluminium	Exchangeable acidity	Total acidity	pH dependent acidity	Exchangeable calcium	Exchangeable magnesium	Exchangeable potassium	Exchangeable sodium	Cation exchange capacity (CEC)	Effective cation exchange capacity (ECEF)	Organic carbon	Base saturation	Exchangeable iron (ppm)	Lime requirements based on: Shoemaker *et al.* method	Lime requirements based on: Exchangeable aluminium	Lime requirements based on: Total acidity
							cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	Per cent	Per cent		$CaCO_3$ t ha^{-1}	$CaCO_3$ t ha^{-1}	$CaCO_3$ t ha^{-1}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A. Malappuram																							
1	Angadipuram	5.15	5.05	4.05	0.50	0.15	0.21	0.44	0.65	0.85	0.20	2.25	1.50	2.08	0.62	7.30	7.10	0.93	88.4	302.0	8.5	0.73	14.0
2	Perinthalmanna	5.40	5.15	4.25	0.40	0.22	0.20	0.25	0.45	3.05	2.60	3.25	0.50	1.94	0.73	9.47	6.87	1.51	67.8	342.0	11.0	0.41	16.0
3	Aliparamba	5.45	5.25	4.20	0.45	0.11	0.59	0.66	1.25	3.15	1.90	3.63	0.88	2.07	0.95	10.66	8.76	1.36	70.4	302.5	9.0	1.11	16.0
4	Thazhekode	5.05	4.95	3.95	0.85	0.12	0.57	0.98	1.55	3.55	2.00	1.13	0.63	0.91	0.52	6.73	4.73	1.49	47.2	298.5	12.5	1.62	18.0
5	Vettathur	5.15	4.95	4.15	0.55	0.15	0.41	0.49	0.90	3.60	2.70	2.38	0.50	1.12	0.84	8.40	5.70	1.27	57.0	293.0	10.0	0.88	18.0
6	Puthanazbi	5.65	5.55	4.25	0.40	0.06	0.20	0.45	0.65	2.55	1.90	2.63	0.50	1.04	0.41	7.12	5.22	1.13	64.2	308.5	8.0	0.74	12.0
7	Iringatiri	4.65	4.35	3.75	1.60	0.11	0.40	2.54	2.94	4.20	1.26	3.75	1.50	1.49	0.97	11.91	10.26	2.42	64.6	341.0	9.5	4.19	11.0
8	Kuttathy	5.10	4.80	3.65	0.85	0.08	0.44	1.91	2.35	3.55	1.20	1.50	0.88	1.27	0.59	7.79	6.59	2.09	54.4	330.0	9.5	3.15	10.0
9	Thuvvur	5.75	5.65	4.30	0.30	0.04	0.31	0.34	0.65	1.85	1.20	1.63	0.38	2.00	0.59	6.45	5.25	0.73	71.3	315.0	9.0	0.56	16.0
10	Kalikavu	5.15	4.95	3.85	0.75	0.07	0.42	0.93	1.35	2.15	0.80	1.75	0.25	0.43	0.29	4.88	3.73	1.06	55.9	319.5	10.0	1.53	14.0
11	Karuvarakundu	5.25	5.05	3.95	0.85	0.06	0.52	0.73	1.25	3.45	2.20	1.38	0.25	0.85	0.68	6.60	4.39	1.21	47.7	317.5	11.5	1.20	19.0
12	Mampuzha	5.25	5.15	3.95	0.95	0.06	0.44	1.71	2.15	2.55	0.40	1.25	0.38	0.39	0.32	4.88	4.48	1.14	47.7	232.0	10.5	2.82	13.0
13	Pandikkad	5.45	5.35	4.35	0.55	0.09	0.11	0.64	0.75	3.05	2.30	2.25	0.63	1.31	1.00	8.24	5.84	1.24	62.9	296.0	8.0	1.06	16.0
14	Vaniyambalam	5.35	5.05	3.95	0.95	0.06	0.52	0.93	1.45	2.85	1.40	1.38	0.75	1.06	0.68	6.71	5.31	1.76	57.5	327.0	11.5	1.53	14.0

Contd.

Table 3. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
15	Edayattur	5.25	5.15	3.90	0.80	0.05	0.32	0.73	1.05	2.15	1.10	2.00	0.25	0.61	0.46	5.72	4.62	1.21	62.3	293.0	10.0	1.20	11.0
16	Melattur	5.45	5.15	3.95	1.05	0.06	0.52	0.83	1.35	3.15	1.80	1.75	0.38	0.83	0.38	6.49	4.69	1.40	51.4	303.0	10.0	1.34	16.0
17	Edappatta	5.05	4.85	3.85	1.00	0.09	0.52	1.03	1.55	2.65	1.10	1.13	0.63	0.68	0.57	5.89	4.79	1.46	54.6	308.0	9.5	1.70	13.0
18	Wandoor	5.20	4.90	3.95	0.65	0.09	0.43	1.17	1.60	3.40	1.80	2.00	0.88	0.82	0.68	7.76	5.96	1.89	56.1	313.5	11.5	1.93	17.0
19	Elamkulam	5.25	5.25	4.20	0.45	0.14	0.41	0.54	0.95	2.15	1.30	2.88	0.63	0.91	0.84	7.39	6.10	1.33	70.9	289.0	8.0	0.89	11.0
20	Keezhattur	5.05	4.85	3.85	1.70	0.15	0.32	0.73	1.05	3.60	2.55	1.50	0.25	1.95	0.71	8.01	5.46	0.97	54.9	298.0	10.5	1.20	19.0
21	Manjeri	5.05	4.80	3.95	0.40	0.11	0.33	1.32	1.65	3.40	1.75	3.00	0.38	1.20	0.89	8.87	7.12	2.17	61.6	404.50	10.0	2.12	16.0
22	Edavanna	5.25	5.05	4.05	0.40	0.14	0.41	0.44	0.85	2.75	1.90	3.00	0.63	1.83	0.76	8.96	7.06	1.28	69.3	343.5	9.0	0.73	15.0
Mean		5.24	5.06	4.01	0.75	0.10	0.39	0.89	1.29	2.89	1.61	2.16	0.62	1.22	0.66	7.56	5.91	1.41	60.8	312.6	9.9	1.48	14.8
B. Palakkad district																							
23	Edathanattukara	5.35	5.25	3.95	0.65	0.07	0.51	0.59	1.10	2.35	1.25	1.63	0.88	0.64	0.52	6.0	4.76	1.18	60.8	189.5	7.5	0.97	11.0
24	Vattamannapuram	5.25	4.95	4.05	0.90	0.09	0.42	0.98	1.40	2.45	1.10	1.38	0.38	0.88	0.54	5.62	4.52	1.12	56.4	182.0	9.0	1.62	12.0
25	Alanallur	5.65	5.55	3.95	0.45	0.12	0.23	1.57	1.80	2.85	1.05	3.88	1.13	1.12	0.49	9.46	7.50	1.42	69.7	196.0	8.5	2.59	10.0
26	Unniyar	5.25	5.05	4.55	0.35	0.09	0.31	0.79	1.10	3.30	2.20	2.13	0.50	2.13	0.95	8.75	6.49	1.17	62.3	188.0	10.5	1.30	16.0
27	Karkidakamkunnu	5.15	5.05	4.05	0.15	0.12	0.41	0.69	1.10	2.55	1.45	2.50	0.38	2.18	0.41	8.01	6.57	1.10	68.2	193.0	10.0	1.14	14.0
28	Kanhirapuzha	5.15	4.95	4.10	1.05	0.06	0.42	0.83	1.25	3.65	2.40	1.50	0.25	0.71	0.57	6.67	4.22	1.80	45.3	199.0	11.5	1.37	20.0
29	Thachampara	5.75	5.65	3.85	0.10	0.10	0.21	0.49	0.70	2.05	1.35	2.38	1.00	2.23	0.46	8.11	6.76	0.88	74.8	203.5	9.5	0.81	11.0
30	Palakkazhi	5.35	5.15	4.85	0.65	0.07	0.31	0.64	0.95	3.35	2.40	2.00	0.38	1.97	0.68	8.34	5.84	1.40	59.9	212.5	8.0	1.06	17.0
31	Kattukulam	5.15	5.05	4.35	0.45	0.05	0.44	2.01	2.45	3.15	0.70	1.00	0.63	0.85	0.79	6.91	6.21	1.72	53.9	188.5	11.6	3.32	16.0
32	Bheemanadu	5.15	4.95	3.95	0.85	0.08	0.32	0.93	1.25	3.70	2.45	2.38	0.25	1.27	0.57	8.16	5.71	1.82	54.7	188.5	12.0	1.53	19.0
33	Kottapadam	5.55	5.35	3.90	0.65	0.08	0.21	0.44	0.65	3.75	3.10	2.75	0.38	1.07	0.46	8.41	5.31	1.94	55.4	208.5	10.0	0.73	19.0
34	Ariyoor	5.25	5.05	4.20	0.35	0.12	0.41	0.74	1.15	4.05	2.90	1.88	0.63	2.08	0.62	9.25	6.35	0.92	56.2	180.5	9.0	1.22	20.0
35	Kumaramputhur	5.35	5.15	3.85	0.85	0.07	0.52	0.93	1.45	3.10	1.65	1.63	0.38	0.61	0.29	6.01	4.36	1.39	48.3	200.0	11.0	1.53	16.0
36	Thathengalam	5.05	4.85	3.95	0.80	0.09	0.29	0.56	0.85	3.70	2.85	1.63	0.88	1.33	0.71	8.23	5.38	1.43	55.1	206.0	10.0	0.92	19.0
37	Mannarkkad	5.45	5.15	3.75	0.85	0.07	0.42	0.73	1.15	2.95	1.80	2.63	0.75	1.09	0.49	7.90	6.10	1.62	62.6	213.0	11.8	1.20	15.0
Mean		5.32	5.14	4.09	0.61	0.09	0.36	0.86	1.22	3.13	1.91	2.09	0.59	1.34	0.57	8.26	5.74	1.39	58.9	196.6	9.9	1.42	15.7

Contd.

Table 3. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
C. Thrissur district																							
38	Nadathara	5.05	5.00	4.25	0.40	0.12	0.31	0.34	0.65	2.20	1.55	2.13	0.88	0.91	0.51	6.68	5.08	1.23	66.2	242.0	8.0	0.56	12.0
39	Ollur	5.35	5.15	4.55	0.25	0.11	0.21	0.29	0.50	1.85	1.35	1.65	0.75	1.03	0.73	5.98	4.63	1.33	69.0	246.0	8.0	0.49	10.0
40	Nanthikkara	5.65	5.55	4.25	0.35	0.14	0.11	0.24	0.35	2.45	2.10	3.00	0.50	0.59	0.25	6.79	4.69	1.82	63.9	239.0	11.3	0.40	11.0
41	Puthukkad	5.90	5.80	4.50	0.80	0.06	0.11	0.44	0.55	1.25	0.70	2.38	1.13	0.56	0.29	5.61	4.91	0.96	77.7	257.5	7.0	0.73	7.0
42	Elamthuruthy	5.70	5.60	4.15	0.55	0.06	0.30	0.55	0.85	1.60	0.75	1.75	0.38	0.50	0.22	4.44	3.69	0.64	63.9	226.0	6.0	0.91	9.0
43	Mannuthy	5.25	5.05	4.15	0.70	0.07	0.51	0.64	1.15	3.25	2.10	2.38	0.75	1.49	0.68	8.49	6.44	0.61	62.3	262.0	9.5	1.07	16.0
44	Vazhukkampara	5.40	5.30	4.05	0.55	0.07	0.42	0.73	1.15	3.45	2.30	2.13	0.75	0.45	0.41	7.18	4.88	1.19	52.9	253.0	10.5	1.20	18.0
45	Thanippara	5.80	5.75	4.55	0.50	0.06	0.42	0.63	1.05	2.35	1.30	2.25	0.50	0.40	0.19	5.69	4.39	1.21	58.7	216.0	6.0	1.04	13.0
46	Kannara	5.50	5.15	3.95	0.35	0.11	0.31	0.54	0.85	3.45	2.60	1.63	0.63	0.59	0.46	7.76	5.16	1.21	55.4	204 0	11.5	0.89	17.0
47	Alpara	5.15	4.85	3.75	0.90	0.08	0.43	1.12	1.55	3.25	1.70	1.75	0.75	0.83	0.44	7.02	5.32	1.16	53.6	213.5	7.5	1.85	16.0
48	Pattikkad	5.60	5.40	4.25	0.55	0.08	0.26	0.29	0.55	2.10	1.55	2.88	1.13	0.63	0.57	7.29	5.74	1.13	71.2	257.5	6.5	0.48	6.0
49	Chuvannamannu	5.45	5.25	3.95	0.90	0.05	0.54	1.66	2.20	2.45	0.25	1.88	0.25	0.64	0.22	5.43	5.18	0.64	54.8	221.0	14.5	2.74	12.0
50	Thottappady	5.40	5.25	3.95	0.75	0.05	0.42	0.93	1.35	2.15	0.80	1.75	0.50	0.89	0.59	5.89	5.09	0.91	63.5	231.0	8.0	1.53	12.0
Mean		5.48	5.32	4.18	0.58	0.08	0.33	0.65	0.98	2.45	1.47	2.12	0.68	0.73	0.43	6.48	5.02	1.08	62.5	236.0	8.8	1.07	12.2

Soil pH(H_2O) exhibited significant positive correlation with pH(KCl) and base saturation while a negative significant correlation was observed with increase in pH on submergence, exchangeable hydrogen, exchangeable acidity, CEC, effective CEC, total acidity, exchangeable aluminimum, different forms of aluminium (extractable and amorphous) exchangeable iron, lime requirement based on Shoemaker *et al.* method, pH, exchangeable Al, and total acidity.

The pH values recorded in 1N KCl solution varied from 3.65 to 4.35 in samples from Malappuram district, 3.75 to 4.85 in Palakkad samples and Thrissur samples varied from 3.75 to 4.55. The pH was found to decrease in 1N KCl in all the soils when compared to pH(H_2O). The pH(KCl) showed positive significant correlation with base saturation, while significant negative correlation was recorded with pH(H_2O), increase in pH on submergence, exchangeable hydrogen, exchangeable acidity, CEC, effective CEC, total acidity, exchangeable aluminium, ammonium oxalate extractable Al (amorphous form) and lime requirement based on Shoemaker *et al.* method and exchangeable aluminium.

The pH values exhibited a positive difference between pH(H_2O) and pH(KCl) which indicates that the soils were negatively charged and contain considerable amount of reserve acidity (Bandyopadhyay and Chattopadhyay, 1997). The correlation study reveals that pH(H_2O) and pH(KCl) show a significant possitive correlation with base saturation while all other factors like different forms of acidities, lime requirement based on various methods, exchangeable aluminium and hydrogen while organic carbon exhibits a significant negative correlation. Halder *et al.* (1985) reported a negative correlation between pH and lime requirement values. pH(H_2O) and pH(KCl) had significant negative correlation with exchangeable acidity (r = -0.418** and -0.553**). Similar results were obtained by Bandhyopadhyay and Chattopadhyay (1997).

1.1.2 Effect of submergence on pH

Fifty surface soil samples were kept under submerged condition for 40 days and the increase of pH was observed at 10 days interval. The pH was stabilized in the fourth sampling (after 40 days). The increase in pH was from 0.3 to 1.7 unit in Malappuram samples 0.1 to 1.05 in Palakkad samples and 0.25 to 0.90 units was recorded by Thrissur samples. Increase of pH units on submergence recorded positive correlation with organic carbon, exchangeable hydrogen, exchangeable acidity, total acidity, exchangeable aluminium, different forms of Al and Fe and lime requirement based on different methods while significant negative correlation with pH(H_2O), pH(KCl), exchangeable calcium and base saturation of the soil.

The data reveal that the increase in pH ranges from 0.3 to 1.7 units. It took four weeks for stabilizing the pH. Marykutty (1986) reported that only pH(H_2O) and pH($CaCl_2$) obtained a significant negative correlation with the effect of submergence on pH values. Under submerged conditions iron and aluminium turns to reduced form using the available H^+ ions present in the soil solution which results in the increase of pH on submergence. Further, under reduced condition, there is an evolution of CO_2 which again form an equilibrium between carbonate and bicarbonate in the system. This also helps the increase of the pH under submerged conditions. This is the reason for the positive correlation of acidity contributing factors and negative correlation with base saturation and exchangeable calcium.

1.1.3 Electrical conductivity (dS m^{-1})

Electrical conductivity ranged from 0.04 to 0.22 in soils from Malappuram district, 0.06 to 0.12 in Palakkad soils and 0.05 to 0.14 in Thrissur samples.

The electrical conductivity of the fifty surface soil samples varied from 0.04 to 0.22. Marykutty (1986) studied the EC of laterite alluvium and reported that the values ranged from 0.03 to 0.49.

1.1.4 Exchangeable hydrogen and aluminium (cmol(+) kg^{-1})

Exchangeable hydrogen values ranged from 0.11 to 0.59 in Malappuram samples, 0.21 to 0.52 in Palakkad soils and those from Thrissur showed a range of 0.11 to 0.54. Exchangeable hydrogen had significant positive correlation with increase in pH on submergence, exchangeable acidity, total acidity, organic carbon, exchangeable aluminium and lime requirement based on exchangeable aluminium, and total acidity and it showed significant negative correlation with pH(H_2O), pH(KCl), exchangeable calcium, base saturation and pH dependent acidity.

Exchangeable aluminium status varied from 0.25 to 2.54 in soils from Malappuram district, 0.44 to 2.01 in Palakkad samples and 0.24 to 1.66 in Thrissur soils. A positive significant correlation was observed with different forms of aluminium, ammonium oxalate extractable iron (amorphous), lime requirements, increase in pH on submergence, organic carbon, exchangeable hydrogen, exchangeable acidity, effective CEC and total acidity while it showed significant negative correlation with pH(H_2O), pH(KCl), pH dependent acidity and base saturation of the soils.

The perusal of the data indicate that all the soils recorded a higher content of the exchangeable aluminium than hydrogen. Yuan (1963) used titration curves of 1N KCl extracts of the soils to determine exchangeable hydrogen and aluminium and found that very acid soils (<4.8 pH) had more hydrogen than aluminium ions, at higher pH values more aluminium than hydrogen ions and both becomes negligible above pH 5.8. From the results of 50 samples studied, the pH ranges from 4.35 to 5.8. The exchangeable hydrogen content varies from 0.11 to 0.59 whereas the exchangeable aluminium content ranges from 0.20 to 2.54. These results clearly indicate that at a pH between 4.8 and 5.8, the soil predominates with aluminium. Bandyopadhyay and Chattopadhyay (1997) studied 21 acid soils ranging in pH from 5.4 to 6.3. Exchangeable H^+ content varied from 0.02 to 0.5 cmol(+) kg^{-1} while exchangeable aluminium varied from 0.2 to 2.3. These results strongly supported the present study.

The exchangeable hydrogen has a significant positive correlation to exchangeable acidity and total acidity (r = 0.57** and 0.297**) whereas the r values for exchangeable aluminium are 0.879** and 0.406** respectively. Further, it is noticed that there is a negative correlation for exchangeable hydrogen and aluminium to pH dependent acidity (r = -0.29** and -0.215*). This means that where the soils contain high amount of H^+ ions and Al^{3+} ions, there the exchangeable acidity predominates while the contribution of pH dependent acidity decreases. This study is supported by the work of Sharma *et al.* (1990), Das *et al.* (1991) and Das *et al.* (1992).

1.1.5 Exchangeable acidity, total acidity and pH dependent acidity ($cmol(+)\ kg^{-1}$)

Exchangeable acidity ranged from 0.45 to 2.94 in Malappuram samples, 0.65 to 2.45 in Palakkad soils and 0.35 to 2.20 in Thrissur samples. It showed a significant positive correlation with organic carbon, increase in pH on submergence, exchangeable hydrogen, total acidity, exchangeable aluminium, different forms of aluminium and lime requirement based on Shoemaker *et al.* method and exchangeable aluminium and observed significant negative correlation with pH(H_2O), pH(KCl), pH dependent acidity, exchangeable calcium and base saturation of soils.

Total acidity values had a range from 0.85 to 4.20 in Malappuram samples, 2.05 to 4.05 in Palakkad soils and 1.25 to 3.45 in Thrissur samples. Total acidity exhibited significant positive correlation with exchangeable aluminium, total aluminium, amorphous iron, different methods of lime requirements, increase in pH on submergence, organic carbon, pH dependent acidity, exchangeable hydrogen, exchangeable acidity, CEC, effective CEC and exhibited negative correlation with pH(H_2O), pH(KCl) and base saturation.

pH dependent acidity varied from 0.20 to 2.70 in Malappuram soil group, 0.70 to 3.10 in Palakkad soils and 0.25 to 2.60 in Thrissur samples. pH dependent acidity recorded significant positive correlation with organic carbon, exchangeable calcium, CEC, total acidity and lime requirement based on Shoemaker *et al.* method and total acidity, while it registered significant negative correlation with exchangeable acidity, base saturation, exchangeable aluminium and lime requirement based on exchangeable aluminium.

Exchangeable acidity includes the exchangeable H^+ and Al^{3+} held at permanent charge sites of the exchange complex (Black *et al.*, 1965). Exchangeable H^+ content at different locations varied from 0.11 to 0.59 while exchangeable Al^{3+} varied from 0.2 to 2.54. Exchangeable Al^{3+} contributes 69 to 86 per cent of the exchangeable acidity. The contribution of exchangeale acidity to total acidity account 50 to 70 per cent for Malappuram soils, 31 to 60 per cent for Palakkad soils and 28 to 64 for Thrissur soil respectively. These values were generally observed to be the highest at lower pH values as observed by Das *et al.* (1992).

pH(H_2O) and pH(KCl) had significant negative relationships with exchangeable acidity and total acidity. Exchangeable acidity is due to the replacement of H^+ and Al^{3+} from the exchange sites by K^+ and their presence in soil solution in active form contributes to soil acidity. Exchangeable aluminium had a positively high significant r value (r = 0.879**) with exchangeable acidity and the r value of total acidity was only 0.406**. This high correlation of exchangeable Al^{3+} should be taken into account in liming and nutrient management of such soils.

The difference between total acidity and exchangeable acidity accounts for pH dependent acidity. The contribution of pH dependent acidity to total acidity varied from 23 to 66 per cent for Malappuram soils, 34 to 76 per cent for Palakkad soils and 20 to 75 per cent for Thrissur soils. Das *et al.* (1992) and bandhyopadhyay and Chattopadhyay (1997) reported that the value of pH dependent acidity and total acidity showed significant positive correlation with clay and free oxides of Fe and Al. Oxides of Fe and Al, usually associated with soil clays are responsible for both component of total acidity. Again, they reported that clay is responsible for both component of total acidity (exchangeable and pH dependent acidity) whereas the oxides are responsible only for the pH dependent acidity. Thus the major soil factors responsible for producing different kinds of acidity are pH, exchangeable and extractabale Al^{3+}, clay, free oxides of Fe^{3+} and Al^{3+}.

Coleman and Thomas (1967) have defined soil acidity in terms of KCl extractable and pH dependent acidity. The first type is ascribed to isomorphous substitution, while the second type to the polymers of Fe and Al and soil organic matter. Similar results were reported by Singh *et al.* (1993) and kailashkumar *et al.* (1995). Dipak *et al.* (1997) reported that pH dependent acidity was the major contributor of total acidity and total acidity is closely associated with oxides of Fe^{3+} and Al^{3+}.

1.1.6 Exchangeable cations (Ca, Mg, K and Na) (cmol(+) kg^{-1})

Exchangeable calcium status of Malappuram soils ranged from 1.13 to 3.75, 1.00 to 3.88 in Palakkad samples and 1.63 to 3.00 in Thrissur soils. It showed significant positive correlation with organic carbon, pH dependent acidity, CEC, effective CEC and base saturation and exhibited significant negative correlation with increase in pH on submergence, exchangeable hydrogen and exchangeable acidity of the soil.

Exchangeable magnesium status varied from 0.25 to 1.50 in Malappuram samples. 0.25 to 1.13 in Palakkad soils and those from Thrissur showed a range of 0.25 to 1.13. Exchangeable potassium showed a range from 0.39 to 2.08, 0.61 to 2.23 and 0.40 to 1.49 respectively in Malappuram, Palakkad and Thrissur surface soil samples. Exchangeable sodium ranged from 0.32 to 1.00 in Malappuram samples, 0.29 to 0.95 in Palakkad soils and 0.19 to 0.73 in Thrissur samples.

The data indicated that among the cations, exchangeable calcium dominates in all soils followed by exchangeable K, Mg and Na. If calcium is predominant among exchangeable cations, soil colloids are in a coagulating state, which is condusive for the formation of water soluble aggregates and improves the soil structure. As calcium precipitates organic and mineral colloids, it enables their retention and accumulations in the soil and enhances its exchange capacity. The positive correlation of exchangeable calcium with CEC, effective CEC and base saturation is due to the increased content of exchangeable calcium in soil which replaces by H^+ ions which in turn gives a negative correlation with exchangeable hydrogen and exchangeable acidity. Marykutty (1986) studied the exchangeable characters of 100 soil samples and found out that exchangeable calcium predominates among the cations. Dipak *et al.* (1997) reported that calcium was the dominant cation on the exchange complex followed by K, Mg and Na in Alfisols and Inceptisols.

1.1.7 Cation exchange capacity and Effective cation exchange capacity (cmol(+) kg^{-1})

Cation exchange capacity (CEC) showed a range from 4.88 to 11.91 in the soils of malappuram district, 5.62 to 9.46 in Palakkad soils and 4.44 to 8.49 in Thrissur samples. CEC exhibited significant positive correlation with effective CEC, base saturation, total acidity, different forms of aluminium, lime requirement based on total acidity, organic carbon, pH dependent acidity and exchangeable calcium while significant negative correlation is obtained with pH(H_2O).

Effective cation exchange capacity (ECEC) recorded a range from 3.73 to 10.26, 4.22 to 7.51 and 3.69 to 6.44 respectively in Malappuram, Palakkad and Thrissur soil samples. ECEC exhibited significant positive correlation with base saturation, total acidity, exchangeable aluminium, different forms of aluminium, exchangeable iron, lime requirement based on exchangeable aluminium, organic carbon, exchangeable calcium and CEC, and a significant negative correlation is observed with pH(H_2O) and pH(KCl).

The cation exchange capacity depends on soil reaction and the ratio of the negatively charged colloids (acidoids) to amphoteric one in soil (Yagodin, 1984). CEC and ECEC had a positive correlation with lime requirement. Marykutty (1986) also reported that CEC and ECEC had a positive direct effect with the lime requirement of the soil. CEC is calculated as the sum of cations and total acidity whereas the ECEC is the sum of cations and exchangeable acidity. So if the total acidity of the soil is more, which directly reflects the CEC and ECEC, hence a positive correlation with lime requirement. The positive correlation with base saturation is to be expected from theoretical considerations.

1.1.8 Organic carbon (per cent)

Organic carbon content varied from 0.73 to 2.42 in Malappuram samples, 0.88 to 1.94 in Palakkad soils and 0.61 to 1.82 in Thrissur samples. Organic carbon obtained significant positive correlation with increase in pH on submergence, pH dependent acidity, exchangeable calcium, exchangeable acidity, CEC, effective CEC, total acidity, exchangeable aluminium, different forms of aluminium, exchangeable iron, amorphous iron, and lime requirements while a significant negative correlation is recorded with pH(H_2O), pH(KCl) and base saturation of soils.

The results show that the organic carbon exhibits a significant positive correlation with all forms of acidity. The total acidity ranged from 0.85 to

4.2 cmol(+) kg^{-1} in the three soils. The lower value of total acidity may be due to low contents of organic carbon as the organic matter might have contributed to total acidity through their functional groups like - COOH and phenolic - OH (Bandyopadhyay and Chattopadhyay, 1997), which explains such relationships. Organic carbon has a significant negative correlation with pH values. Marykutty (1986) also reported that organic carbon had a negative direct effect on pH values. According to Yagodin (1984), in organic colloids (humic substances) the negative charge and the capacity for exchange adsorption of cations are due to the carboxyl (-COOH) and phenolytic hydroxyl (-OH) groups, whose H^+ ions may be substituted by other cations. The four carboxyl groups in humic acid molecule may dissociate H^+ ions and exchange them for other cations at different pH value, the first H^+ ions is replaced at pH 4.5, the second H^+ at pH 7.0 and the third and fourth at pH 9 and above. Hence in acidic and neutral pH values, the exchange and sorption involves only two carboxyls of humic acid molecule.

1.1.9 Base saturation (per cent)

Base saturation exhibited a range from 47.2 to 88.4 in Malappuram samples, 45.3 to 74.8 in Palakkad soils and 51.9 to 77.7 in Thrissur samples. It exhibited significant negative correlation with total acidity, exchangeable aluminium, amorphous iron, lime requirements, increase in pH on submergence, organic carbon, pH dependent acidity, exchangeable hydrogen and exchangeable acidity while observed significant positive correlation with pH(H_2O), pH(KCl), exchangeable calcium, CEC and ECEC of soils.

The data reveal that the maximum base saturation obtained from the soils collected from Malappuram district. The CEC of these soils were registered higher value which also reflected in the higher base saturation. The significant negative correlation with all forms of acidities indicate that H^+ ions from the exchange complex is replaced by cations consequently the base saturation is increased which in turn reduced all the acidities. The negative correlation of lime requirement explains that the soil which has low base saturation requires more lime. The negative correlation of the organic carbon indicates the presence of carboxyl group of the organic matter.

1.1.10 Exchangeable iron (ppm)

Exchangeable iron status varied from 232.0 to 404.5, 180.5 to 213.0 and 204.0 to 262.0 respectively for soils collected from Malappuram, Palakkad and Thrissur districts. It showed significant positive correlation with organic carbon, ECEC, different forms of aluminium and iron while exhibited negative correlation with pH(H_2O).

One of the factor for the acidity of soils is the presence of free oxides of Fe^{3+} and Al^{3+}. The exchangeable iron and aluminium are more available at low pH values. Hence a negative correlation obtained with pH(H_2O). The positive correlation of the organic carbon may be due to the carboxyl (-COOH) and phenolic hydroxyl (-OH) groups of the organic matter content, which decreases the pH of the soil.

1.1.11 Lime requirement based on Shoemaker *et al.* method, exchangeable aluminium and total acidity ($CaCO_3$ t ha^{-1})

The lime requirement values by Shoemaker *et al.* method of determination for the soils collected from Malappuram, Palakkad and Thrissur districts ranged from 8.0 to 12.5, 7.5 to 12.0 and 6.0 to 11.5 respectively. A positive significant correlation was obtained with lime requirement based on exchangeable aluminium and total acidity, increase in pH on submergence, organic carbon, pH dependent acidity, exchangeable acidity, exchangeable aluminium, total aluminium and different forms of aluminium while it showed significant negative correlation with pH(H_2O), pH(KCl) and base saturation of soils.

The lime requirement based on exchangeable aluminium ranged from 0.41 to 4.19 in Malappuram soils, 0.73 to 3.32 in Palakkad soils and 0.40 to 2.74 in Thrissur soils.A significant positive correlation was obtained with increase in pH on submergence, organic carbon, exchangeable hydrogen, exchangeable acidity, ECEC, total acidity, exchangeable aluminium, different forms of aluminium, amorphous iron, and lime requirement based on pH while it recorded negative correlation with pH(H_2O), pH(KCl), pH dependent acidity and base saturation.

The lime requirement values based on total acidity varied from 14.0 to 19.0, 10.0 to 20.0 and 6.0 to 18.0 respectively for Malappuram, Palakkad and Thrissur soil samples. Lime requirement values showed significant positive correlation with organic carbon, pH dependent acidity, exchangeable hydrogen, CEC, total acidity, total aluminium, and lime requirement based on pH and it exhibited negative correlation with pH(H_2O), pH(KCl) and base saturation of the soil.

The perusal of the data indicate that the lime requirement based on exchangeable aluminium (exchangeable aluminium x 1.5 times Ca) recorded very less amount of $CaCO_3$ comparing with other methods. Lime requirement based on total acidity obtained maximum amount of $CaCO_3$. The true meaning of the term 'lime requirement' reflects the amount of lime needed for maximum economic return from a particular crop on particular soil. Total acidity includes both exchangeable and pH dependent acidity. Barium chloride - triethanol solution buffered at pH 8.0 is used for the measurement of total acidity. This value is generally much greater (sometimes 10 times) than that for exchangeable aluminium because it also includes non-exchangeable hydrogen associated with carboxyl groups, iron and aluminium hydroxy oxides. These components have no detrimental effect on plant growth (Kamprath, 1970). Therefore titrable acidity is of no practical value.

When base saturation is calculated as the sum of basic cations divided by the sum of basic cations plus titrable acidity, the value obtained exaggerates the actual acidity of soils that have pH dependent acidity. So a large amount of lime is needed to neutralise the pH dependent acidity also. Again it is found that lime requirement based on exchangeable Al^{3+} is negatively correlated with pH dependent acidity while the other two LR's are positively correlated. The pH dependent acidity is mainly due to the free oxides of Fe^{3+} and Al^{3+}.

All methods have a significant positive correlation with organic carbon, different forms of Fe and Al, exchangeable acidity and total acidity. Sharma and Tripathi (1989) also reported the similar correlations. The negative correlations with pH(H_2O), pH(KCl) and base saturation is to be expected from theoretical considerations. Sharma and Tripathi (1989) further reported the negative correlation of lime requirement based on different methods with base saturation. All these findings were in confirmity with the present study.

1.2 Total elemental analysis, different forms of aluminium and iron and textural classes of surface soil samples (Table 4)

1.2.1 Elemental analysis of Al, Fe, P, K, Ca and Mg (per cent)

Total aluminium content showed a range from 0.134 to 0.799 for

Table 4. Total elemental analysis, different forms of aluminium and iron and textural classes of surface soil samples

Sl. No.	Location	Total elemental analysis (%)						Al (ppm)		Fe (ppm)		Textural classes (%)		
		Al	Fe	P	K	Ca	Mg	Extract-ctable	Amor-phous	Extract-ctable	Amor-phos	Sand	Silt	Clay
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A. Malappuram district														
1	Angadippuram	0.159	0.084	0.073	0.16	0.07	0.08	62.2	341.1	10.6	454.0	54.5	15.9	27.9
2	Perinthalmanna	0.212	0.106	0.090	0.25	0.06	0.05	52.3	292.6	12.1	652.0	49.5	11.9	35.9
3	Aliparamba	0.227	0.097	0.071	0.15	0.09	0.07	42.5	270.8	13.3	524.0	29.8	39.9	27.9
4	Thazhekode	0.188	0.118	0.075	0.15	0.07	0.05	55.4	304.5	9.5	641.5	57.6	11.9	30.0
5	Vettathur	0.243	0.106	0.082	0.14	0.08	0.04	57.5	310.2	10.4	682.5	61.9	8.0	27.9
6	Puthanazhi	0.148	0.121	0.042	0.12	0.12	0.08	40.8	236.3	11.3	720.5	50.1	8.0	39.9
7	Iringatiri	0.169	0.143	0.046	0.12	0.13	0.09	62.9	364.8	14.8	750.0	59.9	11.9	23.9
8	Kuttathy	0.192	0.180	0.050	0.06	0.09	0.06	31.4	177.5	9.4	907.0	36.5	15.9	44.0
9	Thuvvur	0.267	0.108	0.030	0.08	0.11	0.04	38.6	216.2	9.9	719.0	38.9	23.9	36.0
10	Kalikavu	0.274	0.124	0.028	0.13	0.13	0.01	41.6	228.6	10.3	708.5	62.2	7.9	28.0
11	Karuvarakundu	0.417	0.106	0.046	0.11	0.09	0.05	56.8	297.9	16.4	978.5	53.9	7.9	35.9
12	Mampuzha	0.295	0.114	0.044	0.10	0.06	0.05	57.2	320.3	15.7	796.5	70.1	4.0	23.9
13	Pankikkad	0.418	0.109	0.055	0.12	0.05	0.02	61.0	311.1	15.1	480.5	61.9	7.9	27.0
14	Vaniyambalam	0.480	0.112	0.066	0.06	0.08	0.06	47.7	250.1	18.2	696.5	37.0	27.9	31.9
15	Edayattur	0.145	0.120	0.057	0.11	0.11	0.06	39.4	216.4	19.1	708.5	53.9	11.9	32.0
16	Melattur	0.799	0.122	0.046	0.16	0.10	0.08	43.6	252.6	20.0	661.0	49.7	12.0	36.0
17	Edappatta	0.173	0.062	0.032	0.14	0.07	0.05	58.3	302.9	16.3	578.0	57.6	11.9	27.9
18	Wandoor	0.138	0.107	0.147	0.14	0.09	0.05	63.5	336.6	17.2	600.5	56.8	11.9	28.0
19	Elamkulam	0.301	0.125	0.041	0.16	0.05	0.06	42.6	221.3	15.3	522.5	65.8	12.0	19.9
20	Keezhattoor	0.169	0.104	0.042	0.12	0.12	0.08	33.6	184.6	10.7	528.5	54.4	8.0	36.0

Contd.

Table 4. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
21	Manjeri	0.134	0.107	0.033	0.22	0.09	0.05	38.4	208.8	9.5	480.5	56.2	16.0	23.9
22	Edavanna	0.144	0.125	0.056	0.20	0.07	0.06	37.7	199.6	9.7	433.5	58.1	12.0	27.9
Mean		0.259	0.114	0.057	0.14	0.09	0.06	48.4	265.6	13.4	667.2	53.5	13.6	30.5
B. Palakkad district														
23	Edathanattukara	0.189	0.110	0.035	0.09	0.05	0.04	39.1	203.3	8.5	517.0	66.0	4.0	27.9
24	Vattamannapuram	0.220	0.109	0.037	0.15	0.11	0.05	41.0	213.2	10.2	483.0	66.1	7.9	23.9
25	Alamallur	0.110	0.108	0.060	0.17	0.13	0.08	48.0	264.0	9.1	672.0	49.6	11.9	35.9
26	Unniyal	0.380	0.095	0.042	0.16	0.11	0.05	30.1	159.5	8.0	677.0	62.1	11.9	23.9
27	Karkidakamkunnu	0.410	0.101	0.043	0.18	0.06	0.04	35.8	182.6	8.6	445.0	46.2	12.0	39.9
28	Kanhirapuzha	0.248	0.103	0.066	0.17	0.07	0.06	37.6	199.3	9.1	267.5	40.9	12.0	44.0
29	Thachampara	0.263	0.101	0.045	0.16	0.09	0.06	39.0	210.6	8.9	338.0	58.6	11.9	31.0
30	Palakkazhi	0.288	0.114	0.049	0.15	0.11	0.05	43.0	223.1	9.9	676.5	49.6	11.9	36.0
31	Kattukulam	0.306	0.104	0.051	0.20	0.07	0.03	47.0	232.5	8.2	690.0	53.1	15.9	27.9
32	Bheemanadu	0.309	0.103	0.056	0.16	0.09	0.05	38.6	206.6	8.7	641.0	28.9	23.9	44.0
33	Kottopadam	0.260	0.099	0.062	0.11	0.13	0.04	42.8	213.8	10.8	661.0	48.7	16.0	32.0
34	Ariyoor	0.292	0.085	0.033	0.09	0.05	0.02	39.4	200.9	8.1	356.0	66.5	7.9	23.9
35	Kumaramputhur	0.192	0.113	0.052	0.14	0.07	0.04	37.7	195.8	8.1	633.0	49.7	11.9	35.9
36	Thathengalam	0.292	0.109	0.047	0.11	0.09	0.05	35.5	184.4	11.0	747.5	41.6	16.0	40.0
37	Mannarkkad	0.252	0.107	0.056	0.12	0.11	0.07	36.4	182.0	11.5	701.5	33.3	15.9	48.0
Mean		0.267	0.104	0.049	0.14	0.09	0.05	39.4	204.8	9.2	567.1	50.7	12.7	34.3
C. Thrissur district														
38	Nadathara	0.064	0.121	0.052	0.21	0.11	0.06	28.0	148.4	11.9	467.0	29.8	23.9	43.9
39	Ollur	0.211	0.119	0.053	0.24	0.05	0.04	30.0	159.0	12.4	492.5	53.7	11.9	31.9
40	Nandikkara	0.064	0.103	0.054	0.14	0.09	0.06	33.0	169.0	12.0	541.0	40.9	8.0	48.0
41	Puthukkad	0.212	0.105	0.039	0.18	0.05	0.02	37.0	189.8	12.2	513.0	54.4	16.0	28.0

Contd.

Table 4. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
42	Elamthuruthy	0.106	0.110	0.042	0.17	0.06	0.04	25.8	131.6	11.9	545.5	58.9	16.0	23.9
43	Mannuthy	0.428	0.106	0.045	0.18	0.09	0.05	27.0	137.8	12.6	497.5	43.0	11.9	44.0
44	Vazhukkampara	0.138	0.119	0.046	0.22	0.09	0.06	28.0	148.4	12.3	635.5	46.0	15.9	36.0
45	Thanippara	0.110	0.117	0.033	0.23	0.05	0.03	31.5	156.3	11.4	682.0	30.0	24.0	43.9
46	Kannara	0.078	0.125	0.030	0.26	0.07	0.05	28.0	125.3	10.7	715.0	53.9	15.9	27.9
47	Alpara	0.120	0.121	0.029	0.23	0.09	0.04	23.9	111.8	11.3	513.0	50.1	16.0	31.9
48	Pattikkad	0.099	0.107	0.026	0.31	0.05	0.03	22.0	165.0	12.7	709.0	54.9	11.9	32.0
49	Chuvannamannu	0.067	0.123	0.039	0.29	0.05	0.02	33.0	158.8	11.9	255.0	46.9	15.9	36.0
50	Thottappadi	0.012	0.106	0.037	0.19	0.06	0.04	31.0	140.0	12.4	461.0	38.5	20.0	40.0
Mean		0.131	0.114	0.040	0.22	0.07	0.04	29.1	149.3	11.9	540.5	46.2	15.9	35.9

Malappuram soil, 0.110 to 0.410 for Palakkad soils and 0.012 to 0.428 for Thrissur samples. Total aluminium recorded significant positive correlation with total acidity, different forms of aluminium extractable iron (ammonium acetate extractable) and lime requirement based on Shoemaker *et al.* method and total acidity, and negatively correlated with total calcium content of the soil. Total iron status of the soil collected from Malappuram, Palakkad and Thrissur districts showed a range from 0.062 to 0.180, 0.085 to 0.114 and 0.103 to 0.125 respectively.

Total phosphorus content in the soils collected from Malappuram ranged 0.025 to 0.090, Palakkad samples from 0.033 to 0.062 and Thrissur soils from 0.026 to 0.054. Total potassium ranged from 0.06 to 0.25, 0.09 to 0.20 and 0.14 to 0.31 in Malappuram, Palakkad and Thrissur surface soil samples.

Total calcium content recorded a range from 0.05 to 0.13 in Malappuram samples, 0.05 to 0.13 in Palakkad soils and 0.05 to 0.11 in Thrissur samples. Total calcium showed significant positive correlation with increase in pH on submergence and extractable iron, while negatively correlated with total aluminium. Total magnesium content recorded for Malappuram, Palakkad and Thrissur soil samples ranged from 0.01 to 0.09, 0.02 to 0.08 and 0.02 to 0.06 respectively.

The data indicate that the content of Al and Fe are higher than P, K, Ca and Mg. Usually laterite soils contain high amount of sesqui oxides. The positive correlation of total aluminium with total acidity is due to the presence of exchangeable acidity in the total acidity. H^{+} and Al^{3+} ions constitute the exchange acidity. The positive correlation of aluminium with LR explains the fact that if the soil contains higher amounts of aluminium, it requires more lime and vice versa.

Table 5. Correlation coefficient matrix between soil characters of fifty surface soil samples

	Dry pH (H_2O)	pH (KCl)	Increase in pH on submergence	Organic carbon	Total calcium	pH dependent acidity	Exch Ca	Exch H	Exch acidity	CEC	ECEC	Base saturation	Total acidity	Exch aluminium	Total aluminium	Extractable aluminium	Amorphous aluminium	Exch. iron	Total iron	Extractable iron	Amorphous iron	LR based on Shoemaker *et al*	LR based on Exch aluminium	LR based on Total acidity
Dry pH (H_2O)		0.429	-0.481	-0.456	-0.032	-0.185	-0.152	-0.347	-0.418	-0.317	-0.250	-0.377	-0.555	-0.549	-0.109	-0.267	-0.264	-0.247	-0.055	-0.045	-0.113	-0.453	-0.549	-0.333
pH (Kcl)			-0.443	-0.217	-0.090	-0.078	0.104	-0.330	-0.553	-0.376	-0.032	0.314	-0.631	-0.422	0.078	-0.122	-0.264	-0.154	-0.033	-0.113	-0.085	-0.372	-0.422	-0.067
Increase in pH on sumergence				0.234	0.198	-0.031	-0.233	0.314	0.509	-0.046	-0.103	-0.451	0.336	0.499	0.098	0.207	0.218	0.160	0.047	0.322	0.216	0.219	0.499	0.143
Organic carbon					0.092	0.288	0.223	-0.022	0.351	0.404	0.301	-0.254	0.528	0.528	0.030	0.326	0.338	0.257	0.060	0.080	0.353	0.454	0.528	0.202
Total calcium						0.076	0.014	0.076	0.057	0.028	-0.016	-0.111	0.112	0.065	-0.412	0.038	0.079	0.104	-0.021	0.261	0.139	0.129	0.065	0.078
pH dependent acidity							0.226	-0.092	-0.320	0.590	0.162	-0.294	0.749	-0.215	0.185	-0.012	-0.124	-0.065	0.042	-0.154	0.145	0.368	-0.216	0.703
Exch. Ca								-0.305	-0.281	0.669	0.674	0.561	0.027	-0.066	-0.175	0.032	0.123	0.196	-0.124	-0.030	-0.117	-0.191	-0.065	-0.194
Exch. hydrogen									0.570	-0.087	-0.057	-0.487	0.297	0.283	0.169	0.048	0.064	0.060	0.186	0.129	0.123	0.168	0.283	0.297
Exch. acidity										-0.006	0.143	-0.515	0.386	0.879	0.058	0.233	0.216	0.093	0.072	0.083	0.186	0.266	0.878	0.142
CEC											0.881	0.246	0.572	0.196	0.085	0.210	0.266	0.187	-0.039	-0.159	0.009	0.188	0.195	0.285
ECEC												0.482	0.258	0.314	0.002	0.242	0.310	0.248	-0.073	-0.128	-0.077	0.020	0.314	-0.047
Base saturation													-0.642	-0.346	-0.186	-0.037	0.022	0.154	-0.147	-0.060	-0.318	-0.483	-0.346	-0.645
Total acidity														0.406	0.223	0.151	0.136	0.002	0.092	-0.093	0.271	0.542	0.406	0.782
Exch. aluminium															0.004	0.336	0.334	0.126	0.046	0.065	0.280	0.271	1.000	0.048
Total aluminium																0.242	0.244	0.051	-0.031	0.290	0.187	0.300	0.003	0.316
Exctractable aluminium																	0.971	0.400	0.136	0.334	0.210	0.312	0.336	0.097
Amorphous aluminium																		0.475	0.142	0.355	0.260	0.285	0.334	0.033
Exch. iron																			0.078	0.447	0.219	0.086	0.126	-0.077
Total iron																				-0.068	0.035	0.152	0.046	0.083
Exctractable iron																					0.225	0.026	0.065	0.131
Amorphous iron																						0.301	0.280	0.128
LR based on Shoemaker *et al*																							0.270	0.581
LR based on Exch. aluminium																								0.048
LR based on total acidity																								

** Significant at 1% level
* Significant at 5% level

1.2.2 Ammonium acetate extractable iron and aluminium (ppm)

The ammonium acetate extractable iron (extractable iron) status showed a range from 9.4 to 20.0, 8.1 to 11.5 and 10.7 to 12.7 in soils from Malappuram, Palakkad and Thrissur districts respectively. It showed significant positive correlation with increase in pH on submergence, total calcium, total aluminium, different forms of aluminium, exchangeable iron, amorphous iron and lime requirements while it showed a significant negative correlation with base saturation of soils.

The Ammonium acetate extractable aluminium (extractable aluminium) ranged from 31.4 to 63.5 in Malappuram soils, 30.1 to 48.0 in Palakkad samples and 22.0 to 37.0 in Thrissur soils. It indicated significant positive correlation with amorphous aluminium, exchangeable iron, different forms of iron, lime requirement based on Shoemaker *et al.* and exchangeable aluminium, increase in pH on submergence, organic carbon, exchangeable acidity, CEC, ECEC, exchangeable aluminium and total aluminium while it registered significant negative correlation with pH(H_2O).

The data indicated that the extractable iron and aluminium are less when compared to their amorphous forms. The content of aluminium is more than iron content. The extractable aluminium shows a significant correlation with organic carbon and exchangeable acidity, while extractable iron does not indicate any correlation with these characters. This may be due to the contribution of this iron to pH dependent acidity. Both extractable iron and aluminium shows a positive correlation with lime requirement. The work of Sharma and Tripathi (1989) also reported that lime requirement had a positive correlation with organic carbon and extractable forms of iron and aluminium.

1.2.3 Ammonium oxalate extractable iron and aluminium (ppm)

Ammonium oxalate extractable iron (amorphous iron) showed a range from 433.5 to 978.5 in Malappuram samples, 267.5 to 747.5 in Palakkad soils and 255.0 to 715.0 in Thrissur samples. Amorphous form of iron recorded significant positive correlation with increase in pH on submergence, organic carbon, total acidity, exchangeable aluminium, different forms of aluminium, exchangeable iron, extractable iron and lime requirement based on pH and exchangeable aluminium and exhibited negative correlation with base saturation.

The ammonium oxalate extractable aluminium (amorphous aluminium) content varied from 184.6 to 364.8 in Malappuram soils, 159.5 to 264.0 in Palakkad samples and 111.8 to 189.9 in Thrissur soils. The amorphous form of aluminium exhibited significant positive correlation with increase in pH on submergence, organic carbon, exchangeable acidity, CEC, ECEC, exchangeable aluminium, total aluminium, extractable aluminium, different forms of iron and lime requirement based on Shoemaker *et al.* and exchangeable aluminium while it recorded significant negative correlation with pH(H_2O) and pH(KCl).

Ammonium oxalate extracts a higher content of iron and aluminium from the soils. These forms of iron and aluminium are positively correlated with lime requirement values and negatively correlated with base saturation as in the case of their extractable forms. Similar results were reported by Sharma and Tripathi (1989).

1.2.4 Textural classification (per cent)

The sand per cent varied from 29.8 to 70.1, 28.9 to 66.1 and 29.8 to 58.9

in the soil samples collected respectively from Malappuram, Palakkad and Thrissur districts. Their silt content showed a range from 4.0 to 39.9, 4.0 to 23.9 and 8.0 to 24.0. The clay per cent showed a range from 19.9 to 44.0 in Malappuram samples, 23.9 to 48.0 in Palakkad soils and 23.9 to 48.0 in Thrissur samples.

The perusal of the data indicated that the clay content varied from 19.9 to 48.0 per cent. Marykutty (1986) studied the textural classification of 25 soil samples of laterite alluvium and reported that the clay content varied from 23 to 45 per cent and further reported that clay per cent of the soil had a positive correlation with lime requirements. The fine clay and colloidal fractions consists primarily of secondary aluminosilicates. Soils of heavy texture have greater exchange capacity, causing more lime for neutralising the acidity.

Bandyopadhyay and Chattopadhyay (1997) reported that the values of pH dependent acidity and total acidity showed a significant positive correlation with clay and free oxides of iron and aluminium. Almost equal 'r' values of clay and free oxides of Fe and Al indicated that they had almost equal contribution to pH dependent acidity. Again they reported that oxides of Fe and Al, usually associated with soil clays were responsible for the pH dependent acidity. Hence, clay is responsible for both the component of acidity (exchangeable and pH dependent), whereas free oxides are responsible only for pH dependent acidity.

2 Pot culture experiment: Effect of graded level of lime on soil and plant characters

Three soils having low, medium and high exchangeable aluminium content were selected for pot culture experiment. The rice variety used was Triveni. Morphological observations and dry matter production at tillering, flowering and harvesting stages of crop growth were recorded. The soil and plant samples collected in the above three stages were analysed to study the nutrient composition and uptake pattern. The results are discussed under the following sections.

2.1 Effect of graded levelsof lime application on soil characters

2.1.1 pH

The influence of graded levels of lime application on pH of the three soils used in the pot culture experiment is given in Table 6 and Fig.1. The three soils showed significant difference in their pH values. The soil S_2 registered a maximum mean pH value of 6.03 while S_1 and S_3 had a mean value of 5.89 and 5.95 respectively. Lime application significantly increased the pH values. The treatment L_4 recorded the maximum pH (6.18) followed by L_3 and L_2 which were significantly superior to L_0 and L_1. Soil samples collected at the harvest stage (P_3) recorded the maximum pH value of 6.10. Different stages did not marked any significant difference eventhough the pH increased slightly. The increase of pH at the tillering stage (P_1) was 0.05 unit, from tillering to flowering stage (P_2) it was 0.2 unit and from flowering to harvesting stage (P_3) was only 0.08.

The interaction of soil and lime was significant. Soil S_3 registered the maximum pH value of 6.25 after the application of Ca at the rate of 2 times of the exchangeable aluminium equivalent (L_4). The perusal of the data showed that the highest pH recorded for soil S_2 may be due to the higher initial pH value of 5.83.

It has seen from the results that application of lime increased the pH values in all the three soils. Calcium cations displace hydrogen ions from the adsorbing complex of soil and acidity is neutralised. Application of lime at higher

Table 6. pH of the soils as influenced by the treatment at different stages of crop growth of rice

	Level of lime					Stage of crop growth				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	5.70	5.73	5.74	6.13	6.15	5.64	5.65	5.90	6.04	5.89
S_2	5.83	5.86	6.16	6.18	6.13	5.89	5.98	6.11	6.15	6.03
S_3	5.53	5.74	6.05	6.16	6.25	5.78	5.83	6.06	6.11	5.95
Mean	5.69	5.78	5.98	6.15	6.18	5.77	5.82	6.02	6.10	
<u>Stages</u>										
P_0	5.41	5.67	5.85	6.07	6.44					
P_1	5.50	5.62	5.87	6.12	6.00					
P_2	5.87	5.88	6.07	6.20	6.10					
P_3	5.98	5.95	6.15	6.23	6.18					

CD(0.05) for S = 0.036
CD(0.05) for L = 0.047
CD(0.05) for P = NS

CD(0.50) for S x L = 0.081
CD(0.05) for S x P = NS
CD(0.05) for L x P = NS

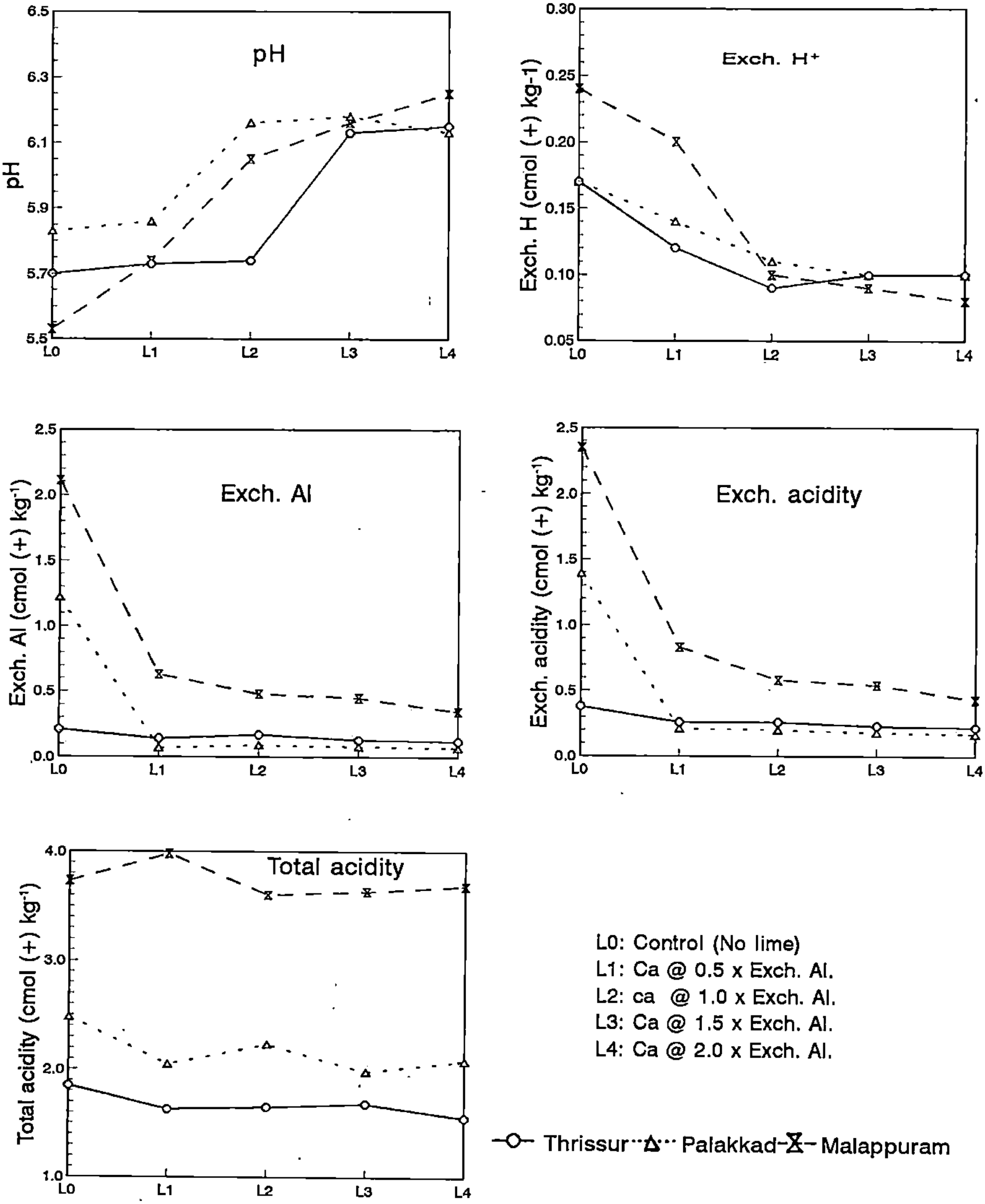


Fig 1. Effect of lime on pH, exchangeable hydrogen and aluminium, exchangeable acidity and total acidity

rates eliminates the active and exchange acidities and minimise the hydrolytic acidity, and raises calcium content in the soil solution. Higher the lime rate higher is the impact on acidity. Similar findings were reported by Marykutty (1986).

2.1.2 Organic carbon (per cent)

The data presented in Table 7 indicated the effect of lime application of the organic carbon content of three soils at different levels of lime. The three soils showed significant difference in their mean organic carbon values. The soil S_3 registered maximum organic carbon (2.54) content while S_1 recorded the minimum value (1.32). Lime application significantly influenced organic carbon content of the soils. The organic carbon content recorded at L_1 and L_4 were 1.70 and 1.74 respectively which were less than the control (1.75). Among the different stages of crop growth the flowering stage (P_2) had the highest organic carbon content (1.85). The interaction of S x L was found to be significant. At the initial stage from L_0 to L_1, there was a substantial decrease in organic carbon content in S_2 and S_3 and this decrease was up to L_3. But from L_3 to L_4 there was an increase in S_3 but a decrease was noticed in S_2. But in S_1 there was an increase from L_0 to L_1 and stable up to L_3 and then decreased at L_4. This differential behaviour in different soils is due to interaction of soil and lime. The treatment combination S_3L_2 registered maximum organic carbon (2.55) and S_2L_1 the minimum (1.29) when compared to other treatment combinations. The effect of other interactions were also found to be significant.

The results show that the organic carbon content decreased as the levels of lime increased. Lime application increased the pH of the soil which in turn decreases the organic carbon content. This is due to H^+ ions in the organic matter is replaced

Table 7. Organic carbon (per cent) of the soils as influenced by the treatments at different stages of crop growth of rice

	Level of lime					Stage of crop growth				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	1.31	1.34	1.34	1.34	1.27	1.26	1.21	1.55	1.26	1.32
S_2	1.41	1.29	1.38	1.47	1.42	1.37	1.26	1.42	1.54	1.40
S_3	2.53	2.46	2.55	2.45	2.53	2.52	2.47	2.59	2.56	2.50
Mean	1.75	1.70	1.75	1.75	1.74	1.71	1.65	1.85	1.78	
<u>Stages</u>										
P_0	1.67	1.63	1.70	1.72	1.72					
P_1	1.59	1.54	1.60	1.81	1.70					
P_2	2.03	1.79	1.87	1.73	1.84					
P_3	1.71	1.83	1.88	1.80	1.70					

CD(0.05) for S = 0.007
CD(0.05) for L = 0.015
CD(0.05) for P = 0.008

CD(0.50) for S x L = 0.016
CD(0.05) for S x P = 0.014
CD(0.05) for L x P = 0.018

by the cations. Das *et al.* (1991) reported that organic carbon possess significant negative correlation with soil pH which is in confirmity with this results.

2.1.3 Available phosphorus (ppm)

The presented data in Table 8 and Fig.2 showed the influence of lime on available phosphorus. The soils were significantly different in their available phosphorus status. The soil S_3 recorded maximum content of available phosphorus (30.62) which was significantly different from the other two soils. The available phosphorus of S_2 and S_1 were 8.91 and 8.05 respectively. The application of lime significantly increased available phosphorus from 13.99 to 18.13. Among the different stages of crop growth tillering stage (P_1 observed highest value (16.98) for available phosphorus. The various interaction effects also showed significance. The maximum value obtained for treatment combinations were 36.24, 33:25 and 30.73 for S_3L_4, S_3P_1 and L_4P_0 respectively.

The resultsreveal that there is an increase in the available phosphorus content of the soil with the application of graded levels of lime. In all the soils, the trend of increasing available phosphorus was observed with increasing level of lime application. But the maximum increase was noticed from L_2 to L_3. This increase is due to the maximum increase of pH is observed from L_2 to L_3, which reflect the maximum increase of available P in soil. Liming intensifies mobilisation of soil phosphates and improves phosphorus nutrition of plants. This is due to the activation of bacteria mineralising organic phosphates and conversion of difficulty soluble iron and aluminium phosphates into more readily available calcium phosphates as a result of neutralisation of soil acidity. Improvement in the availability of soil due to liming

Table 8. Available phosphorus (ppm) in the soils as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	7.77	7.79	7.86	8.38	8.41	8.27	8.44	7.87	7.62	8.05
S_2	8.03	8.51	8.79	9.50	9.74	9.80	9.25	8.59	8.00	8.91
S_3	26.17	27.67	28.36	34.64	36.24	31.48	33.25	31.64	26.12	30.62
Mean	13.99	14.66	15.00	17.51	18.13	16.52	16.98	16.03	13.91	
<u>Stages</u>										
P_0	2.38	7.70	15.62	26.12	30.73					
P_1	18.87	18.27	16.25	17.51	13.99					
P_2	19.13	16.72	14.73	14.88	14.69					
P_3	15.58	15.95	13.40	11.53	13.11					

CD(0.05) for S = 0.432
CD(0.05) for L = 0.558
CD(0.05) for P = 0.499

CD(0.50) for S x L = 0.967
CD(0.05) for S x P = 0.865
CD(0.05) for L x P = 1.116

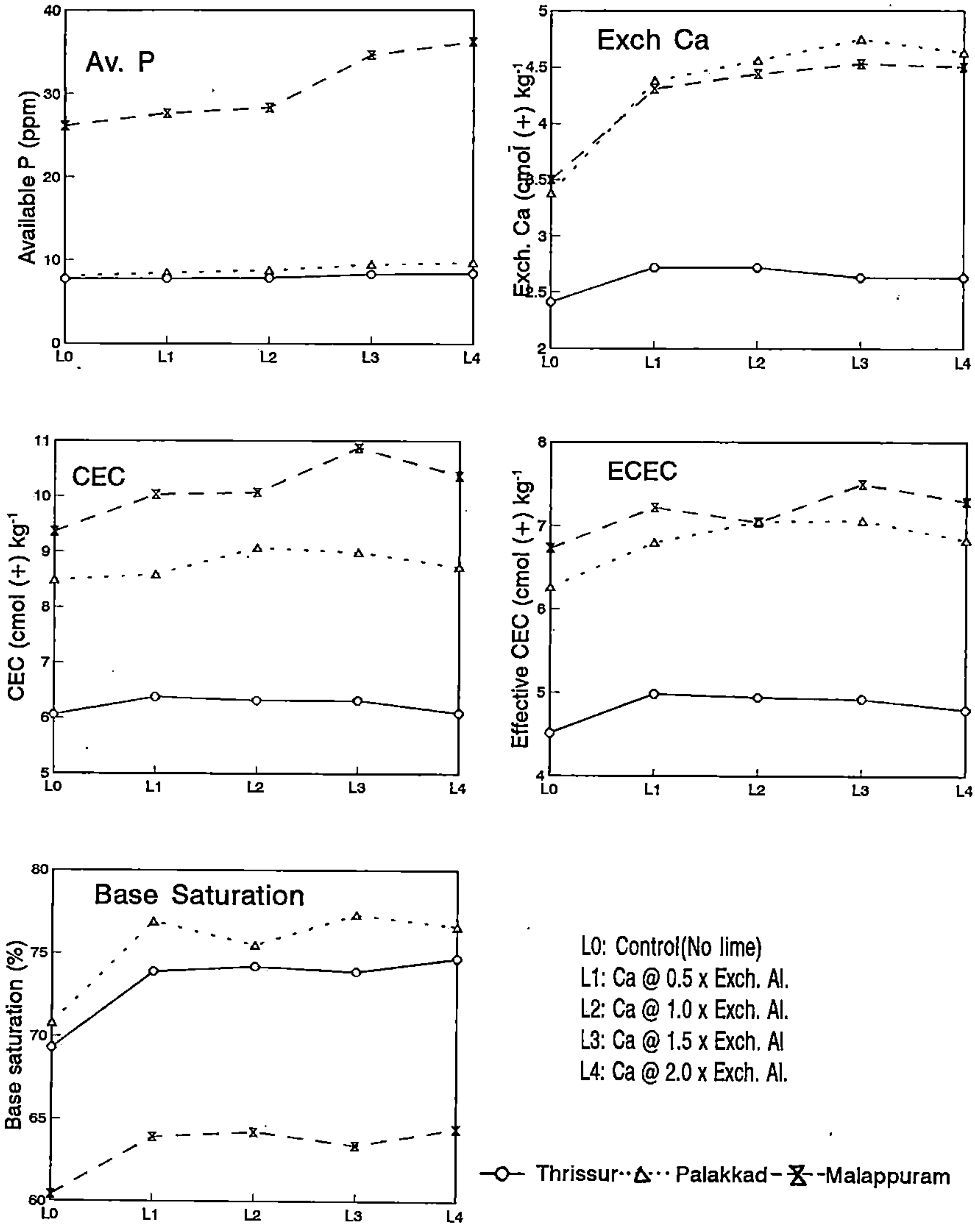


Fig 2. Effect of lime on available P, exchangeable Ca, CEC, ECEC and base saturation

of acid laterite soils has been reported by several workers (Maria *et al.*, 1985; Pande, 1987; Gupta *et al.*, 1989; Marykutty and Aiyer, 1992).

At P_0, available P content of the soil increased with the higher level of lime application. But at other stages, a decreasing trend was noticed, that is for higher levels of lime, the availability of P is decreased. At P_0, there is no plants, so the available P in the soil accumulates resulting an increasing trend at P_0. But in other stages, the plants absorb the available P for their growth and development.

The soils differ appreciably in the content of available phosphorus, although the same amount of phosphorus is applied to all of them. The soils differ significantly in pH and other acidity contributing factors. Singificantly more available phosphorus has been observed in soils at the tillering stage (P_1) and later a decreasing trend is mostly due to the uptake of phosphorus by growing plants.

2.1.4 Exchangeable hydrogen (cmol(+) kg^{-1})

The influence of lime on the exchangeable hydrogen content of the soil is given in the Table 9 and Fig.1 revealed that the exchangeable hydrogen content was significantly different in the three soils. The soil S_3 had higher content of exchangeable hydrogen (0.14). The difference in between the soils is only 0.01. The application of graded levels of lime significantly decreased exchangeable hydrogen content from 0.19 to 0.09. The maximum content was observed before transplanting of seedlings (0.16). The interaction effects were also showed significance.

It is seen that the effect of liming on exchangeable hydrogen is to have a drastic decrease up to L_2 and increasing the level of lime beyond this level has only very marginal effect to decrease the exchangeable hydrogen in all the three soils. This

Table 9. Exchangeable hydrogn (cmol(+) kg^{-1}) of the soils as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	0.17	0.12	0.09	0.10	0.10	0.14	0.11	0.12	0.09	0.12
S_2	0.17	0.14	0.11	0.10	0.10	0.16	0.13	0.13	0.08	0.13
S_3	0.24	0.20	0.10	0.09	0.08	0.18	0.14	0.13	0.12	0.14
Mean	0.19	0.15	0.10	0.10	0.09	0.16	0.13	0.13	0.09	
<u>Stages</u>										
P_0	0.25	0.15	0.13	0.16	0.11					
P_1	0.19	0.17	0.12	0.08	0.08					
P_2	0.18	0.15	0.11	0.09	0.11					
P_3	0.16	0.14	0.05	0.05	0.08					

CD(0.05) for S = 0.001
CD(0.05) for L = 0.001
CD(0.05) for P = 0.001

CD(0.50) for S x L = 0.003
CD(0.05) for S x P = 0.002
CD(0.05) for L x P = 0.003

is due to the increase of pH due to liming and at higher pH the presence of H^+ ions is negligible.

The results indicate that the exchangeable hydrogen content of the soil decreases markedly by the application of graded levels of lime. The exchangeable hydrogen content of the three soils studied were differed by only 0.01. The studies of Yuan (1963) showed that highly acid soils had greater proportion of hydrogen ions than aluminium in the exchange complex. At higher pH, there was more aluminium than hydrogen. Both, however, become negligible above pH 5.8 (pH in 1N KCl). These soils are not very acidic, hence the hydrogen ion content is less compared to aluminium. The work of Maria *et al.* (1985), Marykutty and Aiyer (1992) revealed that liming decreases the exchangeable hydrogen content of the soil. Thus the observation in the study are not different from those of the earlier workers. The hydrogen ion replaced by calcium ion is converted by reaction with OH^- ions of lime. With the maturity of the crop the hydrogen content is decreasing. This is due to the slight increase of the pH of the soil as the crop is matured.

2.1.5 Exchangeable aluminium (cmol(+) kg^{-1})

Data on the influence of lime on exchangeable aluminium are given in Table 10 and Fig.1. The three soils used in the pot culture experiment showed a significant difference in their exchangeable aluminium content. The soil S_3 recorded maximum value (0.81), S_2 obtained a value of 0.31 and S_1 the minimum (0.15). All the three soils studied were significantly differed from each other. A gradual decrease of the exchangeable aluminium content was noticied as the crop matured. The maximum value recorded at the preplanting stage (0.66) and minimum at harvesting stage (0.31). All the interactions were found to be significant. The maximum and

Table 10. Exchangeable aluminium (cmol(+) kg^{-1}) of the soil as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
Soils										
S_1	0.21	0.14	0.17	0.13	0.12	0.12	0.22	0.14	0.15	0.15
S_2	1.22	0.07	0.09	0.08	0.07	0.87	0.17	0.09	0.09	0.31
S_3	2.11	0.63	0.48	0.45	0.35	0.99	0.91	0.62	0.70	0.81
Mean	1.18	0.28	0.25	0.22	0.18	0.66	0.43	0.28	0.31	
Stages										
P_0	2.99	0.08	0.10	0.06	0.09					
P_1	0.74	0.45	0.37	0.27	0.31					
P_2	0.50	0.29	0.23	0.29	0.11					
P_3	0.49	0.30	0.28	0.27	0.21					

CD(0.05) for S = 0.002
CD(0.05) for L = 0.002
CD(0.05) for P = 0.002

CD(0.50) for S x L = 0.004
CD(0.05) for S x P = 0.003
CD(0.05) for L x P = 0.004

minimum values recorded were 2.11 and 0.07 for S_3L_0 and S_2L_4, 0.99 and 0.09 for S_3P_0 and S_2P_2 and S_2P_3, 2.99 and 0.06 for P_0L_0 and P_0L_3 respectively. After the application of graded levels of lime there observed a significant and drastic reduction in the exchangeable aluminium content of soil from 1.18 to 0.18.

Liming at appropriate rates minimises the content of mobile compounds of aluminium and iron in the soil, they pass into an insoluble form, whereby their harmful effect on plant is eliminated. The application of liming material raised the soil pH and reduced the concentration of aluminium and hydrogen have been reported by many workers (Marthur *et al.*, 1985, Meena, 1987, Gupta *et al.*, 1989, Marykutty and Aiyer, 1992). It has been found that the reduction of exchangeable aluminium contents were 76, 78, 81 and 85 per cent over control. The drastic reduction noticed when Ca at the rate of 0.5 times exchangeable aluminium equivalent was applied. At higher doses the reduction was marginal. As the crop matured the aluminium content in the soil decreased. This may be due to the slight increase of pH of the soil at later stages. Gupta *et al.* (1989) and Dixit and Sharma (1993) reported that liming significantly decreased the different forms of aluminium and acidity of the soil. This result also is in confirmity with the above finding.

2.1.6 Exchangeable acidity (cmol(+) ka^{-1})

The influence of lime on the exchangeable acidity indicated significant difference in the three soils (Table 11 and Fig.1). The soil S_3 recorded maximum exchangeable acidity (0.95) when compared to other two soils. The values obtained for S_2 and S_1 were 0.44 and 0.27 respectively. The graded levels of lime application significantly and markedly reduced exchangeable acidity from 1.37 to 0.27. Among the different stages of crop growth samples at preplanting stage (P_0) recorded

Table 11. Exchangeable acidity (cmol(+) kg^{-1}) of soils as influenced by the treatments at different stages of the crop growth of rice

	Levels of lime					Stages of crop growth				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
Soils										
S_1	0.38	0.26	0.26	0.23	0.22	0.26	0.33	0.26	0.24	0.27
S_2	1.39	0.21	0.20	0.18	0.17	1.03	0.30	0.22	0.17	0.44
S_3	2.35	0.83	0.58	0.54	0.43	1.17	1.05	0.75	0.82	0.95
Mean	1.37	0.43	0.35	0.32	0.27	0.82	0.56	0.41	0.40	
Stages										
P_0	3.24	0.23	0.23	0.22	0.20					
P_1	0.93	0.62	0.49	0.35	0.39					
P_2	0.68	0.44	0.34	0.38	0.22					
P_3	0.65	0.44	0.33	0.32	0.29					

CD(0.05) for S = 0.035
CD(0.05) for L = 0.045
CD(0.05) for P = 0.040

CD(0.50) for S x L = 0.079
CD(0.05) for S x P = 0.070
CD(0.05) for L x P = 0.091

maximum exchangeable acidity (0.82) and decreased as the crop matured. Treatment combination S_3L_0 recorded high exchangeable acidity (2.35) when compared to other treatment combinations of lime and soils. All the interaction effects were also found to be significant. The maximum value obtained were 1.17 for S_3P_0 and 3.24 for L_0P_0 respectively.

Exchangeable acidity refers to the acidity (H + Al) released upon exchange by an unbuffered KCl solution (Reeuwijk, 1992).

Soil S_3 contributes 85 per cent aluminium to exchange acidity, while the contribution of S_2 and S_1 amount only 70 and 56 per cent respectively. In all soils the major exchange acidity (permanent charge) contributing factor is aluminimum. Prabhuraj and Murthy (1994) reported that the major contributing factors of different kinds of acidities are exchangeable Al^{3+}, exchangeable H^+ and functional group of soil humus. Kailashkumar *et al.* (1995) concluded that electrostatically bonded H^+ and Al^{3+} acidities constituted 39.3 per cent and 60.7 per cent of exchangeable acidities. In the present study also, the result obtained from the unlimed soil indicates that the contribution of Al^{3+} and H^+ ions to the exchange acidity comprised 86 and 14 per cent respectively. Liming reduced the exchangeable Al^{3+} more than 75 per cent, which in turn reduce the exchange acidity of the soil. The exchangeable acidity gradually decreased and tends to constant. This may be due to the slight increase of pH as the crop is matured, which in turn reduces the Al^{3+} and H^+ ion content.

2.1.7 Total acidity (cmol(+) kg^{-1})

The data presented in Table 12 and Fig.1 revealed that the total acidity was significantly different in the three soils. The soil S_3 had the maximum value of

Table 12. Total acidity (cmol(+) kg^{-1}) of soil as influenced by treatments at the different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	1.85	1.63	1.65	1.68	1.55	2.02	1.96	1.32	1.38	1.67
S_2	2.48	2.05	2.23	1.98	2.08	2.42	2.06	2.06	2.10	2.16
S_3	3.73	3.98	3.60	3.63	3.68	4.66	4.18	3.50	2.54	3.72
Mean	2.68	2.55	2.49	2.43	2.43	3.03	2.73	2.29	2.01	
<u>Stages</u>										
P_0	3.13	2.80	3.13	3.00	3.10					
P_1	3.10	2.80	2.77	2.77	2.23					
P_2	2.50	2.40	2.00	2.27	2.30					
P_3	2.00	2.20	2.07	1.68	2.10					

CD(0.05) for S = 0.08
CD(0.05) for L = 0.10
CD(0.05) for P = 0.09

CD(0.50) for S x L = 0.17
CD(0.05) for S x P = 0.15
CD(0.05) for L x P = 0.19

3.72 and the soil S_1 had the minimum value (1.67). Significant reduction was observed in the total acidity consequent to lime application (2.68 to 2.43). The maximum total acidity was obtained at the preplanting stage P_0 (3.03) and the total acidity was decreased as the crop was matured. The treatment combination S_3L_1 recorded maximum value (3.98), whereas S_1L_4 obtained the lowest value of 1.55.

The total acidity (potential acidity) refers the sum of exchangeable acidity (permanent charge) and the pH dependent acidity (hydrolytic acidity). The perusal of the data show that the per cent contribution of exchange acidity and pH dependent acidity towards total acidity were 16 and 84 for S_1, 20 and 80 for S_2 and 25 and 75 for S_3 respectively. The reduction of total acidity by the application of lime varies from 5 to 9 per cent only, whereas the exchangeable acidity tremendously reduced by more than 70 per cent. Bandyopadhyay and Chattopadhyay (1997) reported that the pH dependent acidity contributed 52 to 84 per cent towards total acidity while the contribution of exchangeable acidity varied from 15.8 to 47.2 per cent towards total acidity. This results also indicate that pH dependent acidity contributes much more to total acidity. The results further indicate that effect of lime application is more to exchangeable acidity, which in turn points out the importance of aluminium for lime requirement.

2.1.8 Exchangeable potassium and sodium (cmol(+) kg^{-1})

The data presented in Table 13 indicated that the exchangeable potassium content of the soils were significantly different. The soil S_2 recorded a maximum mean value of 1.01 for exchangeable potassium content while S_1 and S_3 recorded 0.92 and 0.93 respectively, which were on par. A reduction in the exchangeable potassium content of soil was observed from 0.98 to 0.92 consequent to lime

Table 13. Exchangeable potasium (cmol(+) kg^{-1}) of the soils as influenced by the treatments at different stages of crop growth of rice

	Level of lime					Stage of crop growth				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	0.85	1.02	0.91	0.95	0.90	1.03	0.88	1.21	0.57	0.92
S_2	1.07	0.99	0.94	0.99	1.03	1.04	1.11	1.08	0.80	1.01
S_3	1.01	0.89	0.92	0.97	0.87	1.51	0.82	0.82	0.52	0.93
Mean	0.98	0.97	0.92	0.97	0.93	1.19	0.94	1.04	0.65	
<u>Stages</u>										
P_0	1.19	1.18	1.21	1.19	1.20					
P_1	0.87	0.92	0.88	0.99	1.01					
P_2	1.10	1.14	0.98	1.08	0.89					
P_3	0.75	0.62	0.64	0.62	0.62					

CD(0.05) for S = 0.026
CD(0.05) for L = 0.033
CD(0.05) for P = 0.029

CD(0.50) for S x L = 0.058
CD(0.05) for S x P = 0.052
CD(0.05) for L x P = 0.067

application. The exchangeable potassium content was high at the preplanting stage (P_0) of the crop growth. The interaction effects were also significant. The maximum exchangeable potassium recorded for treatment combinations were 1.07, 1.51 and 1.21 for S_2L_0, S_3P_0 and L_2P_0 respectively.

The Table 14 showed significant difference in the exchangeable sodium content of the three soils used. The soil S_3 registered high content of exchangeable sodium (0.60) which was on par with S_2. S_2 and S_3 were significantly superior to S_1. The lime application had no marked increase on the exchangeable sodium content of soil. The soil collected at flowering stage (P_2) recorded maximum exchangeable sodium content (0.77) and at harvesting stage (P_3) the minimum (0.35).

Gupta *et al.* (1989) reported that liming decreased the available potassium content of the soils. The decrease of potassium content at different stages is due to the uptake of potassium by the plants. Addition of calcium restores the physical balance of the nutrient solution. Calcium acts as a strong antagonist with respect to other cations like H^+, Na^+, K^+, Al^{3+} etc. During liming the potassium present in non-exchangeable form is released at a faster rate. However, the antagonism between calcium and potassium, in their uptake by plants off-sets this effects. In fact, the antagonism is severe to the extent that application of lime often result in a decreased potassium availability to the crop (Maria *et al.*, 1985).

2.1.9 Exchangeable calcium and magnesium (cmol(+) kg^{-1})

The influence of lime application in the exchangeable calcium content of soils (Table 15 and Fig.2) at different stages of crop growth of rice showed significant difference between the three soils. The soil S_2 recorded high content (4.34) and the

Table 14. Exchangeable sodium (cmol(+) kg^{-1}) of the soils as influenced by the treatment at different stages of crop growth of rice

	Level of lime					Stage of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	0.55	0.50	0.58	0.56	0.52	0.44	0.55	0.79	0.39	0.54
S_2	0.63	0.56	0.59	0.60	0.53	0.49	0.57	0.90	0.37	0.58
S_3	0.54	0.57	0.58	0.65	0.64	0.95	0.55	0.61	0.29	0.60
Mean	0.57	0.55	0.59	0.60	0.57	0.63	0.55	0.77	0.35	
<u>Stages</u>										
P_0	0.60	0.62	0.71	0.68	0.52					
P_1	0.55	0.55	0.60	0.52	0.55					
P_2	0.80	0.74	0.68	0.82	0.78					
P_3	0.35	0.27	0.34	0.39	0.41					

CD(0.05) for S = 0.030
CD(0.05) for L = NS
CD(0.05) for P = 0.035

CD(0.50) for S x L = NS
CD(0.05) for S x P = 0.059
CD(0.05) for L x P = 0.077

Table 15. Exchangeable calcium (cmol(+) kg^{-1}) of the soils as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stage of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
Soils										
S_1	2.41	2.72	2.72	2.63	2.63	3.20	2.50	2.43	2.35	2.62
S_2	3.38	4.38	4.56	4.75	4.63	4.80	4.43	4.08	4.05	4.34
S_3	3.50	4.31	4.44	4.53	4.50	4.48	4.20	4.33	4.03	4.26
Mean	3.09	3.80	3.91	3.97	3.92	4.16	3.71	3.61	3.48	
Stages										
P_0	3.71	4.13	4.29	4.21	4.46					
P_1	3.00	3.79	3.92	3.92	3.92					
P_2	2.92	3.75	3.75	3.96	3.67					
P_3	2.75	3.54	3.67	3.80	3.63					

CD(0.05) for S = 0.088
CD(0.05) for L = 0.114
CD(0.05) for P = 0.102

CD(0.50) for S x L = 0.197
CD(0.05) for S x P = 0.176
CD(0.05) for L x P = 0.227

soil S_1 registered 2.62. The lime application significantly increased the exchangeable calcium from 3.09 to 3.97. The perusal of the results show that calcium content of the soil tremendously increased by the application of Ca at the rate of 0.5 times exchangeable aluminium equivalent (L_1) over control. This increase is 23 per cent. But for higher rate of lime application the increase of calcium content is marginal. For L_2 and L_3 the increase of calcium content is 26 and 28 per cent respectively over control. The pre planting stage (P_0) samples recorded high exchangeable calcium content (4.16) and it decreased towards harvesting stage (3.48). The treatment combination S_2L_3 registered maximum exchangeable calcium content (4.75) and S_1L_0 recorded minimum value (2.41). The interaction effects were also significant.

Data presented in the Table 16 showed significant difference in the exchangeable magnesium content in the three soils used. The soil S_2 had high content of 0.68 and S_1 had the minimum of 0.48. Lime application had no significant effect on the exchangeable magnesium content of the soil. The interaction effects were found to be significant. Lime application resulted in different response in the three soils. There is no gradual pattern or its influence. In S_1, there was an increasing trend up to L_3 and decreased at L_4. In S_2 and S_3 there was a decrease up to L_2, then increased and finally decreased at L_4.

Liming will increase the calcium content of the soil is a well known fact. The work of Marykutty (1986), Gupta *et al.* (1989) proved that liming increased the calcium content of the soil. The results further indicate that lower level of lime is more beneficial and economical. Marykutty and Aiyer (1992) reported that maximum yield was obtained when lime dose is well below 0.25 LR, for laterite soils.

Table 16. Exchangeable magnesium (cmol(+) kg^{-1}) of the soils as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	0.41	0.47	0.47	0.56	0.50	0.35	0.35	0.65	0.58	0.48
S_2	0.94	0.69	0.75	0.56	0.47	0.65	0.65	0.58	0.85	0.68
S_3	0.59	0.63	0.53	0.75	0.69	0.95	0.48	0.65	0.48	0.64
Mean	0.65	0.59	0.58	0.63	0.55	0.65	0.49	0.63	0.63	
<u>Stages</u>										
P_0	0.58	0.83	0.67	0.58	0.58					
P_1	0.58	0.38	0.50	0.54	0.46					
P_2	0.71	0.54	0.38	0.83	0.67					
P_3	0.71	0.63	0.79	0.54	0.50					

CD(0.05) for S = 0.068
CD(0.05) for L = NS
CD(0.05) for P = 0.078

CD(0.50) for S x L = 0.152
CD(0.05) for S x P = 0.136
CD(0.05) for L x P = 0.175

Exchangeable calcium and magnesium content of the soil decreases from the initial stages to final stage of the harvest. This may be due to the partial plant utilization of Ca and Mg exchanged by H^+ ions from the exchange sites.

2.1.10 Exchangeable iron (ppm)

The results presented in the Table 17 showed that three soils were significantly different in their exchangeable iron content. The soil S_3 had a maximum content of 306.8 and S_1 recorded 207.4. The minimum value was recorded by S_2 (166.2). The graded levels of lime markedly influenced the exchangeable iron content. The application caused significant reduction from 258.2 to 210.4 in the content of exchangeable iron. The decrease of exchangeable iron content was drastic at L_1 and there after marginal in all the three soils. The samples collected at preplanting stage (P_0) registered maximum mean value (233.9). The effect of interaction were also significant. Considering the treatment combinations the maximum amount of exchangeable iron recorded were 335.2, 316.9 and 261.2 for S_3L_0, S_3P_0 and L_0P_0 respectively.

The perusal of the data show that the maximum reduction of the iron content (12 per cent) over control occurred at the first level of the lime application. As in the case of the exchangeable aluminium at higher levels the gradation of decrease of iron content is less. It is interesting to note that calcium at the rate of 0.5 times exchangeable aluminium equivalent reduced 76 per cent of exchangeable aluminium, where as the iron content reduced only 12 per cent. Based on the studies on the liming of acid soils Bisnoi *et al.* (1988) reported that lime application decreased the exchangeable acidity and toxic levels of Al^{3+}, Fe^{3+} and Mn^{2+}.

Table 17. Exchangeable iron (ppm) of the soils as influenced by the treatments at different stages of crop growth of rice

	Level of lime					Stage of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	248.4	206.0	199.5	195.1	187.9	213.3	207.8	207.1	201.3	207.4
S_2	190.6	164.5	163.0	159.0	153.9	171.5	167.9	163.4	162.0	166.2
S_3	335.6	310.6	302.5	296.0	289.4	316.9	310.4	301.5	298.5	306.8
Mean	258.2	227.0	221.7	216.7	210.4	233.9	228.7	224.0	220.6	
<u>Stages</u>										
P_0	261.2	236.3	230.3	224.5	217.2					
P_1	260.5	229.7	222.2	219.5	211.7					
P_2	255.8	222.5	219.8	214.0	207.8					
P_3	255.3	219.7	214.3	208.8	204.8					

CD(0.05) for S = 1.87
CD(0.05) for L = 2.42
CD(0.05) for P = 2.16

CD(0.50) for S x L = 4.18
CD(0.05) for S x P = 3.74
CD(0.05) for L x P = NS

Gupta *et al* (1989) also concluded that liming decreased the available iron content of the soils. Iron can contribute towards the acidity of the soil by hydrolysis, but has a little effect on pH until most of the soil Al^{3+} has reacted (Tisdale *et al.*, 1995).

Devi *et al.* (1996) reported that by the application of lime the Fe^{2+} content of the soil reduced from 2088 to 1158 ppm of the Chalakkudy soil.

2.1.11 Cation exchange capacity and Effective cation exchange capacity (cmol(+) kg^{-1})

The Table 18 and Fig.2 presented a significant difference in the cation exchange capacity (CEC) of the three soils used in the pot culture experiment. The soil S_3 recorded maximum CEC value of 10.14 while the soil S_1 registered the minimum value (6.24). Maximum CEC was observed in the samples collected at flowering stage (P_2) of the crop growth. Lime application significantly increased CEC from 7.97 to 8.7. The interaction effects studied also showed significance. Cation exchange capacity increased from L_0 to L_1 and then decreased for further increase of lime application in S_1. It is increased up to L_2 and then decreased in S_2, while the increase was up to L_3 in S_3.

The values presented in Table 19 and Fig.2 showed the influence of the lime treatment on the effective cation exchange capacity (ECEC) of the three soils, denoted a significant difference between the three soils in the ECEC. The soil S_3 gave a maximum ECEC of 7.15 and soil S_1 minimum value of 4.83. The effect of lime application had a significant increase in the ECEC of the three soils (5.84 to 6.49). The ECEC of soil at different stages of crop growth indicated significant reduction from 6.89 to 5.51. The treatment combination S_3L_3 recorded maximum ECEC of 7.50 and S_1L_0 registered the minimum value (4.51). ECEC also had almost similar

Table 18. Cation exchange capacity (cmol(+) kg^{-1}) of the soils as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
<u>Soils</u>										
S_1	6.06	6.38	6.32	6.32	6.09	6.40	5.60	7.10	5.85	6.24
S_2	8.49	8.59	9.07	8.99	8.73	9.08	8.84	9.05	8.12	8.77
S_3	9.37	10.03	10.07	10.87	10.37	10.42	9.54	11.06	9.55	10.14
Mean	7.97	8.33	8.49	8.73	8.40	8.63	7.99	9.07	7.84	
<u>Stages</u>										
P_0	8.07	8.45	8.94	8.83	8.86					
P_1	7.50	8.04	7.89	8.29	8.24					
P_2	8.66	8.97	8.92	9.69	9.10					
P_3	7.66	7.86	8.20	8.10	7.38					

CD(0.05) for S = 0.122
CD(0.05) for L = 0.158
CD(0.05) for P = 0.141

CD(0.50) for S x L = 0.273
CD(0.05) for S x P = 0.244
CD(0.05) for L x P = 0.315

Table 19. Effective cation exchange capacity (cmol(+) kg^{-1}) of the soils as influenced by the treatments at different stages of the crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
Soils										
S_1	4.51	4.98	4.94	4.92	4.79	5.28	4.58	5.35	4.11	4.83
S_2	6.26	6.80	7.05	7.06	6.83	7.18	7.01	6.80	6.21	6.80
S_3	6.73	7.22	7.04	7.50	7.29	8.20	7.05	7.16	6.21	7.15
Mean	5.84	6.33	6.34	6.49	6.30	6.89	6.21	6.44	5.51	
Stages										
P_0	6.39	7.02	7.11	6.86	7.04					
P_1	5.79	6.21	6.36	6.33	6.37					
P_2	6.09	6.62	6.12	7.06	6.29					
P_3	5.08	5.48	5.77	5.72	5.51					

CD(0.05) for S = 0.117
CD(0.05) for L = 0.151
CD(0.05) for P = 0.135

CD(0.50) for S x L = 0.262
CD(0.05) for S x P = 0.234
CD(0.05) for L x P = 0.303

trend for lime application as CEC except for S_2 where the increase in ECEC was noticed up to L_3. The other interaction effects were also found to be significant.

Application of the lime drastically increased the calcium content of the soil (25 per cent) at L_1 level which in turn increases the CEC and ECEC of the soils. Bishnoi *et al.* (1988) reported that lime application increased CEC, ECEC and base saturation. Sharma and Tripathi (1989) also revealed that lime application was correlated with CEC. These findings are in confirmity with the above results.

2.1.12 Base saturation (per cent)

The results presented in Table 20 indicated a significant difference in the per cent base saturation of the three soils. The soil S_2 recorded maximum value of 75.4 and soil S_3 minimum of 63.2. Application of graded levels of lime caused significant increase in the per cent base saturation of soils. It decreased significantly towards harvesting stage (P_3) of the crop (77.1 to 65.9). The treatment combination S_2L_3 registered maximum per cent base saturation (77.3) when compared to other treatment combination. The interaction of soil with lime was not significant. All other interaction effects showed significance.

The data indicate that soil S_3 recorded a lower base saturation compared to S_1 and S_2 eventhough S_2 and S_3 obtained a higher CEC and ECEC. Base saturation is calculated on the basis of the sum of Ca, Mg, K and Na towards the total CEC. Soil S_3 contains more Al^{3+} and H^+ ions compared to other soils. This is the reason for low base saturation of S_3. A marked increase of 7.5 per cent of base saturation at the L_1 level of application was noticed. Further addition of lime does not increase the base saturation appreciably which also indicates that higher level of lime application is

Table 20. Base saturation (per cent) of the soils as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stages of crop growh				Mean
	L_0	L_1	L_2	L_3	L_4	P_0	P_1	P_2	P_3	
Soils										
S_1	69.3	73.9	74.2	73.9	74.7	78.4	76.4	71.5	66.6	73.2
S_2	70.8	76.9	75.5	77.3	76.6	77.0	76.6	73.2	74.9	75.4
S_3	60.4	63.9	64.2	63.4	64.4	75.8	63.2	57.7	56.1	63.2
Mean	66.8	71.6	71.3	71.5	71.9	77.1	72.0	67.5	65.9	
Stages										
P_0	75.1	80.3	77.2	75.9	76.8					
P_1	67.2	71.0	75.7	73.2	73.1					
P_2	64.9	69.9	65.6	70.3	66.6					
P_3	60.1	64.9	66.7	66.6	71.1					

CD(0.05) for S = 0.894
CD(0.05) for L = 1.153
CD(0.05) for P = 1.032

CD(0.50) for S x L = NS
CD(0.05) for S x P = 1.787
CD(0.05) for L x P = 2.307

not necessary for laterite soil. These findings are supported by the work of Bishnoi *et al.* (1988).

2.2 Growth and yield characters of rice

2.2.1 Height of the plant at different stages of crop growth (cm)

The average height of the plant was significantly different in the three soils (Table 21). Plants grown in soil collected from Iringatiri (S_3) of Malappuram district were significantly taller (63.2) than those grown in soils collected from Edathanattukara (S_2) of Palakkad district and Pattikkad (S_1) of Thrissur district. This increase in height was marked in treatments with lime application. The treatment corresponding to calcium at the rate of 0.5 times of exchangeable aluminium equivalent (L_1) exhibited a mean height of 58.2, while those in unlimed pots (L_0) attained a height of 55.7. The treatments L_1, L_2, L_3 and L_4 were on par.

Lime application increased the height of plant to 61.5 at flowering stage (P_2). The height showed significant difference during tillering (P_1) and flowering (P_2) stages. At flowering stage and harvesting stage (P_3) the difference was not marked. The interaction of soil with lime, and soil with stages of crop growth were significant whereas the interaction of lime with stages of crop growth was not significant. Lime application did not have an impact on the height of plants in S_1 and S_2, while there was significant increase in height of the plants when L_1 was applied in S_3.

The result indicate that application of lime significantly increases the mean height of the plant over control. At higher levels, the increase is not pronounced. All the levels of lime are on par with each other. Calcium is required for normal

Table 21. Influence of lime on the height of tillers of rice at different stages of crop growth (cm)

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
Soil									
S_1	54.6	56.3	54.4	55.6	56.4	48.5	59.5	58.4	55.5
S_2	52.9	53.5	50.9	54.0	55.1	46.6	56.9	56.3	53.3
S_3	59.6	64.8	66.4	63.8	61.3	54.0	68.1	67.4	63.2
Mean	55.7	58.2	57.2	57.8	57.6	49.8	61.5	60.7	
Stages									
P_1	48.3	50.5	49.2	50.0	50.6				
P_2	59.8	62.5	61.5	62.1	61.6				
P_3	59.1	61.7	60.9	61.3	60.5				

CD(0.05) for S = 1.179
CD(0.05) for L = 1.523
CD(0.05) for P = 1.179

CD(0.05) for SxL = 2.637
CD(0.05) for SxP = 2.043
CD(0.05) for LxP = NS

development of above ground organs which become stunted if the nutrient is deficient. This increase in height is due to the increased availability of soil nitrogen and phosphorus by lime application. The S_3 soil recorded the maximum height. This is due to the higher content of organic matter in that soil. The works of Anilakumar (1980), and Marykutty and Aiyer (1992) are in confirmity with these findings.

2.2.2 Number of tillers of rice plant at different stages of crop growth

The data presented in Table 22 revealed the existance of a significant difference in the number of tillers between the plants grown in three soils. The plants grown in soil S_3 recorded higher mean number of tillers (5.47) than soil S_2 (4.29) and soil S_3 (4.80). Application of lime markedly increased the average number of tillers in all the three soils. Lime applied at L_3 level increased the number of tillers in S_1. But at L_4 there was no effect. The tiller production was influenced by lime application in S_2. At L_1 and L_3 there was increased tiller production in S_3 while L_2 and L_4 did not have any effect. Out of the different levels of lime, the treatment L_3 recorded the highest number of tillers (5.37) while the unlimed pot (control) recorded a mean number of tillers of 4.41. The treatment L_1 was on par with L_2, L_3 and L_4. Among the three soils, soil S_3 recorded maximum number of tillers (6.0) at L_3 and soil S_2 recorded a minimum of 4.11 at L_0 (control).

Significant difference in the number of tillers was observed in all the three soils during the different stages of crop growth. The mean number of tillers were high at flowering (P_2) stages (5.38) and low at harvesting (P_3) stage (4.0). The interaction of soil with lime was significant whereas interaction of soil with stages of crop growth and lime with stages of crop growth were not significant.

Table 22. Influence of lime on the number of tillers of rice at different stages of crop growth

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
<u>Soil</u>									
S_1	4.44	4.67	5.11	5.56	4.22	5.07	5.27	4.07	4.80
S_2	4.11	4.44	4.22	4.56	4.11	4.73	5.00	3.13	4.29
S_3	4.67	5.89	5.00	6.00	4.78	5.73	5.87	4.80	5.47
Mean	4.41	5.00	4.78	5.37	4.70	5.18	5.38	4.00	
<u>Stages</u>									
P_1	4.56	5.33	5.22	5.78	5.00				
P_2	4.89	5.67	5.33	5.89	5.11				
P_3	3.78	4.00	3.78	4.44	4.00				

CD(0.05) for S = 0.286
CD(0.05) for L = 0.370
CD(0.05) for P = 0.286

CD(0.05) for SxL = 0.640
CD(0.05) for SxP = NS
CD(0.05) for LxP = NS

The data reveal that the three soils are significantly different in the production of tillers. The maximum production of tillers by S_3 is due to the higher content of organic carbon in the soil and increased availability of the nutrients by lime application. At the harvesting stage the number of tillers recorded are low comparing with flowering stage. At the flowering stage all the productive and unproductive tillers were accounted, while at the harvesting stage only productive tillers were taken. Anilakumar (1980), Mathur *et al.* (1985) recorded similar results.

2.2.3 Number of leaves of rice at different stages of crop growth

Data on the influence of lime on the number of leaves at different stages of crop growth of rice is presented in Table 23. The number of leaves were more in soil S_3 (18.6) than in soil S_2 (12.0) and soil S_1 (13.0). There was significant difference in the number of leaves in the three soils but the difference in number of leaves in soil S_1 and S_2 were more or less the same.

The application of lime had a significant effect on the number of leaves produced by rice plants, the increase being from 13.1 to 15.6. Among the different levels of lime applied the treatment L_3 recorded maximum value of 15.6 and the treatment L_0 (control) recorded minimum value (13.1). Influence of stages of growth revealed the maximum number of leaves at tillering (P_1) stage (19.0). The flowering (P_2) and harvesting (P_3) stages had exhibited the same number of leaves (12.3). The interaction of soil with lime was significant while interaction of soil with stages of growth and lime with stages of growth were not significant.

The effect of lime application on the number of leaves of the plants was pronounced in S_3. Even at L_1, the number of leaves was increased and further

Table 23. Influence of lime on the number of leaves of rice at different stages of crop growth

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
<u>Soil</u>									
S_1	12.3	13.1	14.2	14.3	11.1	17.7	10.6	10.7	13.0
S_2	11.9	12.0	12.0	12.1	12.2	16.1	9.9	10.1	12.0
S_3	15.2	17.9	17.9	20.3	21.4	23.3	16.3	16.1	18.6
Mean	13.1	14.3	14.7	15.6	14.9	19.0	12.3	12.3	
<u>Stages</u>									
P_1	17.1	20.0	19.0	19.9	19.2				
P_2	11.1	11.6	12.6	13.4	12.8				
P_3	11.2	11.4	12.6	13.4	12.8				

CD(0.05) for S = 0.80
CD(0.05) for L = 1.03
CD(0.05) for P = 0.80

CD(0.05) for SxL = 1.78
CD(0.05) for SxP = NS
CD(0.05) for LxP = NS

increase was noticed at L_3. But there was no effect of lime application on this character in S_2. At L_2 and L_3 the plants produced more number of leaves than control in S_1.

Nair (1970) reported that lime at half the lime requirement had several beneficial effects on growth, yield and quality of rice. Similarly many workers had reported the beneficial effects of lime on the production of leaves.

2.3 Yield characters

2.3.1 Grain yield (g pot^{-1})

The data presented in Table 24 and Fig.3 revealed the existance of a significant difference in the average grain yield of plants grown in the three soils. The rice plants grown in soil S_3 gave a significantly higher yield (33.6) compared to those grown in other soils. The lowest per pot grain yield of 23.2 was recorded form those under soil S_2. The lime application markedly increased mean yield over control from 23.7 to 31.8. There was significant difference in the per pot yield among the graded levels of lime application.

Even at L_1, lime application increased grain yield in S_1, but after L_1, there was a slow decrease in grain yield. At L_3 and L_4, the grain production were not better than control. In S_2, the grain production increased only at L_2 and remained at the same level for L_3 and L_4. Lime application at L_1 failed to have any effect on grain production in S_2. The lime application resulted an increasing trend of grain production even up to L_4 in S_3, though L_2, L_3 and L_4 were on par in this soil.

Calcium at the rate of 0.5 times exchangeable aluminium equivalent (L_1) increases 19 per cent mean yield. But at the higher levels the yield obtained are on par

Table 24. Influence of lime on grain yield and 1000 grain weight of rice

	Levels of lime					Mean
	L_0	L_1	L_2	L_3	L_4	
A. Grain yield (g pot^{-1})						
Soils						
S_1	25.2	34.2	31.2	29.6	28.6	29.7
S_2	18.1	19.1	25.3	27.3	25.9	23.2
S_3	27.8	31.0	37.9	37.8	40.9	33.6
Mean	23.7	28.1	31.5	31.6	31.8	
B. 1000 grain weight (g)						
Soils						
S_1	20.3	20.0	20.6	20.5	20.2	20.3
S_2	21.6	21.5	21.6	21.4	21.5	21.5
S_3	24.5	24.1	24.6	24.3	24.1	24.3
Mean	22.1	21.8	22.3	22.1	21.9	

	Grain yield	1000 grain weight
CD(0.05) for S	= 2.472	0.153
CD(0.05) for L	= 3.811	NS
CD(0.05) for SxL	= 5.529	NS

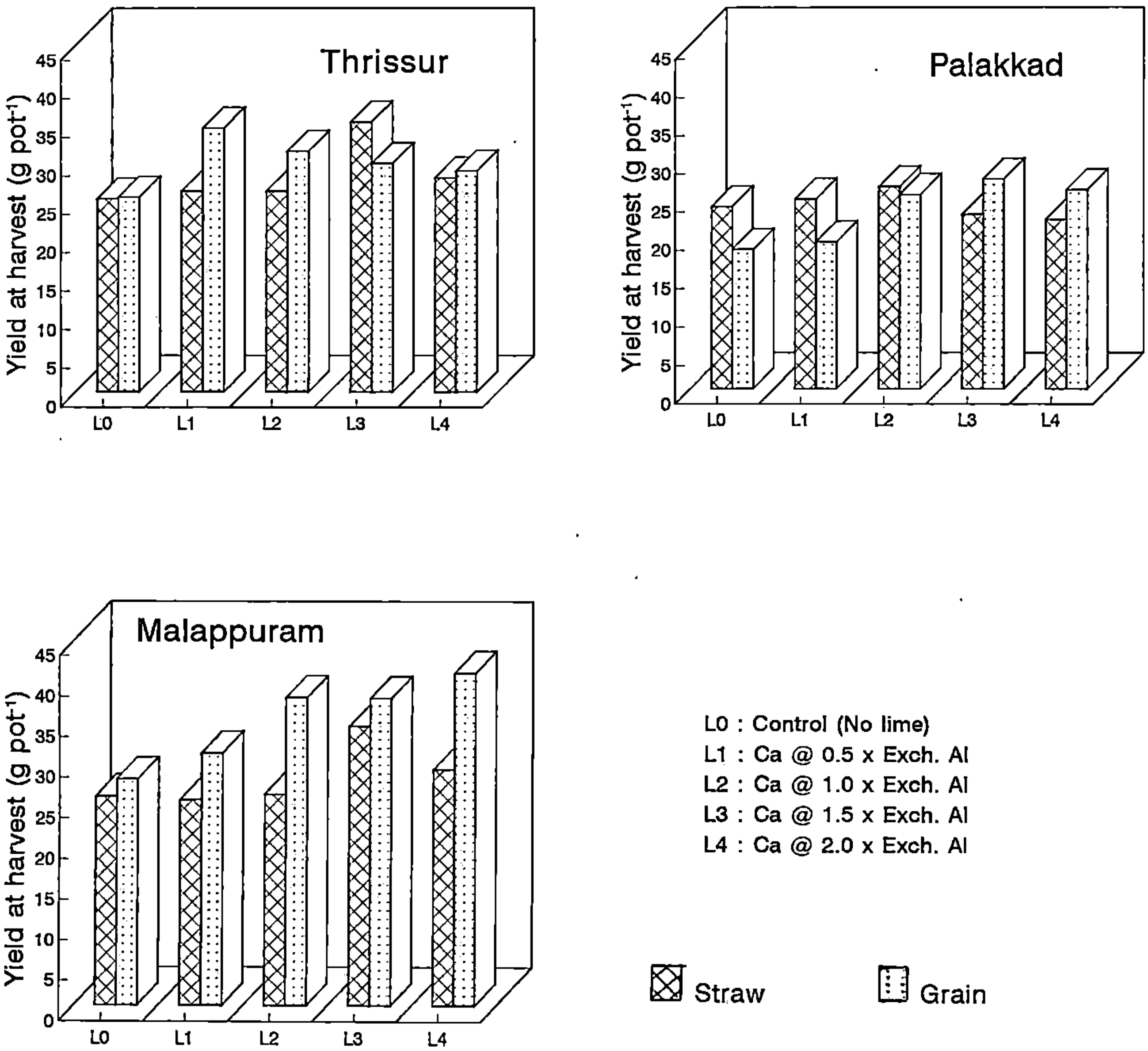


Fig 3. Effect of lime on the yield of straw and grain of three soils

with each other. There is no treatment difference among the levels of lime tried. This results pave the way to adopt the low liming rates for laterite soil, which will be more beneficial and economical. Marykutty and Aiyer (1992) showed that the maximum yield was obtained when lime dose well below 0.25 LR, that is the lowest level of lime application tried for laterite soil. The soil S_1 recorded highest significant yield when Ca at the rate of 0.5 times of exchangeable Al^{3+} was added, and at higher doses the yield was decreased, soils S_2 and S_3 obtained the significant highest yield at L_3 and L_4 respectively. But at higher levels they were on par with L_2. Hence L_2 level of lime application will be beneficial and economical for S_2 and S_3.

2.3.2 Weight of 1000 grain (g)

The influence of different levels of lime on 1000 grain weight is given in Table 24. The rice plants grown in the three soils were found to differ significantly in the weight of 1000 grains. The grains obtained from the plants grown in soil S_3 recorded more weight (24.3) which was significantly superior to those from the other two soils. There was no significant difference in the weight of 1000 grain among the graded levels of lime application.

The significant difference among the soils is due to the difference in nutrient content of the soil. The lime application did not show any significant difference. This may be due to the decrease of available potassium content in the soil by the application of lime.

2.3.3 Straw yield of rice at different stages of crop growth (g pot^{-1})

The data presented in Table 25 indicated significant difference in the yield of straw obtained at different stages of crop growth of rice plants in three soils by the

Table 25. Influence of lime on the weight of straw of rice at different stages of crop growth (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
<u>Soil</u>									
S_1	23.3	25.7	25.9	27.1	23.4	17.0	30.3	27.9	25.1
S_2	19.8	19.6	20.1	19.0	20.0	9.4	25.8	23.9	19.7
S_3	25.6	27.4	35.2	36.0	35.3	25.2	42.5	28.1	31.9
Mean	22.9	24.2	27.1	27.4	26.3	17.2	32.9	26.6	
<u>Stages</u>									
P_1	16.3	16.7	19.2	17.8	16.0				
P_2	27.6	30.7	35.9	33.7	36.6				
P_3	24.8	25.3	26.1	30.7	26.2				

CD(0.05) for S = 1.95
CD(0.05) for L = 2.52
CD(0.05) for P = 1.95

CD(0.05) for SxL = 4.36
CD(0.05) for SxP = 3.38
CD(0.05) for LxP = 4.36

lime application. The plants under the soil S_3 recorded an average straw weight of 31.9, while the straw obtained from the soil S_2 was only 19.7. The three soils were significantly differed from each other.

The graded level of lime caused significant difference among themselves and there was an increase in the straw weight from an mean value of 22.9 to 27.4 by the lime application over the control. The effect of interaction of soil with lime, soil with stages of growth and lime with stages of grwoth were significant. Lime application did not increase the straw yield in S_1 and S_2. But in S_3, lime application at L_2 and higher levels significantly increased the straw yield, though higher level did not have much impact on this character. The treatment combination S_3L_3 resulted in the maximum straw yield (36.0) while S_2L_3 registered the lowest straw yield (19.0). The flowering stage registered maximum straw yield (32.9) and tillering stage the minimum yield (17.2). The yield of straw at harvesting stage is shown in Fig.3.

The application of lime markedly increased the yield of straw. But there has been no significant difference in the yield with higher levels of lime application. Besides neutralising acidity, liming affects many other soil properties creating a more favourable medium for plant growth and development of useful microorganisms. The lime derived calcium coagulates of the soil calloids, improve soil structure and increase the water stability of soil aggregates. Lime also improves water permeability and aeration, prevents crusting and facilitates cultivation of heavy soils. The increase of yield can be attributed to the soil characters and to the correction of free acidity present in them, reduction in the toxicity of iron and aluminium and increase in the availability of nitrogen, phosphorus and enhanced supply of calcium as a nutrient. At harvesting stage the yield was less than at flowering stage. At the harvesting time the grain was separated from the straw and recorded separately. The work of Gupta *et al.* (1989) and Marykutty and Aiyer (1992) supported these findings.

2.4 Nutrient composition of straw and grain at different stages of the crop growth

2.4.1 Nitrogen content (per cent)

The effect of graded level of lime application on the nitrogen per cent of straw at different stages of crop growth of rice and grain is given in Table 26. The nitrogen content of straw from the plants grown in the three soils were found to differ significantly. The plants grown in soil S_1 retained more nitrogen in straw (2.44) while those from soil S_2 and S_3 retained 2.23 and 2.24 respectivley. Application of lime significantly increased the nitrogen content of the straw from 2.21 to 2.35 over control. But there is no significant difference between L_1, L_2, L_3 and L_4.

The different stages of the crop growth showed significant difference in the nitrogen content of the straw. At the tillering stage (P_1) there was more nitrogen in the straw (2.78) and it decreased towards the harvesting stage (1.88). The effects of interactions were significant. The plants grown in soil S_1 at tillering stage (S_1P_1) recorded significantly higher value for nitrogen content of the straw (2.98) compared to other treatment combinations.

The nitrogen content of the grain was significantly different in plants grown in the three soils. The plants grown in the soil S_3 retained high content of nitrogen (1.07) in the grain and those under soil S_2 retained the minimum value (0.94). There was increase in the nitrogen content of grain consequent to lime application from 0.99 to 1.04.

Table 26. Nitrogen content (per cent) of straw and grain as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	2.45	2.33	2.43	2.59	2.38	2.98	2.55	1.78	2.44
S_2	2.05	2.33	2.22	2.19	2.33	2.63	2.16	1.89	2.23
S_3	2.12	2.24	2.40	2.15	2.26	2.72	2.03	1.96	2.24
Mean	2.21	2.30	2.35	2.31	2.33	2.78	2.25	1.88	
Stages									
P_1	2.73	2.71	2.85	2.73	2.87				
P_2	2.17	2.26	2.29	2.24	2.26				
P_3	1.73	1.94	1.91	1.96	1.84				
B. Grain									
Soils						Mean			
S_1	1.01	1.03	1.05	1.06	1.07	1.04			
S_2	0.93	0.93	0.92	0.95	0.96	0.94			
S_3	1.04	1.05	1.08	1.10	1.09	1.07			
Mean	0.99	1.00	1.01	1.04	1.04				

A. Straw

CD(0.05) for S = 0.06 CD(0.05) for SxL = 0.12
CD(0.05) for L = 0.07 CD(0.05) for SxP = 0.09
CD(0.05) for P = 0.06 CD(0.05) for LxP = 0.12

B. Grain

CD(0.05) for S = 0.009
CD(0.05) for L = 0.009
CD(0.05) for SxL = 0.019

The result show that the per cent composition of nitrogen of the straw and grain increases significantly by the lime application. Liming increases the soil available nitrogen which in turn increases the corresponding nutrients in plants. The level of nitrogen in straw is maximum at tillering stage (2.78). During this period, the rate of growth has been significantly greater leading to more absorption of the nutrients. Beyond this stage, concentration of nutrients tends to decrease. The nutrient in the straw may be translocated to grain as the crop matured. This decrease is more due to an increase in dry matter production with decreased nutrient absorption in a dilution of the nutrient concentration. Guptal *et al.* (1989) also reported similar results.

2.4.2 Phosphorus content (per cent)

The data presented in the Table 27 revealed that the rice plants grown in the soil S_3 recorded significantly more phosphorus content of the straw (0.396) compared to plants grown in other soils. Addition of graded level of lime increased phosphorus content from 0.306 to 0.334 and showed significant difference among the treatments. Significantly more phosphorus content (0.415) was recorded at the tiller stage (P_1) of the crop and the content was decreased as the crop was matured (0.265).

The effects of interactions were also found to be significant. The treatment combination (S_3L_3) recorded the maximum phosphorus content of the straw (0.409). Lime application increased the P content of straw significantly in S_1 and S_2 up to L_2 level, whereas in S_3 the increase was noted only at L_3. The treatment combination S_3P_1 retained significantly more phosphorus content in the straw (0.503). The treatment combination L_3P_1 recorded significantly more phosphorus in the straw (0.445).

Table 27. Phosphorus content (per cent) of straw and grain as influenced by the treatments at different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.204	0.224	0.245	0.214	0.212	0.312	0.171	0.176	0.220
S_2	0.325	0.341	0.358	0.358	0.304	0.429	0.302	0.281	0.337
S_3	0.389	0.393	0.399	0.409	0.392	0.503	0.347	0.339	0.396
Mean	0.306	0.319	0.334	0.327	0.303	0.415	0.273	0.265	
Stages									
P_1	0.428	0.414	0.427	0.445	0.361				
P_2	0.254	0.270	0.299	0.264	0.279				
P_3	0.236	0.274	0.276	0.273	0.269				
B. Grain									
Soils						Mean			
S_1	0.059	0.062	0.062	0.065	0.065	0.063			
S_2	0.298	0.072	0.073	0.076	0.077	0.120			
S_3	0.103	0.102	0.106	0.109	0.111	0.106			
Mean	0.153	0.081	0.080	0.083	0.084				

A. Straw

CD(0.05) for S = 0.005 CD(0.05) for SxL = 0.011

CD(0.05) for L = 0.007 CD(0.05) for SxP = 0.009

CD(0.05) for P = 0.005 CD(0.05) for LxP = 0.011

B. Grain

CD(0.05) for S = NS

CD(0.05) for L = NS

CD(0.05) for SxL = NS

The data presented in the Table 27 also revealed that there was no significant difference in the phosphorus content of the grains on application of lime in the three soils studied.

The results reveal that the phosphorus of the straw is significantly different in the three soils. Lime application increased the phosphorus content of the straw. Liming intensifies the mobilization of soil phosphates and improves phosphorus nutrition of plants. This is due to the activation of bacteria mineralising organic phosphate and to coversion of difficulty soluble iron and aluminium phosphates into more readily available calcium phosphate (Maria *et al.*, 1985; Panda, 1987 and Gupta *et al.*, 1989). The level of phosphorus in straw is more at the tillering stage. The observed decrease at later stage may be attributed to the dilution of nutrient concentration consequent to increase in dry matter production and translocation of nutrients to the grain.

It has been noticed that crops take up phosphates during the initial period of the growth at a faster rate than at later stages. A plant build up a reserve of this nutrient, then redistributes it among its various organs depending on their phosphate requirements for synthesis of organic substances by the migration of the phosphates from vegetative into reproductive organs. These findings are in accordance with the results of Marykutty (1986).

2.4.3 Potassium content (per cent)

The rice plants grown in the soil S_3 retained significantly more potassium content of the straw (3.14) compared to plants grown in other soils (Table 28). The

Table 28. Potassium content (per cent) of straw and grain as influenced by the treatment at different stages of crop growth

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	2.59	3.07	3.17	2.72	3.29	3.31	2.90	2.69	2.97
S_2	3.25	2.93	2.79	2.56	2.98	3.52	3.08	2.10	2.90
S_3	2.94	3.30	3.20	3.27	2.97	3.51	3.11	2.79	3.14
Mean	2.92	3.10	3.05	2.85	3.08	3.45	3.03	2.53	
Stages									
P_1	3.46	3.42	3.52	3.40	3.42				
P_2	3.07	3.30	2.89	2.73	3.14				
P_3	2.23	2.57	2.75	2.41	2.68				
B. Grain									
Soils						Mean			
S_1	0.387	0.417	0.440	0.427	0.460	0.426			
S_2	0.427	0.427	0.470	0.460	0.490	0.455			
S_3	0.457	0.470	0.497	0.487	0.510	0.484			
Mean	0.423	0.438	0.469	0.458	0.487				

A. Straw

CD(0.05) for S = 0.17
CD(0.05) for L = NS
CD(0.05) for P = 0.17
CD(0.05) for SxL = 0.38
CD(0.05) for SxP = 0.30
CD(0.05) for LxP = NS

B. Grain

CD(0.05) for S = 0.005
CD(0.05) for L = 0.012
CD(0.05) for SxL = 0.012

graded levels of lime had no significant difference among themselves. Maximum potassium content was observed at the tillering stage (P_1) of the crop (3.45) and it decreased as the crop matured. The effects of interactions except that of lime with stages of growth was significant. The treatment combination S_2P_1 recorded maximum potassium content of straw (3.52) at tillering stage of the crop.

The S x L interaction was also found to be significant. Lime application at L_1 level increased the potassium content of the straw in S_1 significantly, though further increase in K content was not observed for higher levels of lime. Lime application did not influence the K content of straw in S_2 and S_3 significantly.

The plants grown in the three soils were significantly different in the potassium content of the grain. Plants from soil S_3 registered higher value for potassium content of the grain (0.484) while those from the soil S_1 recorded 0.426. The lime application significantly increased the potassium content of the grain from 0.423 to 0.487.

Lime application decreases potassium content in the straw of the plants grown in S_2. During liming, the potassium of the difficulty soluble minerals passes into more mobile compounds. However, because of the antagonism between calcium and potassium its uptake by plants does not increase. Studies of Militesen and Borlan (1965) revealed that the mobility of potassium in the soil and its assimilation by the plants decreased when acid soils were limed. Maria *et al.* (1985) also reported similar results. The levels of potassium are maximum at the tillering stage of the crop growth. The decrease thereafter observed during subsequent periods may be attributed to the dilution of nutrient concentration consequent to increase in dry matter production.

The result shows that there is no significant difference in the potassium content of the straw by lime application except in S_1. But there is a significant increase in the potassium content of the grain. The potassium in the straw may be translocated to the grain as the crop matured. More potassium is needed for grain production. Eventhough the lime application decreased the availability of potassium in the soil, the plants absorbed the maximum potassium from the soil for the production of grain, resulting an increased potassium content of grain. Panda (1984) reported that potassium absorbed after panicle initiation is solely utilized in increasing grain production.

2.4.4 Calcium and magnesium content (per cent)

The data presented in Table 29 revealed the significant difference in the calcium content of the straw of the plants grown in three soils. The plants grown in the soil S_3 recorded more calcium content in straw (0.371) while the soil S_1 gave only 0.337. The application of lime had increased the calcium content of the straw from 0.342 to 0.362. The calcium content of the straw decreased from tillering stage 0.381 to harvesting stage (0.321).

The effects of interaction were significant. The plant grown in the soil S_3 with L_4 level of lime (S_3L_4) gave maximum calcium content of the straw (0.40) and the plants grown in the same soil also ranked first in the calcium content at the tillering stage of the crop (0.424). Lime application did not influence the calcium content of the straw in S_1 significantly, whereas in S_2 it is increased up to L_3. The increase in calcium content of straw in S_3 was noticed only at L_4.

Table 29. Calcium content (per cent) of straw and grain as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.353	0.327	0.347	0.313	0.347	0.360	0.348	0.304	0.337
S_2	0.307	0.324	0.360	0.367	0.340	0.360	0.319	0.340	0.340
S_3	0.367	0.360	0.373	0.353	0.400	0.424	0.368	0.320	0.371
Mean	0.342	0.337	0.360	0.344	0.362	0.381	0.345	0.321	
Stages									
P_1	0.380	0.373	0.373	0.387	0.393				
P_2	0.340	0.324	0.347	0.340	0.373				
P_3	0.307	0.313	0.360	0.307	0.320				
B. Grain									
Soils						Mean			
S_1	0.036	0.038	0.042	0.044	0.045	0.041			
S_2	0.041	0.044	0.046	0.046	0.047	0.045			
S_3	0.050	0.052	0.053	0.057	0.060	0.054			
Mean	0.0.42	0.045	0.047	0.049	0.050				

A. Straw

CD(0.05) for S = 0.014   CD(0.05) for SxL = 0.032
CD(0.05) for L = 0.019   CD(0.05) for SxP = 0.025
CD(0.05) for P = 0.014   CD(0.05) for LxP = NS

B. Grain

CD(0.05) for S = 0.006
CD(0.05) for L = 0.009
CD(0.05) for SxL = 0.015

The plants grown in the soil S_3 showed significantly higher calcium content in the grain (0.054) and those from the soil S_1 and S_2 recorded 0.041 and 0.045 respectively. Lime application increased calcium content of the grain from 0.042 to 0.050 over the control.

The influence of the treatment on the magnesium content of the straw was given in Table 30. The data revealed that the rice plants grown in three soils vary in the magnesium content of straw but there was no significant difference in the content. Plants from the soil S_1 recorded 0.169 magnesium content and soil S_2 and S_3 recorded 0.166 and 0.161, respectively. There was no significant difference in the magnesium content with application of lime. The maximum magnesium content of straw was recorded at the harvesting stage (P_3) of the crop.

The effect of interaction of soil with lime and lime with stages of growth were significant. The treatment combination S_3L_4 registered highest magnesium content (0.192), which was significantly higher than the control. The treatment combination (S_3P_3) recorded high content of magnesium in the straw (0.185). Plants grown in the soil S_1 retained higher content of magnesium (0.032) in their grain while grain from S_2 and S_3 registered 0.024 and 0.028 respectively. The graded level of lime application increased the magnesium content of grain from 0.026 to 0.029 even though there is no significant difference.

The perusal of the data indicate that calcium content of the straw and grain increases significantly while there is no significant difference in the case of magnesium content of straw and grain. Lime application markedly increased the calcium content of the soil which in turn influence the calcium per cent of the straw. But it is noticed that the lime application does not influence magnesium content of the

Table 30. Magnesium content (per cent) of straw and grain as influenced by the treatment of different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.180	0.164	0.162	0.176	0.164	0.181	0.146	0.180	0.169
S_2	0.155	0.184	0.172	0.160	0.156	0.161	0.165	0.173	0.166
S_3	0.160	0.140	0.152	0.160	0.192	0.154	0.144	0.185	0.161
Mean	0.165	0.163	0.163	0.165	0.171	0.165	0.152	0.179	
Stages									
P_1	0.164	0.165	0.158	0.168	0.180				
P_2	0.139	0.152	0.152	0.176	0.140				
P_3	0.192	0.180	0.180	0.152	0.192				
B. Grain									
Soils						Mean			
S_1	0.030	0.030	0.032	0.033	0.034	0.032			
S_2	0.023	0.026	0.026	0.025	0.022	0.024			
S_3	0.026	0.027	0.027	0.030	0.031	0.028			
Mean	0.026	0.027	0.028	0.029	0.029				

A. Straw

CD(0.05) for S = NS　CD(0.05) for SxL = 0.031
CD(0.05) for L = NS　CD(0.05) for SxP = NS
CD(0.05) for P = NS　CD(0.05) for LxP = 0.079

B. Grain

CD(0.05) for S = 0.0006
CD(0.05) for L = NS
CD(0.05) for SxL = 0.0018

soil which automatically reflects the magnesium content of the straw and grain. Panda (1984) also reported similar results in support of these findigns.

2.4.5 Iron and aluminium content (per cent)

The rice plants grown in three soils showed significant difference in the iron content of the straw (Table 31). The plants grown under the soil S_2 registered more iron content of the straw (0.09) while those under soil S_1 and S_3 recorded 0.077 and 0.063 respectively. The different levels of lime application drastically and significantly reduced the iron content from 0.107 to 0.057. The iron content was more at tillering stage (P_1) of crop (0.091) and it reduced to 0.068 at the harvesting stage of the crop.

The interactions were also significant. The unlimed soils S_2 recorded the maximum iron content of the straw (0.131) and the same soil at the tillering stage also recorded more iron content (0.101) compared to other treatment combinations. Except in S_1, iron content is increased when lime application increased from L_3 to L_4. This has resulted in a corresponding increase for L_3 to L_4 when overall means of levels of lime was considered. Such a trend is not observed in the case of iron content of grains. The treatment combination P_1L_0 registered the maximum iron content (0.124) and it was significantly higher than the other treatment combinations of lime with stages of crop growth.

There was a significant difference in the iron content of the grain of the plants grown in the three soils. Plants from soil S_3 registered the maximum mean value for iron content of the grain (0.005) while the soil S_1 recorded minimum value of 0.003. Iron content was reduced from 0.007 to 0.003 consequent to the lime

Table 31. Iron content (per cent) of straw and grain as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.109	0.076	0.070	0.070	0.058	0.085	0.074	0.071	0.077
S_2	0.131	0.080	0.090	0.052	0.098	0.101	0.088	0.082	0.090
S_3	0.079	0.063	0.065	0.048	0.061	0.085	0.054	0.051	0.063
Mean	0.107	0.073	0.075	0.057	0.073	0.091	0.072	0.068	
Stages									
P_1	0.124	0.078	0.092	0.068	0.092				
P_2	0.101	0.072	0.068	0.053	0.065				
P_3	0.094	0.068	0.066	0.049	0.061				
B. Grain									
Soils						Mean			
S_1	0.007	0.002	0.003	0.003	0.003	0.003			
S_2	0.007	0.003	0.003	0.003	0.003	0.004			
S_3	0.008	0.003	0.004	0.004	0.004	0.005			
Mean	0.007	0.003	0.003	0.003	0.003				

A. Straw		B. Grain
CD(0.05) for S = 0.0003	CD(0.05) for SxL = 0.0006	CD(0.05) for S = 0.00003
CD(0.05) for L = 0.0003	CD(0.05) for SxP = 0.0003	CD(0.05) for L = 0.00003
CD(0.05) for P = 0.0003	CD(0.05) for LxP = 0.0006	CD(0.05) for SxL = 0.00003

application. Plants from the unlimed soil S_3 recorded maximum iron content in the grain (0.008). The interaction effect of soil with lime was also significant.

The plants grown in soil S_3 registered significantly more aluminium in the straw (0.160) while those under soil S_1 recorded only (0.054) (Table 32). Application of lime reduced the aluminium content of straw from 0.164 to 0.096. More aluminium content was noted at tillering stage (0.156) and the aluminium content of straw reduced as the crop matured. The plants grown in unlimed soil S_3 retained (S_3L_0) the maximum content of aluminium in the straw (0.231) and at tillering stage (S_3P_1) recorded significantly more aluminium in the straw (0.208). Though there is a drastic reduction of Al content of straw on lime application in all the three soils, an increasing Al content in straw is noticed in S_2 when liming increased from L_2 to L_4, a trend similar to iron in S_2 and S_3. Plant from treatment combination of unlimed soil at the tillering stage (L_0P_1) gave the maximum aluminium content in the straw (0.247). All the interaction effects were also significant.

The plants grown in the soil S_3 retained higher aluminium content in the grain (0.003) while those from the other soils registered a value of 0.002. The plants in unlimed soils S_2 and S_3 recorded maximum aluminium content in the grain (0.004). There was significant decrease from 0.003 to 0.002 consequent to the application of graded levels of lime in the aluminium content of grains. The interaction of soil with lime was also found to be significant.

The levels of iron and aluminium in straw and grain are significantly and drastically reduced by the application of lime. Liming at appropriate rates minimises the content of mobile compounds of aluminium, iron and manganese in the soil, thus their harmful effects on plants is eliminated. Lime reduced the extractable aluminium

Table 32. Aluminium content (per cent) of straw and grain as influenced by the treatment at different stages of crop growth of rice

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.074	0.057	0.052	0.049	0.038	0.061	0.050	0.051	0.054
S_2	0.186	0.128	0.105	0.119	0.134	0.201	0.108	0.094	0.134
S_3	0.231	0.126	0.132	0.158	0.155	0.208	0.142	0.131	0.160
Mean	0.164	0.104	0.096	0.109	0.109	0.156	0.100	0.092	
Stages									
P_1	0.247	0.136	0.114	0.129	0.157				
P_2	0.133	0.090	0.091	0.101	0.085				
P_3	0.122	0.085	0.083	0.096	0.085				
B. Grain									
Soils						Mean			
S_1	0.003	0.001	0.001	0.002	0.001	0.002			
S_2	0.004	0.002	0.002	0.002	0.002	0.002			
S_3	0.004	0.002	0.002	0.003	0.002	0.003			
Mean	0.003	0.002	0.002	0.002	0.002				

A. Straw

CD(0.05) for S = 0.0006 CD(0.05) for SxL = 0.0014
CD(0.05) for L = 0.0008 CD(0.05) for SxP = 0.0011
CD(0.05) for P = 0.0006 CD(0.05) for LxP = 0.0014

B. Grain

CD(0.05) for S = 0.00003
CD(0.05) for L = 0.00003
CD(0.05) for SxL = 0.00003

and iron as well as exchangeable hydrogen and reduced the aluminium toxicity (Martini and Mutters, 1985; Marykutty and Aiyer, 1992). Fragaria and Carvalho (1982) showed the differential behaviour of rice cultivars to aluminium levels and concluded that levels of aluminium in the top of a 21 day old rice plant varied from 100 to 417 ppm.

Tanaka and Yoshida (1970) have fixed 300 ppm of iron as upper critical level of iron in leaf blade. It has been reported that the most critical component of yield in laterite soil is continuous absorption as well as accumulation of iron in the leaf blade which often goes beyond the upper critical level of 300 ppm (Bridgit *et al.*, 1992; Potty *et al.*, 1992). It was also indicated that varieties manifest variations in the absorption and accumulation of iron. Rice varieties viz., Red Triveni and Aswathi recorded 1800 and 940 ppm iron respectively at the active tillering stage (Bridgit *et al.*, 1992). High yielding varieties of rice were more susceptible to Fe toxicity, causing considerable reduction in yield. The traditional tall indicas were resistant to excess soil Fe (Elsy *et al.*, 1994).

Devi *et al.* (1996) studied the single top dressing of lime and water management of iron toxicity and yield of paddy. They reported that by the application of lime at the rate of 600 kg ha^{-1}, iron concentration in the plant could be reduced from 1179 to 675 ppm.

2.5 Uptake of nutrients by straw and grain

2.5.1 Nitrogen (g pot^{-1})

The influence of lime on the uptake of nitrogen by straw and grain is given in Table 33 and Fig.4. The uptake of nitrogen was significantly different in

Table 33. Influence of lime on uptake of nitrogen by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. <u>Straw</u>									
S_1	0.571	0.585	0.606	0.702	0.544	0.507	0.770	0.494	0.590
S_2	0.406	0.441	0.430	0.416	0.413	0.244	0.549	0.452	0.415
S_3	0.542	0.611	0.830	0.774	0.784	0.687	0.867	0.547	0.700
Mean	0.506	0.546	0.622	0.633	0.580	0.479	0.729	0.497	
<u>Stages</u>									
P_1	0.490	0.453	0.568	0.542	0.440				
P_2	0.599	0.696	0.799	0.755	0.812				
P_3	0.429	0.488	0.499	0.602	0.488				
B. <u>Grain</u>									
<u>Soils</u>						Mean			
S_1	0.253	0.353	0.326	0.314	0.305	0.310			
S_2	0.169	0.178	0.232	0.259	0.249	0.217			
S_3	0.288	0.325	0.406	0.394	0.504	0.383			
Mean	0.237	0.285	0.322	0.322	0.353				

<u>A. Straw</u>

CD(0.05) for S = 0.046 CD(0.05) for SxL = 0.103

CD(0.05) for L = 0.059 CD(0.05) for SxP = 0.080

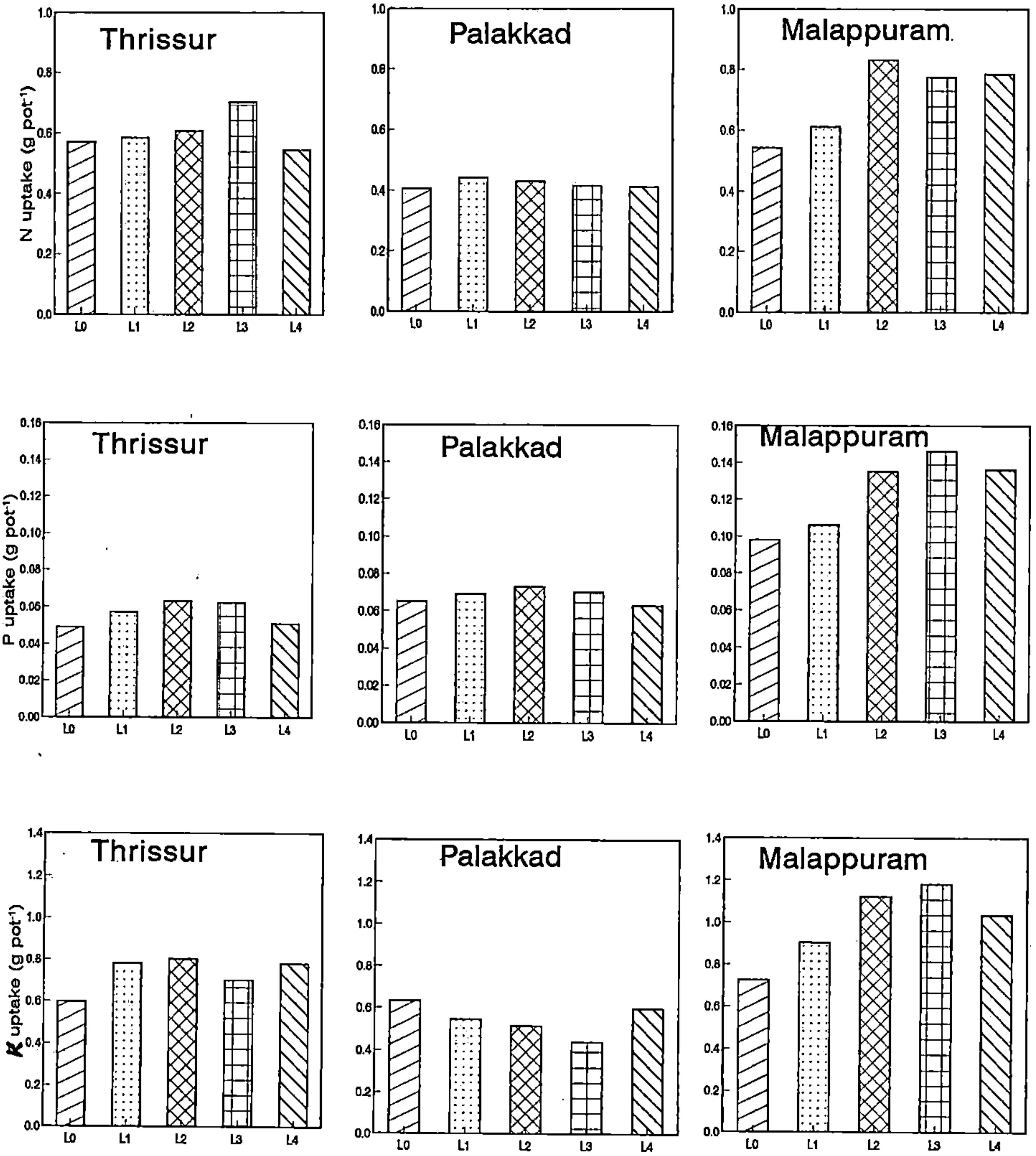
CD(0.05) for P = 0.046 CD(0.05) for LxP = NS

<u>B. Grain</u>

CD(0.05) for S = 0.027

CD(0.05) for L = 0.040

CD(0.05) for SxL = 0.062



Lo: Control (No lime); L1: Ca @ 0.5 x Exch. Al; L2: Ca @ 1.0 x Exch. Al

L3 : Ca @ 1.5 x Exch. Al; L4 : Ca @ 2.0 x Exch. Al

Fig 4. Effect of lime on the uptake of N, P and K plants grown in the three soils. The plants grown in the soil S_3 recorded maximum uptake of nitrogen by straw (0.70) while the plants from the soil S_2 registered only 0.415. Nitrogen uptake of straw increased from 0.506 to 0.633 by the application of lime. The treatment combination S_3L_2 recorded maximum uptake of nitrogen by straw (0.830) and the treatment combination S_2L_0 registered minimum value of 0.406. Maximum uptake was observed at the flowering stage of the crop growth (0.729). The interaction effects were also significant.

The uptake of nitrogen of the plants grown in the three soils was significantly different. The plants from the soil S_3 ranked first in the nitrogen uptake of grain (0.383). Significant increase in the uptake was observed consequent to lime application (0.237 to 0.353). The treatment combination S_3L_4 showed maximum uptake of 0.504 by the grains.

The results show that the plants grown in soil S_3 recorded maximum uptake of nitrogen by straw and grain. The dry matter production and nitrogen content of the straw is more in the plants grown in soil S_3 which influenced the maximum uptake of the nitrogen. Lime application significantly increased the uptake of nitrogen. Jacob and Venugopal (1994) reported that the nitrogen uptake in soyabean was significantly influenced by lime treatments. The maximum value recorded by the treatment with $CaCO_3$ at 1.5 times of exchangeable aluminium. The increased uptake of nitrogen may be due to the increased availability of nitrogen as a result of liming.

2.5.2 Phosphorus (g pot^{-1})

The data presented in Table 34 and Fig.4 indicated the uptake of phosphorus by straw. The plants grown in soil S_3 was significantly superior (0.124)

Table 34. Influence of lime on uptake of phosphorus by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.049	0.057	0.063	0.062	0.051	0.029	0.053	0.087	0.056
S_2	0.065	0.069	0.073	0.070	0.063	0.028	0.073	0.104	0.068
S_3	0.098	0.106	0.135	0.146	0.136	0.088	0.144	0.141	0.124
Mean	0.071	0.077	0.090	0.093	0.083	0.048	0.090	0.111	
Stages									
P_1	0.041	0.046	0.059	0.048	0.047				
P_2	0.066	0.082	0.100	0.096	0.105				
P_3	0.106	0.104	0.111	0.134	0.098				
B. Grain									
Soils						Mean			
S_1	0.015	0.021	0.019	0.019	0.018	0.018			
S_2	0.013	0.015	0.018	0.020	0.020	0.017			
S_3	0.028	0.031	0.040	0.041	0.051	0.038			
Mean	0.019	0.022	0.026	0.027	0.030				

A. Straw

CD(0.05) for S = 0.007
CD(0.05) for L = 0.008
CD(0.05) for P = 0.007
CD(0.05) for SxL = 0.014
CD(0.05) for SxP = 0.011
CD(0.05) for LxP = 0.014

B. Grain

CD(0.05) for S = 0.0030
CD(0.05) for L = 0.0021
CD(0.05) for SxL = 0.0044

to the plants grown in the soil S_1 and soil S_2. They recorded a phosphorus uptake of 0.056 and 0.068 respectively. Lime application markedly increased uptake of phosphorus by straw from 0.071 to 0.093. The effect of interaction was also significant. Lime application significantly increased P uptake of straw in S_3 and such an effect was not noticed in S_1 and S_2.

The uptake of phosphorus by grain showed significant difference in the plants grown in three soils. The plants grown in soil S_3 recorded higher uptake of phosphorus by grain (0.038). Liming significantly increased uptake of phosphorus from 0.019 to 0.030. L_1 level increased the P uptake in grain in S_1 and further increase in lime did not increase the P uptake. But in S_2, the effect was found only at L_2 and higher levels was not useful. In S_3, lime application increased the P uptake in grain even up to L_4.

The perusal of the data indicate that the uptake of phosphorus by straw and grain was significantly different in the plant grown in three soils. The plants grown in S_3 recorded the maximum uptake. The soil S_3 has a higher content of available phosphorus (30.62 ppm) comparing with other soil. Further, lime application enhances the availability of phosphorus in soil. So the plants can absorb the phosphorus for their growth and development. Gupta *et al.* (1989) reported that the uptake of phosphorus has increased by liming. Again the work of Jacob and Venugopal (1994) showed a significant increase in the phosphorus uptake by liming.

2.5.3 Potassium (g pot^{-1})

Influence of lime on uptake of potassium by straw and grain is given in Table 35 and Fig.4. Potassium uptake by straw was significantly more in plants

Table 35. Influence of lime on uptake of potassium by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.597	0.781	0.801	0.702	0.780	0.563	0.882	0.751	0.732
S_2	0.633	0.546	0.515	0.439	0.597	0.326	0.813	0.498	0.546
S_3	0.726	0.903	1.121	1.180	1.033	0.878	1.317	0.784	0.993
Mean	0.652	0.743	0.812	0.774	0.803	0.589	1.004	0.678	
Stages									
P_1	0.564	0.574	0.664	0.600	0.544				
P_2	0.834	1.014	1.047	0.967	1.159				
P_3	0.558	0.642	0.726	0.754	0.708				
B. Grain									
Soils						Mean			
S_1	0.097	0.143	0.137	0.126	0.132	0.127			
S_2	0.078	0.082	0.119	0.126	0.127	0.106			
S_3	0.127	0.146	0.187	0.184	0.235	0.176			
Mean	0.101	0.124	0.148	0.145	0.165				

A. Straw

CD(0.05) for S = 0.074 CD(0.05) for SxL = 0.167

CD(0.05) for L = 0.096 CD(0.05) for SxP = 0.129

CD(0.05) for P = 0.074 CD(0.05) for LxP = NS

B. Grain

CD(0.05) for S = 0.011

CD(0.05) for L = 0.017

CD(0.05) for SxL = 0.025

grown in the soil S_3 (0.993) when compared to the plants grown in other soils. The lime application increased potassium uptake from 0.652 to 0.812. The higher doses of lime reduced the uptake of potassium by the straw. Maximum uptake of potassium by straw was observed at flowering stage (P_2) of the crop growth (1.004). The interaction S x L was found to be significant. Lime at L_1 level increased K uptake of straw in S_1 and higher levels did not increase the K level. Lime application had a decreasing trend in the K uptake in straw in S_2. In S_3, lime increased the K uptake of straw up to L_2 and higher levels was not capable of increasing the K uptake of straw.

The uptake of potassium by the grain was significantly different in plants grown in the three soils. The plants grown in the soil S_3 registered in maximum uptake of potassium by grain (0.176) while the soil S_2 recorded the minimum uptake of potassium (0.106). Lime application significantly increased the uptake of potassium by grain from 0.101 to 0.165.

In the case of grain also the S x L interaction was significant. Lime at L_1 increased the K uptake of grain in S_1 and higher levels failed to further increase of K uptake. In S_2, lime at L_2 could increase the K uptake of grain and at higher levels did not influence. In S_3, the lime application could increase the K uptake up to L_4.

The results reveal that the uptake of potassium by straw and grain has been increased by lime application. The lime application increased the straw and grain yield significantly. The uptake is based on the dry matter production. Eventhough there is no significant difference on the available potassium in the soil as well as the potassium content in the straw by liming, the higher dry matter production nullifies the decreasing trend and enhanced the uptake of potassium. In the case of grain the increasing trend of potassium content and dry matter production enhances the uptake.

The work of Gupta *et al.* (1989) clearly showed that the maximum uptake of potassium followed by phosphorus and calcium by the lime application.

2.5.4 Calcium and magnesium (g pot^{-1})

The data presented in the Table 36 and Fig.5 indicated that the plants grown in the soil S_3 registered significantly more calcium uptake by straw (0.119) when compared to other soils. Significant increase was also observed (0.079 to 0.098) in the calcium uptake with lime application. The interaction effect of S x L was significant. Lime application did not influence the calcium uptake of straw in S_1 and S_2. But in S_3, lime at L_2 increased the calcium uptake of straw. Further increase could be noticed at L_4.

The influence of lime on calcium uptake by grain indicated the same trend as in the case of straw. Maximum calcium uptake (0.02) was observed in the plants grown in the soil S_3. Lime application increased calcium uptake by grain from 0.010 to 0.018. Calcium uptake of grains was increased at L_1 and higher levels could not increase calcium in straw in S_1. Lime application increased calcium uptake of grains up to L_3 in S_2 and in S_3, lime application increased the calcium uptake of grains even up to L_4.

The rice plants grown in the soil S_3 recorded significantly more uptake of magnesium by straw (0.05). The magnesium uptake significantly increased from 0.037 to 0.047 consequent to application of graded levels of lime (Table 37 and Fig. 5).

The influence of lime on magnesium uptake by grain indicated that plants grown in the soil S_3 significantly superior to those from the other soils (0.01). Liming increased uptake from 0.006 to 0.010.

Table 36.Influence of lime on uptake of calcium by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.082	0.084	0.092	0.088	0.084	0.051	0.106	0.101	0.086
S_2	0.061	0.066	0.067	0.071	0.066	0.030	0.082	0.086	0.066
S_3	0.095	0.098	0.129	0.129	0.145	0.081	0.158	0.118	0.119
Mean	0.079	0.082	0.096	0.096	0.098	0.054	0.115	0.102	
Stages									
P_1	0.050	0.053	0.065	0.053	0.050				
P_2	0.095	0.099	0.125	0.116	0.141				
P_3	0.094	0.094	0.098	0.120	0.104				
B. Grain									
Soils						Mean			
S_1	0.009	0.013	0.013	0.013	0.013	0.012			
S_2	0.007	0.008	0.012	0.013	0.012	0.010			
S_3	0.014	0.016	0.020	0.021	0.027	0.020			
Mean	0.010	0.012	0.015	0.016	0.018				

A. Straw

CD(0.05) for S = 0.008　CD(0.05) for SxL = 0.018
CD(0.05) for L = 0.010　CD(0.05) for SxP = 0.014
CD(0.05) for P = NS　CD(0.05) for LxP = 0.018

B. Grain

CD(0.05) for S = 0.0003
CD(0.05) for L = 0.0005
CD(0.05) for SxL = 0.0008

Table 37. Influence of lime on uptake of magnesium by straw and grain at different stages of crop growth of rice (g pot^{-1})

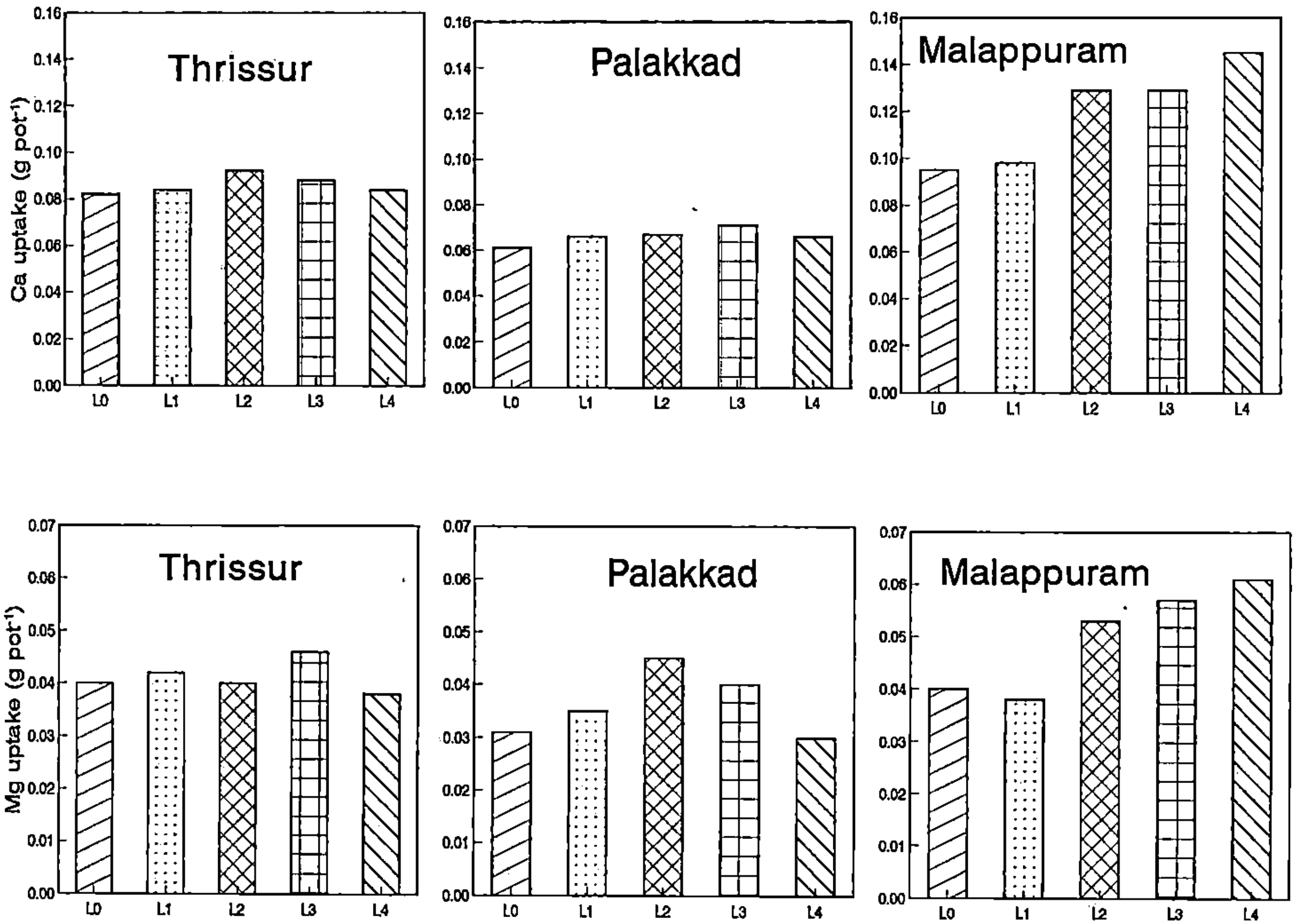
	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.040	0.042	0.040	0.046	0.038	0.030	0.044	0.049	0.041
S_2	0.031	0.035	0.045	0.040	0.030	0.026	0.042	0.041	0.036
S_3	0.040	0.038	0.053	0.057	0.061	0.039	0.061	0.050	0.050
Mean	0.037	0.039	0.046	0.047	0.043	0.031	0.049	0.047	
Stages									
P_1	0.027	0.024	0.038	0.037	0.029				
P_2	0.037	0.046	0.054	0.059	0.050				
P_3	0.047	0.045	0.046	0.044	0.050				
B. Grain									
Soils						Mean			
S_1	0.008	0.010	0.010	0.010	0.010	0.009			
S_2	0.004	0.005	0.007	0.007	0.006	0.006			
S_3	0.007	0.008	0.010	0.011	0.014	0.010			
Mean	0.006	0.008	0.009	0.009	0.010				

A. Straw

CD(0.05) for S = 0.006 CD(0.05) for SxL = NS
CD(0.05) for L = 0.008 CD(0.05) for SxP = NS
CD(0.05) for P = NS CD(0.05) for LxP = NS

B. Grain

CD(0.05) for S = 0.0009
CD(0.05) for L = 0.0012
CD(0.05) for SxL = 0.0018



L0: Control (No lime); L1: Ca @ 0.5 x Exch. Al; L2: Ca @ 1.0 x Exch. Al

L3 : Ca @ 1.5 x Exch. Al; L4 : Ca @ 2.0 x Exch. Al

Fig 5. Effect of lime on the uptake of Ca and Mg

The detailed study of this data indicate that lime has a great influence on the uptake of nutrients. While neutralising acidity, liming affects many other soil properties creating a favourable medium for plant growth and enriching the soils with calcium. Calcium is necessary for normal growth of above ground organs and roots in the plants. The need in this nutrient becomes manifested as early as sprouting stage. If calcium is deficient, the uptake of nutrients upsets (Yagodin, 1984). Fageria and Carvalho (1982) reported that the calcium and magnesium uptake showed an increasing trend with increase in the rate of liming. The results of Panda (1984) showed a similar trend of the nutrient uptake.

2.5.5 Iron and aluminium (g pot^{-1})

The influence of lime on the uptake of iron by straw and grain is given in Table 38. The rice plants grown in the different soils did not show any significant difference. Though the main effect of soil was not significant. S x L interaction was found to be significant. On examining Table 38, when lime was not applied, S_3 had significantly low iron uptake. Lime application did not decrease the iron uptake in S_3, whereas in S_1 and S_2, it decreased iron uptake. In S_1, L_1 level application decreased iron uptake by straw and further decreased was noticed at L_4. In S_2, there was drastic reduction at L_1 level and again at L_3. Lime application significantly decreased the uptake of iron by straw from 0.023 to 0.015.

The rice plants grown in the three soils showed same value for iron uptake by the grain (0.001). The iron uptake decreased as a result of lime application from 0.002 to 0.001.

Table 38. Influence of lime on uptake of iron by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.025	0.020	0.017	0.018	0.014	0.015	0.022	0.019	0.019
S_2	0.026	0.015	0.018	0.010	0.018	0.010	0.022	0.020	0.017
S_3	0.019	0.017	0.023	0.017	0.020	0.021	0.023	0.014	0.019
Mean	0.023	0.017	0.019	0.015	0.017	0.015	0.022	0.018	
Stages									
P_1	0.020	0.013	0.017	0.012	0.014				
P_2	0.027	0.022	0.023	0.018	0.022				
P_3	0.023	0.017	0.017	0.015	0.016				
B. Grain									
Soils						Mean			
S_1	0.002	0.001	0.001	0.001	0.001	0.001			
S_2	0.001	0.001	0.001	0.001	0.001	0.001			
S_3	0.002	0.001	0.001	0.001	0.001	0.001			
Mean	0.002	0.001	0.001	0.001	0.001				

A. Straw

CD(0.05) for S = NS
CD(0.05) for L = 0.002
CD(0.05) for P = NS
CD(0.05) for SxL = 0.004
CD(0.05) for SxP = 0.003
CD(0.05) for LxP = NS

B. Grain

CD(0.05) for S = 0.0003
CD(0.05) for L = 0.0003
CD(0.05) for SxL = NS

Data given in the Table 39 indicated the uptake of aluminium by straw and grain. The aluminium uptake by straw indicated significant difference. The rice plants grown in the soil S_3 recorded maximum uptake of aluminium (0.049). Lime application significantly reduced the aluminium uptake from 0.035 to 0.025 at lower levels. Lime application at L_4 level could reduce aluminium uptake by straw in S_1 whereas in S_2 and S_3 the reduction was noticed at L_1 level and higher levels did not affect Al uptake in S_2, though an increase was noticed in S_3 for higher levels of Al.

The uptake of aluminium by the grains of rice plants grown in the three soils indicated the same value of 0.001. The uptake of aluminium by grain in all the three soils were low when compared to the aluminium uptake by straw. There is no significant difference in the uptake of aluminium by grain due to lime application.

The results indicate that application of lime decreased the uptake of iron and aluminium in straw and grain. The maximum reduction occurred when calcium at the rate of 0.5 times exchangeable aluminium equivalent was applied. This lime level (L_1) drastically reduced exchangeable iron and aluminium of the soil to 12 and 75 per cent respectively. This reflects in dry matter production and uptake of iron and aluminium by straw.

3 Incubation study

The incubation study was conducted with the same soils used in the pot culture experiment. The treatments applied also were the same. The soils were kept at field capacity and under submerged conditions for four months. The samples drawn at monthly intervals were analysed for various parameters and the results obtained are discussed in the following sections.

Table 39. Influence of lime on uptake of aluminium by straw and grain at different stages of crop growth of rice (g pot^{-1})

	Levels of lime					Stages of growth			Mean
	L_0	L_1	L_2	L_3	L_4	P_1	P_2	P_3	
A. Straw									
S_1	0.017	0.015	0.013	0.013	0.008	0.010	0.015	0.014	0.013
S_2	0.033	0.020	0.020	0.021	0.023	0.020	0.028	0.022	0.023
S_3	0.054	0.035	0.046	0.056	0.052	0.049	0.059	0.037	0.049
Mean	0.038	0.025	0.026	0.030	0.028	0.027	0.034	0.024	
Stages									
P_1	0.039	0.020	0.024	0.024	0.026				
P_2	0.037	0.028	0.033	0.037	0.035				
P_3	0.028	0.022	0.022	0.029	0.022				
B. Grain									
Soils						Mean			
S_1	0.001	0.001	0.000	0.001	0.000	0.001			
S_2	0.001	0.001	0.001	0.001	0.001	0.001			
S_3	0.001	0.001	0.001	0.001	0.001	0.001			
Mean	0.001	0.001	0.001	0.001	0.001				

A. Straw

CD(0.05) for S = 0.0025 CD(0.05) for SxL = 0.0059
CD(0.05) for L = 0.0034 CD(0.05) for SxP = 0.0045
CD(0.05) for P = NS CD(0.05) for LxP = 0.0059

B. Grain

CD(0.05) for S = NS
CD(0.05) for L = NS
CD(0.05) for SxL = NS

3.1 Chemical characteristics of soil influenced by graded levels of lime and moisture regimes

3.1.1 pH

The effect of graded level of lime application on pH of three soils used in the incubation study is given in Table 40. The three soils showed significant difference in their pH values. The soil S_1 registered a maximum pH value of 5.64 followed by S_2 (5.49) and S_3 (5.25). Application of graded level of lime significantly icnreased pH from 5.18 to 5.59. The treatment L_4 registered the highest pH value of 5.59 and L_0 recorded the minimum (5.18). All the treatments showed significant increase in the pH values but a rapid increase in pH was observed at L_1. The treatment combination S_1L_4 recorded maximum pH value (5.79) S_3L_0 the minimum pH value (4.86) when compared to other treatment combinations.

From the two moisture regimes tried the soils kept at field capacity (M_1) exhibited lower pH (5.13) and those kept under submerged condition (M_2) recorded higher pH (5.80). In the sampling periods, the fourth sampling (P_3) soils registered maximum pH (5.62) and first sampling (P_0) the minimum pH (5.28).

The different interaction effects were also found to be significant. L_1P_3 recorded highest pH value of 5.75 and L_0P_0 exhibited the lowest value of 5.00. M_2P_3 treatment gave a value of 5.93 whereas M_1P_0 recorded a minimum value of 4.86.

The results indicate that application of lime increased the pH value in all the three soils. As a result of liming, the calcium cations will replace hydrogen irons from the absorbing complex leading to the neutralisation of acidity. A drastic increse

Table 40. pH of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	5.39	5.54	5.72	5.78	5.79	5.30	5.98	5.47	5.63	5.68	5.79	5.64
S_2	5.30	5.50	5.52	5.55	5.60	4.93	6.06	5.35	5.47	5.55	5.61	5.49
S_3	4.86	5.62	5.26	5.11	5.39	5.15	5.35	5.02	5.22	5.31	5.46	5.25
Mean	5.18	5.55	5.50	5.48	5.59	5.13	5.80	5.28	5.44	5.51	5.62	
Periods												
P_0	5.00	5.28	5.34	5.32	5.45	4.86	5.70					
P_1	5.12	5.55	5.47	5.47	5.58	5.13	5.74					
P_2	5.22	5.63	5.56	5.54	5.63	5.22	5.81					
P_3	5.40	5.75	5.63	5.59	5.71	5.30	5.93					
Moisture regimes												
M_1	4.76	5.32	5.22	5.09	5.25							
M_2	5.61	5.78	5.78	5.87	5.93							

CD(0.05) for S = 0.025
CD(0.05) for L = 0.032
CD(0.05) for P = 0.029
CD(0.05) for M = 0.020

CD(0.05) for SxL = 0.020
CD(0.05) for SxP = 0.050
CD(0.05) for LxP = 0.065
CD(0.05) for SxM = 0.036
CD(0.05) for MxL = 0.046
CD(0.05) for MxP = 0.041

in pH is noticed with calcium at the rate of 0.5 times of exchangeable aluminium equivalent (L_1). The higher levels also show a decreasing trend in the pH of the three soils. Similar findings were reported by Marykutty (1986). The same trend was obtained under pot culture studies as in section 2.1.1.

The increase of pH under submerged conditions is due to the development of reduced condition. For reduction, the H^+ ions will be utilised which cause the increase of pH. It has been observed that the increase of pH varied from 0.5 to 1.7 pH units due to submergence. The higher pH values were exhibited by soils in incubation study than pot culture experiment. This may be due to the absorption of some of calcium ions by plants in the pot culture study.

3.1.2 Organic carbon (per cent)

The data presented in the Table 41 indicated the influence of lime application on the organic carbon content of the soils. The three soils differed significantly in their organic carbon content. Soil S_3 registered the maximum value (2.17) and S_1 recorded the minimum value (1.07). The lime application did not exhibit any significant difference in the organic carbon content of the three soils. But it reduced from 1.54 to 1.51.

The soils kept at field capacity (M_1) exhibited higher value (1.54) than these kept under submerged (M_2) condition (1.50). The sampling period does not affected the organic carbon content significantly however towards the fourth sampling a reduction in the content from 1.54 to 1.46 was noticed. The interaction effects of soil with lime, lime with sampling periods and soil with moisture regimes were not significant, while soil with sampling period was significant.

Table 41. Organic carbon (per cent) of soils as influenced by treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	1.09	1.06	1.10	1.06	1.02	1.09	1.04	1.04	1.08	1.11	1.03	1.07
S_2	1.33	1.34	1.28	1.30	1.32	1.33	1.30	1.31	1.34	1.34	1.27	1.32
S_3	2.19	2.20	2.11	2.18	2.19	2.20	2.15	2.25	2.19	2.18	2.08	2.17
Mean	1.54	1.54	1.50	1.51	1.51	1.54	1.50	1.54	1.54	1.54	1.46	
<u>Periods</u>												
P_0	1.52	1.56	1.52	1.54	1.54	1.53	1.54					
P_1	1.59	1.55	1.53	1.52	1.51	1.62	1.46					
P_2	1.58	1.55	1.51	1.54	1.53	1.53	1.55					
P_3	1.45	1.49	1.45	1.43	1.48	1.48	1.44					
<u>Moisture regimes</u>												
M_1	1.55	1.57	1.53	1.51	1.54							
M_2	1.52	1.50	1.47	1.51	1.48							

CD(0.05) for S = 0.029
CD(0.05) for L = NS
CD(0.05) for P = NS
CD(0.05) for M = NS

CD(0.05) for SxL = NS
CD(0.05) for SxP = 0.059
CD(0.05) for LxP = NS
CD(0.05) for SxM = NS
CD(0.05) for MxL = NS
CD(0.05) for MxP = 0.048

The results show that the organic carbon content decreased with the higher rates of lime application. The explanation for this is already discussed under section 2.1.2.

3.1.3 Available phosphorus (ppm)

The presented data in Table 42 indicated the influence of lime on the available phosphorus content of the three soils. The soils were significantly different in their available phosphorus status. The soil S_3 recorded maximum available phosphorus content (37.01) while S_1 registered the minimum content (8.98).

The lime application significantly increased the available phosphorus content of the soils from 17.37 to 20.37. The treatment combination S_3L_4 showed the highest content (39.48) while S_1L_0 the minimum content (8.22). The soils kept under submerged (M_2) condition exhibited high available phosphorus (19.29) than at field capacity level (19.19). The available phosphorus content increased towards the fourth sampling (19.71). The soils from first sampling recorded a value of 18.49.

The interaction effects were also found to be significant. L_4P_3 exhibited an available P content of 20.90 while L_0P_0 recorded a value of 16.91. M_1L_4 and M_2L_4 registered phosphorus content of 20.12 and 20.63 respectively. The available P content of M_1P_3 and M_2P_3 were 19.63 and 19.79.

The perusal of the data indicate that there is an increase in the available phosphorus content of the soil with lime application as well as by keeping the soils under submerged conditions. The detailed explanation given under section 2.1.3 is applicable here also. In the pot culture experiment the available phosphorus content of

Table 42. Available phosphorus (ppm) of the soil as influenced by treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	8.22	8.74	8.92	9.68	9.33	8.90	9.06	8.62	9.02	9.06	9.22	8.98
S_2	11.48	11.15	11.82	11.89	12.30	11.60	11.86	11.41	11.65	11.81	12.05	11.73
S_3	32.41	36.79	37.54	38.82	39.48	37.07	36.94	35.44	37.09	37.64	37.87	37.01
Mean	17.37	18.89	19.42	20.13	20.37	19.19	19.29	18.49	19.25	19.50	19.71	
Periods												
P_0	16.91	18.26	18.38	19.40	19.49	18.57	18.41					
P_1	17.26	18.92	19.55	20.11	20.41	19.16	19.34					
P_2	17.61	19.11	19.73	20.38	20.69	19.41	19.60					
P_3	17.70	19.29	20.03	20.63	20.90	19.63	19.79					
Moisture regimes												
M_1	17.35	19.16	19.40	19.92	20.12							
M_2	17.39	18.63	19.44	20.34	20.63							

CD(0.05) for S = 0.090
CD(0.05) for L = 0.116
CD(0.05) for P = 0.104
CD(0.05) for M = 0.073

CD(0.05) for SxL = 0.201
CD(0.05) for SxP = 0.180
CD(0.05) for LxP = 0.232
CD(0.05) for SxM = 0.127
CD(0.05) for MxL = 0.164
CD(0.05) for MxP = 0.147

the same soils showed a lower value than that in the incubation study. The may be attributed to the uptake of phosphorus by growing rice plants for their growth and development. The findings of Maria *et al.* (1985) and Marykutty and Aiyer (1992) were in confirmity with these results. The increasing trend of available P at later stages may be due to the accumulation of available P in the soil and there is no uptake by the plants.

3.1.4 Exchangeable hydrogen (cmol(+) kg^{-1})

The influence of lime application on the exchangeable hydrogen content of the three soils is presented in Table 43. The data indicated significant difference in the exchangeable hydrogen content of the three soils. But, the difference between the soils were only marginal. Lime application significantly reduced the exchangeable hydrogen content from 0.19 to 0.08.

The soils kept at field capacity recorded a value of 0.14 while under submerged conditions recorded 0.13. The exchangeable hydrogen content was not much affected by the sampling intervals. The interaction effects were also found to be significant. L_0P_1 recorded higher exchangeable hydrogen content (0.21) and L_4P_2 recorded the minimum value (0.07). The interaction of lime with moisture regimes recorded values 0.21 for L_0M_1 and 0.18 for L_0M_2.

The results showed that the exchangeable hydrogen content of the three soils decreased drastically after lime application. The discussion given under section 2.1.4 clearly explain the reasons. The soils kept under field capacity show a lower pH value than the soil kept under submergence. It is a well known fact that submergence of soils leads to increase in pH (Marykutty, 1986), low content of hydrogen ions under submergence may be due to this.

Table 43. Exchangeable hydrogen (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	0.17	0.13	0.11	0.10	0.09	0.12	0.11	0.12	0.13	0.12	0.10	0.12
S_2	0.18	0.15	0.13	0.11	0.07	0.14	0.12	0.12	0.17	0.11	0.11	0.13
S_3	0.23	0.17	0.14	0.10	0.09	0.14	0.15	0.15	0.13	0.12	0.17	0.15
Mean	0.19	0.15	0.13	0.11	0.08	0.14	0.13	0.13	0.14	0.12	0.13	
Periods												
P_0	0.18	0.16	0.14	0.11	0.08	0.14	0.13					
P_1	0.21	0.17	0.13	0.12	0.09	0.17	0.12					
P_2	0.19	0.13	0.11	0.09	0.07	0.10	0.14					
P_3	0.20	0.14	0.14	0.09	0.08	0.13	0.13					
Moisture regimes												
M_1	0.21	0.16	0.13	0.10	0.08							
M_2	0.18	0.14	0.13	0.11	0.09							

CD(0.05) for S	= 0.0006	CD(0.05) for SxL	= 0.0011
CD(0.05) for L	= 0.0006	CD(0.05) for SxP	= 0.0008
CD(0.05) for P	= 0.0006	CD(0.05) for LxP	= 0.0011
CD(0.05) for M	= 0.0003	CD(0.05) for SxM	= 0.0006
		CD(0.05) for MxL	= 0.0008
		CD(0.05) for MxP	= 0.0008

3.1.5 Exchangeable aluminium (cmol(+) kg^{-1})

The effect of graded levels of lime application on the exchangeable aluminium content of the three soils are presented in Table 44. The results revealed that the three soils differed significantly in their exchangeable aluminium status. Lime application showed a drastic reduction in the exchangeable aluminium content from 1.13 to 0.15. The reduction was marked and significant with the application of Ca at the rate of 0.5 times the exchangeable aluminium equivalent (L_1) and with the other levels of lime, reduction was marginal. The treatment combination S_3L_0 recorded maximum exchangeable aluminium content (2.07) while S_1L_2 recorded the minimum value (0.08).

The exchangeable aluminium content of the soils kept at field capacity (M_1) showed a higher level (0.60) than those kept under submerged (M_2) condition (0.21). The exchangeable aluminium content recorded at first sampling was 0.78 and it decreased to 0.23 at the fourth sampling.

The interaction effects were also found to be significant. The interaction of lime with sampling period exhibited maximum content (3.13) and L_4P_0 the minimum content of 0.10. The interaction M_1P_0 and M_2P_0 recorded a exchangeable aluminium content of 1.12 and 0.41 respectively, while L_0M_1 and L_0M_2 registered 1.69 and 0.57.

The mobile forms of aluminium iron and manganese pass into insoluble form consequent to lime application. This change from soluble to insoluble forms eliminates their harmful effect on plant growth and development. The effect of lime

Table 44. Exchangeable aluminium (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	0.14	0.11	0.08	0.09	0.10	0.14	0.07	0.14	0.11	0.10	0.07	0.10
S_2	1.19	0.16	0.10	0.13	0.10	0.51	0.17	0.95	0.18	0.15	0.08	0.34
S_3	2.07	0.74	0.40	0.37	0.26	1.16	0.39	1.24	0.72	0.58	0.54	0.77
Mean	1.13	0.34	0.19	0.19	0.15	0.60	0.21	0.78	0.34	0.28	0.23	
Periods												
P_0	3.13	0.20	0.13	0.22	0.10	1.12	0.41					
P_1	0.45	0.27	0.16	0.17	0.10	0.29	0.18					
P_2	0.46	0.39	0.22	0.17	0.14	0.43	0.12					
P_3	0.48	0.48	0.26	0.22	0.28	0.56	0.13					
Moisture regimes												
M_1	1.69	0.48	0.25	0.30	0.23							
M_2	0.57	0.19	0.13	0.10	0.08							

CD(0.05) for S	= 0.027	CD(0.05) for SxL	= 0.059
CD(0.05) for L	= 0.034	CD(0.05) for SxP	= 0.053
CD(0.05) for P	= 0.031	CD(0.05) for LxP	= 0.068
CD(0.05) for M	= 0.022	CD(0.05) for SxM	= 0.038
		CD(0.05) for MxL	= 0.048
		CD(0.05) for MxP	= 0.047

application on pH, aluminium and hydrogen content of soils were reported by several workers. Liming results in increase of pH and decrease of toxic levels of aluminium and hydrogen ions (Martin *et al.*, 1985 and Gupta *et al.*, 1989). The results indicate that calcium at the rate of 0.5 times of exchangeable aluminium is more effective and economical than the higher levels of lime in reducing the exchangeable aluminium content.

The two moisture regimes studied reveal that the exchangeable aluminium content of soils under the submerged condition is less when compared to those at field capacity level. It may be attributed to the increase of pH on submergence and which in turn decrease the exchangeable aluminium along with lime application. The decreasing trend of exchangeable aluminium towards the fourth sampling period also further reflects the submergence effect on pH and consequent reduction in the exchangeable aluminium content.

3.1.6 Exchangeable acidity (cmol(+) kg^{-1})

The data presented in Table 45 indicated that the three soils differed significantly in their exchangeable acidity. The soil S_3 exhibited maximum exchangeable acidity (0.92) while S_1 recorded the minimum (0.22). The application of graded levels of lime drastically reduced the exchangeable acidity from 1.32 to 0.23. The treatment combination S_3L_0 showed the highest exchangeable acidity value (2.30) while S_2L_4 registered the lowest value (0.17). In S_3, exchangeable acidity could be brought down to 0.35 only at L_4 level of lime application.

The soils kept under submerged condition recorded exchangeable acidity value of 0.34 which was lower than those at the field capacity (0.74). The

Table 45. Exchangeable acidity (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	0.31	0.24	0.19	0.19	0.19	0.26	0.18	0.26	0.24	0.22	0.17	0.22
S_2	1.37	0.31	0.23	0.24	0.17	0.65	0.29	1.07	0.35	0.26	0.19	0.47
S_3	2.30	0.91	0.54	0.47	0.35	1.30	0.54	1.39	0.85	0.70	0.71	0.92
Mean	1.32	0.49	0.32	0.30	0.23	0.74	0.34	0.91	0.48	0.40	0.36	
<u>Periods</u>												
P_0	3.31	0.36	0.27	0.33	0.18	1.26	0.54					
P_1	0.66	0.44	0.29	0.29	0.19	0.46	0.30					
P_2	0.65	0.52	0.33	0.26	0.21	0.53	0.26					
P_3	0.68	0.62	0.40	0.31	0.36	0.69	0.26					
<u>Moisture regimes</u>												
M_1	1.90	0.64	0.38	0.40	0.31							
M_2	0.75	0.33	0.26	0.21	0.17							

CD(0.05) for S = 0.027
CD(0.05) for L = 0.034
CD(0.05) for P = 0.031
CD(0.05) for M = 0.022

CD(0.05) for SxL = 0.059
CD(0.05) for SxP = 0.053
CD(0.05) for LxP = 0.068
CD(0.05) for SxM = 0.038
CD(0.05) for MxL = 0.048
CD(0.05) for MxP = 0.047

exchangeable acidity showed a decreasing trend with sampling periods (0.91 to 0.36). The effects of interactions were also significant. L_0P_0 registered maximum value (3.31) while L_4P_0 the minimum value (0.18). The exchangeable acidity exhibited by M_1P_0 and M_2P_0 were 1.26 and 0.54 respectively.

The acidity ($H^+ + Al^{3+}$) released upon exchange by an unbuffered KCl solution is referred to as exchangeable acidity (Reejuwijk, 1992). The exchangeable acidity of the soil shows the same trend as in the pot culture experiment. The discussions of results under section 2.1.6 also explain the reasons. In the two moisture regimes studied the submerged soils exhibited lower exchangeable acidity value. The exchangeable aluminium content also was low under submerged conditions which also leads to reduction in exchangeable acidity. The increase of pH on submergence also contributes to lower exchangeable acidity at submerged conditions.

3.1.7 Total acidity (cmol(+) kg^{-1})

The data presented in the Table 46 revealed the influence of lime on total acidity. The three soils were significantly different from each other in their total acidity. The soil S_3 recorded the maximum total acidity (2.86) and S_1 recorded the minimum 1.00. Lime application significantly reduced the total acidity from 2.13 to 1.87. The reduction was gradual. The treatment combination S_3L_0 registered highest total acidity value (3.09) while S_1L_1 exhibited the lowest value (0.90).

Lime application did not have any impact in total acidity in S_1. But in S_2, lime application at L_3 level could reduce total acidity significantly. In S_3, L_2 level of application of lime could reduce total acidity and higher levels of lime could reduce the acidity in this soil even up to L_4.

Table 46. Total acidity (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of the incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	0.96	0.90	1.06	1.04	1.03	0.95	1.05	1.15	0.97	0.98	0.89	1.00
S_2	2.34	2.25	2.33	1.98	1.91	2.44	1.89	2.35	2.07	1.76	2.46	2.16
S_3	3.09	3.01	2.71	2.80	2.68	2.95	2.77	3.15	3.04	2.95	2.29	2.86
Mean	2.13	2.05	2.03	1.94	1.87	2.11	1.90	2.22	2.03	1.90	1.88	
Periods												
P_0	1.93	1.77	2.08	1.77	1.93	1.99	1.81					
P_1	2.08	2.05	1.70	2.00	1.57	2.10	1.75					
P_2	2.43	2.30	2.27	2.08	2.00	2.33	2.11					
P_3	2.07	2.10	2.08	1.90	1.98	2.12	1.93					
Moisture regimes												
M_1	2.23	2.24	2.15	2.03	1.90							
M_2	2.03	1.87	1.92	1.84	1.84							

CD(0.05) for S = 0.047
CD(0.05) for L = 0.061
CD(0.05) for P = 0.054
CD(0.05) for M = 0.038

CD(0.05) for SxL = 0.105
CD(0.05) for SxP = 0.094
CD(0.05) for LxP = 0.122
CD(0.05) for SxM = 0.067
CD(0.05) for MxL = 0.086
CD(0.05) for MxP = NS

From the two moisture regimes soil kept at field capacity given higher total acidity (2.11) and those under submerged condition showed only 1.90. The total acidity found to decrease with the sampling periods. Soils from the first sampling period recorded a total acidity of 2.22 while those at fourth sampling period registered 1.88. The various interaction effects were also found to be significant.

Sum of exchangeable acidity (permanent charge) and the pH dependent charge (hydrolytic acidity) is the total acidity (potential acidity). The perusal of the data indicates that liming drastically reduced exchangeable acidity which in turn reduce the total acidity. The discussion of results under section 2.1.7 hold good for those findings also. Under submerged condition there is an increase of pH which reflects in the decrease of total acidity comparing to the moisture at field capacity level. The trend of the result is as same in the pot culture.

3.1.8 Exchangeable potassium and sodium (cmol(+) kg^{-1})

The effect of graded levels of lime on the exchangeable potassium content of the three soils is presented in Table 47. It indicated that the three soils were significantly different in their exchangeable potassium content. The soil S_3 gave maximum value (1.60) and soil S_1 observed the minimum value (0.76). The lime application does not showed any significant difference.

In the two moisture regimes, soils at field capacity recorded high exchangeable potassium (1.24) value while under submerged condition obtained a value of 1.12. The exchangeable potassium content first increased and then decreased with sampling periods. Soils at first sampling recorded a value of 1.20 which increased to 1.22 at second stage and then decreased to 1.12 at fourth stage.

Table 47. Exchangeable potassium (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	0.74	0.75	0.75	0.77	0.76	0.80	0.71	0.80	0.80	0.75	0.67	0.76
S_2	1.13	1.34	1.19	1.18	1.10	1.23	1.15	1.16	1.20	1.20	1.20	1.19
S_3	1.61	1.59	1.57	1.60	1.60	1.69	1.50	1.65	1.66	1.59	1.49	1.60
Mean	1.16	1.23	1.17	1.18	1.15	1.24	1.12	1.20	1.22	1.18	1.12	
<u>Periods</u>												
P_0	1.15	1.29	1.23	1.17	1.17	1.23	1.18					
P_1	1.22	1.21	1.21	1.26	1.21	1.32	1.12					
P_2	1.17	1.21	1.18	1.15	1.19	1.22	1.14					
P_3	1.10	1.21	1.08	1.15	1.05	1.19	1.05					
<u>Moisture regimes</u>												
M_1	1.19	1.31	1.27	1.23	1.20							
M_2	1.13	1.15	1.08	1.14	1.11							

CD(0.05) for S	= 0.011	CD(0.05) for SxL	= 0.025
CD(0.05) for L	= NS	CD(0.05) for SxP	= 0.023
CD(0.05) for P	= 0.013	CD(0.05) for LxP	= 0.029
CD(0.05) for M	= 0.092	CD(0.05) for SxM	= 0.016
		CD(0.05) for MxL	= 0.021
		CD(0.05) for MxP	= 0.019

The effects of interaction were also significant. L_1P_0 showed maximum exchangeable potassium content (1.29) while L_4P_3 registered minimum value (1.05). L_1M_1 and L_1M_2 recorded values of 1.31 and 1.15 respectively. M_1P_1 gave an exchangeable potassium content of 1.32 while M_2P_0 exhibited a value of 1.18.

The Table 48 revealed the influence of lime on the exchangeable sodium content of the three soils. The lime application increased the exchangeable sodium content of the soils from 0.55 to 0.73. The soils kept at field capacity level recorded higher exchangeable sodium content (0.68) than those under submerged contition (0.62). The content showed marginal increase with the sampling periods. The soils at first sampling period recorded a value of 0.63 and those at the fourth sampling period observed a value of 0.67. The various interaction effects were also significant. Exchangeable sodium content reached a peak at L_2 in S_1, while the peak was at L_3 in S_2 and L_4 in S_3.

Lime application decrease the potassium content of the soils. These results were also exhibited by the same soils in the pot culture experiment and is explained clearly under section 2.1.8. Here the potassium content recorded by individuals soils are more as compared to pot culture experiment. The lower amount of potassium recorded in pot culture experiment may be due to the uptake by growing rice plants. The sodium content however indicated an increasing trend with lime application. Soils kept at field capacity registered higher potassium and sodium contents than under submerged condition. The antagonistic effect of Ca and K cause the decreasing trend of exchangeable potassium in the soil. The work of Maria *et al.* (1985) support this work.

Table 48. Exchangeable sodium (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	0.46	0.53	0.67	0.60	0.45	0.56	0.53	0.48	0.55	0.56	0.58	0.54
S_2	0.49	0.61	0.55	0.65	0.64	0.58	0.59	0.56	0.57	0.59	0.62	0.59
S_3	0.70	0.73	0.84	0.93	0.96	0.91	0.76	0.84	0.82	0.86	0.80	0.83
Mean	0.55	0.62	0.69	0.73	0.68	0.68	0.62	0.63	0.65	0.67	0.67	
<u>Periods</u>												
P_0	0.55	0.58	0.67	0.68	0.65	0.65	0.61					
P_1	0.53	0.60	0.71	0.73	0.67	0.69	0.61					
P_2	0.55	0.64	0.71	0.77	0.70	0.70	0.65					
P_3	0.57	0.67	0.65	0.73	0.72	0.70	0.64					
<u>Moisture regimes</u>												
M_1	0.59	0.67	0.70	0.75	0.70							
M_2	0.51	0.58	0.67	0.70	0.66							

CD(0.05) for S = 0.018
CD(0.05) for L = 0.023
CD(0.05) for P = 0.020
CD(0.05) for M = 0.015

CD(0.05) for SxL = 0.040
CD(0.05) for SxP = 0.036
CD(0.05) for LxP = 0.046
CD(0.05) for SxM = 0.025
CD(0.05) for MxL = 0.032
CD(0.05) for MxP = NS

3.1.9 Exchangeable calcium and magnesium (cmol(+) kg^{-1})

The influence of lime on the exchangeable calcium content of the three soils is presented in Table 49. The soil S_2 showed maximum content (4.67) and S_1 the minimum content (2.43). The lime application resulted in a rapid significant increase in the exchangeable calcium content from 2.78 to 4.34. The treatment combination S_2L_4 recorded the highest exchangeable calcium (5.41) while the combination S_3L_0 registered the minimum value (2.13). Lime application resulted in increase of calcium content of the soil only at L_4 level in S_1, whereas there was substantial increase in the calcium content of the soil by lime application right from L_1 to L_4 levels in S_2 and S_3.

Soils kept at field capacity showed higher exchangeable calcium content (3.89) than those kept under submerged condition (3.44). The exchangeable calcium content showed an increasing trend and then decreased with sampling periods. Second sampling (P_1) recorded higher content (3.94) while towards fourth sampling it decreased to 3.13. The different interaction effects were also found to be significant. The interaction combination L_3P_1 recorded highest exchangeable calcium (4.75) and L_0P_0 given the lowest content of 2.65. M_1P_1 exhibited a value of 4.29 while M_2P_3 showed a value of 3.02. L_4M_1 and L_4M_2 showed the calcium content of 4.56 and 4.12 respectively.

The three soils used in the incubation study exhibited significant difference in their exchangeable magnesium status (Table 50). Lime application significantly increased the exchangeable magnesium from 0.59 to 0.79. Calcium at the rate of 0.5 times the exchangeable aluminium equivalent (L_1) gave the highest increase and with the other higher levels the increase was marginal.

Table 49. Exchangeable calcium (cmol(+) kg^{-1})of the soils as influenced by treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	2.28	2.39	2.39	2.70	2.39	2.43	2.43	2.50	2.59	2.48	2.16	2.43
S_2	3.94	4.30	4.70	4.98	5.41	4.96	4.38	4.73	5.11	4.73	4.10	4.67
S_3	2.13	3.03	4.45	4.70	5.22	4.29	3.53	4.26	4.13	4.13	3.11	3.91
Mean	2.78	3.24	3.85	4.13	4.34	3.89	3.44	3.83	3.94	3.78	3.13	
<u>Periods</u>												
P_0	2.65	3.71	4.10	3.96	4.73	3.98	3.68					
P_1	2.85	3.35	4.08	4.75	4.67	4.29	3.59					
P_2	2.98	3.13	4.00	4.19	4.58	4.06	3.49					
P_3	2.65	2.77	3.21	3.63	3.38	3.23	3.02					
<u>Moisture regimes</u>												
M_1	2.80	3.55	4.30	4.24	4.56							
M_2	2.76	2.93	3.40	4.02	4.12							

CD(0.05) for S = 0.056
CD(0.05) for L = 0.072
CD(0.05) for P = 0.065
CD(0.05) for M = 0.046

CD(0.05) for SxL = 0.125
CD(0.05) for SxP = 0.112
CD(0.05) for LxP = 0.145
CD(0.05) for SxM = 0.079
CD(0.05) for MxL = 0.102
CD(0.05) for MxP = 0.092

Table 50. Exchangeable magnesium (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
<u>Soils</u>												
S_1	0.53	0.66	0.75	0.81	0.86	0.72	0.73	0.63	0.78	0.65	0.84	0.72
S_2	0.73	1.06	1.06	0.98	1.00	1.03	0.91	0.85	1.03	1.06	0.94	0.97
S_3	0.52	0.66	0.48	0.44	0.50	0.48	0.56	0.53	0.64	0.45	0.46	0.52
Mean	0.59	0.79	0.77	0.75	0.79	0.74	0.73	0.67	0.81	0.72	0.75	
<u>Periods</u>												
P_0	0.54	0.77	0.67	0.54	0.81	0.71	0.63					
P_1	0.75	0.88	0.81	0.79	0.83	0.80	0.83					
P_2	0.54	0.90	0.81	0.77	0.58	0.73	0.71					
P_3	0.54	0.63	0.77	0.88	0.92	0.73	0.76					
<u>Moisture regimes</u>												
M_1	0.58	0.91	0.71	0.75	0.77							
M_2	0.60	0.68	0.82	0.74	0.80							

CD(0.05) for S	= 0.051	CD(0.05) for SxL	= 0.115
CD(0.05) for L	= 0.066	CD(0.05) for SxP	= 0.102
CD(0.05) for P	= 0.059	CD(0.05) for LxP	= 0.132
CD(0.05) for M	= 0.042	CD(0.05) for SxM	= 0.073
		CD(0.05) for MxL	= 0.094
		CD(0.05) for MxP	= NS

Soils kept at field capacity and under submerged condition did not exhibit much difference in their exchangeable magnesium content. The sampling period showed an increasing trend in the content of exchangeable magnesium. The soils at first sampling recorded a value of 0.67 and at foruth sampling registered a value of 0.75. The interaction effects were also found to be significant.

The results indicate an increasing trend in calcium and magnesium content of the three soils consequent to liming. The same treatments given in the pot culture experiment also showed the same trend. Here the increase in their contents were marked than in the pot culture experiment. This can be attributed to the absence of plants and uptake of nutrients in the incubation study leads to the excess content of these nutrients. The explanation given under section 2.1.9 also explains these results.

3.1.10 Exchangeable iron (ppm)

The data presented in Table 51 showed the effect of lime on the exchangeable iron content of the three soils. The soil S_3 recorded maximum exchangeable iron status (310.0) and S_2 registered the minimum status (166.0). Lime application influenced the content by decreasing it from 246.3 to 210.6. The soils kept at different moisture regimes did not show any significant difference.

The exchangeable iron content showed a decreasing trend with sampling periods. The highest changeable iron content was recorded at first sampling (233.4) while the lowest content was registered at the fourth sampling (220.8). The various effects of interaction were also found to be significant. L_0P_0 exhibited a higher exchangeable iron content of 253.9 while L_4P_3 recorded the lowest content of 205.4.

Table 51. Exchangeable iron (ppm) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	228.2	206.1	193.7	189.6	184.6	193.1	207.8	207.8	199.5	198.9	195.6	200.4
S_2	180.0	172.9	166.5	159.8	150.9	163.5	168.5	168.1	165.9	164.9	165.3	166.0
S_3	330.6	315.6	307.3	300.4	296.3	311.3	308.7	324.4	310.9	303.3	301.5	310.0
Mean	246.3	231.5	222.5	216.6	210.6	222.7	228.3	233.4	225.4	222.3	220.8	
Periods												
P_0	253.9	238.9	231.2	225.1	218.0	226.9	239.9					
P_1	251.3	231.9	215.9	216.8	211.1	222.6	228.2					
P_2	241.3	228.3	221.8	212.4	207.8	221.3	223.3					
P_3	238.6	227.0	221.0	212.0	205.4	219.7	221.9					
Moisture regimes												
M_1	239.2	226.6	221.6	215.3	210.6							
M_2	253.3	236.5	223.3	217.9	210.6							

CD(0.05) for S = 2.122
CD(0.05) for L = 2.739
CD(0.05) for P = 2.450
CD(0.05) for M = NS

CD(0.05) for SxL = 4.745
CD(0.05) for SxP = 4.244
CD(0.05) for LxP = 5.479
CD(0.05) for SxM = 3.001
CD(0.05) for MxL = 3.874
CD(0.05) for MxP = 3.465

The values showed by M_1P_0 and M_2P_0 were 226.9 and 239.9 respectively, while M_1L_0 and M_2L_0 recorded 239.2 and 253.3.

Exchangeable iron content of the three soils indicated a decreasing trend with lime application as in the case of pot culture experiment. The exchangeable iron content recorded by the three soils in pot culture experiment and incubation study remains almost the same. The discussion of results under section 2.1.10 explains clearly the effect of lime on exchangeable iron content of the three soils and it is applicable for these results also.

3.1.11 Cation exchange capacity and effective cation exchange capacity (cmol(+) kg^{-1})

The cation exchange capacity (CEC) of the three soils were significantly influenced by the graded levels of lime application (Table 52). The soil S_3 recorded the maximum CEC value (9.72) and S_1 registered the minimum (5.43). Lime application significantly increased CEC of soils from 7.16 to 8.83. The treatment combination S_3L_4 recorded the highest CEC (10.95) while S_1L_0 registered the lowest CEC value (4.91) when compared to other combinations.

The soils at field capacity possessed high CEC value (8.66) than those kept under submerged condition (7.82). The CEC of soils found to increase from 8.22 to 8.56 upto the third sampling while it decreased towards the fourth sampling (7.66). The interaction effects were also significant. The maximum CEC value was registered by L_3P_1 (9.53) and the minimum by L_0P_0 (6.65). The highest CEC values exhibited by M_1P_1 was 9.08 and by M_2P_2 was 8.09. The interaction M_1L_4 and M_2L_4 showed values of 9.13 and 8.53 respectively.

Table 52. Cation exchange capacity (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of the incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	4.91	5.26	5.62	5.91	5.48	5.43	5.44	5.38	5.56	5.59	5.20	5.43
S_2	8.54	9.65	9.78	9.77	10.06	10.23	8.89	9.06	10.37	9.93	8.88	9.56
S_3	8.02	9.08	10.06	10.47	10.95	10.32	9.12	10.23	9.58	10.17	8.89	9.72
Mean	7.16	7.99	8.49	8.72	8.83	8.66	7.82	8.22	8.51	8.56	7.66	
Periods												
P_0	6.65	8.29	8.75	8.13	9.30	8.55	7.89					
P_1	7.49	8.08	8.51	9.53	8.92	9.08	7.92					
P_2	7.54	8.30	8.97	8.96	9.05	9.04	8.09					
P_3	6.96	7.32	7.72	8.25	8.04	7.96	7.35					
Moisture regimes												
M_1	7.41	8.65	9.13	8.99	9.13							
M_2	6.91	7.34	7.85	8.45	8.53							

CD(0.05) for S = 0.084
CD(0.05) for L = 0.109
CD(0.05) for P = 0.097
CD(0.05) for M = 0.069

CD(0.05) for SxL = 0.188
CD(0.05) for SxP = 0.169
CD(0.05) for LxP = 0.218
CD(0.05) for SxM = 0.119
CD(0.05) for MxL = 0.154
CD(0.05) for MxP = 0.138

The effect of graded levels of lime on effective cation exchange capacity (ECEC) of the three soils is presented in Table 53. The data indicated significant difference in the ECEC of soil S_3 (7.58), S_2 (7.66) and S_1 (4.65). The ECEC of S_2 and S_3 soils were onapar. The lime application significantly increased the ECEC values from 5.68 to 7.22.

The soils at field capacity (M_1) had higher ECEC values (7.07) than those under submerged (M_2) condition (6.19). The value of ECEC at first sampling was 6.70 and it was decreased to 6.13 at the fourth sampling. The second and third sampling showed higher values of 6.97 and 6.73. The different interaction effects were also found to be significant.

The application of graded levels of lime results an increase of calcium and other cations. This increase in turn results in the increase of CEC and ECEC thereby provides a favourable condition for the growth and development of crops in the acid soils. Bishnoi *et al.* (1988) reported that lime application increased the CEC, ECEC and base saturation. The results are more or less same as that of the pot culture experiment. CEC and ECEC are calculated based on the summation of cations plus total acidity and cations plus exchangeable acidity respectively. Under submerged condition the total acidity and exchangeable acidity gets reduced than the soils collected from field capacity level. Naturally the low value of CEC and ECEC were obtained under submerged conditions.

3.1.12 Base saturation (per cent)

The base saturation of the three soils as influenced by lime application is presented in Table 54. The data revealed a significant difference in base saturation of

Table 53. Effective cation exchange capacity (cmol(+) kg^{-1}) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of the incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	4.26	4.51	4.76	5.11	4.64	4.75	4.56	4.63	4.87	4.64	4.48	4.65
S_2	6.58	7.59	7.72	8.05	8.36	8.11	7.21	7.54	8.14	7.82	7.13	7.66
S_3	6.18	6.95	7.90	8.19	8.68	8.35	6.81	7.92	7.91	7.72	6.77	7.58
Mean	5.68	6.35	6.79	7.11	7.22	7.07	6.19	6.70	6.97	6.73	6.13	
Periods												
P_0	5.46	6.72	6.97	6.72	7.61	6.98	6.41					
P_1	5.97	6.40	7.08	7.83	7.58	7.51	6.44					
P_2	5.78	6.40	7.01	7.18	7.28	7.24	6.22					
P_3	5.49	5.89	6.11	6.72	6.43	6.55	5.70					
Moisture regimes												
M_1	5.94	7.04	7.36	7.41	7.58							
M_2	5.41	5.65	6.22	6.82	6.87							

CD(0.05) for S = 0.081
CD(0.05) for L = 0.104
CD(0.05) for P = 0.093
CD(0.05) for M = 0.066

CD(0.05) for SxL = 0.181
CD(0.05) for SxP = 0.162
CD(0.05) for LxP = 0.208
CD(0.05) for SxM = 0.114
CD(0.05) for MxL = 0.147
CD(0.05) for MxP = 0.132

Table 54. Base saturation (per cent) of the soils as influenced by the treatments and moisture regimes at different sampling intervals of the incubation study

	Levels of lime					Moisture regime		Sampling period				Mean
	L_0	L_1	L_2	L_3	L_4	M_1	M_2	P_0	P_1	P_2	P_3	
Soils												
S_1	82.0	81.8	82.1	82.5	81.6	82.8	81.2	82.3	84.3	79.4	81.9	81.9
S_2	74.0	76.0	76.9	79.6	81.2	75.8	79.1	80.7	76.0	76.4	77.1	77.6
S_3	61.8	65.9	72.5	73.4	75.2	70.4	69.1	70.1	75.0	68.3	65.5	69.8
Mean	72.6	74.6	77.2	78.5	79.4	76.4	76.5	77.7	78.5	74.7	74.9	
Periods												
P_0	76.1	78.4	75.9	79.1	79.1	77.4	78.0					
P_1	72.8	75.3	81.0	79.5	83.6	78.9	77.9					
P_2	70.9	71.5	75.5	77.4	78.2	74.9	74.5					
P_3	70.6	73.2	76.2	77.8	76.5	74.4	75.3					
Moisture regimes												
M_1	72.1	75.8	76.5	77.9	79.8							
M_2	73.2	73.4	77.8	79.1	78.9							

CD(0.05) for S	= 0.586	CD(0.05) for SxL	= 1.310
CD(0.05) for L	= 0.756	CD(0.05) for SxP	= 1.172
CD(0.05) for P	= 0.677	CD(0.05) for LxP	= 1.513
CD(0.05) for M	= NS	CD(0.05) for SxM	= 0.829
		CD(0.05) for MxL	= 1.070
		CD(0.05) for MxP	= 0.957

the soils. The maximum base saturation was observed in soil S_1 (81.9) and the minimum value was exhibited by soil S_3 (69.8). The lime application significantly increased the base saturation from 72.6 to 79.4. The treatment combination S_1L_3 recorded the maximum base saturation (82.5) and S_3L_0 registered the minimum value (61.8) when compared to other treatment combinations.

The two moisture regimes viz., field capacity and submerged condition does not indicated any significant difference in the base saturation status of the three soils. The base saturation decreased towards the fourth sampling stage from 77.7 to 74.9. The interaction effects were also found to be significant.

The results indicate that the soil S_3 exhibits lower base saturation than S_1 and S_2. The soil S_3 is having high CEC and ECEC than S_1 and S_2. Eventhough S_3 shows lower base saturation value may be due to the presence of more Al^{3+} and H^+ ions compared to other soils. The soils kept at field capacity and submerged condition show the same base saturation irrespective of the moisture regimes. This clearly explains the reduction in the CEC and ECEC is due to the decrease of total and exchangeable acidity. Appreciable increase in base saturation is noticed at lower levels of applied lime. This result points out the necessity for the addition of lower levels of lime in laterite soils. Bishnoi *et al.* (1988) reported similar results which supports the results of the present study.

The comparison of the pot culture experiment and incubation study with same treatments indicate that the chemical characteristics of the nutrients recorded are more or less of the same trend. The incubation study does not give any new information than those from the pot culture experiment except moisture regimes treatments. The soils kept under submerged conditions gave better results than those kept at field capacity. But the soils under pot culture study were also maintained in submerged conditions. So, it is advisable to avoid the incubation study under submerged conditions.

Summary

SUMMARY

A study was taken up to assess the lime requirement in terms of exchangeable aluminium, to correlate pH and lime requirement values with the exchangeable aluminium content of the soil and to study the effect of liming on crop performance with special reference to exchangeable aluminium content of the soil. The investigation consisted of three phases. The first phase included a laboratory study with fifty surface soil samples from the rice growing tracts representing the laterite zone viz., Malappuram, Palakkad and Thrissur districts to investigate the different characteristics of the soils and to inter-correlate important parameters. Three soils were selected from these fifty samples based on their exchangeable aluminium content (low, medium and high) for the second phase of the study in a pot culture experiment, with graded levels of lime based on the exchangeable aluminium content using a rice variety Triveni. The third phase consisted of an incubation study with the same soils and treatments as in the case of pot culture experiment under two moisture regimes viz., field capacity and submerged conditions. The important findings from these experiments are summerised below.

1. The pH values of the fifty surface soil samples obtained a positive difference between pH (H_2O) and pH (KCl) which indicated that the soils were negatively charged and contained considerable amount of reserve acidity. The correlation studies revealed that pH showed a significant positive correlation with base saturation while all other acidity contributing factors had a negative correlation. There was an increase of pH from 0.25 to 1.70 units under submergence after four weeks.

2. The exchangeable hydrogen content varied from 0.11 to 0.59 cmol(+) kg^{-1} whereas the exchangeable aluminium content ranged from 0.25 to 2.54 cmol(+) kg^{-1}. The result clearly indicated that at a pH 4.8 to 5.8 the soils predominated with exchangeable aluminium. The exchangeable hydrogen had a significant positive correlation with the exchangeable acidity and total acidity (r = 0.57** and 0.297**) whereas the r values for exchangeable aluminium were 0.897** and 0.406** respectively.

3. Exchangeable aluminium contributed 69 to 86 per cent towards the exchangeable acidity. This high contribution of exchangeable aluminium should be taken into account in liming and nutrient management of the soils. The contribution of pH dependent acidity to total acidity varied from 23 to 66 per cent for Malappuram soils, 34 to 76 per cent for Palakkad soils and 20 to 75 per cent for Thrissur soils.

4. Among the exchangeable cations studied, exchangeable calcium dominated in all the soils followed by K, Mg and Na. Cation exchange capacity (CEC) and effective CEC (ECEC) were positively correlated with base saturation, total acidity, lime requirement values, organic carbon, pH dependent acidity and exchangeable calcium and negatively correlated with pH. Maximum base saturation obtained in the soils collected from Malappuram district.

5. High content of organic carbon was recorded in the soils from Malappuram district. The organic carbon had a positive significant correlation with different forms of acidities, aluminium and iron and CEC while observed negative correlation with pH and base saturation.

6. Lime requirement based on exchangeable aluminium (Exchangeable Al x 1.5 times of Ca) recorded very less amount of $CaCO_3$ (0.40 to 4.19 $CaCO_3$ t ha^{-1}) comparing with other methods. Lime requirement based on total acidity obtained maximum amount of $CaCO_3$ (6.0 to 20.0 $CaCO_3$ t ha^{-1}) followed by Shoemaker *et al.* procedure (6.0 to 12.5 $CaCO_3$ t ha^{-1}). All these methods had significant positive correlation with organic carbon, forms of iron and aluminium, exchangeable acidity and total acidity and was negatively correlated with base saturation.

7. The total elemental analysis data showed that the contents of iron and aluminium were higher than phosphorus, potassium, calcium and magnesium. From the different forms of iron and aluminium studied ammonium oxalate extractable (amorphous) iron and aluminium recorded much higher value than ammonium acetate extractable forms (extractable).

8. The sand particles varied from 29.8 to 70.0 per cent, silt ranged from 4.02 to 39.9 per cent and clay fraction showed a range from 19.9 to 48 per cent in these soils.

9. In the pot culture experiment, application of lime significantly increased pH in all the three soils and decreased the exchangeable hydrogen and aluminium and different forms of acidities. The increase of pH at tillering stage was 0.05 unit, tillering to flowering stage it was 0.2 and from flowering to harvesting stage it was only 0.08 units.

10. The percentage contribution of exchangeable acidity and pH dependent acidity towards total acidity were 16 and 84 for S_1, 20 and 80 for S_2 and 25 and 75

for S_3 respectively. The reduction of total acidity by application of lime varied from 5 to 9 per cent only whereas the exchangeable acidity tremendously reduced more than 70 per cent. All the forms of acidities were maximum at pre-planting stage and acidity was found to decrease as the crop matured.

11. The available phosphorus content of all the three soils increased with application of graded levels of lime whereas the organic carbon content was slightly decreased. Among the different stages of crop growth, tillering stage obtained highest value for available phosphorus whereas organic carbon content was higher at flowering stage.

12. Exchangeable calcium content of the soils was tremendously increased by the application of calcium at the rate of 0.5 times aluminium equivalent (L_1) over control, while exchangeable potassium content was decreased. There was no significant increase in the exchangeable Mg and Na contents of the soil after lime application. Exchangeable Ca and Mg contents of soil were maximum at the pre-planting stage of rice.

13. The three soils were significantly differed in their exchangeable iron content. Application of lime caused significant reduction in exchangeable iron content. The pre-planting stage registered maximum content of exchangeable iron.

14. Graded levels of lime application significantly increased CEC, ECEC and base saturation of the soils.

15. Application of graded levels of lime resulted in significant increase in various growth parameters like height of plant, number of leaves and number of tillers of the rice grown in the three soils.

21. The soils kept under submerged conditions exhibited good results than those kept at the field capacity.

The studies of the chemical characteristics of the fifty surface soil samples point out some salient results. The values obtained for the lime requirement based on Shoemaker *et al.*, total acidity and exchangeable aluminium ranged from 6 to 12.5, 6 to 20 and 0.40 to 4.19 $CaCO_3$ t ha^{-1} respectively for laterite soils. This clearly shows that the lime requirement value calculated based on exchangeable aluminium is very much less than the other methods. Moreover exchangeable aluminium contributes 69 to 86 per cent towards exchangeable acidity. This high contribution of exchangeable aluminium should be taken into account in liming and nutrient management of the laterite soils. Further it is noticed that calcium at the rate of 0.5 and 1.0 times of exchangeable aluminium equivalent resulted in better yield in rice. If we adopt this method for lime requirement determination it will be more efficient and economical. The results of the present study thus point to the advantage in adopting the exchangeable aluminium as an index of lime requirement in the laterite soils of Kerala.

References

REFERENCES

Abraham, A. 1984. The release of aluminium in soils under submerged conditions and its effect on rice. Ph.D. thesis, Kerala Agricultural University, Trichur

Adams, F. and Hatchcock, P.J. 1984. Aluminium toxicity and Ca deficiency in acid subsoil horizons of two coastal plain soil series. *Soil Sci. Soc. Am. J.* **48**:1305-1309

Adams, F. and Lund, Z.F. 1966. Effect of chemical activity of soil solution aluminium on cotton root penetration of acid subsoils. *Soil Sci.* **101**:193-198

Amedee, G. and Peech, M. 1976. The significance of KCl-extractable Al (III) as an index to lime requirement of soils of the humid tropics. *Soil Sci.* 121:227-233

Ananthanarayana, R. and Hanumantharaju, T.H. 1994. Nature of soil acidity and lime requirement in the agro-climatic zones of Shimoga District, Karnataka. *J. Indian Soc. Soil Sci.* **42**:361-364

Anilakumar, K. 1980. Studies on the response of paddy to lime application in acid soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agrl. Univ., Trichur

Anonymous. 1993. *The Package of Practice Recommendations*. Kerala Agricultural University, Trichur

Bache, B.W. 1985. Soil acidification and aluminium mobility. *Soil Use Manag.* **1**:10-14

Bache, A.W. and Crooke, W.M. 1981. Interactions between Al, P and pH in the response of barley to soil acidity. *Pl. Soil* **61**:365-375

Baligar, V.C.,Wright, R.J., Bennet, O.L., Hern, J.L., Perry, H.D. and Smedley, M.D. 1985. Lime effect on forage legume growth and mineral composition in an acid subsoil. *Commun. Soil Sci. Pl. Anal.* **16**:1079-1093

Ballard, R. and Fiskell, J.G.A. 1974. Phosphorus retention in coastal plain forest soils. I. Relationship to soil properties. *Proc. Soil Sci. Soc. Am.* **38**:250-255

Bandyopadhyay, P.K. and Chattopadhyay, G.N. 1997. Nature of acidity in some Alfisols and Inceptisols of Birbhum District of West Bengal. *J. Indian Soc. Soil Sci.* **45**:5-8

Bhor, S.M., Kibe, M.M. and Zende, G.K. 1970. Interrelationship between free lime status of soils and the uptake of Mn, P and Ca by paddy and jowar plants. *J. Indian Soc. Soil Sci.* **18**:479-484

Bishnoi, S.K., Tripathi, B.R. and Sharma, P.K. 1988. Studies on liming of acid soils of Himachal Pradesh. *J. Indian Soc. Soil Sci.* **36**:257-263

Black, C.A. 1973. *Soil Plant Relationships*. Willey Eastern Private Limited, New Delhi, p.273-355

Black, C.A., Evans, D.D., Ensminger, L.E., White, J.L. and Clark, F.E. 1965. *Methods of Soil Analysis*. Part 2, No.9 in the series of Agronomy. Am. Soc. Agron. Inc. Madison, U.S.A.

Blair, A.W. and Prince, A.L. 1923. Studies on the toxic properties of soils. *Soil Sci.* **15**:109-129

Blamey, P.C., Edwards, D.G. and Asher, C.J. 1983. Effects of aluminium OH:Al and P:Al molar ratios and ionic strength on soybean root elongation in solution culture. *Soil Sci.* **136**:197-207

*Blasko, L. 1983. Certain correlations between the acidic or overlimed state of the soil and phosphorus supply in meadow soils. *Agrokemia es Talajitan* **32**:399-406

Bloom, P.R., Mc Bridge, M.B. and Weaver, R.M. 1979. Aluminium and organic matter in acid soils. Buffering and solution aluminium activity. *Soil Sci. Soc. Am. J.* **43**:488-493

*Brauner, J.L. and Catani, R.A. 1967. Effect of $CaCO_3$ on exchangeable Al in soil. *Anais ESC. Sup. Agric. Luiz Queivoz.* **24**:57-69

Bridgit, T.K., Potty, N.N. and Marykutty, K.C. 1992. Elemental composition of leaf in rice and its role in crop productivity. *Proc. 4th Kerala Sci. Congr.* STEC, Trivandrum, p.82-83

Butorac, A. and Uscumlic, L. 1978. Accumulation of trace elements in the stem and leaf of lucerne as affected by fertilizing with Mo and liming. *Soils Fertil.* 41:432-434

Cate, R.B. and Sukhai, A.P. 1964. A study of aluminium in rice soils. *Soil Sci.* 98:85-93

* Chenn, T.T. 1968. Effect of aluminium ion on rice growth. *Soil Fert. Taiwan* 33:406-409

Cochrane, G.T., Salinas, J.G. and Sanchez, P.A. 1980. An equation for liming acid mineral soils to compensate crop aluminium tolerance. *Trop. Agric.* 57:133-140

Coleman, N.T., Kamprath, E.J. and Weed, S.B. 1958. Liming. *Adv. Agron.* 10:475-517

Coleman, N.T. and Thomas, 1967. The basic chemistry of soil acidity. *Soil Acidity and Liming* No.12 in the series of Agronomy. Am. Soc. Agron., Inc. Madison, USA.

Coleman, N.T., Weed, S.B. and Mc Gracksen, R.J. 1959. Cation exchange capacity and exchangeable cations in Piedmont soils of North Carolina. *Proc. Soil Sci. Soc. Am.* 23:146-149

Coulter, B.S. 1969. The chemistry of hydrogen and Al ions in soils, clay minerals and resins. *Soils Fertil.* 32:215-223

Curtain, D. and Smillie, G.W. 1986. Effects of liming on soil chemical characteristics and grass growth in laboratory and long term field amended soils. *Pl. Soil* 95:15-22

Das, A.N., Laskar, B.K., De, G.K. and Debnath, N.C. 1991. Nature of acidity of some acid soils of West Bengal. *J. Indian Soc. Soil Sci.* 39:246-251

Das, P.K., Sahu, G.C. and Nanda, S.S.K. 1992. Nature of acidity and exchange chemistry of some laterite soils of Orissa. *J. Indian Soc. Soil Sci.* 40:425-430

Datta, M. and Gupta, R.K. 1983. Response of wheat and maize to lime in acid soils of Nagaland. *J. Indian Soc. Soil Sci.* 31:236-240

Devi, C.R.S. 1983. The nature of acidity in upland and rice fallows in relation to response of pulse crop to liming. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Trichur

Devi, K.M.D., Gopi, C.S., Santhakumari, G. and Prabhakaran, P.V. 1996. Effect of lime and water management on iron toxicity and yield of paddy. *J. trop. Agric.* 34:44-47

* Dewan, H. 1966. Acidity of certain Virginia soil as related to their mineralogy and chemistry. *Diss. Abstr.* 26:3575

Dipak, S., Khandare, N.C., Sah, K.D. and Sehgal, J. 1997. Nature of soil acidity as influenced by climate and topography in some Ultisols and Alfisols of Orissa. *J. Indian Soc. Soil Sci.* 45:1-15

Dixit, S.P. and Sharma, P.K. 1993. Effect of lime and potassium on soil acidity, forms of aluminium and iron and yield of crops in a sequence. *J. Indian Soc. Soil Sci.* 41:522-526

Elsy, C.R., Rosamma, C.A. and Mathew, J. 1994. Varietal response of rice to iron toxicity. *Oryza* 31:67-68

Evans, C.E. and Kamprath, E.J. 1970. Lime response as related to per cent Al saturation, solution Al and organic matter content. *Proc. Soil Sci. Soc. Am.* 34:893-896

Farina, N.P.W., Sumner, N.E., Plank, C.O. and Letzach, W.S. 1980. Exchangeable aluminium and pH as indicators of lime requirement for corn. *Soil Sci. Soc. Am. J.* 44:1036-1041

Foy, C.D., Fleming, A.L., Burns, G.R. and Armiger, W.H. 1967. Characterisation of differential aluminium tolerance among varieties of wheat and barley. *Proc. Soil Sci. Soc. Am.* 31:513-521

Fageria, N.K. 1985. Influence of aluminium in nutrient solutions on chemical composition in two rice cultivars at different growth stages. *Pl. Soil* **85**:423-429

Fageria, N.K. and Carvalho, J.R.P. 1982. Influence of aluminium in nutrient solution on chemical composition in upland rice cultivars. *Pl. Soil* **69**:34-44

Franco, A.A. and Munns, D.N. 1982. Acidity and aluminium restraints on nodulation, nitrogen fixation and growth of *Paseolus vulgaris* in solution culture. *Soil Sci. Soc. Am. J.* **46**:296-301

Gilly, G. 1958. Acidity and exchangeable aluminium. *Ann. Agron. Paris* **9**:679-689

Goswami, N.N., Leelavathi, L.R. and David, M.S. 1976. Response of cereals to lime as affected by its rate of application and fertilizer treatments in acid soils. *Bull. Indian Soc. Soil Sci.* **11**:238-245

Gupta, R.K., Rai, R.N., Singh, R.D. and Prasad, R.N. 1989. Effect of liming acid soil on yield and soil characteristics. *J. Indian Soc. Soil Sci.* **37**:126-130

Halder, B.R. and Mandal, L.N. 1985. Lime requirement of acid soils in relation to pH, exchangeable acidity extractable acidity and exchangeable aluminium content of the soils. *J. Indian Soc. Soil Sci.* **33**:528-535

Haynes, R.J. and Ludecke, T.E. 1981. Effect of lime and phosphorus application on the concentrations of available nutrients and on P, Al and Mn uptake by two pasture legumes in an acid soil. *Pl. Soil* **62**:117-128

Helyar, K.R. and Anderson, A.J. 1971. Effects of lime on growth of five species, on aluminium toxicity and on P availability. *Aust. J. agric. Res.* 22:707-721

Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis*. John Murray Publishers Ltd., London

Hoyt, P.B. 1977. Effect of organic matter content on exchangeable Al and pH dependent acidity of very acid soils. *Can. J. Soil Sci.* **57**:221-222

Hoyt, P.B. and Nyborg, M. 1971. Toxic metals in acid soil 1. Estimation of plant available aluminium. *Proc. Soil Sci. Soc. Am.* **35**:236-240

Jackson, M.L. 1958. *Soil Chemical Analysis*. Prentice Hall of India (P) Ltd., New Delhi

Jacob, T. and Venugopal, V.K. 1993. Redistribution of exchangeable calcium, magnesium and aluminium following application of different liming materials in combination with gypsum in a low acidity clay soils of Kerala. *J. trop. Agric.* **31**:131-136

Jones, U.S., Semonte, H.P. and Jariel, D.M. 1982. Response of corn and inoculated legumes to urea, lime, P and S on Guadalupe clay. *Soil Sci. Soc. Am. J.* **46**:296-301

Kabeerathumma, S. 1969. Effect of liming on exchangeable cations and availability of nutrients in acid soils of Kuttanad. M.Sc.(Ag.) thesis, Univ. Kerala, Trivandrum

Kabeerathumma, S. and Nair, C. 1973. Effect of liming on exchangeable cations and pH of acid soils of Kuttanad. *Agric. Res. J. Kerala* **11**:9-13

Kailashkumar, Rao, K.V.P. and Singh, L.J. 1995. Forms of acidity in some acid Inceptisols under different land use in Manipur. *J. Indian Soc. Soil Sci.* **43**:338-342

* Kaminski, J. and Bohnen, H. 1976. Acidity factors. Combination of variables in the determination of time requirement for acid soils *Revista do Centro de Ciencian Ruvais* **7**:47-54

Kamprath, E.J. 1970. Exchangeable Al as a criterion for liming leached mineral soils. *Proc. Soil Sci. Soc. Am.* **34**:252-254

Koshy, M.M. 1960. Influence of lime and P application to three soils on yield and nutrient uptake by sorghum. M.S. thesis, University of Tennessee, U.S.A.

*Kuruvila, V.O. 1974. Chemistry of low productive acid sulphate soils of Kerala and their amelioration for growing rice. Ph.D. thesis, Central Rice Research Institute, Cuttack

Lockard, R.C. and McWalter, A.R. 1956. Effect of toxic levels of sodium, arsenic, iron and aluminium on the rice plants. *Malayan Agric. J.* **39**:256-267

Mandal, S.C. 1976. *Acid Soils of India and Their Management*. Bull. No.II, Indian Society of Soil Science, New Delhi

*Manrique, L.A. 1986. The relationship of soil pH to Al saturation and exchangeable aluminium in Ultisols and Oxisols. *Commun. Soil Sci. Pl. Anal.* **17**:439-455

Maria, V., Eibert, J. and Szoke, L. 1985. Effect of liming on EUF nutrient fractions in the soil, on nutrient content of grape leaves and on grape yield. *Pl. Soil* **83**:55-63

Martini, J.A., Kochhann, R.A., Gomes, E.P. and Langer, F. 1977. Response of wheat cultivars to liming in some high aluminium Oxisols of Rio Grande doSul, Brazil. *Agron. J.* **69**:612-616

Martini, J.A. and Mutters, R.G. 1985. Effect of lime rates on nutrient availability, mobility and uptake during the soyabean growing season. 1. Aluminium, manganese and phosphorus. *Soil Sci.* **137**:219-226

Marykutty, K.C. 1986. Factors governing response of rice to liming in Kerala soils. Ph.D. thesis, Kerala Agric. Univ., Trichur.

Marykutty, K.C. and Aiyer, R.S. 1987. Effect of liming and washing on soil characters. *Agric. Res. J. Kerala* **25**:27-35

Marykutty, K.C. and Aiyer, R.S. 1990. Principal component analysis for grouping acid soils. *National Sym. on Rice in Wet Land Ecosystem*, Kerala Agrl. University, Kottayam, p.87-97

Marykutty, K.C. and Aiyer, R.S. 1992. Yield response to lime and residual effect of liming - A statistical evaluation. *Agric. Res. J. Kerala* **30**:89-97

Mathur, B.S., Rana, N.K., Singh, H. and Lal, S. 1985. Lime as an effective source of fertilizer in acid red loam soils of Bihar. *J. Indian Soc. Soil Sci.* **33**:328-332

Meena, K. 1987. Exchangeable aluminium as an index of liming for acidic upland soils of Kerala. M.Sc.(Ag.) thesis, Kerala Agric. Univ., Trichur

Mendez, J. and Kamprath, E.J. 1978. Liming of latosols and the effect of phosphorus response. *Soil Sci. Soc. Am. J.* **42**:86-88

Militesen, C.L. and Borlan, Z. 1965. Potassium mobility in limed acid soils. *Probl. Agric.* **17**:55-66

* Motowicka-Terelak, T. 1978. Investigations on the effect of days liming of an acid loamy soil in a long term pot experiment. *Pamietnik Pulawski* **69**:27-42

* Mukhopadhyay, P., Haldar, M. and Mandal, L.N. 1984. Effect of Calcium carbonate on the availability of Al, Mo, P, Ca and Mg in waterlogged acidic rice soils. *AgroChemica* **28**:125-132

Nair, S.P.N. 1970. The influence of different levels of calcium and phosphorus on the growth, yield and composition of two high yielding varieties of rice, Padma and Jaya. M.Sc.(Ag.) thesis, Univ. of Kerala, Trivandrum

Nhung, M.T. and Ponnamperuma, F.N. 1966. Effects of $CaCO_3$, MnO_2, ferric hydroxide and prolonged flooding on chemical and electrochemical changes and growth of rice in a flooded acid sulphate soil. *Soil Sci.* **102**:29-41

Njos, A. 1978. Effects of tractor traffic and liming on yields and soil physical properties of silty clay loam soil. *Meldinger Fra. Norges Landbrukshogs Kole* **57**:26-28

Nye, P., Craig, D., Coleman, N.T. and Ragland, J.L. 1961. Iron exchange equilibria involving aluminium. *Proc. Soil Sci. Soc. Am.* **25**:14-17

Ota, Y. 1968. Mode of occurrence of Bronzing in rice plant. *Jap. agric. Res. J.* **3**:1-5

Panda, N. 1984. Fertilizer management in low land rice. *Oryza* 21:46-57

Panda, N. 1987. Acid soils of eastern India - Their chemistry and management. *J. Indian Soc. Soil Sci.* 35:368-581

Panse, V.G. and Sukhatme. 1978. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi, p.339

Patiram, Rai, R.N. and Singh, K.P. 1989. Liming for maize production on acid soils of Sikkim. *J. Indian Soc. Soil Sci.* 37:121-125

Pavar, H. and Marshall, C.E. 1934. The role of aluminium in the reaction of the clays. *J. Indian Soc. Chem.* 53:750-760

Piper, C.S. 1942. *Soil and Plant Analysis*. Asian Reprint (1966). Ham Publishers, Bombay

Potty, N.N., Bridgit, T.K. and Anilakumar, K. 1992. Absorption and distribution pattern of iron by rice. *Proc. 4th Kerala Sci. Congr.*, STEC, Trivandrum, p.68-69

Prabhuraj and Murthy. 1994. Forms of acidity in some acid soils. *J. Indian Soc. Soil Sci.* 42:455-456

Reeuwijk, L.P.V. 1992. *Procedures for Soil Analysis.* International Soil Reference and Informn. Centre, Netherlands, p.11-13

Reeve, N.G. and Summer, M.E. 1970. Effects of aluminium toxicity and phosphorus fixation on crop growth on oxisols in Natal. *Proc. Soil Sci. Soc. Am.* 34:263-267

Reid, D.A., Fleming, A.L. and Foy, C.D. 1971. A method for determining aluminium response of barley in nutrient solution in comparison to response in Al toxic soils. *Agon. J.* 63:600-603

Reid, D.A., Jones, G.D., Armiger, W.H., Foy, C.D., Koch, E.J. and Starling, T.M. 1969. Differential aluminium tolerance of winter barley varieties and selections in associated green house and field experiments. *Agron. J.* 61:218-222

Saigura, M., Shoji, S. and Takahashi, T. 1980. Plant root growth in acid endosols from north eastern Japan. Exchange acidity Y, as a realistic measures of aluminium toxicity potential. *Soil Sci.* **130**:242-280

Sanchez, P.A. 1976. *Properties and Management of Soils in Tropics*. John Wiley and Sons, New York, p.223-253

Schofield, P.K. 1949. Effect of pH on electrical charges carried by clay particles. *J. Soil Sci.* **1**:1-8

* Serda, M. and Gonzalez, M.A. 1979. Lime requirement of three acid soils of Costa Rica. *Agronomia Cosntarriceuse*. **3**:101-108

* Shamshuddin, J. and Tessens, E. 1983. Potentiometric titration of acid soils from Penninsular Malasia. *Pertarika* **6**:71-76

Sharma, S.P., Sharma, P.K. and Tripathi, B.R. 1990. Forms of acidity in some acid soils of India. *J. Indian Soc. Soil Sci.* **38**:189-195

Shoemaker, H.E., McLean, E.O. and Pratt, P.F. 1961. Buffer methods for determining lime requirements of soils with appreciable amounts of extractable aluminium. *Proc. Soil Sci. Soc. Am.* **25**:274-77

Sharma, S.P. and Tripathi, B.R. 1989. Studies on lime requirement of acid soils of India. *J. Indian Soc. Soil Sci.* **37**:363-370

Singh, R.N. and Aleoshin, S.N. 1983. Nature of soil acidity in some acidic soils of USSR. *J. Indian Soc. Soil Sci.* **31**:373-380

Singh, R.N., Diwakar, D.P.S. and Singh, A.K. 1993. Nature of acidity in soils developed on granite griesis and Mahananda alluvium. *J. Indian Soc. Soil Sci.* **41**:29-32

Singh, A.K., Singh, R.N. and Diwakar, D.P.S. 1993. Lime requirement of acid soils. *J. Indian Soc. Soil Sci.* **41**:152-154

Subramoney, N. 1961. Studies on soils of Kuttanad, Part I. Toxic factors. *Agric. Res. J. Kerala* **1**:53-57

Tanaka, A. and Navasero, S.A. 1966. Growth of rice plant on acid sulphate soils. *Soil Sci. Pl. Nutr.* 12:23-30

Tanaka, A. and Yoshida, S. 1970. Nutritional disorders of the rice plant in Asia. *Int. Rice Res. Int. Tech. Bull.* 10

Thawornwong, N. and Diest, A. Van. 1974. Influence of high acidity and aluminium on the growth of lowland rice. *Pl. Soil* 41:141-145

Thomas, G.W. 1960. Forms of aluminium in cation exchange. *Trans. 7th int. Congr. Soil Sci.* 2:364-369

Tisdale, S.L., Nelson, W.L., Beaton, J.D., Horlin, J.L. 1995. *Soil Ferility and Fertilizers*. Prentice Hall of India Pvt. Ltd., New Delhi, p.633

Tomlinson, T.F. 1957. Relationship between mangrove vegetation soil texture and reaction of surface soil. *Trop. Agric.* 34:41-50

Varghese, T. 1963. The influence of Ca and Mg in increasing the efficiency of fertilizers for rice and Ca and Mg status of some typical rice soils. M.Sc.(Ag) thesis, Kerala University, Trivandrum

Verma, T.S. and Singh, S. 1996. Effect of lime and gypsum on different forms of soil aluminium and acidity and crop yields in acid Alfisols of Himachal Pradesh. *J. Indian Soc. Soil Sci.* 44:417-421

Yagodin, B.A. 1984. *Agricultural Chemistry*. Mir Publishers, Moscow, p.161-169

Yuan, T.L. 1963. Some relationship among hydrogen aluminium and pH in solutions and soil systems. *Soil Sci.* 95:155-163

Zelazny, L.W. and Fiskell, J.G.A. 1971. Acidic properties of some Florida soils. II. Exchangeable and tiltrable acidity. *Proc. Soil Crop Sci. Soc. Fla.* 31:149-154

* Originals not seen

EXCHANGEABLE ALUMINIUM AS AN INDEX OF THE LIME REQUIREMENT OF THE LATERITE SOILS OF KERALA

By

N. M. MUHAMED SAKEER.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirements for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science & Agricultural Chemistry
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 654
KERALA, INDIA

1997

ABSTRACT

An investigation was taken up to assess the lime requirement in terms of exchangeable aluminium, to correlate pH and lime requirement values with exchangeable aluminium content of the soil and to study the effect of liming on crop performance with special reference of exchangeable aluminium content of the soil. The study was carried out at College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during the period from 1993-95. The investigation consisted of three phases.

A laboratory study with fifty surface soil samples from the rice growing tracts representing the laterite zone of Kerala viz., Malappuram, Palakkad and Thrissur districts revealed considerable amount of reserve acidity because of the positive difference between pH(H_2O) and pH(KCl). pH showed significant positive correlation with base saturation while it showed negative correlation with the acidity contributing factors.

The exchangeable aluminium content of the soils ranged from 0.25 to 2.54 cmol(+) kg^{-1}. The soils in the pH range of 4.8 to 5.8 were predominant with exchangeable aluminium. Exchangeable aluminium obtained a higher r value of 0.897** with exchange acidity than exchangeable hydrogen (r = 0.57**). Moreover exchangeable aluminium contributed 69 to 86 per cent towards the exchangeable acidity. This high contribution should be taken into account in liming and nutrient management of the soils.

The pH dependent acidity contribution towards total acidity was 23-63 per cent, 34-76 per cent and 20-76 per cent respectively for Malappuram, Palakkad and Thrissur soils. Among the cations studied exchangeable calcium dominated in all soils followed by K, Mg and Na. Maximum base saturation value and organic carbon contents were observed in Malappuram soils. Lime requirement based on exchangeable aluminium recorded the lowest quantity of $CaCO_3$ when compared to LR's based on Shoemaker *et al.* and total acidity. The soils had higher concentrations of total iron and aluminium contents.

A pot culture experiment was conducted to study the effect of graded levels of lime application using the rice variety Triveni in three soils. Lime application increased the pH, exchangeable calcium, magnesium and sodium, available phosphorus, CEC, ECEC and base saturation of the soils while decreased exchangeable aluminium, hydrogen and potassium content of the soils. Different forms of acidities were maximum at the pre-planting stage but decreased as the crop matured.

Lime application significantly increased the straw and yield characters of rice over control in all the three soils. Maximum yield was obtained with calcium at the rate of 0.5 and 1.0 times of exchangeable aluminium equivalent in soil (S_1) having low exchangeable aluminium and those having medium (S_2) and high (S_3) contents respectively.

The per cent composition of N, P, Ca and Mg increased significantly in the straw while that of iron and aluminium decreased with lime application. N, P, K and Ca content were observed maximum content at tillering stage. The N, K, Ca and

Mg content in the grain increased while that of P, Fe and Al decreased with graded levels of lime application. The total uptake of N, P, K, Ca and Mg by both straw and grain was found to increase while that of Fe and Al were found to decrease with increased levels of lime.

Incubation study exhibited similar results and trend as in the pot culture experiment. The soil characters such as pH, available phosphorus, exchangeable Ca, Mg, Na, CEC, ECEC and base saturation were increased whereas exchangeable aluminium, iron, hydrogen and potassium, and different forms of acidities were decreased by the application of graded levels of lime. The soils kept under the submerged conditions exhibited good results than those kept at field capacity level.

The lime requirement of soils calculated based on various methods revealed that the LR based on exchangeable aluminium content of soils required very less quantity of $CaCO_3$. The exchangeable aluminium contributed 69 to 86 per cent towards exchangeable acidity. This high contribution of exchangeable aluminium should be taken into account in liming and nutrient management of the laterite soils. If we adopt this method for lime requirement determination it will be more efficient and economical. Thus the results of the present study point out the advantages in adopting the exchangeable aluminium as an index of the lime requirement of the laterite soils of Kerala.