CHARACTERISATION OF ACIDITY AND ITS MANAGEMENT IN RUBBER GROWING SOILS

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BY
SYAMALA V.K.

RUBBER RESEARCH INSTITUTE OF INDIA
KOTTAYAM- 686 009, KERALA, INDIA.

DECEMBER 2006

DEDICATED TO MY PARENTS

DECLARATION

I hereby declare that the thesis entitled "**Characterisation of acidity and its management in rubber growing soils**" is a bonafide record of the research work carried out by me at Rubber Research Institute of India, Kottayam-686009, under the supervision of Dr. Mercykutty Joseph, Senior Scientist, Agronomy/Soils Division, RRII, Kottayam-686009. I further declare that the thesis has not been previously formed for the basis for the award of any degree.

SYAMALA V.K.
Scientist - S3
Agronomy/Soils Division,
RRII, Kottayam - 686009

Kottayam
22-12-2006

The Rubber Research Institute of India
Rubber Board (Ministry of Commerce and Industry, Govt. of India)
Kottayam – 686 009, Kerala, India

Dr.(Mrs.) Mercykutty Joseph M.Sc.(Agri.), Ph.D.
Senior Scientist (Agronomy/Soils)

22-12-2006

CERTIFICATE

This is to certify that the thesis entitled **Characterisation of acidity and its management in rubber growing soils** is an authentic record of the original research work carried out by Smt. Syamala V.K., Scientist – S3, Agronomy/Soils Division, RRII, Kottayam-686009, under my supervision and guidance and that no part of this has been presented before for any other degree.

Dr. Mercykutty Joseph

Phone : 91 – 481 – 2353311 to 2353320 Fax: 91 – 481 – 2353327 Mobile: 9446304282
Email : mercyjoseph@rubberboard.org.in

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ABSTRACT

Soils under rubber cultivation are acidic in reaction. Most of the rubber plantations in the traditional belt of rubber cultivation in India are in the second or third planting cycle. Continuous cultivation of rubber was reported to reduce the soil pH because of removal of basic cations and increase in Al content. The present investigation was carried out with the following studies viz., i) collection of soil samples representing the major soil series and characterization of the nature of soil acidity ii) estimation of the lime requirement of these soils iii) incubation experiment to study the changes in nutrient availability through liming (iv) field experiment to study the effect of liming on growth of rubber seedlings in the nursery (v) experiment in the glass house with poly bags to understand the translocation of Ca in different plant parts upon liming and (vi) two nursery experiments to compare the direct and residual effect of different liming materials on growth of rubber seedlings in the nursery.

Characterisation of acidity in the major soil series of the traditional tract revealed that the dominance of different forms of acidities were total potential acidity.>pH-dependent acidity> exchangeable acidity. The important factors responsible for acidity in these soils were different forms of Al, organic carbon and clay. High Al saturation of the exchange complex was recorded due to the high concentration of different forms Al viz., soluble, exchangeable, extractable and non exchangeable Al. Subsoil acidity was observed in these soils. Soluble Al content was

found to increase with increase in Al saturation percent. The inverse relation between exchangeable Al and exchangeable Ca points to the deleterious effect of soil acidity on Ca availability. Aluminium toxicity coupled with Ca deficiency reduces the root penetration into the subsoil leading to lower utilization of mineral nutrients and water from subsoil

Hence, further studies will be needed in areas where high concentration of Al in soil solution is recorded to understand how far subsoil acidity will influence the root growth and in turn the growth and yield of rubber.

Wide variation was observed in the LR estimated by different methods and were in the order SMP > Peech > Adams and Evans >Exchangeable Al. All these methods showed highly significant positive correlation with different forms of acidity, forms of Al, organic carbon, clay and negative correlation with pH. For tropical crops tolerant to certain level of Al in the soil, acidity management through liming is aimed to bring down the exchangeable Al to the required level. Hence, exchangeable Al method even though it is not rapid for routine analysis is found to be more appropriate for the estimation of LR of rubber growing soils.

Results from the incubation study revealed that liming had significant effect on soil pH, which increased progressively with increase in the rate of lime addition. pH was brought to neutrality at the 75 and 100 per cent LR treatments. Irrespective of the rate of application, pH decreased significantly with increase in incubation time. The improvement in pH was maintained up to 90 days. Liming improved the availability of Ca, P, K and Zn and reduced the availability of Fe, Mn, Cu, and exchangeable Al.

Nursery experiment conducted to study the effect of liming on availability of nutrients and growth of rubber seedlings, revealed that the growth of plants which received application of fertilizer alone or in combination with various doses of lime were on par and were significantly superior to application of lime alone or control.

Nutrient availability assessed after one year of plant growth indicated that lime in combination with fertilizer significantly increased the availability of P, K and Ca in the soil and is thus beneficial in maintaining /improving the soil fertility.

Incorporation of lime and regular dose of fertilizer significantly increased the dry matter production over fertilizer alone or lime alone application, in plants raised in poly bags. Liming significantly increased the Ca concentration in different plant parts. Highest Ca accumulation was recorded in petiole followed by stem.

Two more experiments were conducted in the rubber seedling nursery to compare the direct and residual effect of quick lime (powdered shell lime), dolomite and phosphogypsum alone and in combination with regular fertilizer application. Application of quick lime and dolomite improved the pH of the soil significantly over control. However, pH of the soil was reverted back to original after one year indicating the strong buffering capacity of the soil. Dolomite or quick lime and regular dose of fertilizer was found to be significantly superior in influencing the growth of seedlings. . Availability of Ca and P in the soil was significantly improved with liming and the availability of Mg was slightly reduced. Residual effect of liming was established through a second experiment in the same field.

Key words: Acid soils, Aluminium, Liming, Lime requirement, Quick lime, Dolomite, Shell lime, Soil acidity, Rubber, *Hevea brasiliensis*

PREFACE

Soil is one of the most precious natural resource on earth for survival of the atural habitat and human civilization. Soil acidity inhibits plant growth because of ow nutrient status and the presence of toxic elements particularly exchangeable Al.

In the traditional belt of rubber cultivation, plantations are in the second or ird planting cycle. Continuous cultivation of rubber was reported to reduce the soil H due to removal of basic cations like Ca and Mg and increase in Al content which ay adversely affect the plant growth and yield. Hence, a need was felt to haracterize the nature of acidity in these soils and its management for better growth f rubber plants.

The thesis is presented in five chapters. The first chapter introduces the topic escribes the main objectives of the study. A review of the related work on soil cidity and its management is given in the second chapter. The third chapter explains e experimental details followed in the study. Results and discussions of the vestigations are presented in the fourth chapter and the fifth chapter contains ummary and conclusions of the study.

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Abbreviations

%	Per cent
@	At the rate
Al	Aluminium
Al_2O_3	Aluminium oxide
Al^{3+}	Aluminium ions
Al_d	Dithionite citrate bicarbonate extractable aluminium
Al_o	Oxalate extractable aluminium
B	Boron
Ba^{2+}	Barium ion
$BaCl_2$	Barium chloride
BS	Base saturation
Ca	Calcium
$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CD	Critical difference
CEC	Cation exchange capacity
cm	Centimetre
cmol/kg	Centi mol per kilogram
CRD	Completely randomized design

Continued....

Abbreviations (Continued)

Cu	Copper
DTPA	Di ethylene tri amine penta acetic acid
EA	Exchangeable acidity
ECEC	Effective cation exchange capacity
et al	And others
Ex. Al	Exchangeable aluminium
Extr. Al	Extractable aluminium
Fe	Iron
Fe_2O_3	Iron oxide
Fe_d	Dithionite citrate bicarbonate extractable iron
Fe_o	Oxalate extractable iron
Fig,	Figure
g	Gram
H^+	Hdrogen ion
Ha	Hectare
HC	Hydrochloric acid
HF	Hydrogen fluoride
i.e.	That is
K	Potassium
KCl	Potassium chlorides

Continued...

Abbreviations (Continued)

Kpl	Kanjirappally
Ktr	Kunnathur
Lah	Lahai.
LR	Lime requirement
M	Molar
meq/100 g	Milli equivalent per 100 gram
Mg	Magnesium
Mg	Metric gram
mg	Milligram
ml	Milli litre
Mn	Manganese
N	Normal
N	Nitrogen
NaF	Sodium fluoride
NaOH	Sodium hydroxide
$-NH_2$	Amine group
NH_4^+	Ammonium
NH_4OAc	Ammonium acetate
nm	Nanometre
NO_3^-	Nitrate ion
NS	Non significant

Continued....

Abbreviations (Continued)

^{o}C	Degree celsius
OC	Organic carbon
OH^-	Hydroxyl group
P	Phosphorus
PA	pH dependent acidity
Pck	Panachikkad
ppm	Parts per million
R-COOH	Organic acids
R-OH	Organic alcohols
SD	Standard deviation
SE	Standard error
SMP	Shoemaker Mclean and Pratt
S	Sulphur
t /ha	Tonnes per hactre
TEA	Tri ethanol amine
Tmg	Thrikkannamangal
TPA	Total potential acidity
Tvr	Thiruvanchoor
viz.	Namely
Vpm	Vijayapuram
Vzr	Vazhoor
Zn	Zinc

CHAPTER-1

INTRODUCTION

Soil is one of the most precious natural resources on earth for survival of the natural habitat and human civilization. A soil suitable for optimum growth of any plant is one which encourages vigorous root development ensuring a firm anchorage and also provides an adequate store house for water and plant nutrients. The suitability of a soil for a crop is therefore very much dependent on physical and chemical making of the soil. Improvement of soil fertility is a critical component of soil health management which also plays a key role in sustainable agricultural production.

Soil acidity inhibits plant growth and this result from variety of specific factors and interactions between these factors. Low nutrient status and the presence of toxic elements particularly Al are major constraints to intensive crop production in acid soils (Adams, 1981). In general, acid soils are deficient in P, K, Ca, Mg, S, B and Mo. Under heavy rainfall conditions all the exchangeable bases (Ca, Mg and K) and salts are leached from the soil profile leaving behind materials rich in Al and Fe oxides which render the soil acidic and infertile. Aluminium toxicity become very severe at pH <5.0 and can be a problem even at pH 5.5 for soils dominated by kaolinite mineral (Foy, 1984). Aluminium toxicity inhibits root growth and in turn reduces the uptake of nutrients and water. The toxic action of Al results in stubby root because of inhibition of elongation of the main axis and lateral roots (Klotz and Horst, 1988). With increasing soil acidification root penetration into the subsoil is inhibited leading to a more shallow root system (Marschner, 1991a), with lower utilization of mineral nutrients and water from subsoil.

According to Dijikman (1951) rubber trees grow on majority of the soils of the tropics with good soil depth and pH range from 4.0 – 6.5. Later on, it was reported that the growth of *Hevea* is greatly influenced by physical, chemical and minerological properties of the soil (Eshett and Omueti, 1989; Krishnakumar (1989).

In India the cultivation of rubber traditionally was confined to a narrow tract in the western side of Western Ghats mainly in Kerala State and Kanayakumari district in Tamil Nadu and south Kannada and Coorg district in Karnataka. Earlier, most of the rubber plantations were raised in freshly cleared forests where the soil fertility conditions were good in comparison to the cultivated areas of the same agro climatic zones. The economic life span of rubber tree is about 30-32 years and after this period the trees are cut down and removed for replanting. This continuous relay cropping which involves considerable recycling of nutrients and import/export of biomass may have significant influence on soil health and nutrient status. After each cycle biomass of about 400 to 450 tonnes per hectare is removed. In kerala most of the plantations are in the 3rd cycle of replanting.

Soils in the rubber growing tract are mostly laterite, lateritic, red and alluvial and are reported to be deficient in available P and K (Karthikakuttyamma *et al*., 2000). Soils are acidic in reaction and in the surface layer the pH values range from 4.5-5.5. Extremely acid soils (pH 4.5) occur in some parts of Kanyakumari, Thiruvanathapram, Kollam, Kottayam and Ernakulam districts covering 9.0 per cent of the area. (NBSS and LUP,1999; Karthikakuttyamma *et al*., 2000). In most of these soils acidity is expressed due to the presence of exchangeable Al along with the loss of cations through erosion, leaching and also by crop removal. Norhayti and Lau (1990) reported a decrease in pH in the surface and subsurface soils due to the cultivation of rubber. Similar results from Nigeria were reported by Asawlam *et al*., (1991). Significant reduction in soil pH up to a depth of 60 cm due to continuous cultivation of rubber was reported by Karthikakuttyamma (1997). In one cultivation cycle of *Hevea* the highest depletion was noticed for Ca (1260 kg/ha) followed by Mg and continuous cultivation of rubber for over 70 – 80 years, Ca to the tune of 2900 kg was reported to be lost from 0 – 60 cm layer of the soil. Sanchez *et al.*, (1985) reported loss of 56.0 per cent Ca in rain forests upon replanting of pinus and attributed this to the differential uptake by the trees due to the spatial variation in soil augmented by the degree of leaching. Rubber trees appear to have a fair degree of adaptability to low Ca environment (Bolton, 1960). The ratio of Ca to the total cations should be around 0.15 for roots to grow freely and for penetration of roots to the subsoil (Howard and Adam, 1965). Al/Ca molar ratio influence root development in acid soils. A ratio of 0.02 is considered to be the upper limit beyond which growth will be affected (Marschner, 1986).

Subsoil acidity retards root growth resulting in drought stress and is reported to be one of the major yield-limiting factors in acid soils (Saigusa *et al.*, 1980; 1985; Shoji *et al.*, 1985). Suresh *et al.*, (1994) reported the contribution of exchangeable Al to subsoil acidity in rubber growing tract. No study has yet been done in rubber growing soils to understand the nature of acidity and associated factors and its influence on rubber growth. Hence the present investigation was carried out with the following objectives

1. Characterize the nature of acidity in rubber growing soils
2. Estimate the lime requirement of rubber growing soils
3. Study the effect of liming on nutrient availability
4. Study the effect of liming on growth of rubber seedlings.
5. Assess the uptake and translocation of Ca in different plant parts upon liming
6. Compare the effectiveness of different liming materials on growth of rubber seedlings

CHAPTER-II

REVIEW OF LITERATURE

Soil reaction is one of the characteristics of the soil solution expressed in terms of pH indicating whether the soil is acid, alkaline or neutral. It exercises significant influence on many soil properties including nutrient availability, biological activity and soil physical condition. A soil which is in acid reaction (pH <6.60) throughout the root zone is called an acid soil. Such soils have more H^+ ions than OH^- ions in soil solution. Brady and Weil (1999), divided soil acidity into strongly acidic (pH<5.0) and moderately acidic, pH (5.0 and 6.5). Somani *et al.*, (1996) further grouped it into five categories *viz.*, extremely acidic (pH <4.50), very strongly acidic (pH 4.50 –5.0), strongly acidic (pH 5.10 – 5.50), and medium acidic (pH 5.60 – 6.0) and slightly acidic (pH 6.10 – 6.50). Broadly, acid soils are base unsaturated, low water retentive, nutrient imbalanced and problematic from the management standpoint. Acid soils are very old and vulnerable to degradation.

II. 1. Major constraints of acid soils

The pH can be viewed as the master variable of all the driving factors because it can affect the surface charge and subsequent adsorption of solutes by variable charge soil components such as layer silicate clays, organic matter and oxides of Fe and Al. (Adriano, 2001). Lower pH values elevate the concentration of Al in soil solution, taking up a greater proportion of cation exchange sites and reduce base saturation.

Soil acidity inhibits plant growth and this result from variety of specific factors and interactions between these factors. In acid mineral soils major constraints to plant growth are increased solubility and toxicity of H, Al, Mn and Fe, deficiencies of Mg and Ca, reduced availability of P and Mo and reduced microbial activity, inhibition of root growth and reduced water uptake. The relative importance of these constraints depends on plant species, soil type, parent material, concentration and species of Al, soil structure and aeration and climate (Marschner, 1991b). Soil acidification has a negative effect on fine root development (Marschner, 1991a).

In oxisols and ultisols and in heavily leached soils of the humid tropics, one of the most important growth-limiting factors is Al toxicity (Sanchez, 1976; Wright, 1989). Aluminium in excess is found to affect the root growth of crops. Aluminium *toxicity reduces length and branching of root (Sarkar and Debnath, 1989), cell division,* shoot growth and respiration. Klotz and Horst (1988) reported that the toxic action of Al results in stubby root because of inhibition of root elongation of the main axis and lateral roots. With increasing soil acidification root penetration into the subsoil is inhibited leading to a more shallow root system (Marschner, 1991b) which limits utilization of mineral nutrients and water from the subsoil which in turn results in reduced crop yield. The inhibition of root growth by Al toxicity increases the risk of P deficiency in acid mineral soil. According to Coleman *et al.*, (1960), one cmol/kg of soil exchangeable Al can fix about 70 ppm of P. Hence for successful crop production heavy dose of P are required to satisfy the high P-fixing capacity of the soils.

The toxicity become very severe at pH <5.0 and can be a problem at pH values of 5.0 – 5.5 for kaiolinite soils (Foy, 1984). According to Kamprath (1984) the toxicity is exacerbated by low levels of exchangeable Ca. It is reported that, in acid soils with pH below 5.5 an increasing proportion of the cation exchange sites of clay minerals is occupied by Al, replacing other cations such as Ca and Mg and simultaneously acts as a strong adsorber of P. Phosphate availability in these highly weathered acid soils is low because of the high P fixing capacity due to soluble Fe and Al.

Mandal and Khan (1972) reported that 86 per cent P in super phosphate got converted to unavailable form within 15 days of application. Pradhan and Khera (1976) reported that in acid soils of Sikkim (pH 4.20 - 5.60) almost 90 per cent of the applied P got fixed and the P use efficiency was very low.

Mineralization of organically bound nutrients and the subsequent availability to plants are generally influenced by soil acidity. Nitrification is markedly reduced below pH 6.0 and even undetectable below pH 4.5 (Alexander, 1977). The activity of Nitrosomonas and Nitrobacter *we*re significantly reduced by soil acidity. Acetobacter population was almost nil in acid soils (Nair and Ramaswamy, 1965). Soil acidity has deleterious effect on the symbiotic N-fixation and in soils with pH below 6.0 nodulation and N-fixation were very poor. This might be due to the poor supply of Ca and Mo, which are essential for N-fixation in legumes. Similarly, due to Al-toxicity root growth is limited which in turn reduces the nodule formation. Increased attack by soil pathogens and high concentration of organic acids and other toxic compounds due to unfavorable redox conditions were also reported in acid soils (Thripathi *et al.,* 1982).

In variable charge soils, increasing acidity decreases CEC which in turn reduces the ability to retain K resulting in more soil solution K. This solution K would be prone to leaching (Alibrahim *et al*, 1988).

Soil acidification results in the decline in basic cations, such as Ca and Mg leading to their deficiency for plant growth. In acid soils most of the Ca present exists in soluble form. Both soluble and exchangeable Ca decreases with decreasing soil pH (Haynes and Ludecke, 1981). Poor soil physical conditions like structure, aggregate stability *etc.* arising due to Ca deficiency affect root growth and water retention and can significantly reduce plant growth in coarse textured or highly leached soils with low cation exchange capacity. At low pH, bio-availability of Ca is reduced by high concentration of Al. Aluminium inhibits Ca uptake by blocking Ca^{2+} channels in the plasma membrane (Huang *et al.,* 1992) and Mg uptake by blocking the binding sites of transport protein (Rengel and Robinson, 1989) Al/Ca molar activity ratio influence root development in acid soils. A ratio of 0.02 is considered to be the upper limit beyond which growth will be affected (Marschner, 1986).

Sanches *et al.*, (1985) reported loss of 58 per cent Ca in rain forest upon planting of *Pinus due* to the differential uptake by the trees and also the variations in the degree of leaching in forest. Influence of Ca in plant nutrition is very important primarily because of its influence in alleviating Al toxicity thereby increasing the availability of P and K. Rubber trees appears to have a fair degree of adaptability to low Ca environment (Bolton, 1960). The ratio of Ca to total cations should be around 0.15 for the roots to grow freely in acid soils, especially for the penetration of roots to the subsoil (Howard and Adams, 1965).

Magnesium retention in exchangeable form decreases in acid soils due to decrease in variable charge and are mainly present in soluble form. Also, Mg being a poor competitor with Al and Ca for the exchange sites tends to accumulate in solution phase and subjected to leaching losses (Edmeades, *et al.*, 1985; Myers *et al.,* 1988).

Solubility and phyto-availability of metals are inversely related to soil pH. Copper deficiency is likely to occur due to reduced retention in acid soils because of the slow decomposition of organic matter (Cavallaro and McBride, 1980; Jeffery and Uren, 1983). Activity of Zn increases rapidly with decreasing pH and below pH 5.5 Zn nutritional problems are seldom encountered. Manganese toxicity is noticed in soils with pH below 5.0 and excess Mn interferes the metabolism. An increase in solubility of Mn in toxic levels with decreasing pH below 6.0, can adversely affect the growth of sensitive plants (Jones and Fox, 1978).

II. 2. Distribution of acid soils

Acid soils occur in the tropics and sub tropics as well as moderate climate areas. World over about 3.95 billion ha of land is acidic. It accounts for nearly 30 per cent of the ice-free land area of the world and it occur in the two major global regions; the northern cold temperate belt and the southern tropical belt (Von Uexkull and Mutert, 1995). The latter belts include much of the agriculture land of South East Asia, Africa and central South America.

Acid soils in India occupy about 100 million ha, out of which 51 million ha is under forest and 49 million ha is under cultivation. Out of 49 million ha 25 million ha has pH<5.6 and 23 million ha has pH value between 5.6 and 6.5 (Sarkar, 2002). These soils have been classified under the orders, ultisols, alfisols, mollisols, entisols and inceptisols. Murthy *et al.* (1976) classified acid soils in to following groups *viz*., (1) laterites, (2) laterite and lateritic red soils, (3) Ferruginous red soils, (4) mixed red and yellow soils, (5) podzolic soils, (6) brown podzolic soils, (7) brown forest soils, (8) grey brown soils, (9) foot hill soils, (10) peaty soils, (11) acid sulphate soils, (12) degraded saline or saline-acid soils, (13) alluvial acid soils, (14) coastal alluvial soils and (15) marshy soils.

Largest area under acid soils is covered by laterites and latosols occurring in Assam, West Bengal, Bihar, Orissa, Andhra Pradesh, Kerala, Madhya Pradesh, Karnataka, Tamil Nadu and Maharastra. In Himalayan region, soils are acid podzols while in West Bengal, Bihar and Assam acid alluvial soils are mostly present. Peat and marshy soils are found in some parts of Assam, Kerala, costal tracts of Orissa, south-east coast of Tamil Nadu and tarai regions of Uttar Pradesh and Bihar (Tripathi *et al.*, 1982). These soils are grouped into three categories *viz.*, about 12 per cent strongly acidic (pH< 5), 48 per cent moderately acidic (pH 5 – 5.5) and 40 per cent mildly acidic (pH 5.5 – 6.5). According to Tripathi *et al.*, (1982) about 88 per cent of the soils of Kerala are acidic. The laterite zone of Tamil Nadu and nearly 45 per cent soils of Karnataka are estimated to be acidic (Panda, 1998).

II. 3. Rubber growing soils in India

Rubber cultivation in India had been traditionally confined to a narrow belt extending from Kannyakumari district of Tamil Nadu in the South to Dakshin Kannada and Kodagu districts of Karnataka in the north and lying in general west of the Western Ghats and parallel to them for approximately 400 km. Later on, it was extended to non traditional regions including northeast India, hinterlands of coastal Karnataka, Goa, Konkan regions of Maharastra, hinterlands of coastal Andra Pradesh, Orissa and certain areas of West Bengal.

Because of the tropical climate with heavy rainfall and high temperature, the soils in these regions are highly weathered and are mostly laterite and lateritic type. Early studies reported that the soils in the rubber growing tract were mostly laterite and lateritic, red and alluvial and acidic in nature (George, 1961; George, 1962; Koshy and Varghese, 1972). Krisnakumar (1989) reported that these soils had kaolinitic mineralogy. Presence of oxides of Fe, gibbsite and illite in degraded form was also reported. Presence of oxides of Fe and Al and kaolinitic nature of clay impart good physical properties to these soils and is well suited for rubber even though nutrient status is poor. The soils are friable and have good aggregate stability, which facilitate good aeration and free drainage. These soils are acidic in reaction with pH ranging from 4.5-6.0 (Pushpadas and Karthikakuttyamma, 1980; Krishnakumar, 1989).

Soils of the traditional region comprising Kerala and parts of Tamil Nadu were grouped according to modern soil taxonomy into 62 soil series under the three orders *viz.*, ultisols, inceptisols and entisols. Majority of the soils (51series) belong to ultisols, which are moderately deep to very deep. These are low base status soils with consequent higher acidity. Texture of these soils ranges between loamy and clayey, and clay percent increases down the profile. With increasing contents of coarse fragments, the soils are classified as clayey to clayey skeletal, which ultimately govern the effective soil volume (NBSS and LUP, 1999). The dominant clay mineral is kaolinite, which is low in activity. Mixed mineralogy could be found in soils belonging to entisols and inceptisols, which occur in association with ultisols depending on the topographical position. The soils are found to be very porous and well drained, moderately to highly acidic, deficient in available P and variable with regard to available K and Mg. Majority have higher organic matter status. The red soils found in some areas are characterized by their reddish to brown colour and fine loamy texture.

The soil pH is often less than 5.2 in the surface horizon (Karthikakuttyamma *et al.*, 1989; NBSS and LUP, 1999). In most of these soils acidity is developed due to the high levels of exchangeable Al^{3+} and the loss of basic cations due to erosion, leaching and crop removal.

In general, organic carbon status is high in the rubber growing soils. At the same time, these soils are reported to be deficient in available P and K (George, 1961 and Karthikakuttyamma *et al.*, 1976). Available K status is low in most of the conventional rubber growing regions (Joseph *et al.*, 1990; Karthikakuttyamma *et al.*, 1991). Available Mg status is high in the northern disricts of Kerala, Karnataka, Goa and Maharastra regions and Kanyakumari districts in Tamil Nadu and low in the southern districts of Kerala (Karthikakuttyamma *et al.*, 1991). Lower values of exchangeable cations (Krishnakumar, 1989) and high total Al content (Karthikakuttyamma, 1997) were reported in these soils. Suresh *et al.*, (1994) reported that exchangeable Al in the surface soil (0 - 25 cm depth) ranged from 0.36 to 0.98 cmol/kg. The highest concentration of 0.58 to 2.23 cmol/kg was recorded at a depth of 50 – 75 cm.

Majority of the soils in the northeastern regions belongs to entisols, inceptisols, ultisols and alfisols because of varied parent materials and topography. Soils are generally deep to very deep, well drained and acidic with low base status. Kaolinite is the dominant mineral with inclusions of mixed mineralogy depending on the nature of the soil. These soils are poor in organic carbon status due to the traditional practice of shifting cultivation. Phosphorus and K status range from low to medium and Mg status is high (Krishnakumar and Potty, 1989). Major soils under rubber in Tripura are ultisols and alfisols (Bhattacharya *et al.*, 1996). These soils are acidic in reaction (pH 4.5) and low in organic carbon content. Available P and K are low and Mg is high.

II. 4. Impact of rubber cultivation on soil properties

Most of the rubber plantations in the traditional region in India are now in the 2nd or 3rd cycle of replanting (Krishnakumar and Potty, 1992; Karthikakuttyamma, 1997). Karthikakuttyamma (1997) found that continuous growing of rubber for three cycles resulted in significant reduction in soil pH up to a depth of 60 cm and an increase in total Fe Al and sesquioxides. Asawalam *et al.*, (1991) noticed decrease in pH values due to cultivation of rubber in Iyanomo, Nigeria. It was reported that due to continuous cultivation of clover for more than 30 years soil pH was decreased by one unit (Williams, 1980). Mongia and Bandhopadhyay (1994) reported significant reduction in pH under plantation crops in South Andaman Islands. A decrease in pH in surface and subsurface soil was reported by Adejuwon and Ekanade (1988), due to the replacement of rain forest and cultivation of cocoa, in southwest Nigeria. A decrease of pH in surface and subsurface soil, when rubber was cultivated after clearing forest was reported by Norhayti and Lau (1990).

Karthikakuttyamma (1997), reported that in one cultivation cycle of *Hevea* the highest depletion was noticed for Ca (1260 kg/ha) followed by Mg and continuous cultivation of rubber for over 70 to 80 years, about 2900 kg of Ca was lost from 0- 60 cm layer of the soil. Contribution by litter addition in rubber plantation is insufficient to maintain the base status.

II. 5. Sources of soil acidity

Formation and distribution of acid soils depends on several factors like topography, temperature, vegetation, parent material, hydrologic condition *etc.* Weathering of acid parent materials, excessive leaching of bases under humid climate (especially tropical and sub-tropical regions), imbalanced cycling of basic and acidic substances and organic as well as inorganic acids produced from plant roots, dry and wet acid deposits, fertilization, legume cultivation *etc.* contributes to formation of soil acidity. Hence acid soils vary in their properties also.

According to Tisdale *et al.*, (1985), humus or organic matter, alumino silicate clays, hydrous oxides of Fe and Al, exchangeable Al, soluble salts and carbon dioxide are the main sources of acidity in soil. In addition to Al^{3+} and H^+, Fe and Mn forming the major hydrolysable ions on the exchange sites of the soil complex also produce acidity (Yuan, 1963).

The process of acid generation in soil can be broadly classified in to two categories *viz.*, acidification occurring under natural ecosystems through industrial activities, and acidification occurring under managed farming systems through plant and soil induced processes (Bolan *et al.*, 2003).

Carbon assimilation during photosynthesis (Raven, 1985: Felle, 1988) and fixation of atmospheric N were reported to be sources of acidity (Haynes, 1983: Liu *et al.*, 1989). The acidity generated by fixation of N by legume has been found to be equivalent to the excess uptake of cations over anions by the plant and vary from 0.2 to 0.7 mol H^+/mol of fixed N (Helyar, 1976; Bolan *et al.*, 1991; de Klein *et al.*, 1997). Similarly, acidity is reported to be generated through ammonium and nitrate assimilation (Raven, 1985).

Decomposition of organic matter (Parfitt *et al.*, 1997) and transformation of N and S were reported to contribute to soil acidity. Application of N-fertilizers such as urea and ammonium sulphate to soils produce H^+ by two processes *viz.*, nitrification and nitrate leaching. Part of the H^+ produced is neutralized by $(OH)^-$ released by the plant during the subsequent uptake of the NO_3^- ion, the negatively charged NO_3^- carry positively charged Ca, K, Mg and NH_4^+ in order to maintain the electric charge on the soil particles. The depletion of basic cations during the leaching of NO_3^- ions accelerates the acidification processes.

The accumulation of plant organic matter lower pH by releasing H^+ associated with organic anions, by nitrification or by increased CEC and corresponding increase in exchangeable acidity (Williams, 1980; Helyar and Porter, 1989; Bolan *et al.*, 1991). According to Williams (1980), in many soils, the most acidified layers were below 10 cm.

Soil organic matter contains reactive - COOH, phenolic - OH, - NH_2 groups, which are capable of bonding H^+ and the degree of contribution to acidity depends on the nature of organic matter as it varies from place to place. According to Schnitzer and Gupta (1965) the carboxylic and phenolic groups attached to the humic substances of organic matter are primary sources of acidity. In mineral soils fulvic acid was more acidic than humic acid mainly due to the presence of more carboxylic groups in fulvic acid (Wright and Schnitzer, 1959).

Pocknee and Sumner (1997) observed that the soil pH change was well correlated with the amount of basic cations in plant materials. Presence of salt content (NaCl, Na_2SO_4 or $Ca(NO_3)_2$) in the soil solution formed by the weathering of minerals or organic matter decomposition or added in the form of fertilizers lower the pH by the displacement of adsorbed Al from the exchange complex and increase acidity by hydrolysis. The level of Al in soil increases with increasing salt content because other cations then displace exchangeable Al by mass action (Brenes and Pearson, 1973).

II. 6. Forms of soil acidity

Soil acidity may be partitioned into exchangeable (mainly monomeric Al^{3+}) and non-exchangeable (titrable or pH dependent acidity) components based on extraction with a neutral salt solution such as 1M KCl (Coleman and Thomas, 1967). Acidity develops on soil colloids mainly by two mechanisms, *viz.*, first by isomorphous substitution of H^+ and Al^{+3} in silicate clay minerals, which forms exchange sites throughout the pH ranges and is termed as permanent charge acidity (exchangeable acidity) and the second due to polymers of Fe and Al and organic matter, where the exchange sites solely depends on soil pH and is termed as pH- dependent acidity. Aluminium complexed with organic matter and some of the oxides of Fe and Al associated with soil clay are responsible for pH- dependent acidity (Marshall, 1965) and is expressed at soil pH values > 5.5.

Sharma *et al.* (1990) reported that the electro statically bonded H^+ and Al^{3+} comprised 21 per cent and 79 per cent of exchange acidity, whereas, pH- dependent and exchange acidity accounted for only 71 per cent of the total acidity. The remaining part may be contributed by the hydrolysis of Fe and Mn on the exchange sites of the soil complex.

According to Yuan (1963), H^+ and Al^{3+} were not the only ions contributing to the soil acidity but Fe and Mn also produce acidity following hydrolysis. Bear (1964) reported that weak acids formed during soil organic matter decomposition also contribute to soil acidity.

Total potential acidity comprises pH- dependent and exchangeable acidity (PA) and was estimated in the $BaCl_2$ - TEA extraction, includes acidity from the replacement of H^+, Al^{3+} and from the dissociation of acidic group (Peech 1965). The exchangeable acidity includes the exchangeable H^+ and Al^{3+} held at the permanent charge sites of the soil exchange complex (Mc Lean, 1965). Mc Lean *et al.*, (1965) reported the order of activity of the various forms of acidity as exchangeable or permanent charge H^+> exchangeable or permanent charge Al^{3+}> hydroxy-Al monomers>hydroxyl-Al polymers ≈ lattice Al-OH or Si-OH acidity.

According to Coleman and Thomas (1967) the exchangeable acidity as a part of the total potential acidity varies with the nature of soil and base saturation. Surface soils had lower exchangeable Al at pH< 5.0 than sub soils. In highly weathered cultivated soils of southern USA, occurrence of subsoil layers with high exchangeable Al had been reported by Sumner *et al.*, (1986). Sharma *et al.*, (1990) reported that exchangeable acidity was mainly due to monomeric Al^{3+} ion. This was in agreement with the finding of Coleman and Thomas (1967). High content of exchangeable Al in the subsoil was reported to be responsible for relatively high values of exchange acidity (Nayak *et al.*, 2002).

II. 7. Forms of Al

Aluminium exists in soil in various forms such as soluble, exchangeable, non exchangeable, amorphous and crystalline hydroxides (Hesse, 1971) depending on pH and some of these forms are toxic to plants. Below pH 5.0 the toxic species, hexaaqua

Al ion ((Al (OH)$_6^{3+}$ 6H$_2$O) exists in soil. Solubility of Al is quite low within the soil water pH of 5.5 – 7.5. At pH values above 5.0, hydrated hydroxy-Al ions exist in the exchangeable form. Al^{3+} is predominant below pH 4.7, while Al (OH)$^{2+}$ between 4.7 and 6.5 and relatively insoluble Al(OH)$_3$ between 6.5 and 8.0 (Panda, 1998).

Exchangeable Al is a mixture of monomeric Al ions (Al^{3+}, Al (OH)$^{2+}$ Al(OH)$_2^+$) with an average charge per Al between 2 and 3 and decreases as pH increases (Wild, 1988). Aluminium is tightly held to exchange sites and as a result, concentrations, in soil solution are characteristically low, often ranging between 10 and 250 μM (Kamprath, 1978; Adams and Moore, 1983; Curtin and Smillie, 1983). Devidescu and Devidescu (1982) grouped the exchangeable Al in to four classes as low (50 ppm), medium (51-150 ppm), high (151-300 ppm) and very high (above 300 ppm).

Organically bound Al has the important role of controlling Al in soil solutions in the surface horizons of mineral soils (Bloom *et al*; 1979) and in O- horizons of forest soils (Walker *et al.,* 1990). Organically bound Al is bound to carboxylate groups in soil organic matter (Bloom, 1981). Organically bound Al is less reactive than Al on the exchange sites of clays while it is more reactive than crystalline and non-crystalline Al hydroxide and Al in aluminosilicates (Bloom *et al.,* 1979; Cronan *et al.,* 1986; Walker *et al.,* 1990).

The non-crystalline Al may be in colloidal phase largely associated with organic matter. Another form of Al which are occupying the interstitial spaces of clay minerals are present as non-crystalline hydroxides and oxides or complex hydroxy-polynuclear components and can be partially soluble in extracts.

Since the solubility of Al is highly pH- dependent, when acid soils are limed exchangeable and soluble Al precipitate as hydroxy Al- species. The positively charged monomeric Al(OH)$^{2+}$ and Al(OH)$_2^+$ can polymerize to form both large and small positively charged polynuclear complexes which become sorbed to clay mineral and organic matter surfaces (Stole *et al.*, 1976; Rengaswamy and Oades, 1978).

Aluminium species in soil solution is influenced by pH (Jarvis, 1986) and the concentrations of organic matter and salt content (Kamprath, 1972). In the topsoil where organic matter content is higher, H^+ toxicity may dominate, but in the subsoil, root growth may be depressed by Al toxicity.

Jarvis (1986) reported that, the Al^{3+} present in 0.01 M $CaCl_2$ extract may be considered to be comparable to that found in soil solution. The activity of Al^{3+} in soil solution (0.01M $CaCl_2$ extractable) was measured from pH and Al concentration. Aluminium ion in soil solution has been observed to be more closely related to inhibition of plant growth in acid soils (Evans and Kamprath, 1970; Adams and Moore, 1983). Soils high in organic matter contained small amount of soluble Al (Evans and Kamprath; 1970).

The relationship between pH and Al saturation provides a quantitative assessment whether Al toxicity is likely to be a problem. Poor crop growth in acid soils can be correlated with Al saturation in most situations (Sartain and Kamprath, 1977; Abruna-Rodriguez *et al.*, 1982). Exchangeable Al and Al saturation percent have been used as a measure of potential Al toxicity (Pearson, 1975; Mc Cray and Sumner, 1990).

Evans and Kamprath (1970) reported that Al in the soil solution will be less than one ppm when the Al saturation is lower than 60 per cent and its concentration in soil solution increases sharply beyond 60 per cent Al saturation. High Al saturation particularly in sub soils has been reported for ultisols and inceptisols (Sanchez, 1976). Lower Al saturation in surface layer may be due to the downward movement of Al as organo Al complexes or chelates (Schnitzer and Skinner, 1963) and also enrichment of basic cation through litter fall. The concentration of soil solution Al depends upon the soil organic matter and salt content (Kamprath, 1972).

Alva and Sumner (1990) reported the inverse relation of exchangeable Ca and Al and pointed out that the major deleterious effects of soil acidity occur when Al toxicity was coupled with Ca deficiency.

II. 8. Management of acid soils

Liming is a widely accepted amelioration practice for efficient utilization of native and applied soil nutrients and economic use of fertilizers (Sarkar *et al.*, *1996*). The problems related to acid soils could be managed by liming which improves pH, base status, CEC, inactivates Al, Fe and Mn in soil solution, reduce acidity and P-fixation (Panda and Koshy, 1982a and b; Misra *et al.*, 1989; Sahu and Patnaik, 1990; Mishra, 2002). The use of lime to neutralize toxic concentration of Al, Mn and H and supply plants with sufficient amount of Ca and Mg has been practiced from centuries.

Agriculturally, lime may be said to be any compounds of Ca or Mg capable of counteracting the harmful effects of H and Al ions in the soil solution of acid soils.

II. 9. Lime requirement

Lime requirement is defined as the amount of liming material needed to create a favourable soil condition for plant growth. A series of methods have been developed to estimate the lime requirement (LR) of soils (Adams and Evans, 1962; Shoemaker *et al.*, 1961; Peech, 1965). All methods however, are based on identical underlying principles. The measured lime requirement must accurately reflect the amount of liming materials needed to raise the pH of the soils to the target value when lime is applied under field condition for optimum plant growth and to prevent over liming hazards in soils.

Studies showed that organic matter, pH and CEC are highly correlated with lime requirement (Keeney and Corey, 1963; Ross *et al.*, 1964). Lime requirement of soil depends on the buffering capacity as reflected by clay and organic matter (Tisdale *et al.,* 1985; Bache, 1988). Carboxylic group contribute to buffering over the pH range 2.0 - 7.0 while phenolic hydroxyl groups control at pH more than 7.0 (Bache, 1988). Exchangeable Al and organic matter contents were the two main factors determining the amount of lime requirement to bring the pH to the desired level (Reeve and Sumner, 1970; Curtin *et al.*, 1984).

Over liming reduces the availability of important plant micronutrients such as Fe, Mn and Zn to yield limiting levels particularly in the case of soils with low buffering capacities (Sims, 1996).

Studies have shown that liming to pH 5.5 particularly in highly weathered soils where exchangeable Al is neutralized is acceptable for maximizing crop production (Evans and Kamprath, 1970; Mclean, 1970; Reeve and Sumner, 1970; Webber *et al.,* 1982). The target pH values of 5.2- 5.5 are used for peat and muck soils and high organic matter soils because economic crop responses to lime rarely occur above this pH values (Mc Lean, 1973; van Lierop, 1983). Kamprath (1970) suggested that lime recommendation based on the amount of exchangeable Al on the topsoil and that lime rates be calculated by multiplying the milli equivalents of Al by 1.5. Lime rates calculated by this method neutralize 85 to 90 per cent of the exchangeable Al in soils containing 2 to 7 per cent organic matter. Kamprath (1970) further reported that, liming rates calculated based on exchangeable Al raise the soil pH to 5.5 - 6.0 in most mineral soils. For highly weathered oxisols and ultisols in which hydrous oxides of Fe and Al are predominant, a soil pH of around 5.5 with exchangeable Al being less than 20 per cent of ECEC would produce satisfactory growth (Adams, 1984).

Kamprath (1984) pointed out that in acid soils of the tropics exchangeable cation population consists primarily of KCl - extractable Al. The major objective of a liming programme in these highly weathered soils is to remove this exchangeable Al rather than attaining certain pH levels. The use of soil pH in diagnosis of acidity problem should be based on the relationship between pH and Al - saturation of ECEC.

McLean (1982) suggested that lime requirement to neutralize exchangeable Al would be adequate for Al tolerant crops. It was reported that lime application based on exchangeable Al could do well in acid soils of Sikkim (Predhan and Khera, 1976).

Tropical crops like coffee, rubber, pine apple *etc.* are very tolerant to high levels of Al saturation and it is reported that for such crops liming should be aimed at decreasing Al saturation to 20 to 40 per cent (Sanchez, 1976).

II. 10. Liming materials

A range of liming materials is available, which vary in their ability to neutralize the acidity. Lime refers to CaO or quick lime and the commonly used liming materials are calcium hydroxide, calcium carbonate, calcium magnesium carbonate and calcium silicate. The effectiveness of agricultural limestone in neutralizing soil acidity is governed by its Ca and Mg content, particle size, moisture content, neutralizing value and unit cost (Somani *et al.,* 1996). The amount of liming material required to neutralize soil acidity depends on the neutralizing value of the liming material, pH and the buffering capacity of the soils. The time of application, the methodology adopted and the other agro management practices also influence the efficiency of the liming programme. Liming should be cost effective and the recommendation should be made in small doses.

Reducing Al toxicity in the subsoil is a major but difficult management task in many areas of the tropics. Direct mixing of lime with the subsoil is costly and mechanically infeasible. Phosphogypsum and gypsum, which have higher solubilities than $CaCO_3$, have been used to ameliorate subsoil acidity in highly weathered soils such as oxisols and ultisols (Ritchey *et al.,* 1980; Farina and Channon, 1988; Alcordo and Rechcigl, 1993; Norton and Zang, 1998).

Beneficial effects of application of gypsum in alleviating subsoil acidity and Al toxicity and promoting root growth and crop yield was reported by Reeve and Sumner (1972); Ritchey *et al.,* (1980); Pavan *et al.*, (1984); Oates and Caldwell, (1985): Sumner *et al.*, (1986); Noble *et al.,* (1988). Suresh *et al.,* (1996) reported that phosphogypsum could be used as a better amendment for control of exchangeable Al in the rubber growing soil. Field investigations on the effect of gypsum have shown both positive and negative crop responses, indicating that the amelioration of acid soil infertility factors by gypsum may depend on the mineralogy and charge characteristics of soils (Alva *et al.*, 1990).

II. 11. Effect of liming on soil properties

Liming acid soils has significant impact on physical, chemical and biological properties through its direct effects on the amelioration of acidity and indirect effects on the mobilization of plant nutrients, immobilization of toxic heavy metals and improvement in soil structure (Haynes and Naidu, 1998). Liming also increases the atmospheric N-fixation as well as N mineralization in acid soils through enhanced microbial activity (Sen, 2003). Improvement in the availability of P by liming in acid lateritic soils has been reported by Panda and Mishra (1970) and Panda and Panda (1969). Lime application has a positive influence on sulphur availability in acid soils (Badajena, 2003).

According to Black (1968), when acid soils are limed, the composition of microbial population gets changed and a portion of the organic matter becomes more susceptible to mineralization. But after some time, mineralization returns to near original level, despite altered composition of the soil microbial population. Increased microbial activity due to more favourable soil reaction and increased metal binding strength of organic sites were reported by Bloomfield *et al.*, (1976) upon liming of acid mineral soils. Chan and Heenan (1996) reported that liming resulted in an initial decrease in soil organic carbon because liming initially promoted carbon mineralization. Increase in water stability of macro aggregates due to liming was reported by Chan and Heenan (1998).

Application of lime at rates higher than necessary may create over liming problems. Liming to neutrality may cause structural deterioration, reduce P availability and induce Zn, B and Mn deficiency (Sanches, 1976; Njoku *et al.,* 1987). According to Eze and Loganathan (1990) the reduced P availability may be due to an increase in fixation of P by the amorphous Fe and Al hydroxides precipitated by lime addition as well as due to Ca mediated phosphate precipitation. Reduced availability of K and Mg were reduced with high rate of lime application was reported by Juo and Uzu, (1977). Liming the soils to near neutrality resulted in Mg sorption or precipitation with the newly formed Al hydroxide compounds (Kinniburgh *et al.*, 1976 and Grove *et al.,* 1981).

The availability of micronutrient cations decreases as soil pH increases due to lime addition. The increase in pH might have hydrolyzed metal ions into insoluble hydrated oxides or adsorbed them onto organic, clay and oxide surfaces. Such decrease has often been ascribed to movement of these cations from a more available to a less available pool (Neilson *et al.,* 1986; Stahl and James, 1991).

II. 12. Crop responses to liming

Crops differ in their response to lime application. Adams (1984) defined critical soil pH value as the maximum pH at which liming increases crop yield and the critical pH vary for different crops. Generally, pH between 6.5 and 7.0 is considered to be the optimum pH for crop production and liming is done with this objective. Mc Lean and Brown (1984) reported that most crops grown on soils of pH <5.5 showed a tendency to yield more upon liming to pH 6.0 Application of lime increased the yield of wheat, maize, soybean and barley in acid soils of Sikkim (Gupta *et al.*, 1989) and yield of upland rice at Palakkad district of Kerala and Koorg district of Karnataka (Mandal and Jha, 1970) Kamprath, (1970) proposed that crop production could be maximized with the addition of lime to remove exchangeable Al. Kamprath (1971) reported the lack of positive response to lime when highly leached soils are limed to pH values greater than 6.0. Fox *et al.*, (1964) reported that uptake of P by sorghum and Desmodium increased upon liming the soil from pH 5.3 to 6.1. However, P uptake decreased and severe P deficiency was observed when this soil was limed to pH 7.0. Sumner (1979) reported that lime induced crop yield depressions were associated with soils containing high levels of exchangeable Al usually >0.5 meq/100g.

CHAPTER-111

MATERIALS AND METHODS

A brief description of the experimental details and methodology followed in this investigation is presented in this chapter.

III.1. Characterization of soil acidity in rubber growing soils

III.1.1. Collection of soil samples

On the basis of NBSS and LUP report (1999), eight major soil series were identified for the study. The soil series selected were Vijayapuram (Vpm), Thrikkannamangal (Tmg), Thiruvanchoor (Tvr), Vazhoor (Vzr), Kunnathur (Ktr), Kangirappally (Kpl), Panachikkad (Pck) and Lahai (Lah). Details of the series are presented in Table 1. Profile sites were located at the type location and pits were taken up to the parent rock. Profiles were examined for morphological characters as per United States Soil Survey Staff (1975) and horizons were identified. Samples were collected horizon-wise from each profile representing the series. The soil samples were processed, dried and sieved through 2 mm sieve and stored for analysis.

Table-1. Details of the soil series

Series	Landform	Area (ha)	Soil Taxonomy
Kanjirappally (Kpl)	Charnokite	65739	Clayey-skeletal,Ustic Kandihumults
Thruvanchoor (Tvr)	Charnokite	59614	Clayey-skeletal,Ustic Kandihumults
Vazhoor (Vzr)	Charnokite	55717	Clayey-skeletal,Ustic Kandihumults
Vijayapuram (Vpm)	Charnokite	54378	Clayey,Ustic Kandihumults
Lahai (Lah)	Charnokite	21270	Clayey,Ustic Kanhaplohumult
Kunnathur (Ktr)	Khondalite	76580	Clayey-skeletal,Ustic Kanhaplohumult
Thrikannamangal(Tmg)	Khondalite	60748	Clayey-skeletal, Ustic Kandihumult
Panachikkadu (Pck)	Laterite	14727	Clayey-skeletal,Ustic Kanhaplohumult

III.1.2. Physicochemical properties

III.1.2.1. Soil reaction (pH)

pH of the soil was measured in water, 1M KCl, 0.01M $CaCl_2$, 1M NaF (Black, 1965; Page *et al.*, 1982). A measured quantity of soil was equilibrated with a specified quantity of solvent *viz.*, water (1:2.5 soil solvent ratio), 1M KCl (1:2.5 soil solvent ratio) 0.01M $CaCl_2$ (1:2 soil solvent ratio) and 1M NaF (1:50 soil solvent ratio), respectively. The pH of the suspension was determined electrometrically on a direct reading pH meter with combined calomel- glass electrode. Lime potential was obtained by subtracting 1.14 from pH (0.01 M $CaCl_2$).

III.1.2.2. Cation exchange capacity (CEC)

Cation exchange capacity (CEC) was estimated using neutral normal ammonium acetate (Black, 1965).

III.1.2.3. Base saturation per cent

Exchangeable Ca and Mg were estimated from the ammonium acetate extract for CEC determination by Atomic Absorption Spectrophotometer (Model GBC, Avanda). Sodium and K were estimated from the same extract by Flame Photometer. Percentage base saturation was calculated using the equation outlined in Jackson (1958).

$$\text{Base saturation (\%)} = \frac{\text{Total exchangeable bases (cmol /kg soil)}}{\text{Cation exchange capacity (cmol /kg soil)}} \times 100$$

III.1.2.4. Particle size analysis

Mechanical analysis of the soil samples was done by international pipette method (Jackson, 1958).

III.1.2.5. Organic carbon (OC)

Organic carbon was estimated by Wakley and Black method (Jackson, 1958).

III.1.3. Forms of acidity

III.1.3.I. Total potential acidity (TPA) (Peech *et al.*, 1962)

Soil was leached with a solution containing 0.5N $BaCl_2$ – 0.055N tri ethanol amine (TEA) buffered at pH 8.0 ± 0.02 at a soil, solution ratio of 1:10. After shaking for 30 minutes the suspension was kept overnight. This pH corresponds closely with the pH of complete neutralization of hydroxyl- Al compounds. The high concentration of Ba^{2+} not only help in the replacement of H^+ and Al^{3+} ions, but also facilitate the hydrolysis of adsorbed Al^{3+} ions and the dissociation of acidic R-COOH and R-OH groups, present in the soil organic matter. The acidity resulting from the replacement of

H^+ and Al^{3+} ions and from the dissociation of acidic groups was neutralized by TEA, a weak base. The excess TEA was estimated by titrating with standard acid (0.2 N HCl) using mixed indicator (methyl red- bromocresol green) to a pink end point. A blank titration was done with the same volume of original extracting solution using the same amount of indicator.

Total potential acidity = (B-S) 10 N (cmol/ kg)

B= volume of acid consumed by the blank (ml); S= volume of acid consumed by the sample (ml); N= Normality of the acid.

III.1.3.2. Exchangeable acidity (EA) (Mc Lean, 1965)

This method is based on the principle of exchange reaction with the H^+ and Al^{3+} retained on the permanent charges of the adsorbed complex when the soil is treated with neutral salt with negligible buffering properties.

Soil was leached with unbuffered 1M KCl in the ratio 1:10 and the replaced exchangeable H and Al forms the exchangeable acidity, and was estimated by titrating the leachate with standard alkali (0.1N NaOH) using phenolphthalein as indicator to a permanent pink end point.

III.1.3.3 pH dependent acidity (PA)

The difference between total potential acidity and exchangeable acidity was taken as the pH dependent acidity.

III.1.4. Forms of Al

III.I.4.I. Exchangeable Al (Ex. Al) (Mclean 1965)

Soil was leached with unbuffered 1M KCl in the ratio 1:10 and the exchangeable Al in the leachate was estimated colorimetrically with aluminon

(aluminon methos) and the intensity of the colored complex was measured at 535 nm. (Hsu, 1963; Jayman and Sivasubramhaniam, 1974).

III.I.4.2. Extractable Al (Extr. Al) (Mclean 1965)

Soil was extracted with normal ammonium acetate (pH 4.8) in the ratio 1:10. The soil suspension was equilibrated for 2 hrs and the Al in the extract was estimated colorimetrically by aluminon method.

III.I.4.3. Non exchangeable Al (Non Ex.Al)

The difference between extractable Al and exchangeable Al forms non-exchangeable Al.

III.I.4.4. Soluble Al (Sol. Al)

Soil was extracted with 0.01M $CaCl_2$ (soil solvent ratio 1:2.5) by shaking for 5 minutes and the Al in the extract was estimated colorimetrically by aluminon method.

III.I.4.5. Total Al

Total Al was determined by HCl-HF method as per Hossner (1996) and estimated by aluminon method.

III.I.4.6. Oxalate extractable and dithionate extractable Fe and Al

The oxalate Fe and Al (Fe_o and Al_o) were determined by extraction with ammonium oxalate in the dark (Mc Keague and Day, 1966) and the dithionite citrate bicarbonate extractable Fe and Al (Fe_d and Al_d) were determined by the method of Mehra and Jackson (1960).

III.1.5. Total, DTPA extractable and exchangeable Mn and Fe

Total Mn and Fe were estimated by HCl extraction (Jackson, 1958). DTPA - extractable Mn and Fe was determined by Lindsay and Norvell (1978). Exchangeable

Mn and Fe were extracted with neutral normal ammonium acetate in soil solvent ratio of 1:10 and the concentration of Mn in the extract was estimated by Atomic Absorption Spectrophotometer.

III.1.6. Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was determined by summation of exchangeable Na, K, Ca, Mg and Al in the 1M KCl extract (Reeuwijk, 1993).

III.1.7. Aluminium saturation per cent

Aluminium saturation percent was expressed as per cent to the ECEC as follows

$$\text{Aluminium saturation per cent} = \frac{\text{Exchangeable Al}}{\text{ECEC.}} \times 100$$

III.2. Lime requirement (LR)) of rubber growing soils

Surface soil (0 – 15 cm) samples were collected from Vijayapuram (Vpm), Thrikkannamangal (Tmg), Thiruvanchoor (Tvr), Vazhoor (Vzr), Kunnathur (Ktr), Kangirappally (Kpl), Panachikkad (Pck) and Lahai (Lah) series and were processed, dried and sieved through 2 mm sieve. Lime requirement was estimated by four methods.

III.2.1. Shoemaker, Mc Lean and Pratt method (SMP method)(Shoemaker *et al.*, 1961)

The principle of this method is based on the relationship between soil- buffer pH measurement and lime requirement determined from a soil - lime incubation study. The extracting buffer has an initial pH of 7.5 and is intended for soils with LR>4.5 Mg/ha. With increasing soil pH, the predictive accuracy of SMP decreases. Similarly for soils with high organic matter the decreased reactivity of H^+ with the buffer causes error in the LR predicted by SMP buffer method.

In this method, the pH of a soil buffer system was determined after equilibrating 10 ml of buffer (p-nitrophenol - tri ethanolamine-chromate-acetate) with 5.00 g of soil for 30 minutes and the LR values were taken from a table prepared by the authors.

III.2.2. Peech method ($BaCl_2$-TEA method) (Peech, 1965)

Exchange acidity was determined by single equilibrium extraction of soil using one part (4 g) of soil to 25 part (100 ml) of extracting solution (0.5 N $BaCl_2$ – 0.055 N TEA). A definite aliquot was used for estimating exchange acidity by titrating with 0.2N HCl using mixed indicator (Methyl red and Bromocresol green) and LR was calculated as $CaCO_3$ pounds per acre using the equation N (B - S) 50, 000.

Where N – Normality of HCl; B - Blank titre value: S - Sample titre value

III.2.3. Adams and Evans method (Adams and Evans, 1962)

In this method, the soil was treated with buffer solution containing p- nitro phenol, boric acid, potassium chloride and potassium hydroxide and the pH was determined. Lime requirement was read directly from the appropriate table using soil water and soil buffer system.

III.2.4. Exchangeable Al method (Kamprath, 1970)

The exchangeable Al value obtained from extraction of soil with unbuffered KCl solution was used to estimate the LR of the soil based on the equation of Kamprath (1970). Lime requirement as $CaCO_3$ (t ha^{-1}) = 1.65 x exchangeable Al in meq/100g soil.

III.3. Effect of liming on nutrient availability - Incubation Experiment

Soil used for the study was collected from the farm of Rubber Research Institute of India, Kottayam, Kerala State. Lime requirement (LR) of the soil was estimated (6.3 t/ha $CaCO_3$) by Peech method (Peech, 1965). The treatments comprised of four levels of lime, at the rates of 25, 50, 75 and 100 per cent of LR and a no lime control. Powdered shell lime was used as the source of lime. In each treatment the required dose of lime was thoroughly mixed with one kg soil and incubated in the laboratory at ambient temperature of 24 - 28 ^{0}C for a period of 90 days. Moisture level was maintained at field capacity throughout the period of incubation. The design of the experiment was CRD with six replications.

The physicochemical properties of the initial soil were determined by the standard procedure outlined in Jackson (1958). The incubated soil samples were collected at 15 days intervals up to 90 days and analyzed for organic carbon, available P, K, Ca and Mg (Jackson, 1958). Available P was extracted using Bray – II extractant (0.03 N ammonium fluoride in 0.1N HCl) (Bray and Kurtz, 1945) and estimated colorimetrically by molybdenum blue method at 660 nm wavelength. Available K was extracted by Morgan's reagent (sodium acetate + acetic acid buffer of pH 4.8) (Morgan, 1941) and estimated by flame photometer. Calcium and Mg from the Morgan extract was estimated by atomic absorption spectrophotometer. The soil pH (1:2.5, soil: water ratio) was measured by glass electrode method. Exchangeable Al was extracted with 1M KCl and estimated by aluminon method (Hsu, 1963; Jayman and Sivasubramhaniam, 1974) and available Mn, Fe, Cu and Zn by DTPA extractant (Lindsay and Norvell, 1978) were estimated after 90 days of incubation.

The individual parameters were statistically analyzed in CRD and the changes over a period of time were estimated by factorial analysis (Snedecor and Cochran, 1967).

III.4. Effect of liming on availability of nutrients and growth of rubber seedlings in the nursery

A nursery experiment was laid out at the Regional Nursery of the Rubber Board, Perumpulickal in Pathanamthitta District, during 1998-1999 season. Lime requirement estimated by Peech method (Peech, 1965) was 8.0 t/ha as $CaCO_3$. The treatments included an absolute control (no lime, no fertilizer), fertilizer and three levels of shell lime viz., 1/3rd, 2/3rd and full LR alone and in combination with fertilizer. The design of the experiment was randomized block design with three replications.

Nursery beds (4.5 x 1.5 m) were prepared according to nursery practice and powdered shell lime as per the treatments was incorporated by forking. Two weeks after liming germinated rubber seeds were planted (gross 60 seeds and net 30 seeds per plot) in 30 x 30 cm spacing. NPKMg fertilizers (urea, mussoorie rock phosphate, muriate of potash and magnesium sulphate) were applied six weeks after planting and a second dose of urea alone was applied six weeks after the first fertilizer application as per the general fertilizer recommendation. Cultural operations were done according to the nursery practices. Monthly diameter of plants was recorded from March to August 1999.

The physicochemical properties of the pre treatment soil were determined by the standard procedure (Jackson, 1958). Soil samples (0-30 cm) collected two week after liming and one year after planting were analyzed for organic carbon, available nutrients and pH by standard methods. Leaf samples collected one year after planting were analyzed for total nutrient concentration (Piper, 1942). The data were analyzed statistically.

III.5. Effect of liming on translocation of calcium in different plant parts

A pot culture experiment was conducted in the glass house of Rubber Research Institute of India with RRII 105 plants to study the effect of liming on uptake and translocation of Ca in different parts of rubber plant.

Cement pots of size 60 cm height and 30 cm diameter were filled with 35 kg air-dry soil collected from a typical rubber-growing tract. Lime requirement of the soil determined by exchangeable Al method was 4t/ha as $CaCO_3$. Powdered shell lime (quick lime) was the liming material The treatments were lime at the rate of 25, 50, 75 and 100 percent of LR along with fertilizer (NPKMg) at the recommended level, lime at 100 per cent LR alone, fertilizer alone and absolute control. The experiment was laid out in CRD with three replications.

Pre-treatment soil sample was analysed for nutrient status (Jackson, 1958). Soil in the pot was thoroughly mixed with lime treatments to a depth of 15 cm. Three weeks after liming budded stumps with one set of whorl were planted and watered regularly. Fertilizers at the recommended level were applied two weeks after planting. Plants were uprooted after four months. Plant parts viz., leaf, stem, petiole and root were separated, dried and weighed and were analyzed for macro and micronutrients (Piper 1942) and soil samples were analyzed for available Ca and pH (Jackson, 1958).

III. 6. Comparative evaluation of liming materials on nutrient availability and growth of rubber seedlings in the nursery

Nursery experiments were laid out at the Central Nursery of the Rubber Board, Karikkattoor in Pathanamthitta District, Kerala during 2002-2003 and 2003-2004 seasons. The lime requirement was estimated by Peech method (Peech, 1965) and was 8.0 t/ha as $CaCO_3$.The treatments included were an absolute control (no lime and no fertilizer), fertilizer alone and three sources of lime viz; powdered shell lime (quick lime), dolomite and phosphogypsum @ of 100 per cent lime requirement with and without fertilizer. The experiment was laid out in a randomized block design with four replications.

Nursery beds (4.5 x 1.5 m) were prepared according to nursery practice and powdered liming materials were incorporated by forking. Two weeks after liming, germinated rubber seeds were planted (gross 60 seeds and net 30 seeds per plot) in 30 x 30 cm spacing. NPKMg fertilizers (urea, mussoorie rock phosphate, muriate of potash and magnesium sulphate) were applied six weeks after planting and a second dose of urea alone was applied six weeks after the first fertilizer application as per the general fertilizer recommendation. Cultural operations were done according to the nursery practices. Monthly diameter of plants was recorded in January, March and May 2003.

The physicochemical properties of the pre treatment soil were determined by the standard procedure outlined in Jackson (1958). Soil samples (0-30 cm) collected at the time of planting, before fertilizer application and one year after planting were analyzed for organic carbon. available nutrients and pH by standard methods. The data were analyzed statistically (Snedecor and. Cochran1967).

To study the residual effect of liming materials, the experiment was repeated in the same beds in 2003-2004 season also. Diameter of the plants was recorded and soil samples (0-30 cm) were collected after one year of planting and analyzed for pH and availability of nutrients. The data were analyzed statistically (Snedecor and. Cochran1967).

CHAPTER-1V

RESULTS AND DISCUSSION

Physicochemical analysis of the soil samples, forms of acidity, forms of Al, lime requirement estimated by different methods, changes in nutrient availability through liming, effect of liming on growth of rubber seedlings, translocation of Ca in different plant parts upon liming and comparative evaluation of liming materials on growth of rubber seedlings are discussed in this chapter.

IV.1. Characterization of soil acidity in rubber growing soils

IV.1.1. Physicochemical properties of the soil

IV.1.1.1. Soil reaction- Soil pH in different solvents and lime potential

Results of the soil pH measured in water, 1M KCl, 0.01 M $CaCl_2$ and 1M NaF and lime potential are given in Table 2. Soils are strongly to moderately acidic, with varying pH values. In general, pH of the soil profiles does not show any regular pattern. pH$_{(water)}$ ranged from 4.29 (Kpl) to 5.48 (Vzr). In the surface soil it ranged from 4.46 in Vpm to 5.4 in Pck series. pH above 5.0 is encountered in the surface horizons of Tvr, Vzr, Tmg , Ktr and Pck. In all the profiles except Vpm and Vzr, pH decreased with increase in depth.

In the case of pH$_{(KCl)}$, the values in the surface soil ranged from 3.80 to 4.79. The lowest value of 3.80 was recorded in the 0 - 15 cm layer soil of Vpm series to the highest value of 4.79 in the 0 - 15 cm layer soil of Pck series. The values are lower than pH$_{(water)}$ indicating that all the soils under natural pH conditions carry a net negative charge and contain considerable amount of reserve acidity (Bleeker and Sageman, 1990). The difference in pH$_{(KCl)}$ and pH$_{(water)}$, (ΔpH) was negative indicating the presence of negative charges and of variable charge colloids. This indicates the presence of significant amount of silicate clay minerals in these soils as reported by Bleeker and Sageman (1990). ΔpH values showed a gradual, though irregular, increase with depth. The high negative ΔpH in the surface horizon may be due to high organic matter (Eswaran and Bin, 1978). The ΔpH is less than one in Vpm, Kpl, Lah, Ktr and Pck series. The lower values of ΔpH indicate that the pH of these soils was closer to their zero point charge, and indicate the presence of pH- dependent charge minerals. Patil and Dasog, (1996) reported that these soils had both permanent charge (layer silicate system) and variable charge because of the presence of pH- dependent minerals such as iron and aluminium hydroxides as well as organic matter.

$pH_{(CaCl2)}$ represents more nearly the pH of soil solution under actual field condition and therefore should reflect accurately the H^+ ion environment of plant roots and soil microorganism, than $pH_{(water)}$. The values ranged from 3.76 to 4.80 in the surface soil. The lowest value of 3.73 was recorded in 37 – 69 cm layer soil of Tvr series and the highest value (4.80) was recorded in 0 – 15 cm layer of Pck series $pH_{(CaCl2)}$ showed an increasing trend with increase in depth in Vpm, Kpl, Lah and Tmg and a reverse trend was noted in Tvr, Ktr, Vzr and Pck series.

The $pH_{(NaF)}$ is a measure of "active aluminium" (USDA, 1995). The values ranged from 9.17 in the 0 – 15 cm soil of Pck to 10.68 in 0 – 15 cm soil of Lah series. The higher values observed is indicative of the presence of amorphous aluminosilicate in these horizons (Eswaran and Bin, 1978).

The lime potential varied from 2.59 to 3.66. The surface soil showed higher lime potential than the lower horizons. The smaller lime potential in the sub- surface than the surface is an indication of greater lime buffering capacity in the sub surface, which was further supported by the greater content of clay of sub soils.

Table 2. Soil pH and lime potential

Soil Series	Depth (cm)	pH				ΔpH	Lime potential
		H_2O	KCl	0.01M $CaCl_2$	NaF		
Vpm	0-15	4.46	3.80	3.76	9.55	- 0.66	2.62
	15-40	4.69	3.87	3.90	9.95	- 0.82	2.76
	40-70	4.84	3.93	4.01	10.06	-0.91	2.87
	70-103	4.79	3.92	4.02	10.01	-0.87	2.88
	103-151	4.87	3.98	4.09	10.02	-0.89	2.95
Tvr	0-13	5.02	3.85	4.00	9.84	-1.17	2.86
	13-37	5.12	3.87	3.96	10.07	-1.25	2.82
	37-69	4.91	3.85	3.73	10.08	-1.06	2.59
	69-104	4.82	3.84	3.74	10.07	-0.98	2.60
	104-132	4.93	3.89	3.81	10.01	-1.04	2.67
Vzr	0-12	5.38	3.85	4.36	9.65	-1.53	3.22
	12-31	5.19	3.99	3.95	9.81	-1.20	.2.82
	31-53	5.32	4.09	4.12	10.06	-1.23	2.98
	53-83	5.48	4.18	4.17	10.13	-1.30	3.03
Kpl	0-13	4.61	3.99	3.98	10.35	-.0.62	2.84
	13-32	4.72	4.08	4.03	10.48	-0.66	2.89
	32-56	4.85	4.11	4.10	10.51	-0.74	2.96
	56-83	4.47	4.14	4.00	10.30	-0.33	2.86
	83-112	4.29	4.12	4.01	10.32	-0.17	2.87
	112-150	4.58	4.10	4.05	10.33	-0.48	2.91
Lah	0-15	4.71	4.04	4.10	10.68	-0.67	2.96
	15-38	4.77	4.10	4.16	10.67	-0.67	3.02
	38-74	4.53	4.10	4.13	10.50	-0.43	2.99
	74-104	4.64	4.09	4.16	10.29	-0.54	3.02
	104-138	4.69	4.20	4.23	10.21	-0.49	3.09
Tmg	0-14	5.04	3.93	3.78	9.84	-1.11	2.64
	14-35	5.10	3.94	3.80	9.99	-1.06	2.66
	35-67	5.21	3.95	3.87	10.03	-1.26	2.73
	67-103	5.08	3.86	3.75	9.99	-1.22	2.61
	103-152	5.04	3.85	3.82	10.11	-1.19	2.68
Ktr	0-16	5.20	4.11	4.31	9.82	-1.10	3.17
	16-38	5.18	4.15	4.27	10.10	-1.03	3.13
	38-72	5.06	4.08	4.11	10.15	-0.98	2.98
	72-103	5.00	4.05	4.05	10.13	-0.95	2.91
	103-130	4.90	4.01	3.98	10.20	-0.89	2.84
Pck	0-15	5.40	4.79	4.80	9.17	-0.61	3.66
	15-46	5.21	4.31	4.22	9.54	-0.90	3.08
	46-74	4.60	4.01	3.75	9.78	-0.59	2.61
	74-99	4.80	3.86	4.04	9.68	-0.94	2.90
	99-136	4.85	3.84	4.06	9.87	-1.01	2.92

IV.1.1.2. Organic carbon (OC)

Organic carbon content was high in the surface horizon. It ranged from 0.68 per cent (Tmg and Ktr) to 2.0 per cent (Pck) and the distribution showed a decline with depth (Table 3). High OC content in the surface layer might be due to the organic matter additions through cover crops and rubber litter and dense fine root system of rubber and cover crops. Absence of tillage operations further help in the build up of organic matter in the surface layer.

IV.1.1.3. Exchangeable bases

IV.1.1.3.1. Exchangeable calcium

Exchangeable Ca ranged from 0.06 cmol/kg to 1.50 cmol/kg (Table 3). In the surface soil the exchangeable Ca ranged from 0.10 cmol/kg in Lah series to 1.50 cmol/kg in Ktr series. In Vpm, Tvr, Kpl, Ktr and Pck exchangeable Ca decreases with increasing depth. Except Vzr in all the other series subsurface horizon had lower exchangeable Ca than surface horizon. Compared to upper and lower layers high level of exchangeable Ca was recorded in 74 – 104 cm layer soil of Lah and similar observation was noticed in 35- 67 cm layer of Tmg.

IV.1.1.3.2. Exchangeable magnesium

Exchangeable Mg varied from 0.02 cmol/kg in the lowest horizon (112 – 150 cm) of Kpl to 0.71 cmol/kg in the surface horizon of Ktr (0 – 16 cm) (Table 3). The values in the surface layer ranged from 0.05 cmol/kg in Vzr series to 0.71 cmol/kg in Ktr series. There was no regular pattern in the distribution of exchangeable Mg except in Tvr where the values decreased with increasing depth. Among the pedons, comparatively high values were noticed in Ktr followed by Pck. Low values of exchangeable Mg were noticed in Kpl.

IV.1.1.33. Exchangeable potassium

Exchangeable K values ranged from 0.07 cmol/kg in the middle horizon of Lah (38 – 74 cm), Tmg (35 – 67 cm) and Pck (46 – 74 cm) to 0.42 cmol/kg in the middle horizon (38 – 72 cm) of Ktr (Table 3). In the surface layer, the values ranged from 0.10 cmol/kg in Vzr series to 0.29 cmol/kg in Kpl series. Among the profiles higher values were noticed in Ktr. In general, a reduction in exchangeable K was noticed from surface to lower horizons except for Ktr and Tmg series.

IV.1.1.4. Cation exchange capacity (CEC)

Cation exchange capacity values varied from 2.41 cmol /kg in 83 - 112 cm layer of Kpl to 11.28 cmol /kg in 46 - 74 cm layer of Pck (Table 3). Cation exchange capacity was low in all the pedons and it decreased down the profile. In the surface soils the values ranged from 4.20 cmol /kg in Tmg series to 8.66 cmol /kg in Lah series. High organic matter might have contributed to the comparatively high value of CEC in the surface horizons. In general, the CEC values are low and this might be due to the dominance of kaolinite clay minerals. The pH- dependent charge sites might be occupied either by hydrogen or hydroxy aluminium ions at low pH (Patil and Dasog, 1996).

IV.1.1.5. Base saturation per cent (BS)

Base saturation percentage ranged from 4.40 in the 15 – 38 cm horizon of Lah to 41.83 in the 38 – 72 cm horizon of Ktr (Table 3). In the surface layer the values ranged from 4.42 per cent in Lah series to 41.77 per cent in Ktr series. In Vpm and Lah, base saturation percent increased with depth whereas, in other series there was no regular pattern. Soils with low pH have low base saturation and this is in agreement with Yuan (1963). The base saturation in general is low due to preponderance of Al^{3+} and H^+ in the exchange sites.

Table 3. Physicochemical properties of the soil

Soil Series	Depth (cm)	OC (%)	Exchangeable cations (cmol/kg)				CEC (cmol/ kg)	BS (%)	EC (dSm^{-1})
			Ca	Mg	K	Na			
Vpm	0-15	1.01	0.44	0.13	0.20	0.09	5.34	16.16	0.04
	15-40	0.70	0.28	0.11	0.20	0.09	4.47	15.21	0.03
	40-70	0.46	0.41	0.12	0.16	0.09.	4.38	17.76	0.01
	70-103	0.42	0.32	0.14	0.16	0.04	3.39	19.29	0.01
	103-151	0.23	0.27	0.11	0.13	0.09	2.50	23.92	0.02
Tvr	0-13	1.17	0.63	0.22	0.20	0.18	6.79	17.98	0.03
	13-37	0.88	0.50	0.11	0.13	0.13	5.00	17.40	0.02
	37-69	0.52	0.38	0.09	0.10	0.13	4.91	14.22	0.02
	69-104	0.52	0.10	0.08	0.10	0.09	4.73	7.55	0.02
	104-132	0.29	0.06	0.07	0.07	0.09	3.21	8.22	0.02
Vzr	0-12	1.47	0.62	0.05	0.10	0.09	7.14	12.04	0.05
	12-31	0.82	0.65	0.12	0.09	0.09	5.18	18.34	0.02
	31-53	0.49	0.40	0.10	0.09	0.09	4.29	15.85	0.02
	53-83	0.26	0.43	0.09	0.08	0.09	3.84	17.92	0.02
Kpl	0-13	1.34	0.12	0.09	0.29	0.07	6.61	8.67	0.06
	13-32	0.91	0.10	0.05	0.13	0.07	4.82	7.12	0.02
	32-56	0.49	0.10	0.03	0.15	0.03	3.13	9.87	0.02
	56-83	0.49	0.09	0.03	0.10	0.03	2.68	9.29	0.03
	83-112	0.33	0.08	0.04	0.10	0.03	2.41	10.41	0.04
	112-150	0.33	0.08	0.02	0.08	0.03	2.86	7.34	0.03
Lah	0-15	1.60	0.10	0.08	0.13	0.07	8.66	4.42	0.03
	15-38	1.56	0.06	0.06	0.16	0.07	7.86	4.40	0.03
	38-74	1.43	0.12	0.08	0.07	0.03	5.89	5.09	0.03
	74-104	0.53	0.28	0.11	0.13	0.10	5.00	12.40	0.04
	104-138	0.36	0.22	0.09	0.10	0.07	3.19	15.05	0.03
Tmg	0-14	0.68	0.29	0.14	0.13	0.13	4.20	16.48	0.02
	14-35	0.42	0.23	0.09	0.13	0.22	4.02	16.57	0.01
	35-67	0.52	0.50	0.08	0.07	0.09	4.20	15.76	0.02
	67-103	0.55	0.16	0.07	0.13	0.13	4.47	11.07	0.02
	103-152	0.52	0.17	0.09	0.16	0.09	3.66	13.61	0.01
Ktr	0-16	0.68	1.50	0.71	0.20	0.98	5.98	41.77	0.02
	16-38	0.68	1.25	0.50	0.15	0.10	5.36	37.31	0.02
	38-72	0.42	0.88	0.70	0.26	0.18	4.82	41.83	0.02
	72-103	0.33	0.84	0.55	0.42	0.18	5.54	35.84	0.02
	103-130	0.07	0.76	0.40	0.23	0.13	5.09	29.90	0.02
Pck	0-15	2.00	1.06	0.50	0.20	0.05	8.22	22.00	0.08
	15-46	0.75	0.95	0.35	0.13	0.07	6.70	22.38	0.03
	46-74	0.72	0.94	0.29	0.07	0.07	11.25	12.20	0.04
	74-99	0.45	0.84	0.20	0.07	0.02	5.53	20.43	0.05
	99-136	0.16	0.61	0.24	0.10	0.05	6.34	15.77	0.04

IV.1.1.6. Electrical conductivity (EC)

Generally, electrical conductivity decreased with increasing depth and it ranged from 0.01 dSm^{-1} in 40 – 70 cm and 70 – 103 cm layer of Vpm series and 14 – 35 cm and 103 – 130 cm layer of Tmg series to 0.08 dSm^{-1} in 0 – 15 cm layer of Pck series (Table .3). In the surface layer, the values ranged from 0.02 dSm^{-1} in Tmg and Ktr series to 0.08 dSm^{-1} in Pck series. As expected the electrical conductivity values are very low in these highly weathered soils.

IV.1.1.7. Particle size analysis

In general, the coarse sand showed a decreasing trend with depth while no such pattern was noticed in the case of fine sand (Table .4). The textural class of surface soil is sandy clay for Vpm, clayey for Tvr, Lah and Ktr, clay loam for Vzr, sandy clay loam for Kpl, Tmg and sandy loam for Pck series.

The clay content generally showed an increasing trend with depth and it varied from 18 to 62 per cent (Fig. 1). Clay accumulation was highest in the third layer of Vpm, Tvr, Vzr and Ktr series. Increase in clay content with increasing depth and the highest clay accumulation in lower layer was noticed in Lah, Tmg, Ktr and Pck series. *Hevea* is reported to thrive well in soils of varied texture and in Malaysian soils the clay content was reported to range from 14.8 to 71.7 per cent (Soong and Lau, 1977).

Table 4. Particle size composition of the soil

Soil Series	Depth (cm)	Soil separates (%)			
		Coarse sand	Fine sand	Silt	Clay
Vpm	0-15	51.0	8.4	2.0	39.5
	15-40	47.0	10.0	3.0	40.0
	40-70	44.0	8.4	1.6	47.0
	70-103	43.0	7.0	5.0	40.0
	103-151	40.0	8.0	8.0	44.0
Tvr	0-13	38.0	9.0	5.7	47.0
	13-37	27.0	8.6	10.0	54.0
	37-69	29.0	6.0	3.0	62.0
	69-104	28.0	5.9	6.7	58.0
	104-132	29.0	7.0	5.8	55.0
Vzr	0-12	46.0	9.0	9.3	31.0
	12-31	45.0	9.4	9.4	34.0
	31-53	38.0	8.2	8.2	46.0
	53-83	41.0	6.9	6.9	40.0
Kpl	0-13	54.0	8.2	8.2	27.0
	13-32	51.0	9.0	9.0	31.0
	32-56	48.0	9.0	10.0	33.0
	56-83	47.0	12.0	10.0	31.0
	83-112	44.0	10.0	9.5	36.0
	112-150	48.0	8.0	8.0	36.0
Lah	0-15	31.0	8.0	5.0	45.0
	15-38	34.0	6.0	5.0	43.0
	38-74	36.0	7.0	10.0	47.0
	74-104	30.0	5.0	7.0	49.0
	104-138	32.0	9.0	5.0	52.0
Tmg	0-14	52.0	11.2	1.8	35.0
	14-35	44.0	10.1	1.9	44.0
	35-67	44.0	10.5	2.2	43.0
	67-103	39.0	9.0	8.0	44.0
	103-152	38.0	8.0	7.0	45.0
Ktr	0-16	41.0	6.0	5.9	42.0
	16-38	41.0	7.8	7.8	43.0
	38-72	34.0	6.3	6.3	50.0
	72-103	28.0	11.5	11.5	48.0
	103-130	27.0	10.0	10.2	50.0
Pck	0-15	61.0	10.0	7.0	18.0
	15-46	46.0	8.0	8.0	33.0
	46-74	34.0	11.0	9.0	44.0
	74-99	37.0	5.2	4.0	46.0
	99-136	32.0	7.0	5.0	56.0

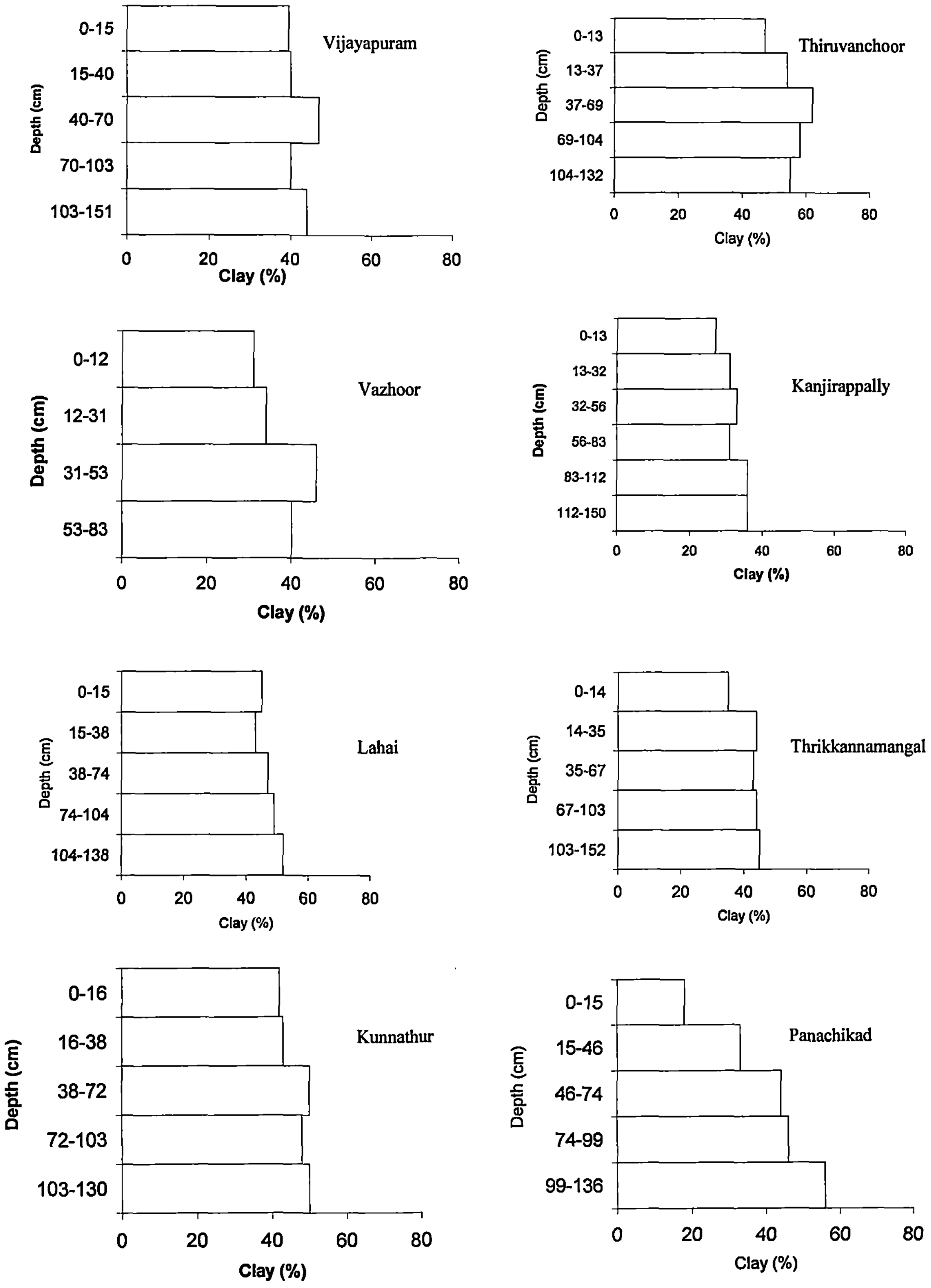


Fig.1 Distribution of clay in different soil series

IV.1.2. Nature of Soil Acidity

The nature of soil acidity and the extent of occurrence of various forms of acidity in the soil under investigation are presented in Table 5 and Fig.2 and described in detail below.

IV-1.2.1. Total Potential Acidity (TPA)

Total potential acidity, comprises pH- dependent and exchangeable acidity and was estimated in the $BaCl_2$ - TEA extraction. This includes acidity resulting from the replacement of H^+, Al^{3+} and from the dissociation of acidic group (Peech, 1965). The advantage of $BaCl_2$-TEA is that, it not only serve to replace more completely the exchangeable Al^{3+} and H^+ ions but also increase the extent of hydrolysis of adsorbed Al^{3+} and the degree of dissociation of the acidic groups on the clay surfaces.

Generally surface horizons showed higher values of total potential acidity. The total potential acidity of the surface horizon of the soil varied from 6.39 cmol/kg in Ktr series to 27.70 cmol/kg in Lah series. Highest value of 28.88 cmol/kg was noticed in the subsurface layer (15 - 38 cm) of Lah series. The high values in the surface layer is possibly due to high organic carbon status. The soil organic matter contribute to TPA through their –COOH, and –OH functional group. The high amount of H^+ and Al^{3+} ions extracted by $BaCl_2$ –TEA might be due to the extraction of pH dependent H^+ and Al^{3+} ions, which were otherwise inactive in combination with organic colloid.

Since H^+ and Al^{3+} combined with organic matter are inactive and hence may not be involved directly in controlling pH of the soils. The TPA decreased down the profile except in Ktr series. Among the profiles, comparatively higher values were noticed in Lah followed by Kpl and low values were recorded in Vzr, Tmg and Ktr series.

Table 5. Forms of acidity in different soil series (cmol/kg)

Soil Series	Depth (cm)	TPA	EA	PA
Vpm	0-15	11.29	2.97	8.32
	15-40	10.01	1.90	8.11
	40-70	11.08	2.48	8.60
	70-103	10.65	2.23	8.42
	103-151	9.37	2.23	7.14
Tvr	0-13	12.57	2.92	9.65
	13-37	12.34	3.47	8.87
	37-69	8.52	3.96	4.56
	69-104	7.67	3.47	4.20
	104-132	6.39	3.47	2.92
Vzr	0-12	9.16	0.99	8.17
	12-31	8.52	1.49	7.03
	31-53	7.67	0.99	6.68
	53-83	5.33	0.99	4.34
Kpl	0-13	20.77	2.78	17.99
	13-32	15.44	1.99	13.45
	32-56	11.72	1.99	9.73
	56-83	9.59	1.59	8.00
	83-112	9.59	1.59	8.00
	112-150	2.13	1.99	0.14
Lah	0-15	27.70	3.58	24.12
	15-38	28.22	2.39	25.83
	38-74	19.17	1.99	17.18
	74-104	16.00	1.59	14.40
	104-138	12.78	1.19	11.59
Tmg	0-14	8.10	1.98	6.12
	14-35	6.39	2.97	3.42
	35-67	7.46	1.98	5.48
	67-103	7.03	2.97	4.06
	103-152	8.09	3.22	4.87
Ktr	0-16	6.39	0.98	5.41
	16-38	7.24	1.04	6.20
	38-72	7.67	1.49	6.18
	72-103	8.09	1.49	6.60
	103-130	8.09	1.98	6.12
Pck	0-15	12.25	3.50	8.75
	15-46	11.72	2.45	9.27
	46-74	12.25	2.50	9.75
	74-99	11.18	2.79	8.39
	99-136	12.20	1.59	10.6

IV.1.2.2. Exchangeable Acidity (EA)

The exchangeable acidity includes the exchangeable H^+ and Al^{3+} held at the permanent charge sites of the soil exchange complex (McLean, 1965). Unlike TPA and PA the EA of all the profiles were much low and the values ranged from 0.98 to 3.96 cmol/kg. In almost all series contribution of EA to TPA is relatively low, and it ranged from 8.46 to 54 per cent. Similar results were reported by Das *et al.*, (1991) and Sharma *et al.*, (1990). Exchange acidity as a part of TPA varies with the nature of the soil and base saturation (Coleman and Thomas, 1967). In Vpm, Kpl, Lah and Pck the surface horizon had higher values of EA. The hydrolysis of Fe and Al oxides might have released the exchangeable H^+ and Al^{3+} contributing to high values of exchange acidity. In Tvr, Vzr, Tmg and Ktr series the surface layer showed low EA than the subsurface layer. The reason may be due to the removal of exchangeable Al^{3+}, which is the major contributor of EA, through chelation with organic acids in the lower horizons (Nayak *et al.,* 2002). Except in Vzr and Ktr series the other pedons had relatively high values of EA, which is indicated by the higher amount of exchangeable Al^{3+} in the sub soils. Sharma *et al.*, (1990), reported that exchange acidity in soil is mainly due to monomeric Al^{3+}. The relation between exchangeable Al and EA is given in Fig. 3.

IV.1.2.3. pH- dependent acidity (PA)

This form of acidity due to variable charge (pH dependent) is the difference between TPA and EA and it varied from 0.14 cmol/kg in the lowest horizon (112 – 150 cm) of Kpl to 25.83 cmol/kg in the subsurface horizon (15 – 38 cm) of Lah. Lahai series had highest values of PA while comparatively lower values were recorded in Tmg.

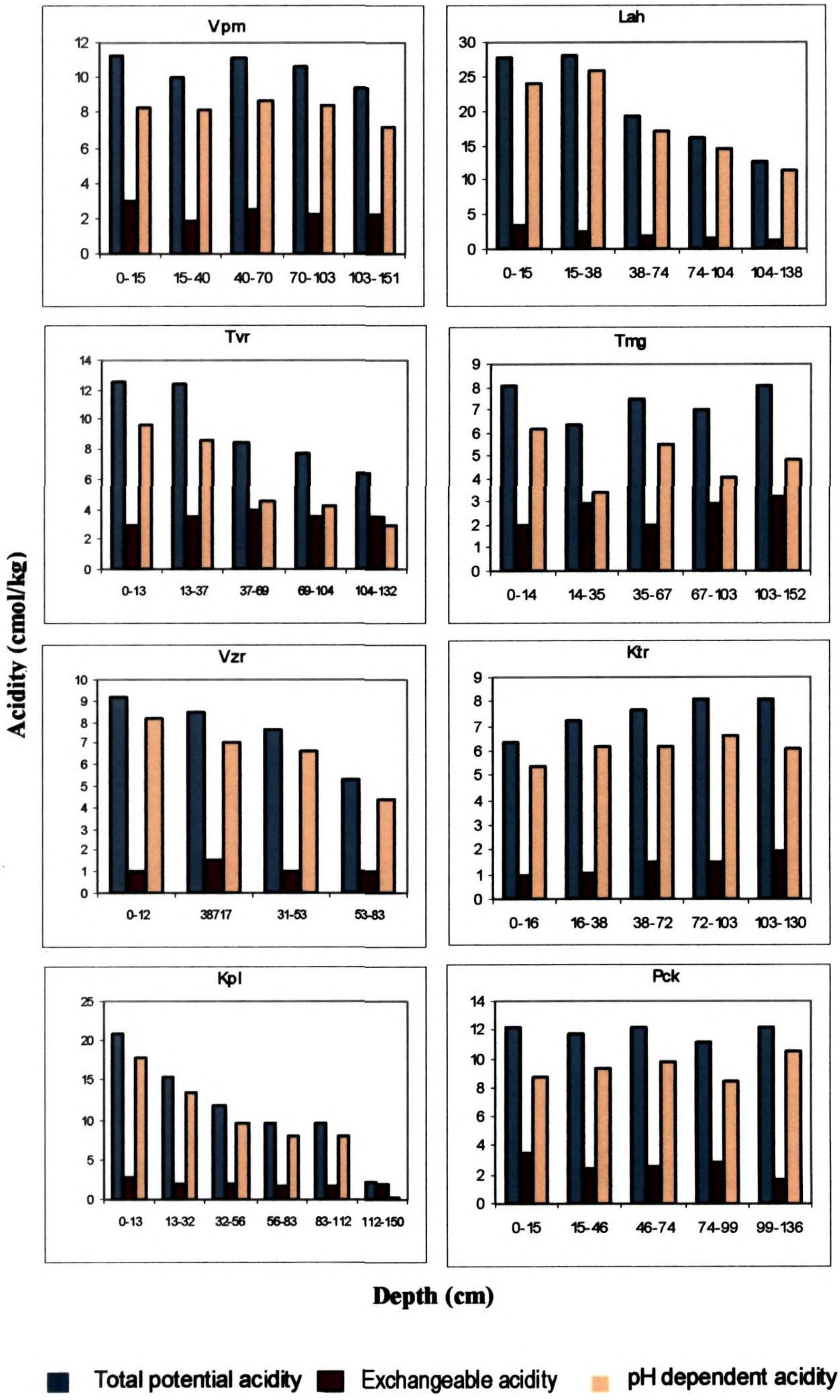


Fig. 2 Forms of acidity in different soil

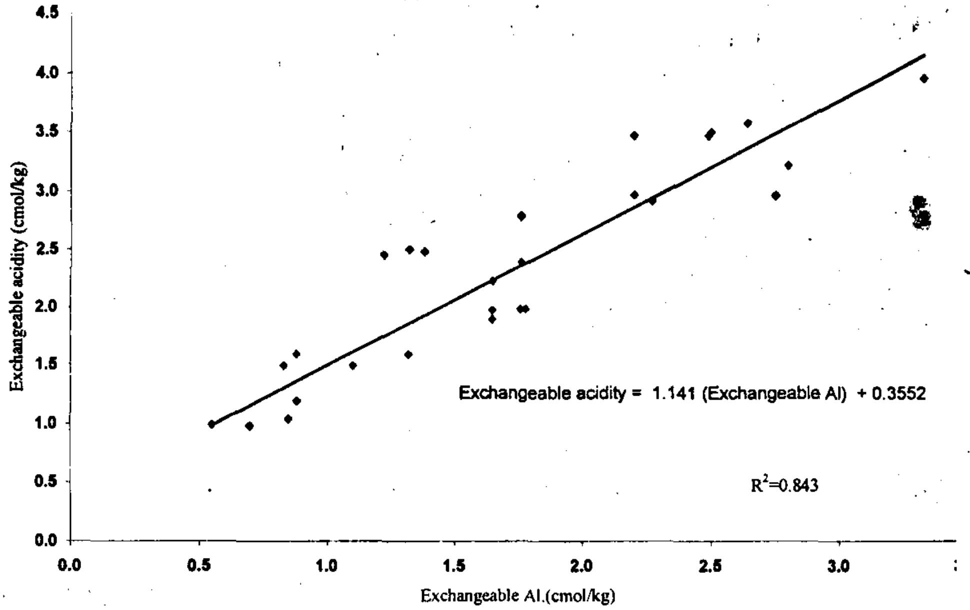


Fig . 3 Relation between exchangeable acidity and exchangeable Al

In Tmg, Ktr and Pck the values increased down the profile while Tvr, Vzr, Kpl and Lah it decreased down the profile. In Vpm there was no regular pattern in the distribution of PA. The decline in PA in the subsoil, which contains relatively low organic carbon, might be an indication of possible role of organic matter in the development of variable charge. Misra *et al.*, (1989) reported that pH-dependent acidity increased linearly with increasing free Fe_2O_3+Al_2O_3 plus organic carbon in the soil.

IV.1.3. Forms of Al

Distribution of different forms of Al *viz*; exchangeable, soluble, extractable, non-exchangeable and total Al are given in Table 6.

IV.1.3.1. Exchangeable Al (Ex. Al)

No regular pattern was observed in the distribution of exchangeable Al. Exchangeable Al ranged from 0.55 cmol/kg (0 – 15 cm, 31 – 53 cm and 53 – 83 cm) in Vzr to 3.33 cmol/kg in the middle horizon (37 – 69 cm) of Tvr series. Higher values of exchangeable Al were found in Tvr followed by Tmg, Pck and Kpl and lower values found in Vzr and Ktr series.

Table 6. Forms of Al in different soil series

Soil Series	Depth (cm)	Total Al (%)	Sol. Al (ppm)	(cmol/kg)		
				Ex. Al	Extr. Al	Non Ex. Al
Vpm	0-15	3.8	5.63	2.20	3.89	1.69
	15-40	2.8	6.25	1.65	3.61	1.96
	40-70	9.0	6.00	1.38	3.89	2.51
	70-103	4.8	5.63	1.65	4.17	2.52
	103-151	3.8	4.25	1.65	3.89	2.24
Tvr	0-13	2.2	5.50	2.27	6.11	3.84
	13-37	2.2	6.50	2.20	6.66	4.46
	37-69	1.6	8.50	3.33	5.56	2.23
	69-104	2.2	10.63	2.49	4.44	1.95
	104-132	3.0	7.00	2.20	3.89	1.69
Vzr	0-12	2.0	3.50	0.55	2.20	1.65
	12-31	1.6	4.00	0.83	3.61	2.78
	31-53	6.2	2.13	0.55	2.77	2.22
	53-83	5.2	1.38	0.55	2.77	2.22
Kpl	0-13	4.2	5.75	1.76	4.44	2.68
	13-32	4.2	5.90	1.76	5.28	3.52
	32-56	4.6	4.50	1.76	3.89	2.13
	56-83	2.4	2.50	1.32	3.50	2.18
	83-112	3.8	5.13	1.32	8.33	7.01
	112-150	3.2	5.13	1.78	2.78	1.00
Lah	0-15	5.8	3.25	2.64	8.20	5.56
	15-38	7.0	5.38	1.76	2.11	0.35
	38-74	9.8	5.45	1.76	2.06	0.30
	74-104	4.6	4.13	0.88	1.50	0.62
	104-138	4.6	2.75	0.88	1.36	0.48
Tmg	0-14	6.0	6.38	1.65	3.61	1.96
	14-35	2.0	8.00	2.20	4.72	2.52
	35-67	2.6	5.38	1.65	3.89	2.24
	67-103	4.2	9.00	2.75	5.56	2.81
	103-152	2.2	7.00	2.80	4.44	1.64
Kti	0-16	3.8	1.13	0.70	1.67	0.97
	16-38	1.8	0.75	0.85	2.50	1.65
	38-72	4.8	1.88	1.10	4.17	3.07
	72-103	4.2	2.75	1.10	6.60	5.50
	103-130	4.8	3.63	1.65	6.11	4.46
Pck	0-15	4.2	2.75	2.50	4.20	1.70
	15-46	4.2	2.90	1.22	3.00	1.78
	46-74	5.0	1.13	1.32	3.50	2.18
	74-99	3.8	3.00	1.76	1.94	0.18
	99-136	3.8	3.75	1.32	2.36	1.04

In Vpm, Tvr, Kpl, Lah and Pck high values of exchangeable Al was noticed in the surface horizon while in Tmg and Ktr the sub surface layers had high exchangeable Al^{+3} than surface layer. Vzr had very low values of exchangeable Al through out the profile. Except in Vpm, Lah and Pck exchangeable Al increased down the profiles but the pattern was not uniform.

Among the exchangeable cations high contribution of exchangeable Al was in all the soils (Vpm, Tvr, Kpl, Lah, Tmg, Ktr and Pck) except Vzr particularly in sub soil, which indicate the occurrence of subsoil acidity. In Vzr, Tmg and Ktr series, the exchangeable Al content of the subsurface layer was higher than their respective surface layer.

Among the profiles Vzr had lowest value of exchangeable Al and exchange acidity. Calcium content was also low. Occurrence of subsoil layers with high exchangeable Al had been reported by Sumner *et al.* (1986) in highly weathered cultivated soils of southern USA.

The high contribution of the exchangeable Al towards EA and TPA is in agreement with the findings of Sharma *et al.*, (1990) who reported that EA in soil is mainly due to monomeric Al^{3+} ion. Profile distribution of soluble, exchangeable, extractable and non exchangeable forms of Al are presented in Fig. 4 and the distribution of exchangeable Al and pH down in each profile is given in Fig. 5.

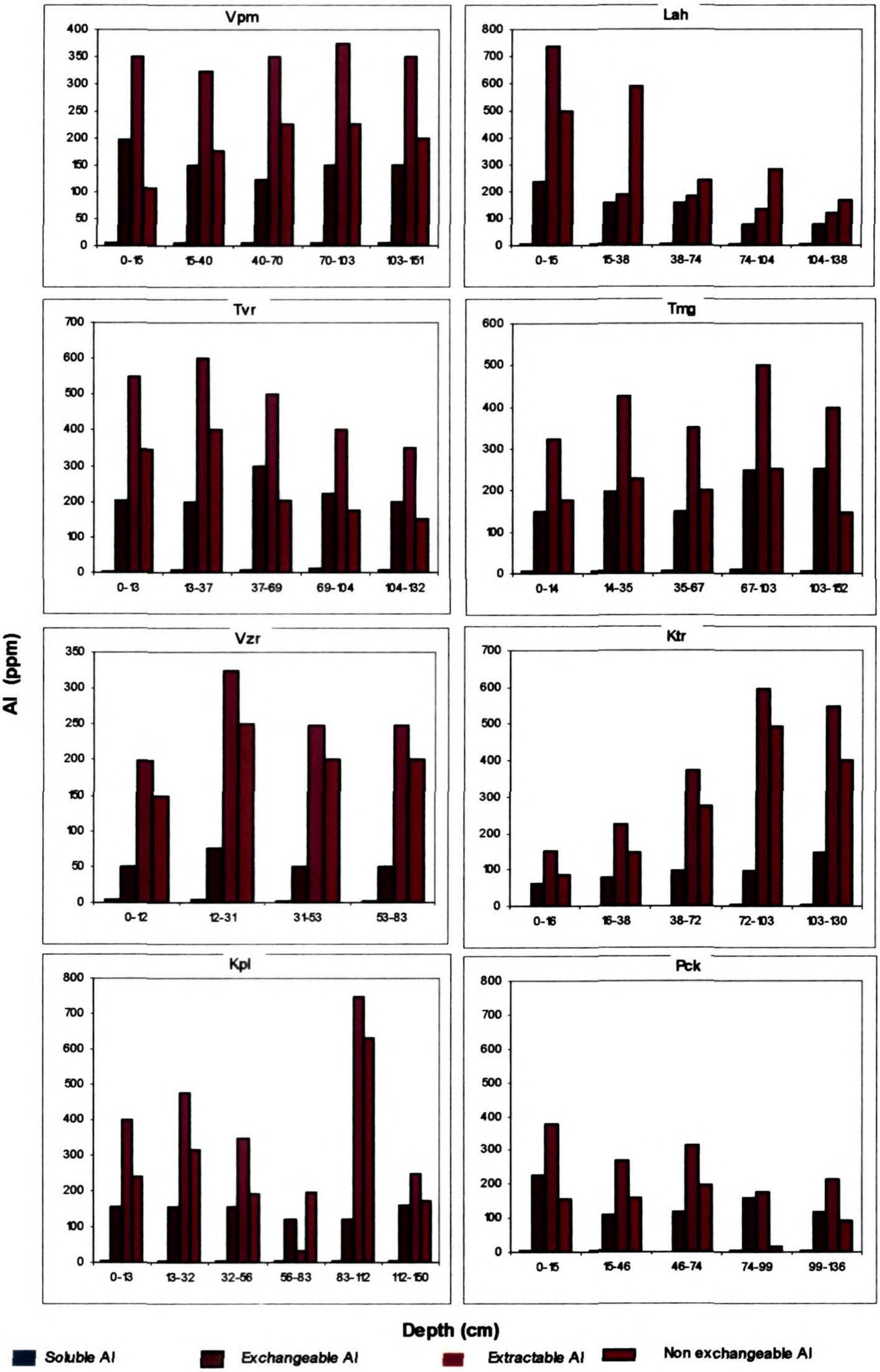


Fig- 4 Forms of Al in different soil series

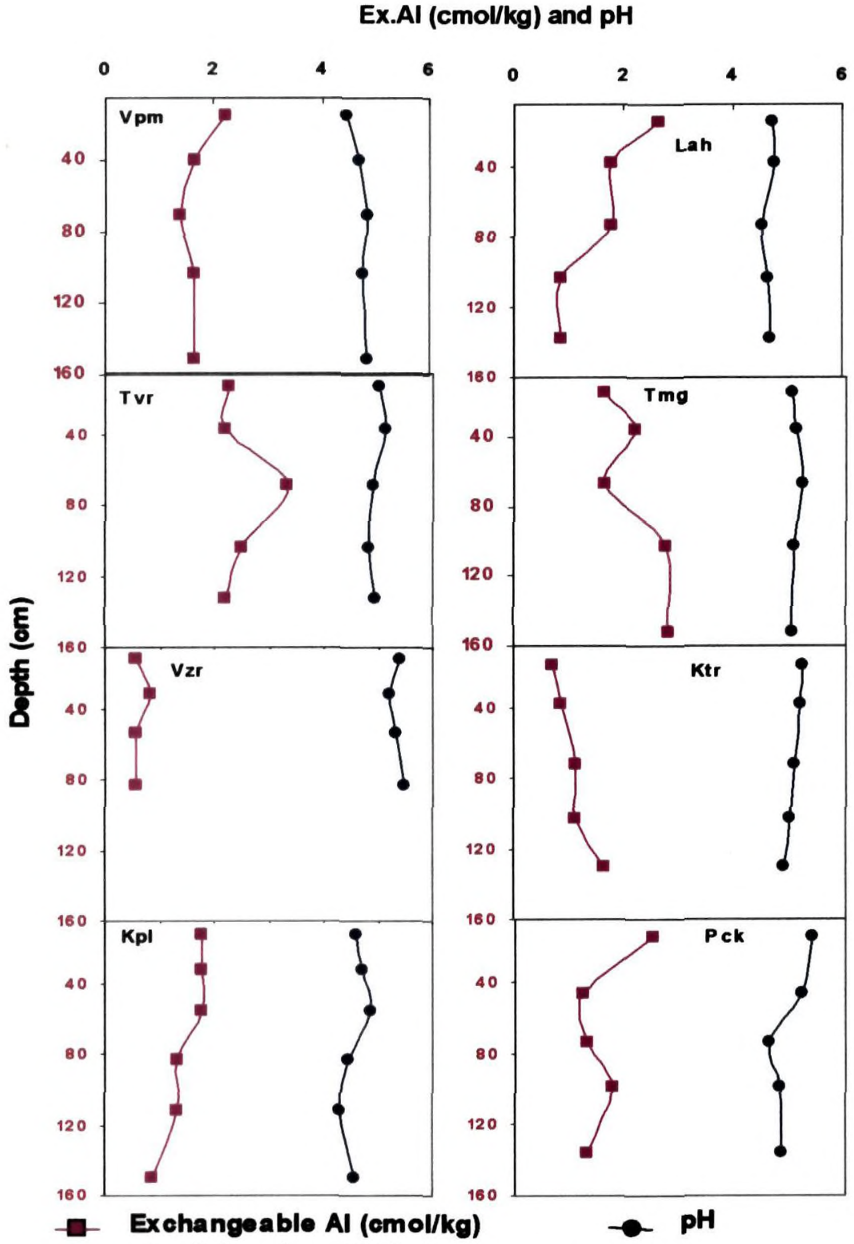


Fig. 5 Distribution of exchangeable Al and pH

IV.1.3.2. Soluble Al (Sol. Al)

Soluble aluminium values ranged from 0.75 ppm in 16 – 35 cm layer of Ktr to 10.63 ppm in 69 – 104 cm layer of Tvr. Comparatively high values of soluble Al were noticed in Tvr, Tmg, Vpm, Kpl, Lah and low values were found in Vzr, Pck and Ktr series. In general, soluble Al content was found to be high in the subsurface layer compared to the surface layer. Lower soluble Al content in the surface horizon may be due to the presence of organic matter. Thomas (1975) reported decrease in soluble Al with addition of organic matter.

According to Kamprath, (1972) the concentration of soil solution Al depends upon the soil organic matter and salt content. Soil solution Al increases with salt content because other cations then displace exchangeable Al by mass action (Brenes and Pearson, 1973). According to Adams and Moore (1983) and Evans and Kamprath (1970) in acid soils, inhibition of root growth is closely related to soil solution Al.

IV.1.3.3. Extractable Al (Extr. Al)

Extractable Al values ranged from 1.36 cmol/kg in 104 - 138 cm horizon of Lah series to 8.33 cmol/kg in 83 - 112 cm layer of Kpl series. In the surface horizon, the values varied from 1.67 in Ktr series to 8.20 cmol/kg in Lah series. In Vpm, Vzr, Kpl, Tmg and Ktr in lower horizons, extractable Al content was higher than the surface layer. Among the series, low content of extractable Al was noticed in Vzr. Except in Lahai, extractable Al^{+3} increases with increase in depth. Small amount of extractable Al in soils occurring as coating on the external and interlamellar surfaces of other soil constituents, have a disproportionately high influence on surface properties such as ion retention and exchange (Schwertmann and Tayler, 1981). In all the pedons the amount of Al extracted by 1M NH_4OAc buffered at pH 4.8 was higher than the Al extracted by 1M KCl, which indicate that extractable Al^{3+} includes exchangeable Al^{3+} and soluble

$Al(OH)_3$ (Pratt and Blair, 1961) and the hydroxy-Al monomers or polymers which may be adsorbed by the soil colloids (Thomas, 1961). Alexander (1974) reported that Al in soil solution, which is related to NH_4OAc extractable Al has been identified as the factor responsible for exchange acidity as well as poor crop growth in acid soils.

IV.1.3.4 Non exchangeable Al (Non Ex.Al)

The difference between NH_4OAc (pH 4.8) and 1MKCl extractable Al has been taken as non- exchangeable Al. There was no regular pattern in the distribution of non exchangeable Al in the profiles. The values varied from 0.18 cmol /kg in 74 – 99 cm layer of Pck to 7.01 cmol/kg in the 83 – 112 cm horizon of Kpl series.

The non-exchangeable Al is associated with organic matter, interlayer Al and hydroxyl - Al polymers. Bache and Sharp (1976) opined that protons arising from the acidic component of a salt solution may increase the dissolution of Al from the interlayer of clay minerals and organic matter bound Al with decrease of pH.

IV.1.3.5. Total Al

Highest value of 9.8 per cent total Al was noticed in the 38 – 74 cm layer of Lah series and lowest value of 1.6 per cent in the 37 – 69 cm horizon of Tvr. Except in Tvr and Tmg in all the other pedons highest total Al content was noticed in third horizon. Profile distribution of total Al is given in Fig.6.

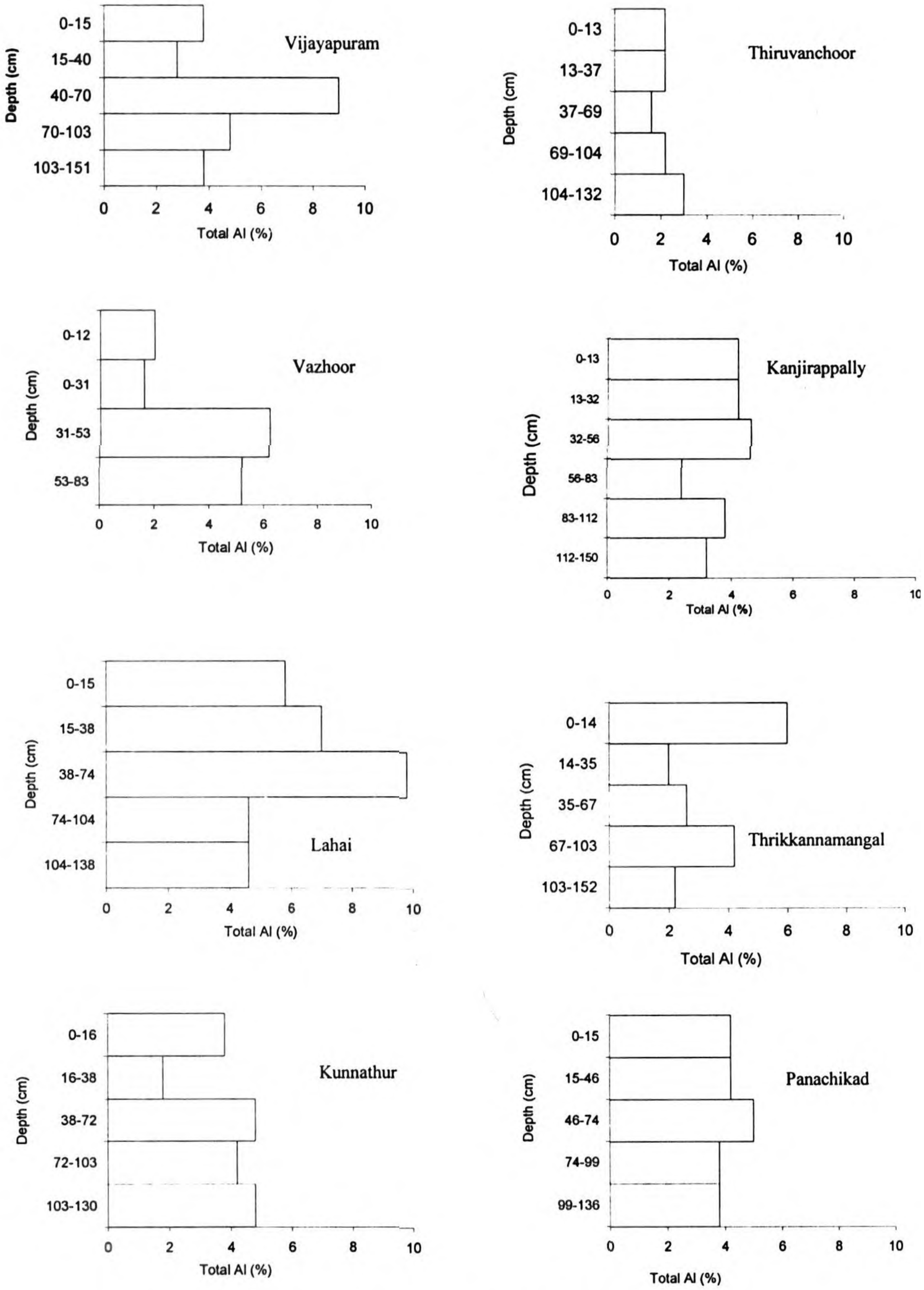


Fig.6 Distribution of total Al in different soil series

IV.1.4. Exchangeable, DTPA and Total Mn

Distribution of exchangeable, DTPA and total Mn is presented in Table 7. Wide variation in exchangeable Mn ranging from 0.09 ppm to 46.22 ppm was recorded. In general, the surface layer recorded high exchangeable Mn and the values decreased down the profile except in Pck series.

Very high values of exchangeable Mn in the surface layer were recoded in Ktr, Vzr and Vpm series (Fig.7). DTPA extractable Mn ranged from 0.10 ppm in the bottom horizon of Tvr to 42.0 ppm in the surface horizon of Pck series (Fig.8). Total Mn content ranged from 35.1 ppm in the bottom layer of Tmg to 450 ppm in the 16 – 38 cm horizon of Ktr series (Fig 9). Comparatively high values of exchangeable and total Mn were noticed in Ktr series. Generally exchangeable, extractable and total Mn decreased with increase in the depth of profiles.

Table 7. Exchangeable, DTPA and total Mn

Soil Series	Depth (cm)	(ppm)		
		Exchangeable Mn	DTPA* - Mn	Total Mn
Vpm	0-15	12.14	18.04	231.00
	15-40	3.20	4.97	227.00
	40-70	2.27	3.86	200.00
	70-103	1.14	1.16	135.00
	103-151	0.36	0.52	90.00
Tvr	0-13	3.42	5.07	114.40
	13-37	0.92	0.85	101.20
	37-69	0.67	0.73	86.30
	69-104	0.25	0.25	49.50
	104-132	0.09	0.102	38.50
Vzr	0-12	18.41	21.29	160.00
	12-31	8.39	12.12	140.40
	31-53	4.42	3.18	100.50
	53-83	3.31	1.69	84.90
Kpl	0-13	0.44	2.20	178.10
	13-32	0.13	0.49	158.60
	32-56	0.13	0.44	147.40
	56-83	0.32	1.24	134.10
	83-112	0.52	1.25	138.10
	112-150	0.37	1.41	142.40
Lah	0-15	2.75	14.16	110.50
	15-38	0.55	1.46	119.10
	38-74	0.53	1.68	95.00
	74-104	2.57	1.35	75.40
	104-138	2.53	0.86	49.00
Tmg	0-14	5.89	7.50	104.60
	14-35	3.59	3.77	96.15
	35-67	3.13	3.26	70.10
	67-103	1.83	1.21	45.00
	103-152	1.00	0.63	35.10
Ktr	0-16	46.22	34.67	344.40
	16-38	29.15	20.63	450.00
	38-72	18.22	6.08	386.00
	72-103	13.23	4.89	212.80
	103-130	5.82	1.72	167.50
Pck	0-15	0.26	42.30	346.80
	15-46	0.92	16.50	325.20
	46-74	9.25	9.79	310.90
	74-99	11.53	4.00	158.70
	99-136	5.50	1.40	142.20

* **DTPA- Diethylene tri amine penta acetic acid**

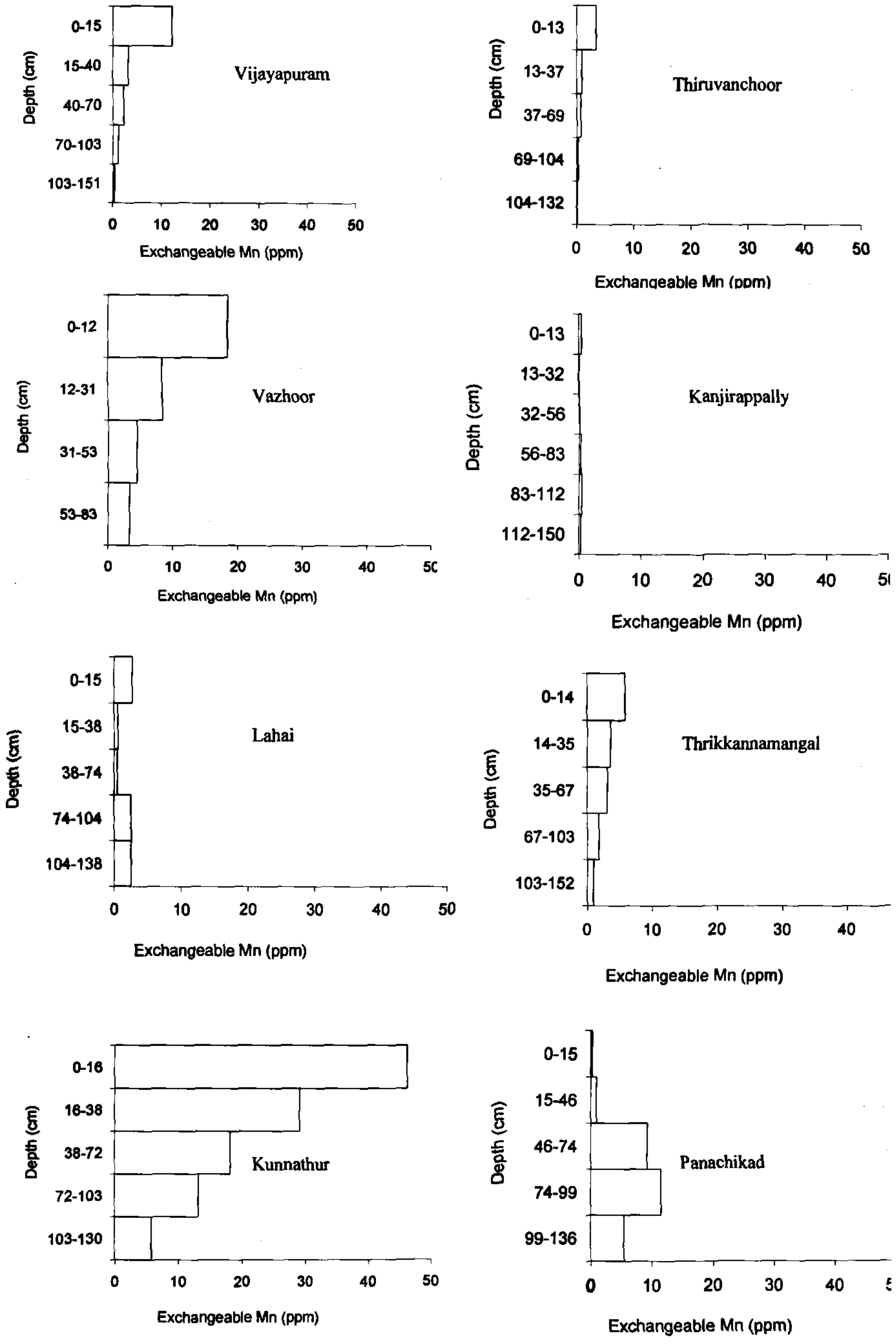


Fig. 7. Distribution of exchangeable Mn in different soil series

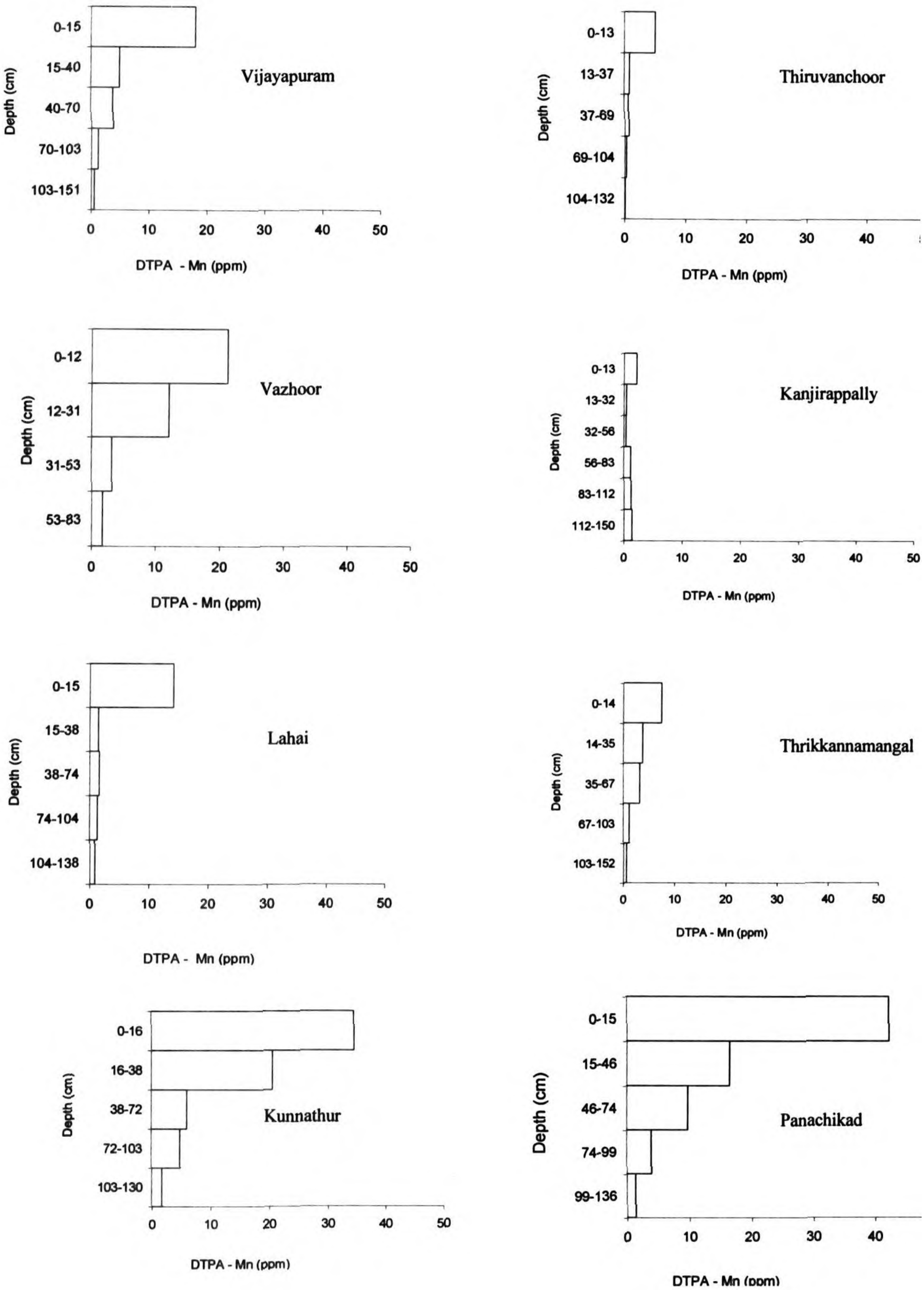


Fig. 8 Distribution of DTPA – Mn in different soil series

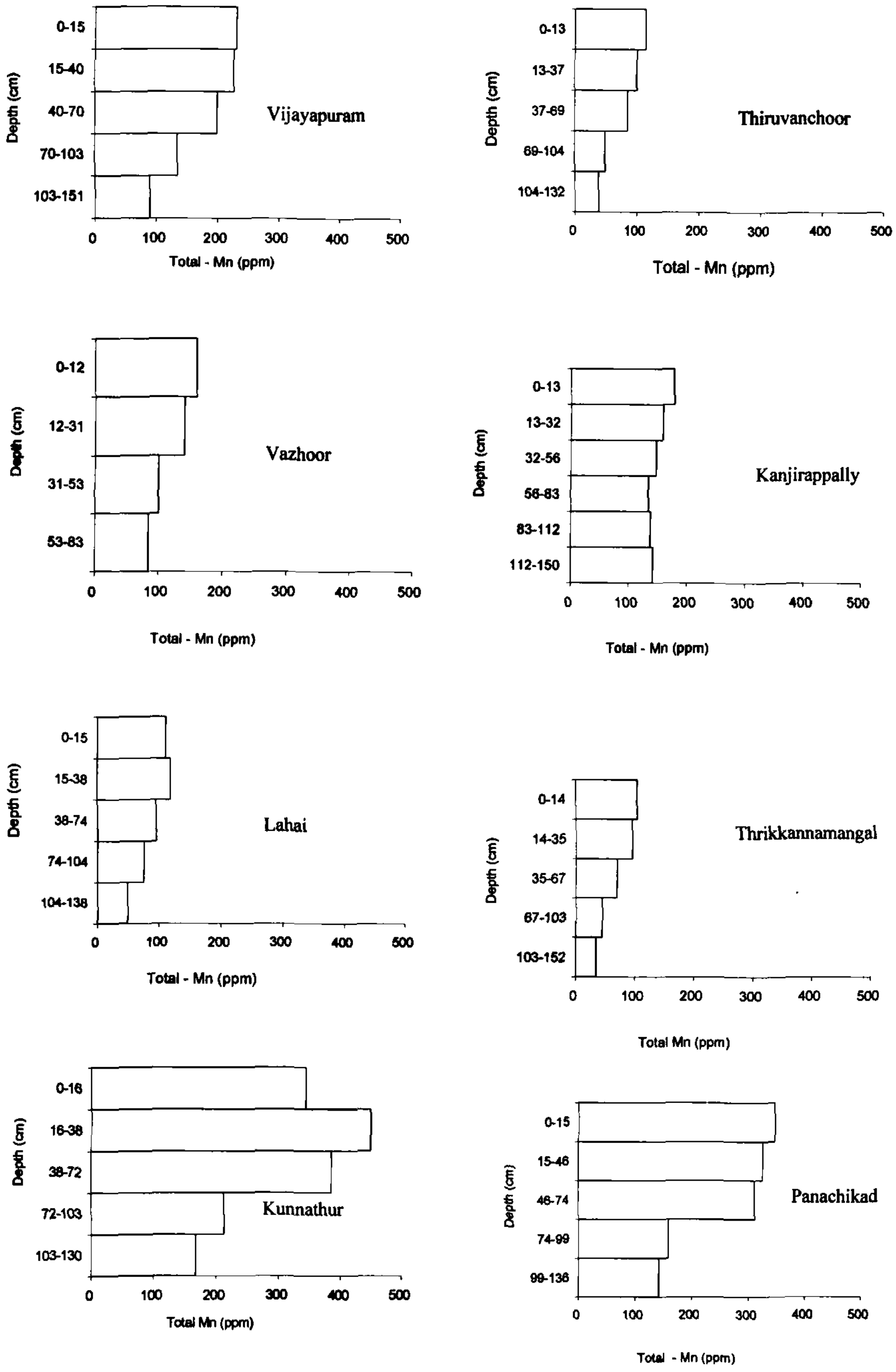


Fig. 9 Distribution of total Mn in different soil series

IV.1.5. Exchangeable, DTPA and total Fe

Exchangeable, DTPA and total Fe in the profiles is given in Table 8. Exchangeable Fe ranged from 0.01 to 0.74 ppm in the profiles. Higher content of exchangeable Fe was noticed in the surface layer and it varied from 0.12ppm (Ktr) to 0.74 ppm (Pck) (Fig. 10).

The values of DTPA extractable Fe ranged from 1.18 ppm in the bottom layer of Vzr to 115.31 ppm in the surface horizon of Pck series (Fig.11). In all the profiles surface layer recorded more extractable Fe than the lower layers. Among the profiles comparatively higher values were noticed in Pck series and lower values in Ktr series. Total Fe content varied from 5.4 per cent in the bottom layer of Pck to 18.86 per cent in the (40 -70 cm) layer of Vpm (fig. 12). Among the different series higher total Fe was observed in Vpm series.

Table 8. Exchangeable, DTPA extractable and total Fe

Soil Series	Depth (cm)	Exchangeable Fe (ppm)	DTPA*-Fe (ppm)	Total Fe (%)
Vpm	0-15	0.69	81.17	17.31
	15-40	0.13	24.67	18.24
	40-70	0.04	15.26	18.86
	70-103	0.02	5.06	15.68
	103-151	0.01	3.30	14.98
Tvr	0-13	0.55	51.51	9.9
	13-37	0.11	30.76	8.9
	37-69	0.15	9.83	8.4
	69-104	0.01	3.01	7.0
	104-132	0.17	2.42	7.6
Vzr	0-12	0.30	35.75	8.5
	12-31	0.32	25.92	9.7
	31-53	0.25	4.16	10.98
	53-83	0.01	1.18	10.88
Kpl	0-13	0.63	49.02	7.9
	13-32	0.01	24.13	8.3
	32-56	0.01	17.33	9.13
	56-83	0.01	11.94	8.54
	83-112	0.05	9.25	7.86
	112-150	0.05	8.58	7.50
Lah	0-15	0.42	30.07	9.87
	15-38	0.01	19.96	11.61
	38-74	0.01	6.02	11.64
	74-104	0.12	4.17	12.60
	104-138	0.01	4.07	12.48
Tmg	0-14	0.04	32.12	9.36
	14-35	0.01	11.91	8.92
	35-67	0.01	13.82	9.27
	67-103	0.01	8.47	7.97
	103-152	0.01	2.62	7.45
Ktr	0-16	0.12	16.15	9.91
	16-38	0.31	10.18	9.25
	38-72	0.06	5.41	9.45
	72-103	0.12	2.14	12.35
	103-130	0.28	1.49	11.61
Pck	0-15	0.74	115.31	9.97
	15-46	0.14	50.99	10.52
	46-74	0.03	22.90	8.96
	74-99	0.01	13.61	8.58
	99-136	0.09	7.67	5.45

*** DTPA- Diethylene tri amine penta acetic acid**

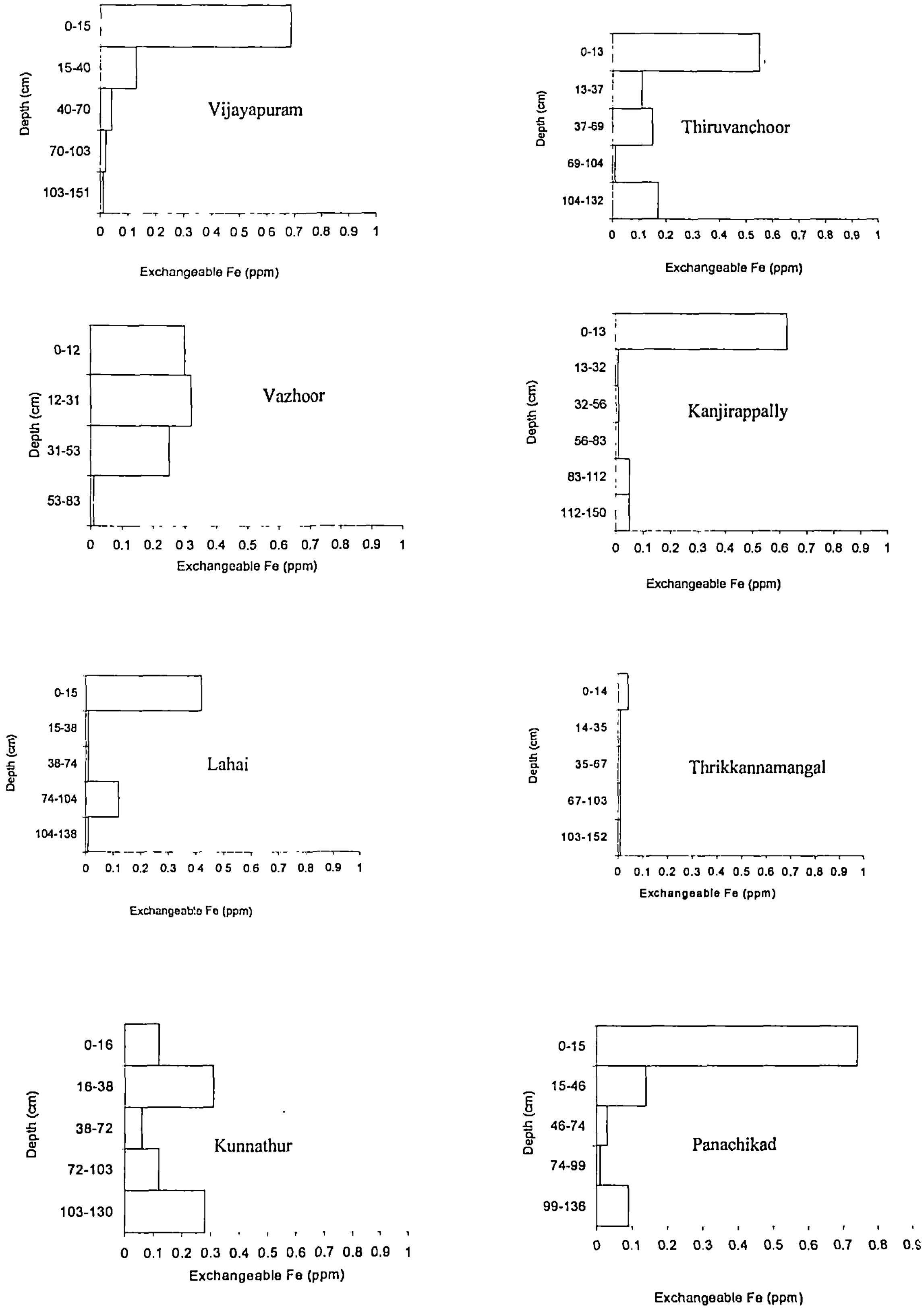


Fig. 10 Exchangeable Fe in different soil series

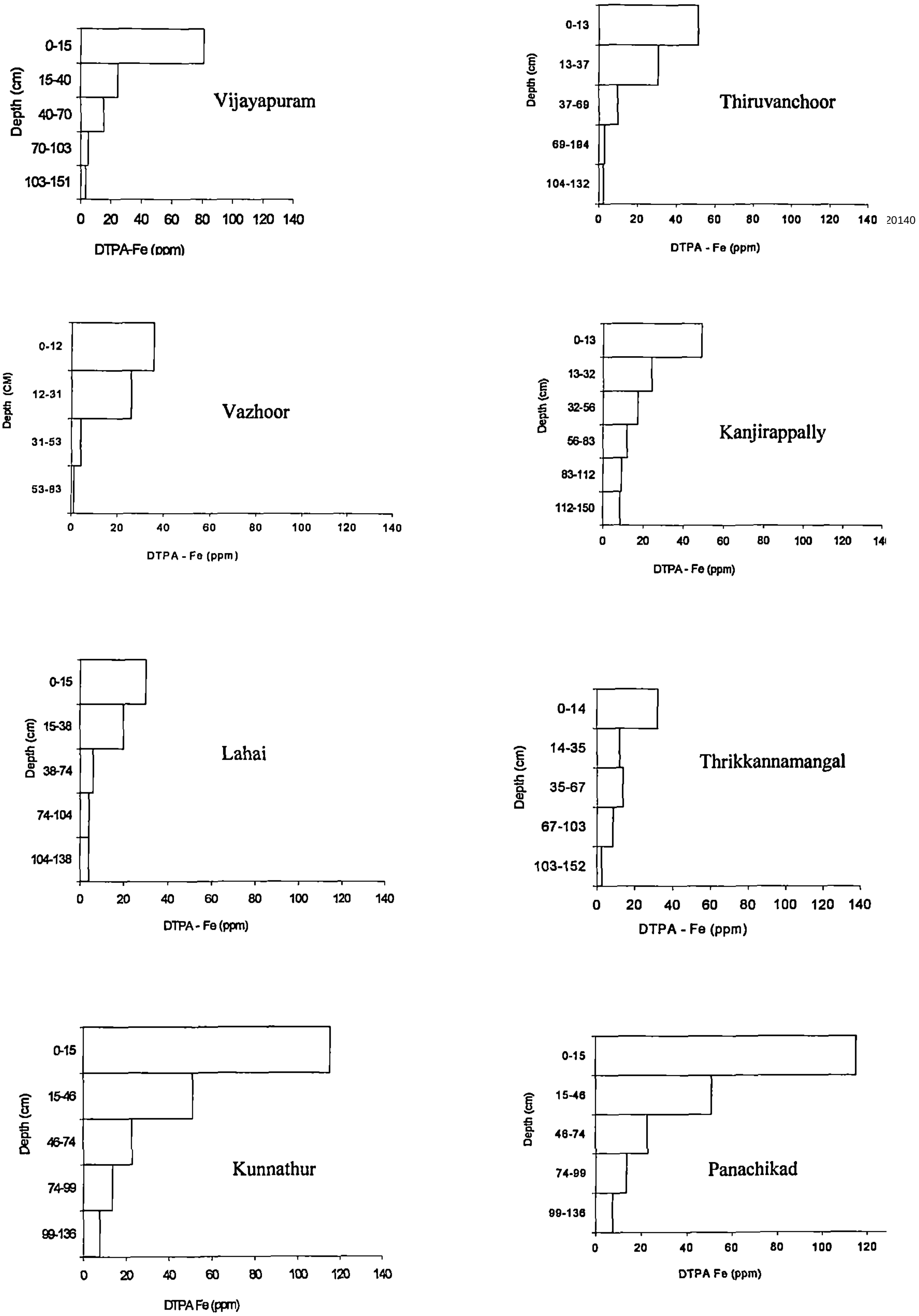


Fig. 11 Distribution of DTPA – Fe in different soil series

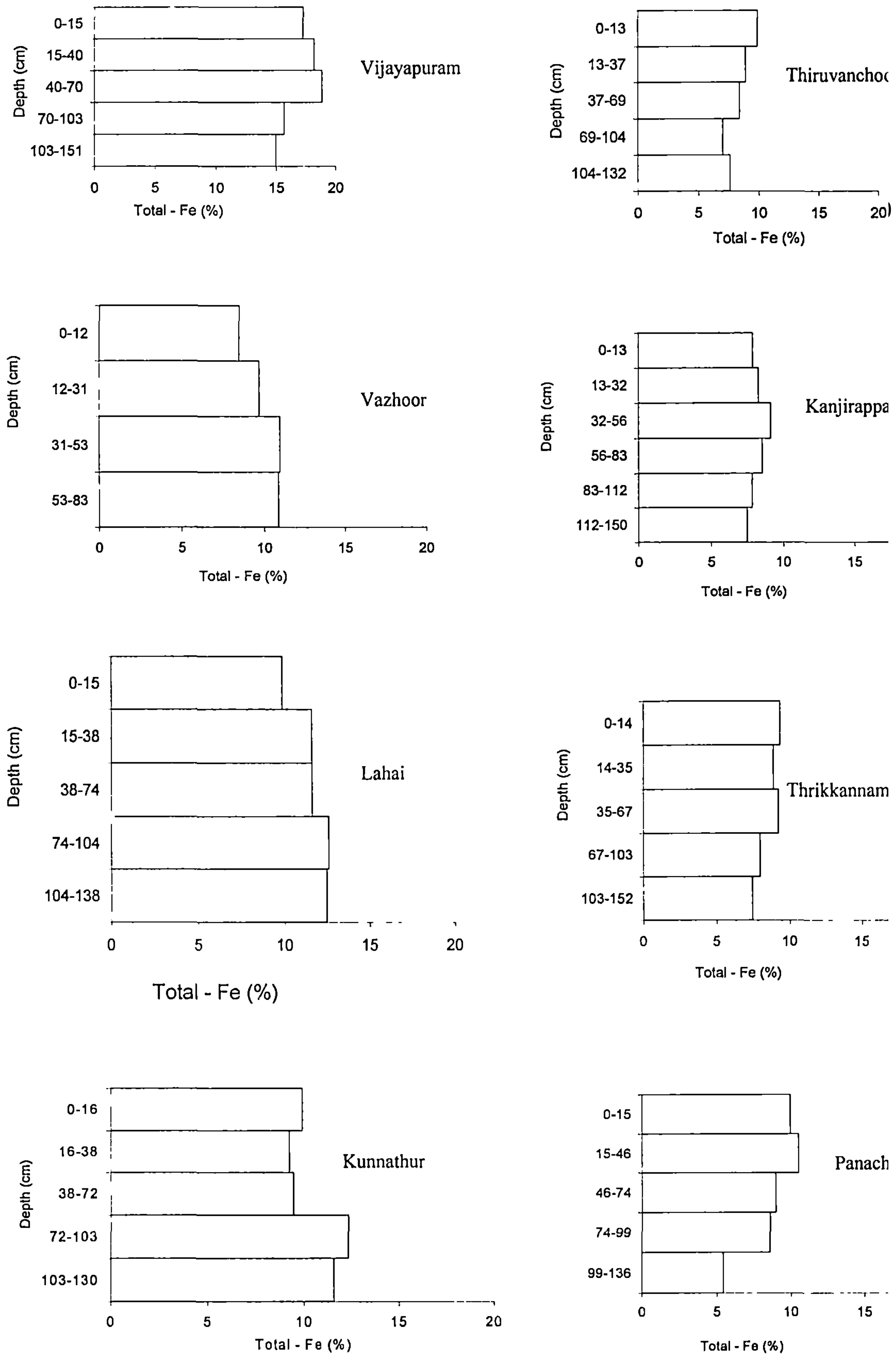


Fig. 12 Distribution of total Fe in different soil series

IV.1.6. Acid ammonium oxalate extractable Al (Al_0) and Fe (Fe_0)

Acid ammonium oxalate extracts Al and Fe mostly from amorphous, exchangeable and organically bound forms but little from crystalline form (Table 9). The depth function showed an irregular trend in the distribution of oxalate Al in these profiles and the values ranged from 1.39 to 8.33 cmol/kg . Oxalate extractable Al was much less than citrate extractable Al. In Vpm,Kpl and Pck series surface layer contained higher content of Al_0.

No regular pattern was observed in the distribution of oxalate extractable Fe and the values varied from 0.34 to 1.94 per cent . Comparatively high values were noticed in Kpl and Lah series and low values in Tvr and Tmg series. Oxalate extractable Fe was markedly less than citrate extractable Fe, indicating the dominance of crystalline forms of Fe in this soils.

Table 9. Acid ammonium oxalate extractable Al (Al_o) and Fe (Fe_o)

Soil Series	Depth (cm)	Al_o (cmol/kg)	Fe_o (%)
Vpm	0-15	6.94	1.85
	15-40	5.56	0.81
	40-70	1.39	1.27
	70-103	1.39	0.58
	103-151	4.72	0.34
Tvr	0-13	1.39	0.90
	13-37	1.39	0.89
	37-69	4.17	0.54
	69-104	1.39	1.07
	104-132	4.17	0.68
Vzr	0-12	1.39	0.79
	12-31	4.17	0.84
	31-53	4.17	1.17
	53-83	1.39	1.15
Kpl	0-13	6.94	1.39
	13-32	8.33	1.32
	32-56	1.39	1.14
	56-83	1.39	0.93
	83-112	3.89	1.15
	112-150	1.39	1.01
Lah	0-15	6.94	1.61
	15-38	8.33	1.06
	38-74	1.39	1.31
	74-104	1.39	1.94
	104-138	1.39	1.39
Tmg	0-14	4.17	0.53
	14-35	5.56	0.88
	35-67	1.39	0.72
	67-103	4.17	0.84
	103-152	6.94	0.83
Ktr	0-16	4.17	1.08
	16-38	1.39	1.45
	38-72	2.78	1.28
	72-103	4.17	0.84
	103-130	5.56	0.71
Pck	0-15	5.56	1.57
	15-46	1.39	1.19
	46-74	1.39	1.19
	74-99	1.39	0.84
	99-136	1.39	0.85

IV.1.7. Dithionate citrate bicarbonate extractable Al (Al_d) and Fe (Fe_d)

Dithionate citrate bicarbonate extracts mostly crystalline forms of Al and Fe. No regular pattern was observed in the distribution of Al_d and the values (Table 10) varied from 26.39 cmol/kg in 70 – 103 cm horizon of Vpm series to 186.11 cmol/kg in the bottom layer (53 - 83 cm) of Vzr (Fig. 13)

Table 10. Dithionate citrate bicarbonate extractable Al (Al_d) and Fe (Fe_d)

Soil Series	Depth (cm)	Al_d (cmol /kg)	Fe_d (%)	Fe_o/ Fe_d
Vpm	0-15	94.44	1.63	1.03
	15-40	77.78	2.28	0.36
	40-70	55.56	2.55	0.50
	70-103	26.39	2.65	0.22
	103-151	27.78	2.66	0.13
Tvr	0-13	63.89	1.98	0.45
	13-37	66.67	2.50	0.36
	37-69	88.89	2.32	0.23
	69-104	94.44	2.87	0.36
	104-132	46.26	3.00	0.23
Vzr	0-12	105.56	3.65	0.25
	12-31	102.78	3.00	0.28
	31-53	86.11	3.30	0.35
	53-83	186.11	3.12	0.37
Kpl	0-13	105.56	2.18	0.64
	13-32	97.22	1.87	0.71
	32-56	52.78	2.20	0.61
	56-83	102.78	2.59	0.36
	83-112	88.89	2.12	0.54
	112-150	86.11	1.76	0.57
Lah	0-15	127.78	3.34	0.48
	15-38	141.67	2.87	0.37
	38-74	88.89	3.90	0.34
	74-104	100.00	3.17	0.61
	104-138	100.00	3.39	0.41
Tmg	0-14	83.33	2.55	0.21
	14-35	80.56	2.87	0.31
	35-67	66.67	2.34	0.31
	67-103	72.22	2.02	0.42
	103-152	77.78	2.42	0.34
Ktr	0-16	58.33	2.89	0.37
	16-38	77.78	2.47	0.59
	38-72	77.78	2.95	0.43
	72-103	91.67	3.62	0.23
	103-130	83.33	3.08	0.23
Pck	0-15	69.44	1.08	0.45
	15-46	108.33	2.66	0.49
	46-74	80.56	2.42	0.46
	74-99	44.44	1.82	0.47
	99-136	77.78	1.32	0.48

Dithionate extractable Fe ranged from 1.08 per cent in the surface horizon of Pck to 3.90 per cent in the 38 – 74 cm layer of Lah series (Fig.14). Higher values suggest that amorphous Fe had been transformed to crystalline Fe. This trend is reflected in active Fe ratio (Fe_o/Fe_d) (Fig.15). According to Alexander (1974), active Fe ratio is an indicator of age of the soils and low ratios indicate older soils. Further, decreasing proportion of (Fe_o/Fe_d) with depth in most of the pedons suggests that higher proportion of oxides occur in crystalline form in lower horizons (Juo *et al*, 1974).

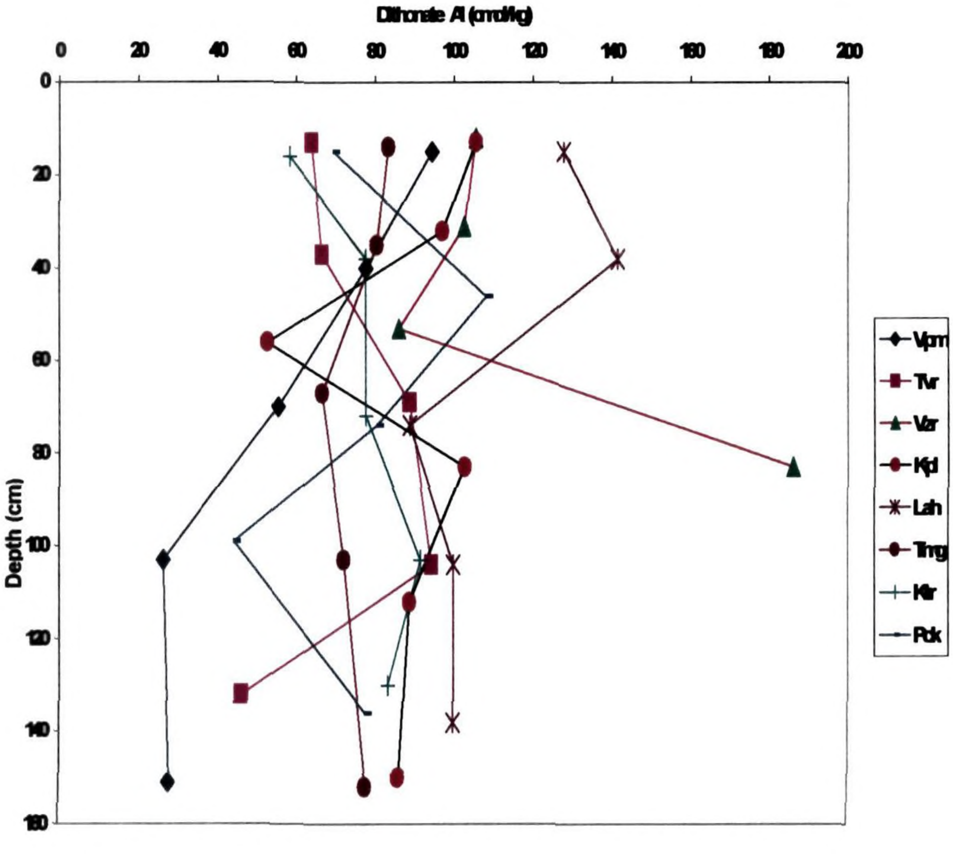


Fig. 13 Distribution of dithionate - Al in different soil series

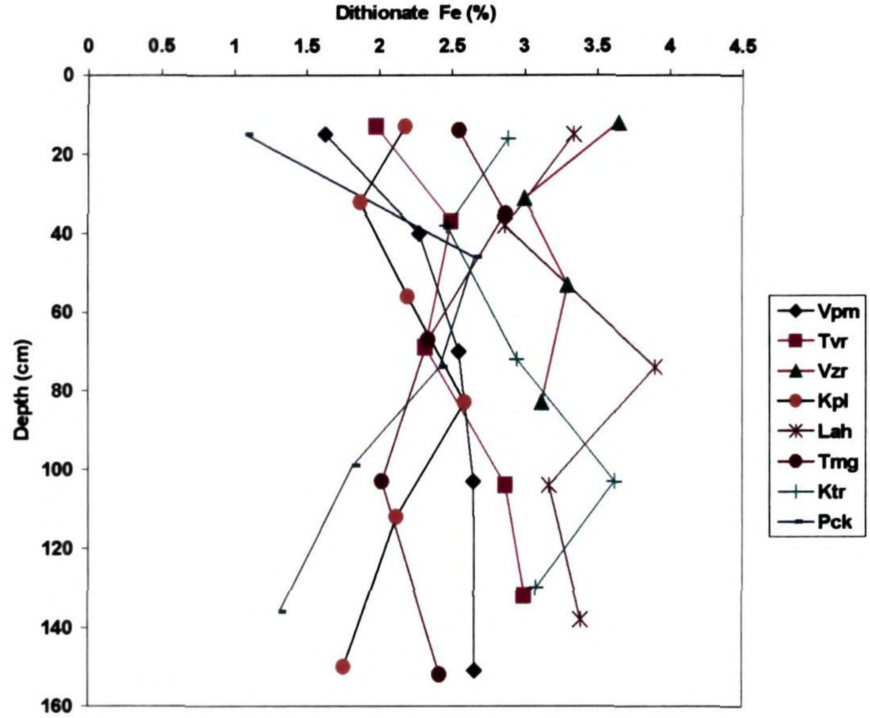


Fig. 14 Distribution of dithionate Fe in different soil series

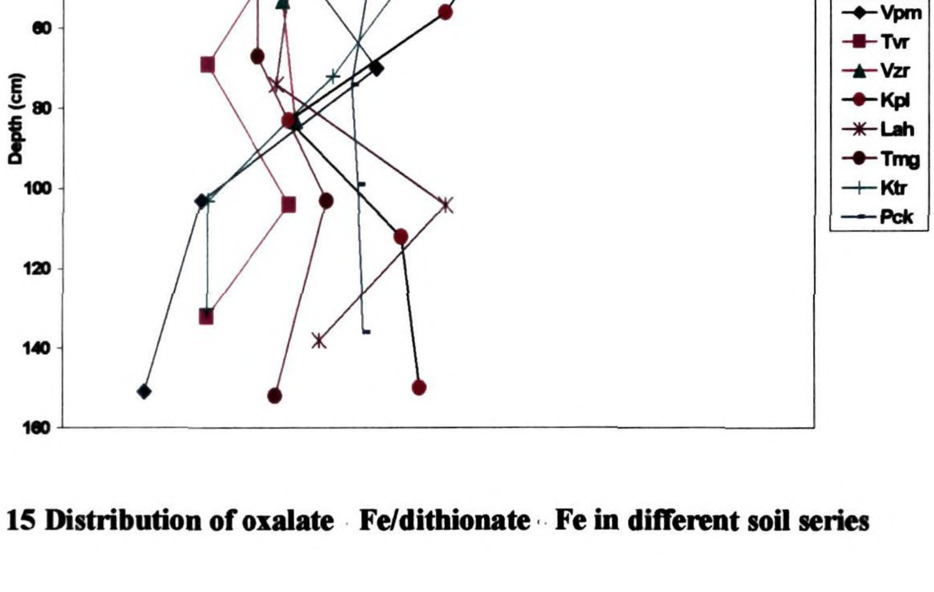


Fig. 15 Distribution of oxalate Fe/dithionate Fe in different soil series

IV.1.8. Effective cation exchange capacity (ECEC)

In the surface soil, the values ranged from 1.41 cmol/kg in Vzr to 4.31 cmol /kg in Pck series (Table 11). In Vpm, Kpl, Lah, Ktr and Pck the surface horizon had high values of ECEC than the lower horizons. Among the pedons, lowest ECEC values were noticed in Vzr series. No regular pattern was observed in effective cation exchange capacity values with depth.

Table 11. Effective cation exchange capacity(ECEC)

Soil Series	Depth (cm)	ECEC (cmol/kg)
Vpm	0-15	3.06
	15-40	2.34
	40-70	2.16
	70-103	2.30
	103-151	2.24
Tvr	0-13	3.49
	13-37	3.08
	37-69	4.03
	69-104	2.85
	104-132	2.48
Vzr	0-12	1.41
	12-31	1.78
	31-53	1.23
	53-83	1.24
Kpl	0-13	2.33
	13-32	2.10
	32-56	2.07
	56-83	1.57
	83-112	1.57
	112-150	1.99
Lah	0-15	3.03
	15-38	2.11
	38-74	2.06
	74-104	1.51
	104-138	1.36
Tmg	0-14	2.34
	14-35	2.87
	35-67	2.31
	67-103	3.24
	103-152	3.30
Ktr	0-16	3.20
	16-38	2.85
	38-72	3.12
	72-103	3.09
	103-130	3.17
Pck	0-15	4.31
	15-46	272
	46-74	2.69
	74-99	2.89
	99-136	2.32

IV.1.9 Relation between pH and aluminium saturation per cent

Aluminium saturation per cent was calculated from the effective cation exchange capacity (ECEC) and is given in Table 12. The surface layers had generally lower Al saturation per cent, which increased with depth. It ranged from 21.88 per cent in the surface horizon (0 – 16 cm) of Ktr to 89.45 per cent in the bottom layer (112 – 150 cm) of Kpl series. Except in Vpm, Lah and Pck subsurface horizons had high values of Al saturation than the surface layer. In Vzr, Ktr and Pck Al saturation was less than 60 per cent in the surface and subsurface horizons while the rest of the profiles showed high Al saturation. Lowest value was noticed in Ktr followed by Vzr. Low Al saturation in the surface layer may be due to the downward movement of Al as organo - Al complexes or chelates (Schnitzer and Skinner, 1963) and also enrichment of the surface layer with basic cations through litter fall.

The relationship between pH and Al saturation provides a quantitative assessment whether or not Al toxicity is likely to be a problem. The pH was significantly and indirectly related to Al saturation per cent ($R^2 = 0.34^{**}$) (Fig.16). The saturation of exchangeable complex with exchangeable Al was highest at pH 4.58 and lowest at pH 5.20. This relationship was reported to be around 20 per cent, when the pH is near 5.5. High Al saturation is reported to be harmful for most crops. The higher the Al saturation the more the soils will be deficient in Ca, Mg and K. In Ktr, Vzr and Pck, Al saturation was less than 60 per cent in the surface and subsurface horizons while the rest of the profiles showed high aluminium saturation. Evans and Kamprath (1970) reported that there is less than 1ppm Al in the soil solution when the Al saturation is lower than 60 per cent and its concentration in soil solution increases sharply beyond 60 per cent Al saturation. Soluble Al content was found to increase with increase in Al saturation per cent as evidenced in Vpm, Tvr, Kpl, Lah, and Tmg series. Highest soluble Al of 10.63 ppm was noticed in 69-104 cm layer of Tvr series and the corresponding Al saturation was 87 per cent. High Al saturation particularly in sub-soils has been reported for ultisols (Sanchez, 1976). Because of the high concentration of Al in the sub soil the root growth will be affected and in turn reduces the uptake of nutrients especially Ca and P.

Management of these soils should be aimed at minimizing the aluminium saturation well below 60 per cent. To achieve this, liming of these soils to neutralize exchangeable Al may be required which will also augment the supply of basic nutrient ions like Ca and Mg and raise the pH of these soil. For more tolerant species, liming should be aimed at decreasing Al saturation to 20 or 40 per cent (Sanchez, 1976). It was reported that liming rates calculated based on exchangeable Al raise the soil pH to about 5.5 – 6.0 in most mineral soils, (Kamprath, 1970). For highly weathered oxisols and ultisols in which hydrous oxides of Fe and Al are predominant a soil pH of around 5.5 with exchangeable Al being less than 20 per cent of ECEC would produce satisfactory crop growth (Adams, 1984).

Table 12. Relation of pH with soluble Al and Al saturation

Soil Series	Depth (cm)	pH $_{(H2O)}$	Al saturation (%)	Soluble Al(ppm)
Vpm	0-15	4.46	71.90	5.63
	15-40	4.69	70.50	6.25
	40-70	4.84	63.89	6.00
	70-103	4.79	71.74	5.63
	103-151	4.87	73.66	4.25
Tvr	0-13	5.02	65.04	5.50
	13-37	5.12	71.43	6.50
	37-69	4.91	83.63	8.50
	69-104	4.82	87.37	10.63
	104-132	4.93	88.71	7.00
Vzr	0-12	5.38	39.01	3.50
	12-31	5.19	46.63	4.00
	31-53	5.32	44.72	2.13
	53-83	5.48	44.35	1.38
Kpl	0-13	4.61	75.54	5.75
	13-32	4.72	83.81	5.90
	32-56	4.85	85.02	4.50
	56-83	4.47	84.08	2.50
	83-112	4.29	84.08	5.13
	112-150	4.58	89.45	5.13
Lah	0-15	4.71	87.13	3.25
	15-38	4.77	83.34	5.38
	38-74	4.53	85.44	5.45
	74-104	4.64	58.67	4.13
	104-138	4.69	67.71	2.75
Tmg	0-14	5.04	70.60	6.38
	14-35	5.10	76.76	8.00
	35-67	5.21	54.60	5.38
	67-103	5.08	84.67	9.00
	103-152	5.04	79.02	7.00
Ktr	0-16	5.20	21.88	1.13
	16-38	5.18	29.82	0.75
	38-72	5.06	35.25	1.88
	72-103	5.00	35.60	2.75
	103-130	4.90	52.05	3.63
Pck	0-15	5.40	58.00	2.75
	15-46	5.21	44.85	2.90
	46-74	4.60	49.07	1.13
	74-99	4.80	60.09	3.00
	99-136	4.85	56.90	3.75

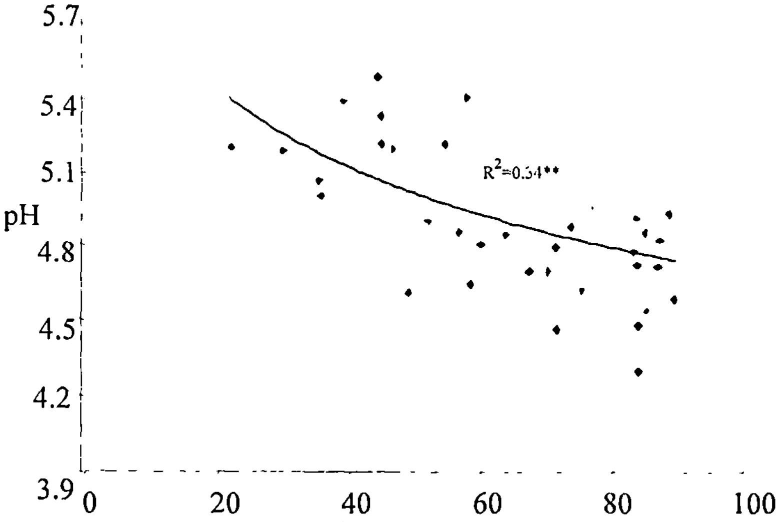


Fig. 16 Relation between pH and Al saturation

IV.1.10. Correlations

Relationship between different forms of acidity and soil properties are given in Table 13 and Table 14. Highly significant correlation between total potential acidity and pH dependent acidity ($r = 0.99^{**}$). Total potential acidity and pH dependent acidity showed significant positive correlation with organic carbon ($r = 0.53^{**}$ and $r = 0.52^{**}$ respectively). Such correlations were expected because soil organic matter possesses number of functional groups like carboxylic (-COOH) and phenolic, which liberate H^+ ions on ionization contributing to different forms of acidity depending on their magnitude. Exchangeable acidity had highly significant positive correlation with exchangeable Al ($r = 0.91^{**}$) and extractable Al ($r = 0.56^{**}$). pH dependent acidity correlated significantly with organic carbon ($r = 0.52^{**}$). Exchangeable Al showed significant positive correlation with extractable Al ($r = 0.58^{**}$) and negative correlation with exchangeable Ca ($r = -0.33^{*}$). The inverse relation of exchangeable Ca and Al had been reported by Alva and Sumner (1990) and they had pointed out that the major deleterious effect of soil acidity was observed when Al toxicity was coupled with Ca deficiency. A significant positive correlation was observed between extractable Al and clay (r = 0.38*).

There is significant influence between pH$_{(water)}$ and pH$_{(CaCl2)}$ (r = 0.56**) and exchangeable Ca (r = 0.61**). pH$_{(CaCl2)}$ correlated positively with organic carbon (r = 0.46**) and exchangeable Ca (r = 0.52**) and negatively with clay (r = - 0.48**).

Table 13. Correlation between forms of acidity and soil properties

Factors	EA	PA	OC	Ex.Al	Ex.Al	Ex.Ca	Clay
TPA	0.22	0.99**	0.53**	0.21	0.03	-0.26	-0.10
EA		0.07	0.10	0.91**	0.56**	-0.26	0.19
PA			0.52**	0.07	-0.06	-0.23	-0.13
OC				0.09	0.14	0.35*	-0.37*
Ex. Al					0.58**	-0.33*	0.21
Extr. Al							0.38*

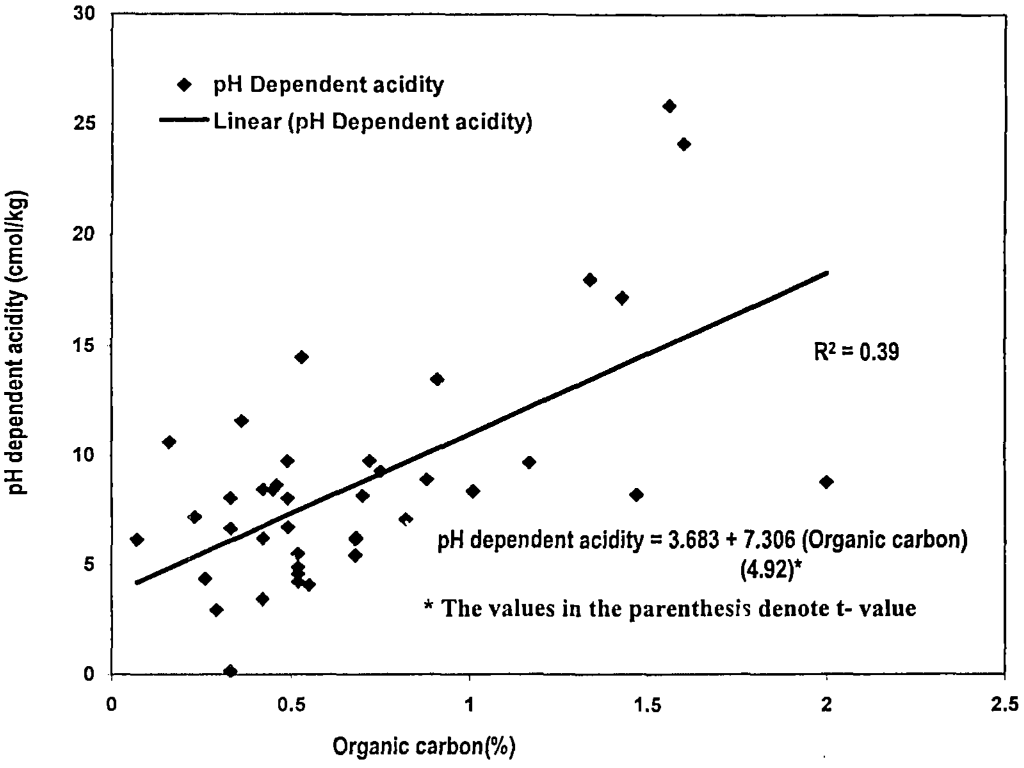
*** Significant at 5 per cent level ** Significant at 1 per cent level**

Table 14. Correlation between forms of acidity and soil properties

Factors	pH$_{CaCl2}$	OC	Ex.Al	Extr. Al	Ex.Ca	Clay
pH$_{(Water)}$	0.56**	0.17	0.005	0.21	0.61**	-0.19
pH$_{(CaCl2)}$		0.46**	-0.20	-0.21	0.52**	-0.48**
OC			0.18	0.08	0.05	-0.48**
Ex. Al				0.56**	-0.32	0.23
Extr. Al						0.39*
Ex. Ca						-0.03

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

Some important indications are shown in Fig.17 and Fig.18 with the respective bivariate linear regression equation of the pairs (1% level with respect to38 d.f.). For pH dependent acidity, organic carbon was correlated with highest significant (1% level with respect to 38 d.f.) and positive value, thereby indicating the most constructive interrelation with this form of acidity.



pH dependent acidity = 3.683 + 7.306 (Organic carbon)
(4.92)*

* The values in the parenthesis denote t- value

Fig. 17 Effect of organic carbon on pH dependent acidity

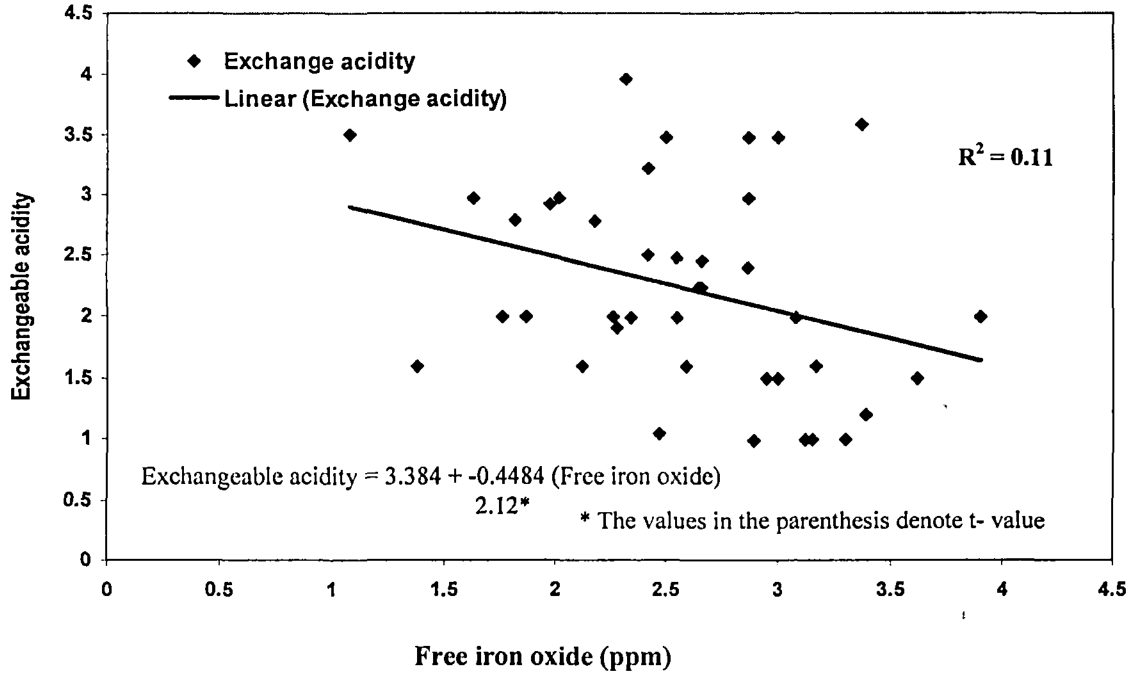


Fig. 18 Effect of Free iron oxide on exchange acidity

IV.2 Lime requirement of rubber growing soils

IV.2.1. Estimation of Lime requirement

Lime requirement (LR) of eight soil series was estimated by four methods and the LR in terms of $CaCO_3$ (t/ha) are presented in Table 15 and Fig. 19. Wide variation between methods was recorded. Similarly, wide variation was noticed between soils also. The SMP-LR values ranged from 6.25 for Ktr and Pck to 23.5 t/ha for Lah.

Table 15. Lime Requirement by different methods (t/ha)

Soil series	SMP method	Peech method	Adams and Evans method	Ex. Al method
Vpm	15.00	9.70	12.00	3.63
Tvr	15.00	9.62	9.60	3.75
Vzr	10.50	6.92	8.40	0.91
Kpl	20.75	13.48	12.00	2.90
Lah	23.50	20.00	12.00	4.36
Tmg	8.00	4.70	9.00	2.72
Ktr	6.25	4.42	7.90	1.16
Pck	6.25	4.60	4.90	4.13

Among the methods, highest quantity of LR was recorded by SMP method and lowest by exchangeable Al method. Exchangeable Al -LR values ranged from 0.91 to 4.36 t/ha. In Peech method LR quantity varied from 4.42 t/ha (Ktr) to 20.0 t/ha (Lah). For Adams and Evans method the values ranged from 4.9 t/ha (Pck) to 12 t/ha (Vpm, Kpl and Lah). In all the methods highest LR were recorded by Lah series and this may be due to high values of acidity, exchangeable Al, organic carbon and clay content of this series. Tisdale *et al.*, (1985) showed that the LR of the soil depends on the buffering capacity as reflected by clay and organic matter. Different forms of acidity contribute to the lime requirement of the acid soils (Ananthanarayana and Ravikumar, 1997). Lime requirement increases with increase in reserve acidity and CEC of the soil (Tisdale *et al.*, 1985). The relatively high base saturation in Ktr series compared to other soils may be the reason for low lime requirement in Ktr and this is in agreement with Kelley (1984).

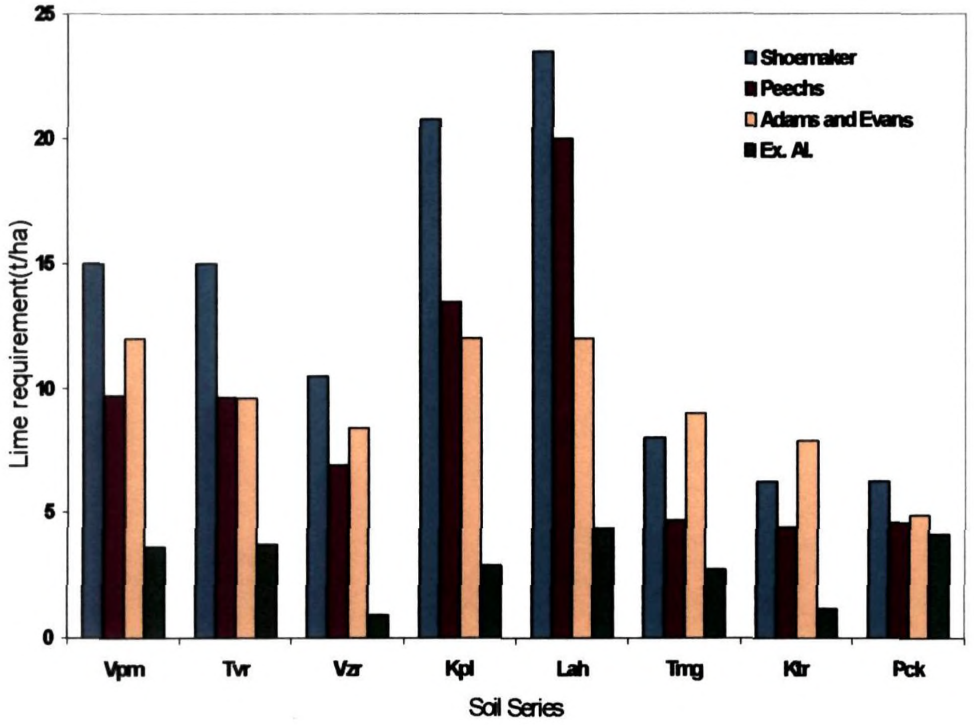


Fig. 19 Lime requirement by different methods

IV.2.2. Correlation between LR and soil properties

Correlation between LR and some soil properties are presented in Table 16. SMP LR correlated significantly with EA (r = 0.56**), PA (r = 0.73**), soluble Al (r = 0.45*), exchangeable Al (r = 0.53**), Extractable Al (0.59**), non-exchangeable Al (r = 0.73**), OC (r = 0.40*) and negatively with pH (r = -0.60**). Peech LR showed highly significant positive correlation with TPA (r = 0.93**), non-exchangeable Al (r = 0.75**), OC (r = 0.60**), CEC (r = 0.46*) and a significant negative relation with pH (r = -0.60**). Adams and Evans method exhibited significant positive correlation with PA (r = 0.65**), non-exchangeable Al (r = 0.45*) and highly significant negative relation with pH (r = -0.83 **).

Lime requirement calculated from exchangeable Al method correlated with TPA (r = 0.51*), PA (r = 0.92**), soluble Al (0.63**), non exchangeable Al (r = 0.45*) and extractable Al (r = 0.70**).

Table 16. Correlation between LR and soil properties

LR Method	Soil properties									
	TPA	EA	PA	Sol. Al	Ex. Al	Extr. Al	Non Ex. Al	OC	pH	CEC
SMP		0.56**	0.73**	0.45*	0.53**	0.59**	0.73**	0.40*	- 0.60 **	
Peech	0.93**						0.75**	0.60**	- 0.60**	0.46*
Adams and Evans			0.65**				0.45**		- 0.83**	
Ex. Al	0.51*		0.92**	0.63**		0.70**				

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

pH showed highly significant and negative correlation to LR estimated by SMP (r = - 0.60**), Peech (r = - 0.60**) and Adams and Evans (r = - 0.83*) methods. pH represent the intensity factor of soil acidity. Lime requirement involves the replacement of exchangeable H from the exchange complexes as well as free hydrogen in the soil solution (Tisdale *et al.,* 1985). Organic carbon showed significant influence on SMP LR (r = 0.40*) and Peech LR (r = 0.0.60**) methods and it was reported that organic matter is the major contributor of hydrolytic and total potential acidity (Hoyt, 1977) and lime requirement of soils low in exchangeable Al (Keeney and Corey, 1963). Reeve and Sumner (1970) and Curtin *et al.,* (1984) reported that exchangeable Al and organic matter contents were the two main factors determining the amount of LR to bring the pH 6.0 – 7.0. Extractable Al showed positive correlation with SMP (r = 0.35*) and exchangeable Al method (r = 0.62**). Although different forms of acidity and methods of LR are highly correlated with organic carbon, higher 'r' values were given by extractable Al, exchangeable Al, soluble Al, non - exchangeable Al and clay. It is evident therefore, that organic matter and Al are the major sources of acidity in these soils.

Nature of soil and the cost factors decides the quantity and nature of lime to be applied. However, in ordinary practice, it is seldom wise to apply more than 7 – 9 t/ha (3 – 4 t/acre) of finely ground limestone to a mineral soil at any one time and even at lower rate may be appropriate on sandy soils (Brady and Weil, 1999).

Studies have shown that in highly weathered acid soils liming to pH 5.5 to neutralize exchangeable Al is acceptable for maximum crop production (Evans and Kamprath, 1970; Mc Lean, 1970; Revee and Sumner, 1970). Also, Kamprath, (1970) suggested that soils having 2 - 7 per cent organic matter, lime requirement based on the amount of exchangeable Al of the topsoil and the lime rates calculated to neutralize 85 to 90 per cent of the exchangeable Al is more effective. Mc Lean (1982) suggested that LR to neutralize exchangeable Al would be adequate for Al tolerant crops. In acid soils of Sikkim, lime application on the basis of exchangeable Al was found more effective (Pradhan and Khera, 1976).

Tropical crops like coffee, rubber, pine apple etc. are very tolerant to high levels of Al saturation and it was reported that for such species liming should be aimed at decreasing Al saturation to 20 to 40 (Sanchez, 1976). Acidity management through liming should be aimed to bring down the Al to the required level for crops tolerant to Al.

Considering all these, exchangeable Al method even though it is not rapid for routine analysis is found to be more appropriate for the estimation of LR of rubber growing soils.

IV.3. Effect of liming on soil nutrient availability – Incubation study

IV.3.1. Pre-treatment nutrient status of soil

Physico-chemical properties of the soil used for the study are given in Table 17. Texture of the soil was sandy clay loam and the pH was 4.80. Values for available P, K and Mg were in the medium range. Lime requirement was estimated by Peech method and was 12.0 t/ ha of $CaCO_3$.

Table 17. Initial nutrient status of the soil- Incubation experiment

OC(%)	Available nutrients (ppm)									Texture
	P	K	Ca	Mg	Mn	Fe	Cu	Zn	pH	
0.75	16.9	67.5	140.0	26.4	3.0	19.9	4.0	0.69	4.8	Scl*

***Scl- sandy clay loam**

IV.3.2. Effect of liming on soil pH

Effect of liming on soil pH is given in Table 18 and Fig 20. As expected, lime had significant positive effect on soil pH, which increased progressively with increase in the rate of lime addition. At each interval, the lowest and highest pH values attained due to lime addition at the rate of 25 and 100 per cent LR, respectively. Among the intervals, highest pH values noted for each treatment was on 15th day and the lowest values on 90th day of incubation. pH values ranged from 5.67 to 7.20 by the addition of lime at the rate of 25 and 100 per cent LR respectively, on 15th day of liming and the corresponding pH values on 90th day of incubation ranged from 5.01 to 6.88. Liming

@ 50 per ecnt LR maintained pH between 6-7 up to 45th day of incubation. Values above neutral were reached at the highest rate of lime application (100 per cent LR). Irrespective of the rate of application, pH decreased significantly with increase in incubation time.

Table 18. Effect of liming on soil pH

Treatment	Days after application						Mean
	15	30	45	60	75	90	
Control (No lime)	4.90	4.69	4.46	4.14	4.14	4.04	4.40
25% LR*	5.67	5.42	5.43	5.29	5.24	5.01	5.34
50% LR	6.37	6.21	6.24	5.89	6.07	5.85	6.10
75% LR	7.03	6.82	6.94	6.69	6.69	6.46	6.77
100% LR	7.20	7.15	7.0	6.96	7.01	6.88	7.03
SE	0.04	0.04	0.04	0.09	0.04	0.12	
CD (P=0.05)	0.12	0.13	0.12	0.26	0.11	0.36	

For factorial analysis: CD (P= 0.05): Treatment = 0. 06; Treatment x time = 0.15
*** LR- Lime requirement**

Even in the control treatment a significant reduction in pH was noticed. This might be due to the liberation of H^+ ions at the field capacity moisture level. However, at the 75 per cent and 100 per cent LR treatments, the pH was maintained at neutral level.

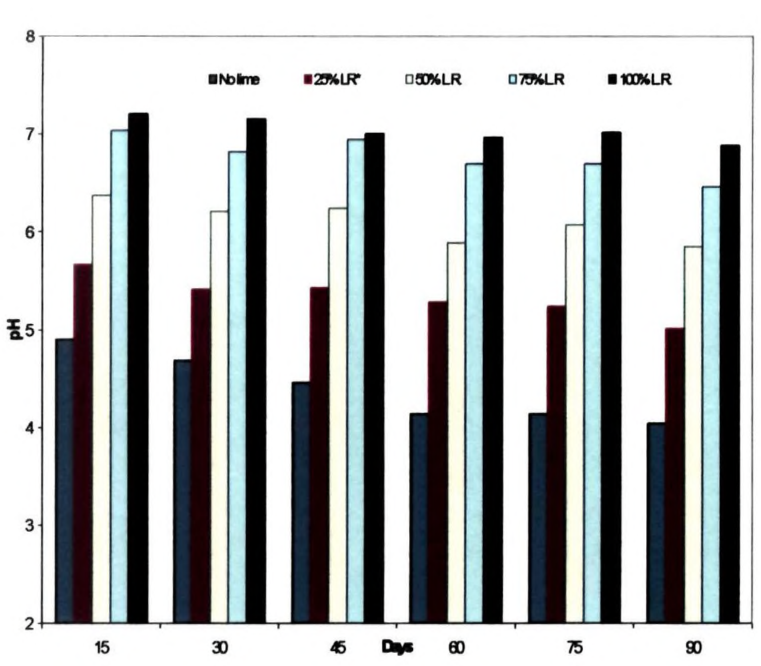


Fig. 20 Effect of liming on soil p^H

IV.3.3. Effect of liming on soil organic carbon (OC)

Soil organic carbon was not influenced significantly by liming (Table 19 and Fig. 21), but numerical decrease was noted with increase in rate of lime application over the control. In general, with the advancement of incubation time, an increase in the organic carbon status was noticed in all the treatments including control up to 60th or 75th day and thereafter it decreased till the 90th day. According to Black (1968), when acid soils are limed, the composition of microbial population gets changed and a portion of the organic matter becomes more susceptible to mineralization; but after some time, mineralization returns to near original level, despite altered composition of the soil microbial population. Chan and Heenan (1996) reported that liming resulted in an initial decrease in soil organic carbon because liming initially promoted carbon mineralization. Increased microbial activity due to more favorable soil reaction and increased metal binding strength of organic sites were reported by Bloomfield *et al.*, (1976) upon liming of acid mineral soils.

Table 19. Effect of liming on soil organic carbon (%)

Treatment	Days after lime application						Mean
	15	30	45	60	75	90	
Control (No lime)	0.74	0.77	0.86	0.84	0.81	0.74	0.79
25% LR*	0.69	0.76	0.82	0.77	0.81	0.77	0.77
50% LR	0.69	0.74	0.84	0.78	0.83	0.69	0.76
75% LR	0.69	0.78	0.79	0.85	0.81	0.70	0.77
100% LR	0.68	0.80	0.77	0.86	0.74	0.77	0.70
SE	0.03	0.04	0.03	0.04	0.03	0.05	
CD (P= 0.05)	NS	NS	NS	NS	NS	NS	

For factorial analysis: CD (P=0.05) : Treatment = NS; Treatment & time = NS
***LR-Lime requirement**

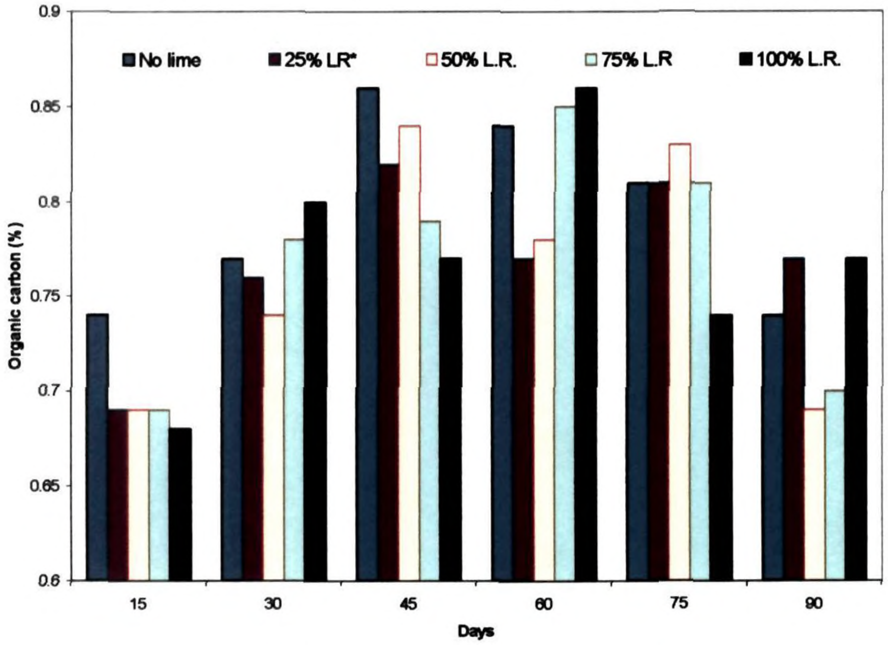


Fig. 21 Effect of liming on organic carbon

IV. 3.4. Effect of liming on available phosphorus

Liming decreased the available P compared to the control (Table .20 and Fig. 22) and the effect was statistically significant for 100 per cent LR treatment. This effect of decrease in available P with lime addition was noticed up to the 60th day. Afterwards, the treatment effects were not significant and at the 75th day, liming numerically improved the P availability. Njoku *et al.*, (1987) also noted a decrease in available P with increase in the rate of lime addition. The temporary decrease in P availability might probably be due to increase in fixation of P by the amorphous Fe and Al hydroxides precipitated by lime addition as well as due to Ca mediated phosphate precipitation (Eze and Loganathan, 1990). The interaction between treatments and time was significant.

Table 20. Effect of liming on available P (ppm)

Treatment	Days after lime application						Mean
	15	30	45	60	75	90	
Control (No lime)	26.48	27.53	23.33	33.17	27.12	18.17	25.97
25% LR*	21.68	25.02	18.00	31.67	30.08	18.33	24.13
50% LR	26.07	24.00	17.17	26.50	28.02	19.33	23.51
75% LR	25.43	21.50	23.33	20.83	24.38	21.50	22.83
100% LR	16.90	23.93	27.00	21.17	23.55	20.83	22.23
SE	2.33	2.60	1.60	1.40	2.60	1.70	
CD (P=).05)	6.78	NS	4.8	4.10	NS	NS	

For factorial analysis: CD (P = 0.05): Treatment = 2.36 ; Treatment x time = 5.78

*** LR -Lime requirement**

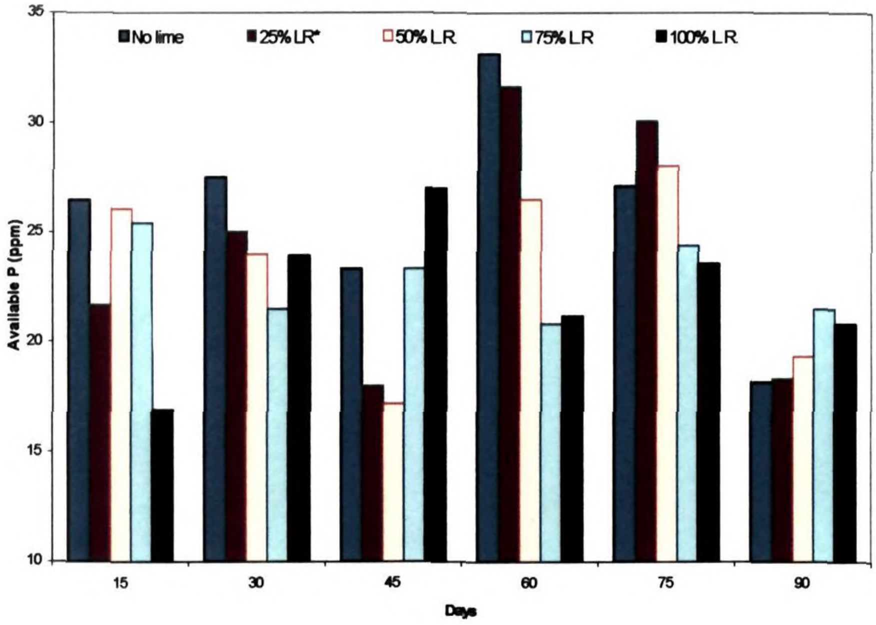


Fig. 22 Effect of liming on available phosphorus

IV. 3.5. Effect of liming on available potassium and magnesium

Available K and Mg were reduced significantly with increasing rate of lime application (Tables 21 & 22 and Figs.23& 24) and the effect was statistically significant from the 30th day onwards, the trend being maintained up to the 90th day. Similar results were reported by Juo and Uzu (1977). Decrease in extractable Mg may be attributed to the Mg sorption or precipitation with the new Al hydroxide compounds formed after liming soils to near neutrality (Kinniburgh *et al.*, 1976; and Grove *et al.*, 1981). The increased supply of Ca at the higher rates of lime has probably competed with K and Mg for exchange sites, thereby reducing available K and Mg. As the incubation time advances, available K increased in all the treatments including no lime control. The highest values being noted on the 75th day after incubation in treatments 25 per cent LR and 75 per cent LR. However, in treatments 50 per cent LR and 100 per cent LR the highest values were noticed on 45th day after the addition of lime. In all the lime treatments except 50 per cent LR, the highest available Mg was noticed on 15th day after lime addition and among these different levels, highest value was given by the treatment 25 per cent LR. In the present study the source of lime was calcium oxide and the higher availability of Ca might have reduced the Mg availability.

Table 21. Effect of liming on available K (ppm)

Treatment	Days after lime application						Mean
	15	30	45	60	75	90	
Control (No lime)	65.17	70.77	90.42	70.83	85.42	78.33	76.82
25% LR*	67.63	70.43	80.80	70.83	88.75	77.92	77.33
50% LR	61.57	65.47	89.17	72.08	85.42	75.75	74.91
75% LR	59.77	60.87	76.67	66.67	79.58	66.25	68.30
100% LR	63.73	61.90	78.33	67.08	75.00	65.00	68.50
SE	4.30	1.50	2.40	1.90	2.80	2.20	
CD P=(0.05)	NS	4.50	7.10	NS	8.20	6.40	

For factorial analysis : CD (P= 0.05): Treatment = 2.95 ; Treatment x time = NS
***LR-Lime requirement**

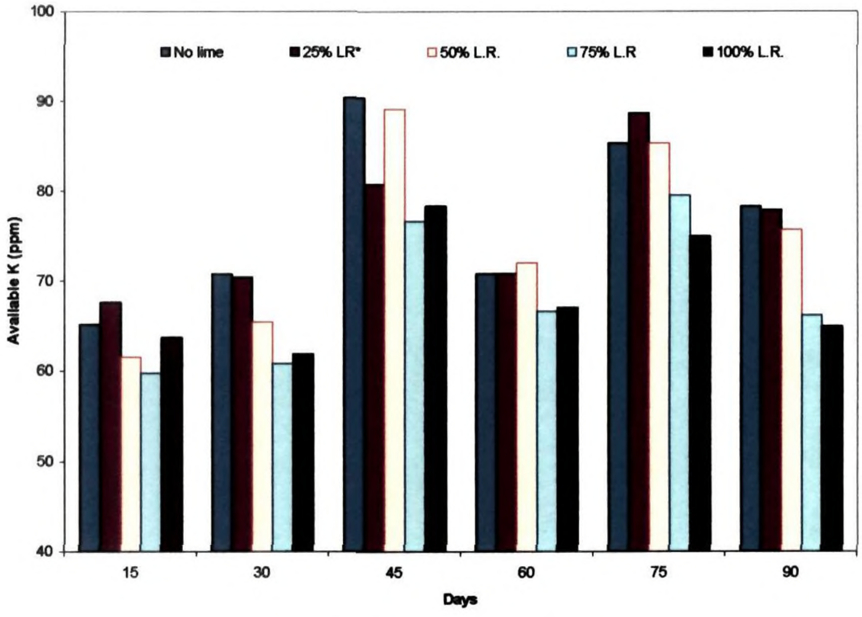


Fig. 23 Effect of liming on available K

Table 22. Effect of liming on available Mg (ppm)

Treatment	Days after lime application						Mean
	15	30	45	60	75	90	
Control(No lime)	24.33	22.5	23.5	30.33	25.17	26.17	25.33
25% LR*	35.83	25.33	13.33	26.83	25.83	23.83	25.17
50% LR	19	10.17	11.67	19.33	14	18.83	15.50
75% LR	17	7.67	7.67	16.67	10.17	13.50	12.11
100% LR	15.67	5.83	5.83	13.67	12.33	12.83	11.02
SE	1.0	2.0	0.7	1.2	1.1	1.1	
CD (P=0.05)	3.1	5.7	2.0	3.5	3.1	3.1	

For factorial analysis : CD (P=0.05): Treatment = 1.46 ; Treatment x time = 3.58

***LR - Lime requirement**

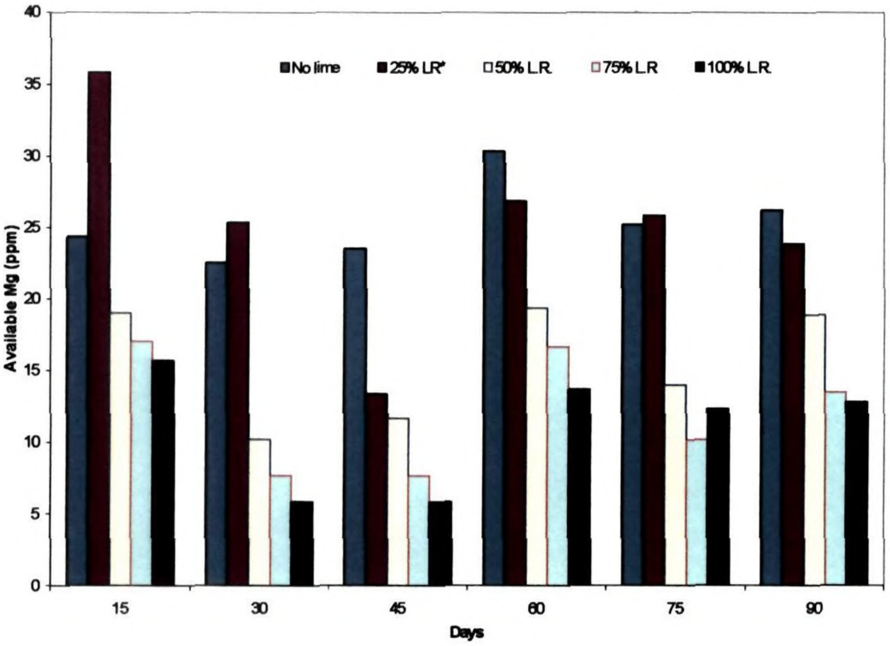


Fig. 24 Effect of liming on available Mg

IV.3.6. Effect of liming on available calcium

Effect of liming on available Ca is given in Table 23 and Fig. 25. Progressive addition of lime increased the availability of Ca significantly and the highest available Ca content was noticed when lime was applied at full rate (100 per cent LR). In 25 and 50 per cent LR treatments the highest values were noted on the 30th and 45th day after application of lime and in 75 per cent LR and 100 per cent LR treatments, highest values were noticed on 60th day after incubation and the availability thereafter decreased.

Table 23. Effect of liming on available Ca (ppm)

Treatment	Days after lime application						Mean
	15	30	45	60	75	90	
Control(No lime)	93.57	134.80	183	136.33	81.17	63.83	115.45
25% LR*	556.75	748.83	683.33	572.83	379.67	382.33	554.04
50% LR	812.92	991.83	1081	1064.83	548.17	590.83	848.26
75% LR	1156.75	1312.83	1493.17	1566.83	853.33	892.67	1212.60
100% LR	1496.67	1475.50	1536.50	1673.83	1081.50	1013.67	1379.61
SE	80.50	76.20	57.70	66.80	44.60	38.20	
CD (P=0.05)	234.80	221.90	168.20	165.40	129.90	111.20	

For factorial analysis : CD (P=0.05) : Treatment = 68.45 ; Treatment x time = 167. 67
***LR - Lime requirement**

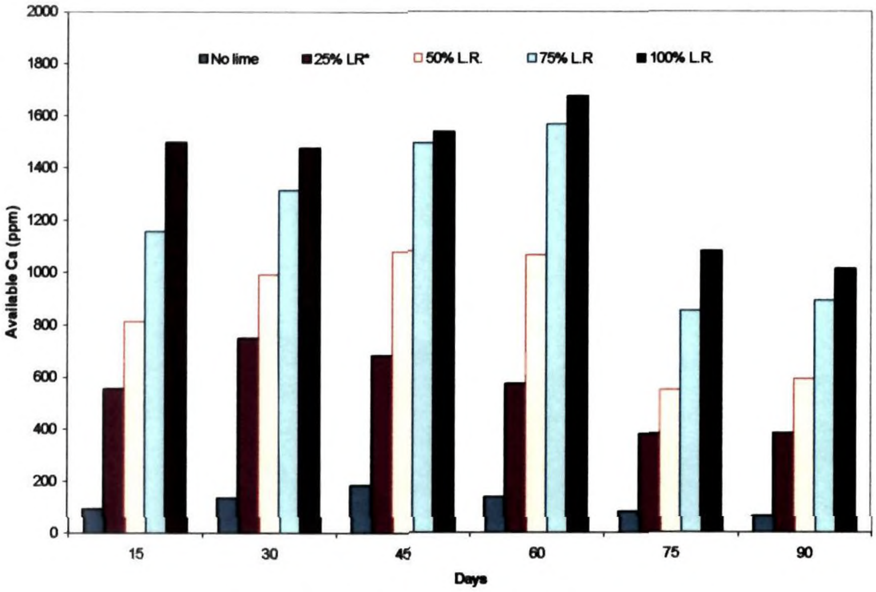


Fig. 25 Effect of liming on available Ca

IV.3.7. Effect of liming on available micronutrients and exchangeable Al

Effect of liming on available micronutrients and exchangeable Al 90 days after incubation is presented in Table 24. With increase in the quantity of added lime, significant decrease was noticed in the availability of all these micronutrients except Zn, which gave an increase at 100 per cent LR treatment. Exchangeable Al also decreased drastically with increase in the amount of added lime and at the 100 per cent LR treatment the exchangeable Al was brought down to traces. The availability of micronutrient cations decreased as soil pH increases due to lime addition (Stahl and James, 1991). The increase in pH might have hydrolyzed metal ions into insoluble hydrated oxides or adsorbed them onto organic, clay and oxide surfaces. Such decrease has often been ascribed to movement of these cations from a more available to a less available pool (Neilson *et al.*, 1986).

Table 24. Effect of liming on available micronutrients and exchangeable Al - 90th day

Treatment	Available micronutrient (ppm)				Ex.Al (cmol/kg)
	Mn	Fe	Cu	Zn	
Control (No lime)	3.46	19.66	0.35	0.46	1.45
25% LR*	1.46	17.41	0.33	0.38	0.65
50% LR	1.10	13.33	0.29	0.28	0.31
75% LR	1.20	10.48	0.27	0.29	0.10
100% LR	1.18	8.55	0.26	0.41	0.01
SE	0.24	0.56	0.01	0.04	0.04
CD (P=0.05)	0.71	1.63	0.04	0.13	0.12

***LR -Lime requirement**

IV.4. Effect of liming on growth of rubber seedlings in the nursery

IV.4.1. Initial nutrient status of the soil

The nursery field selected for this study was acidic in reaction with a pH of 4.70 (Table .25). The soil had medium level of available P and Mg and was deficient in available K.

Table 25. Initial nutrient status of the soil - Seedling nursery experiment

OC (%)	Available nutrients (ppm)									Texture
	P	K	Ca	Mg	Mn	Fe	Cu	Zn	pH	
0.60	17.4	30.0	121.0	41.0	2.9	7.7	0.47	0.16	4.7	Scl*

***scl- sandy clay loam**

IV.4.2. Effect of liming on soil nutrient status - 15 days after liming

Fifteen days after lime application, available Ca, Fe, Cu and soil pH were influenced significantly by liming (Table 26). Progressive addition of lime increased available Ca and the highest value of 544 ppm was noticed in 100 per cent LR applied plots. Similar observation was noticed with pH also and the highest pH of 5.98 was attained in full lime applied plots.

Table 26. Effect of liming on soil nutrient status (0-30 cm) -15 days after liming

Treatment	OC (%)	Available nutrients (ppm)								pH
		P	K	Ca	Mg	Mn	Fe	Cu	Zn	
Control*	0.88	233	27	119	24	2.32	7.66	0.22	0.13	4.68
NPKMg alone	0.95	223	30	119	25	2.21	9.19	0.24	0.15	4.80
1/3rd LR	0.88	211	33	315	19	1.48	7.62	0.16	0.15	5.07
2/3rd LR	0.89	183	38	444	22	0.63	7.90	0.17	0.12	5.42
Full LR	0.83	217	42	520	24	1.10	7.28	0.19	0.15	5.98
1/3rd LR+ NPKMg	0.87	200	36	337	20	1.63	10.32	0.19	0.14	5.07
2/3rd LR+ NPKMg	0.85	187	31	395	19	1.45	9.35	0.19	0.16	5.70
Full LR + NPKMg	0.87	167	34	541	21	0.91	5.74	0.14	0.10	5.57
SE	0.08	21	4.4	39	3.7	0.23	0.57	0.01	0.02	0.02
CD (P=0.05)	NS	NS	NS	119	NS	NS	1.71	0.03	NS	0.60

LR- Lime requirement ***No lime and no fertilizer**

IV.4.3. Effect of liming on diameter of plants

Effect of liming on diameter of plants from six to ten months after planting was given in Table 27 and Fig. 26. The diameter of plants which received application of fertilizer alone or in combination with various doses of lime were on par and were significantly superior to application of lime alone or the control. In the first two months of observation, i.e. during sixth and seventh month of growth, the treatment with 2/3rd lime and NPKMg fertilizer was numerically superior to NPKMg fertilizer alone.

However, in the later months the difference narrowed down and in the last two i.e., during ninenth and tenth months, plants in both the treatments had the same diameter. As growth measurements were made on seedlings, the inherent heterogeneity among the seedlings might have masked the treatment differences.

Also, in this experiment, the plant population was different in different treatments and in the lime and fertilizer applied plots 100 per cent stand was observed. After a period of time, plants in the denser field were at a disadvantage because of competition for space and sunlight. In less dense fields the surviving plants grew more vigorously and attained greater diameter.

Table 27. Effect of liming on diameter of plants

Treatment	Diameter (cm)				
	1999				
	March	April	May	June	August
Control *	0.64	0.74	0.90	1.02	1.23
NPKMg	0.79	0.94	1.25	1.53	1.84
1/3rd LR	0.67	0.75	0.88	1.09	1.19
2/3rd LR	0.71	0.74	0.93	1.03	1.21
Full LR	0.76	0.78	0.92	1.04	1.20
1/3rd L.R + NPKMg	0.78	0.94	1.24	1.45	1.70
2/3rd L.R + NPKMg	0.88	1.03	1.29	1.54	1.84
Full L.R + NPKMg	0.80	0.89	1.17	1.40	1.65
SE	0.04	0.04	0.04	0.05	0.07
CD (P=0.05)	0.12	0.12	0.12	0.16	0.20

LR -Lime requirement ***No lime and no fertilizer**

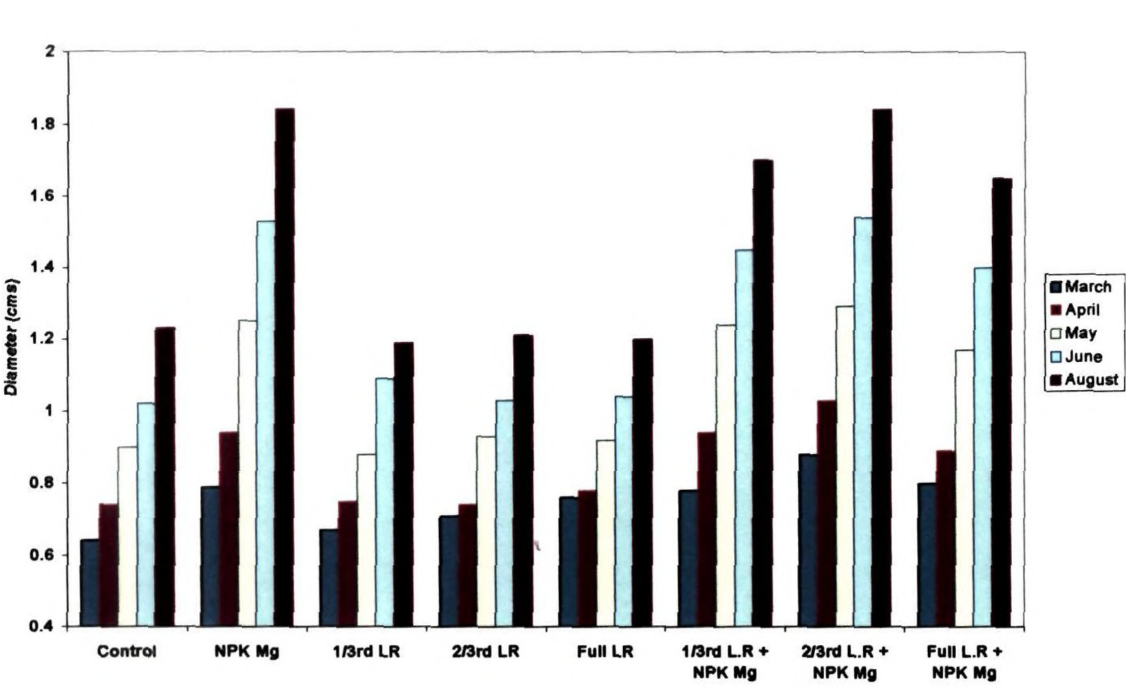


Fig. 26 Effect of liming on diameter of plants

IV.4.4. Effect of liming on the leaf nutrient concentration

Effect of liming on leaf nutrient content is given in Table 28. Liming had significant effect on leaf N compared to the control. Highest leaf N was noticed in the treatment 2/3rd LR followed by 1/3rd LR. However, the different combinations of lime with fertilizer were on par with absolute control and fertilizer alone treatments. Liming had no significant effect on leaf P, K and Mg.

However, leaf Ca increased significantly due to liming and significantly higher leaf Ca was noticed in the 1/3rd LR closely followed by 2/3rd LR treatments compared to absolute control. Increase in foliage Ca after liming was reported by Ljungstrom and Nihlgard (1995). Leaf Mg showed no significant effect due to liming but in treatments 1/3rd and 2/3rd LR leaf Mg showed numerical decreasing trend. Liming significantly influenced the leaf Mn and Cu concentrations. While the Mn concentration reduced with liming, the Cu concentration increased.

Table 28. Effect of liming on leaf nutrient status

Treatment	Macro nutrients (%)					Micro nutrients (ppm)			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
Control *	3.20	0.15	0.96	0.84	0.32	230	345	5.7	23
NPKMg	3.23	0.15	0.90	1.19	0.29	222	353	8.8	25
1/3rd LR	3.46	0.12	0.83	1.52	0.32	245	322	11.3	25
2/3rd LR	3.61	0.15	0.92	1.39	0.29	258	370	9.1	26
Full LR	3.05	0.14	0.94	1.05	0.31	173	330	10.5	24
1/3rd LR+ NPKMg	3.33	0.13	0.78	0.79	0.31	245	354	9.7	21
2/3rd LR+ NPKMg	3.28	0.14	0.89	0.64	0.32	174	308	11.6	25
Full LR+ NPKMg	3.31	0.14	0.78	1.25	0.29	268	417	8.3	25
SE	0.01	0.01	0.05	0.16	0.03	11.90	37.86	1.1	2.84
CD (P=0.05)	NS	NS	NS	0.49	NS	35.70	NS	3.2	NS

LR -Lime requirement ***No lime and no fertilizer**

IV.4.5. Effect of liming on soil nutrient status - one year after liming

Effect of liming on soil nutrient status (0-30 cm), one year after liming is given in Table 29. Liming significantly influenced the availability of P, K, Mg and Cu. Available P was reduced in the lime alone treatments and the reduction was progressive with increasing levels of lime. At the same time lime in combination with NPK Mg improved the P availability and NPKMg + full lime treatment recorded the highest available P. Similarly, availability of K was also reduced in lime alone treatments. However, in combination with the fertilizer, K availability improved significantly and 2/3rd LR + NPKMg or full LR + NPKMg recorded statistically superior values over the NPKMg alone treatment. Lime alone or in combination with fertilizer significantly increased the Ca availability. Copper availability was found to decrease with lime alone or in combination treatments especially at higher levels. The fertilizer alone treatment recorded the lowest pH. Similarly, in fertilizer alone treatment, the available Ca status of the soil was reduced drastically. The pH changes achieved by liming were not significant after one year of lime addition and the highest pH value of 5.1 was recorded by the full lime treatment.

Table 29. Effect of liming on soil nutrient status (0 - 30 cm) - one year after liming

Treatment	OC (%)	Available nutrients (ppm)								pH
		P	K	Ca	Mg	Mn	Fe	Cu	Zn	
Control *	0.64	47	38	178	18	4.6	19.8	0.47	0.60	4.9
NPKMg	0.60	53	32	78	16	6.3	20.2	0.45	0.33	4.5
1/3rd LR	0.69	45	20	203	19	5.1	20.6	0.36	0.49	4.9
2/3rd LR	0.67	36	23	352	18	1.9	14.8	0.26	0.30	4.8
Full LR	0.64	25	24	368	12	1.5	12.2	0.26	0.24	5.1
1/3rd LR + NPKMg	0.69	49	35	151	17	1.8	16.7	0.38	0.39	4.7
2/3rd LR + NPKMg	0.61	47	51	209	17	5.4	22.3	0.45	0.51	4.7
Full LR + NPKMg	0.64	56	49	445	19	1.0	25.9	0.28	0.50	4.8
SE	0.03	4.0	5.0	70.2	2.0	1.8	5.3	0.05	0.09	0.09
CD (P=0.05)	NS	13	15	212	NS	NS	NS	0.14	NS	0.27

LR -Lime requirement ***No lime and no fertilizer**

Available P, K and Cu status were influenced significantly by liming at (30-60 cm) also (Table 30). Phosphorus availability reduced in lime alone or in combination with fertilizer and the reduction was progressive with increasing the rate of lime application. Liming influenced the pH significantly and the highest pH of 4.83 and 4.85 were maintained in both the full LR treatments at this depth after one year of liming. This might be due to the downward movement of Ca from the top layer.

Table 30. Effect of liming on soil nutrient status (30-60 cm) - one year after liming

Treatment	OC (%)	Available nutrients (ppm)								pH
		P	K	Ca	Mg	Mn	Fe	Cu	Zn	
Control *	0.61	20	18	131	16	7.0	15	0.33	0.29	4.59
NPK Mg	0.56	21	30	68	15	9.0	15	0.28	0.25	4.44
1/3rd LR	0.60	21	16	182	16	4.0	10	0.23	0.24	4.69
2/3rd LR	0.63	18	16	200	14	4.0	11	0.22	0.25	4.76
Full LR	0.63	15	23	223	11	4.0	11	0.24	0.21	4.83
1/3rd LR + NPKMg	0.63	31	30	100	17	4.0	12	0.28	0.25	4.58
2/3rd LR + NPKMg	0.60	25	37	105	17	6.0	13	0.40	0.46	4.52
Full LR + NPKMg	0.59	18	36	216	19	2.0	8	0.17	0.35	4.85
SE	0.02	2.5	3.8	38.8	2.0	1.54	1.47	0.04	0.09	0.07
CD (P=0.05)	NS	7.7	11.6	NS	NS	NS	NS	0.12	NS	0.21

LR Lime requirement ***No lime and no fertilizer**

IV.5. Effect of liming on translocation of calcium in different plant parts

Soil used for the study was acidic with pH 4.5 and was medium in nutrient status (Table 31).

Table 31. Initial nutrient status of soil - glass house experiment

OC (%)	Available nutrients (ppm)								pH
	P	K	Ca	Mg	Mn	Fe	Cu	Zn	
0.75	16.8	67.5	390.0	20.0	2.9	20	0.47	0.65	4.5

IV.5.1 Effect of liming on dry matter production in budded stumps-glass house experiment

Effect of liming on dry matter production is given in Table 32 and Fig 27. Liming showed significant positive effect on dry matter production. Incorporation of lime in the form of powdered shell lime @ 25, 75 and 100 per cent LR of soil along with NPK Mg significantly increased the dry matter yield over the control and NPK Mg alone treatment thereby signifying the response to lime. Highest dry matter production of 70.0g was noticed when lime was applied @ 75 per cent LR with fertilizer and lowest of 55.69g with control treatment. Application of lime alone and fertilizer alone treatments were significantly superior to control indicating positive response to lime and fertilizer application.

Table 32. Effect of liming on dry matter production in budded stumps

Treatment	Dry matter yield (g/pot)
Control*	55.69
NPK Mg	60.00
100% LR	61.83
25% LR + NPK Mg	64.00
50% LR + NPK Mg	60.00
75 % LR + NPK Mg	70.00
100% LR+ NPK Mg	65.00
SE	1.19
CD (P=0.05)	3.57

LR-Lime requirement ***No lime and no fertilizer**

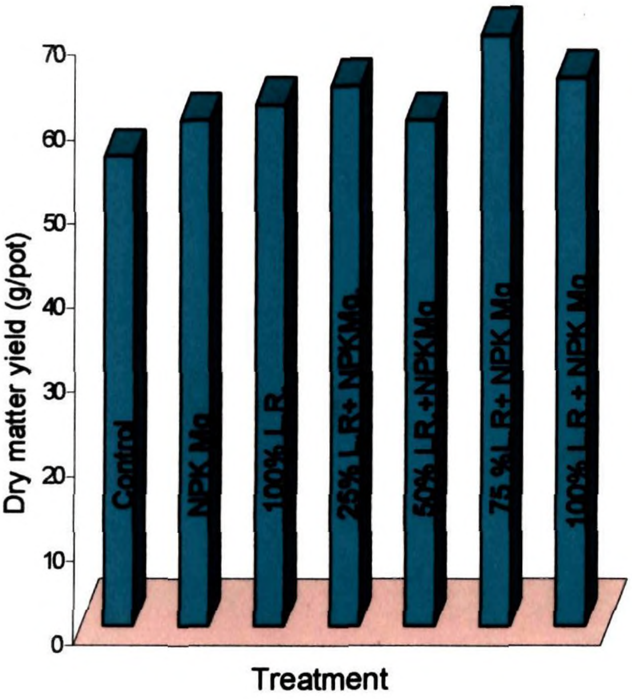


Fig. 27 Effect of liming on dry matter production

IV.5.2. Effect of liming on nutrient content of leaves

Effect of liming on leaf nutrient concentration is given in Table 33. Liming influenced the N, K Ca, Mn, Fe and Cu content. Liming at the rate of 25 per cent LR along with fertilizer showed significant positive effect on foliage N over the control while liming at full rate reduced it below the control.

Table 33. Effect of liming on leaf nutrient concentration

Treatment	Macronutrients (%)					Micronutrients(ppm)			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
Control*	3.10	0.17	1.20	0.87	0.26	203	239	11	29
NPK Mg	3.54	0.15	1.27	0.81	0.27	169	178	9	30
100% LR	3.03	0.17	0.89	1.72	0.25	125	252	9	23
25% LR. + NPK Mg.	3.50	0.16	0.96	1.55	0.26	163	308	6	21
50% LR. + NPK Mg	3.53	0.16	0.94	1.41	0.24	150	151	9	27
75% LR. + NPK Mg	3.22	0.15	0.86	1.82	0.25	177	238	8	22
100% LR.+ NPK Mg	2.95	0.16	1.04	1.89	0.23	134	265	13	24
SE	0.07	0.01	0.05	0.06	0.01	9.12	8.33	0.50	2.16
CD	0.22	NS	0.16	0.18	NS	27.3	24.99	1.50	NS

LR Lime requirement ***No lime and no fertilizer**

Leaf N showed significant negative relation with Ca (r = - 0.40*) and positive relation with Mg (r= 0.45**). Liming showed no significant effect on P and Mg content of leaf. In all lime treatments leaf K content decreased while Ca content increased significantly. Leaf K showed a highly significant negative relation with Ca (r = - 0.64**) and Mg ((r = - 0.45**). Highest leaf Ca content of 1.89 per cent was noticed in 100 per cent LR along with fertilizer treatment. Except Zn, all the micronutrients were influenced significantly by liming. Leaf Mn and Cu content reduced significantly by liming over the absolute control. Leaf Fe content increased with levels of liming.

IV.5.3. Effect of liming on nutrient status of petiole

Nitrogen, Ca and micronutrients Fe, Mn and Cu content of petiole were influenced significantly by liming (Table 34). Calcium content increased significantly with increasing rate of lime application and highest value of 4.71 per cent was noticed in full rate of lime along with NPKMg. Petiole K and Mg content showed a significant negative relation (r = -0.46*). Application of lime in combination with fertilizer significantly reduced the concentration of Mn in petiole compared to NPKMg alone application.

Table 34. Effect of liming on nutrient status of petiole

Treatment	Macro nutrients (%)					Micro nutrients (ppm)			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
Control*	0.93	0.08	0.80	2.19	0.17	397	143	7.07	24
NPKMg	0.97	0.08	1.21	2.99	0.14	372	229	7.80	21
100% LR.	1.03	0.07	0.79	3.69	0.15	226	195	5.47	18
25% LR. + NPK Mg	1.02	0.07	0.77	3.49	0.21	365	143	5.33	17
50% LR. + NPK Mg	0.89	0.07	0.97	3.59	0.15	292	126	5.33	19
75% LR. + NPK Mg	1.10	0.07	0.80	4.64	0.15	224	130	5.20	16
100% LR.+ NPKMg	0.89	0.08	0.96	471	0.17	208	108	5.47	18
SE	0.05	0..01	0.04	0.17	0.01	10.08	18.6	0.41	1.68
CD (P=0.05)	0.15	NS	NS	0.53	NS	30.57	56.3	1.27	NS

LR Lime requirement ***No lime and no fertilizer**

IV.5.4. Effect of liming on nutrient content of stem

Influence of liming on stem nutrient status is given in Table 35. Nitrogen and micronutrients were reduced significantly by liming. Lime and fertilizer treatment combinations significantly increased the Ca concentration.

Table 35. Effect of liming on nutrient content of stem

Treatment	Macro nutrients (%)					Micro nutrients (ppm)			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
Control*	1.00	0.08	0.73	2.63	0.31	183	488	15	32
NPK Mg	0.82	0.08	0.84	2.33	0.33	156	280	12	25
100% LR.	0.53	0.07	0.56	2.88	0.28	107	337	20	17
25% LR. + NPK Mg	0.93	0.09	0.62	2.67	0.29	151	336	17	21
50% LR. + NPK Mg	0.82	0.09	0.7	3.34	0.28	113	343	12	25
75% LR. + NPK Mg	0.81	0.08	0.68	3.30	0.29	118	334	9	19
100% LR. + NPK Mg	0.81	0.1	0.65	3.32	0.3	121	351	13	25
SE	0.045	0.01	0.06	0.17	0.027	10.08	29.55	1.36	1.7
CD (P=0.05)	0.14	NS	NS	0.53	NS	30.57	89.64	4.14	5.2

LR - Lime requirement ***No lime and no fertilizer**

IV.5.5. Effect of liming on nutrient content of root

Effect of liming on nutrient content of root is given in Table 36. Liming showed significant influence on root K, Ca and micronutrients. Application of lime @ 25 and 50 per cent LR along with fertilizer increased root K content significantly over the control treatments. However, at higher rate of lime, i.e., @ 75 and 100 per cent LR along with NPKMg the K content was reduced and was on par with the control. Root

Ca content increased with increasing rate of liming and highest value of 2.04 per cent was noticed in 75 per cent LR with fertilizer.

Root N content correlated negatively with Ca (r=- 0.52*). Similarly, P content also showed an inverse relation with Ca (r=-0.60**). Leaf Ca content showed direct relation with petiole Ca (r = 0.85**), stem Ca (r=0.45*) and root Ca (r=0.92**). Petiole Ca showed highly significant positive correlation with root Ca (r= 0.78 **).

Table 36. Effect of liming on nutrient content of root

Treatment	**Macro nutrients (%)**					**Micro nutrients (ppm)**			
	N	**P**	**K**	**Ca**	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**
Control*	1.70	0.16	1.51	0.82	0.29	592	5668	59	47
NPKMg	1.82	0.15	1.57	1.06	0.35	600	7590	34	42
100% LR.	1.87	0.13	1.42	1.99	0.31	188	5460	39	31
25% LR. + NPK Mg	1.86	0.13	1.71	1.41	0.32	337	4716	28	28
50% LR. + NPK Mg	1.76	0.14	1.77	1.46	0.27	383	5824	31	28
75% LR. + NPK Mg	1.89	0.14	1.49	2.04	0.33	249	5939	30	31
100% LR.+ NPK Mg	1.98	0.15	1.41	2.00	0.27	284	5403	31	31
SE	0.72	0.006	0.054	0.06	0.023	55.0	422.0	3.5	2.7
CD P=0.05)	NS	NS	0.16	0.13	NS	168.0	1288.6	10.7	8.2

LR - Lime requirement ***No lime and no fertilizer**

IV.5.6. Influence of liming on uptake of nutrients

Influence of liming on uptake of nutrients is presented in Table- 37. Application of lime significantly influenced the nutrient uptake. Liming @ 25 per cent LR along with NPK Mg significantly increased N uptake over the control and NPK Mg treatment. Phosphorus uptake was influenced significantly at 75 and 100 per cent LR with fertilizer than control and fertilizer alone treatments. Liming increased the availability of P, which in turn improved the uptake and dry matter production. Potassium uptake was influenced positively in full LR with fertilizer while in all the other lime treatments a negative influence in the uptake of K was recorded. Lime alone application reduced N, P, K and Mg uptake over the control. This might be due to the antagonistic relationship between these nutrients and Ca.

Table 37. Influence of liming on total nutrient uptake (mg/pot)

Treatment	N	P	K	Ca	Mg
Control*	1082	74	621	936	169
NPKMg	1257	73	713	933	177
100% LR	1086	73	552	1341	162
25% LR + NPK Mg	1288	73	611	1251	167
50% LR+ NPK Mg	1244	75	618	1390	168
75% LR + NPK Mg	1237	82	643	1725	170
100% LR + NPK Mg	1168	85	753	1796	172
SE	1.26	1.08	1.03	1.56	1.03
CD (P=0.05)	3.84	3.27	3.15	4.73	3.13

LR - Lime requirement ***No lime and no fertilizer**

Calcium uptake was significantly increased by liming and highest value of 1796 mg/pot was noticed in full LR with NPK Mg treatment followed by 75 per cent LR with fertilizer. The increased supply of Ca had antagonistic effect on the uptake of Mg. Liming alone or in combination with fertilizer reduced the uptake of Mg.

IV.5.7. Effect of liming on soil available Ca and pH - after uprooting plants

Available Ca and pH of the soil after uprooting plants are given in Table 38. Available Ca and pH increased significantly with increasing rate of liming. Highest pH was observed in the treatment receiving 100 per cent LR with NPKMg. With increasing rate of liming, the availability of Ca increased and highest available Ca was noticed in 100 per cent LR alone treatment.

Table 38. Effect of liming on available Ca and pH - after uprooting the plants

Treatment	Available Ca (ppm)	pH
Control *	400	5.38
NPKMg	593	5.57
100% LR	1693	8.04
25% LR + NPK Mg	890	7.12
50% LR + NPK Mg	996	7.20
75% LR + NPK Mg	1447	7.53
100% LR + NPK Mg	1540	8.19
SE	208	0.24
CD (P=0.05)	632	0.75

LR - Lime requirement ***No lime and no fertilizer**

IV.6. Comparative evaluation of liming materials on nutrient availability and growth of rubber seedlings in the nursery

The results of the nursery experiment are presented and discussed. Pre treatment soil analytical data are presented in Table 39. The soil was acidic in reaction with high P and low K status.

Table 39. Initial nutrient status of soil - Nursery experiment

OC (%)	Available nutrients (ppm)								pH
	P	K	Ca	Mg	Mn	Fe	Cu	Zn	
1.47	48	28	39	17	1.02	22	1.96	0.22	4.20

IV.6.1. Effect of liming materials on soil pH

Application of liming materials significantly increased soil pH over control except in phosphogypsum applied plots (Table- 40). At the time of planting (2 weeks after liming) highest pH of 6.36 was noted in dolomite applied plots and was followed by shell lime applied plots. Similarly, at the time of fertilizer application (8 weeks after liming) highest pH was noticed in the same treatments and corresponding pH values were 6.89 and 6.50 respectively. Among the treatments, lowest pH was recorded by phosphogypsum applied plots.

Table 40. Effect of liming materials on soil pH

Treatment	pH	
	I	II
Control	4.25	4.53
NPKMg	4.36	4.58
Quick lime* @100% LR	5.89	6.18
Quick lime @100% LR + NPK Mg	6.34	6.50
Dolomite@100% LR	6.27	6.40
Dolomite@100% LR + NPK Mg	6.36	6.89
Phosphogypsum@ 100% LR	4.22	4.54
Phosphogypsum@100% LR + NPK Mg	4.32	4.69
SE	0.07	0.19
CD	0.19	0.57

LR- Lime Requirement, I - pH at the time of planting (2 weeks after liming), II - pH at the time of manuring (8 weeks after liming); * Powdered shell lime

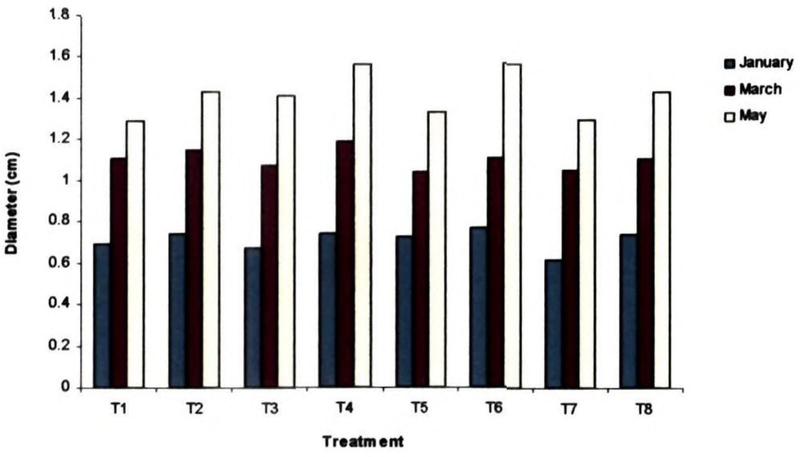
IV.6.2. Effect of liming materials on diameter (cm) of rubber seedlings

All the treatments except quick lime and gypsum showed numerical increase in the diameter of plants over absolute control during January (Table 41 and Fig. 28). Treatmental effect is significant in all the three months. Dolomite or quick lime in combination with fertilizer was found to be significantly superior to all other treatments.

Table 41. Effect of liming materials on diameter of rubber seedlings

Treatment	Diameter (cm)		
	2003		
	January	March	May
Control	0.69	1.11	1.29
NPKMg	0.74	1.15	1.43
Quick lime * @100% LR	0.67	1.07	1.41
Quick lime @100% LR + NPK Mg	0.74	1.19	1.56
Dolomite@100% LR	0.73	1.04	1.33
Dolomite@100% LR + NPK Mg	0.77	1.11	1.57
Phosphogypsum@ 100% L.R.	0.68	1.15	1.30
Phosphogypsum@100% LR + NPK Mg	0.74	1.11	1.43
SE	0.03	0.04	0.04
CD	0.09	0.11	0.12

LR Lime requirement *** Powdered shell lime**



T1 - No lime and no NPKMg
T2- NPKMg
T3 - Quick lime @100%LR
T4 - Quick lime @100%LR + NPKMg
T5-Dolomite @100% LR
T6- Dolomite @100% LR +NPKMg
T7 - Phosphogypsum@100% LR
T8 - Phosphogypsum@100%LR+NPKM

Fig. 28 Effect of different liming materials on diameter of rubber seedlings

IV.6.3. Effect of liming materials on leaf nutrient status - one year after liming

Application of liming materials showed no significant effect on leaf nutrient status one year after liming.

IV.6.4. Effect of liming materials on soil nutrient status (0-15cm) - one year after liming

One year after application of the liming materials the pH of the soil was reverted back and treatment effect was not statistically significant (Table 42). The availability of P and Ca in the soil was significantly improved with liming. The increase in P availability might be due to the dissociation of Fe and Al phosphate complex present in acid soil and to some extent due to the enhanced mineralization of P from the organic pool. In the 15-30 cm soil layer, liming significantly influenced the available Ca and Mg while the availability of Ca was improved with liming, the available Mg was reduced with liming (Table 43).

Table- 42. Effect of liming materials on nutrient status of the soil (0- 15cm) - one year after liming

Treatment	O.C (%)	Available nutrients (ppm)				pH
		P	K	Ca	Mg	
Control	1.47	63.0	44.4	78.9	10.6	4.53
NPKMg	1.47	66.8	34.7	92.6	15.4	4.46
Quick lime* @ 100% LR	1.40	138.8	28.8	113.2	8.5	4.71
Quick lime @ 100% LR + NPKMg	1.47	144.0	31.9	115.6	11.1	4.53
Dolomite @100% LR	1.43	67.3	25.6	132.4	11.7	4.60
Dolomite @100% LR + NPKMg	1.48	105.0	36.3	157.2	10.1	4.42
Phosphogypsum @ 100% LR	1.41	113.0	36.9	187.7	12.1	4.53
Phosphogypsum @ 100% LR + NPKMg	1.51	97.5	37.5	112.8	9.9	4.34
SE	0.05	10.3	6.1	20.5	1.5	0.07
CD (P=0.05)	NS	30.9	NS	61.5	NS	NS

LR - Lime requirement **** Powdered shell lime***

Table 43. Effect of liming materials on nutrient status of the soil (15-30cm) - one year after liming

Treatment	OC (%)	Available nutrients (ppm)				pH
		P	K	Ca	Mg	
Control	1.40	31.9	32.5	71.9	13.4	4.43
NPKMg	1.51	21.3	27.7	64.7	8.2	4.40
Quick lime* @100% LR.	1.42	18.3	35.6	137.5	15.4	4.46
Quick lime @100% LR + NPKMg	1.53	34.0	34.4	64.0	7.7	4.43
Dolomite@100% LR	1.34	25.3	29.4	74.4	8.5	4.40
Dolomite@100% LR + NPKMg	1.54	16.6	31.3	74.7	8.3	4.50
Phosphogypsum @100% LR	1.47	21.1	25.6	153.0	5.4	4.40
Phosphogypsum @100% LR + NPKMg	1.46	29.5	45.0	129.9	8.4	4.39
SE	0.09	6.1	5.2	9.1	1.0	0.05
CD (P=0.05)	NS	NS	NS	27.3	3.0	NS

LR - Lime requirement *** Powdered shell lime**

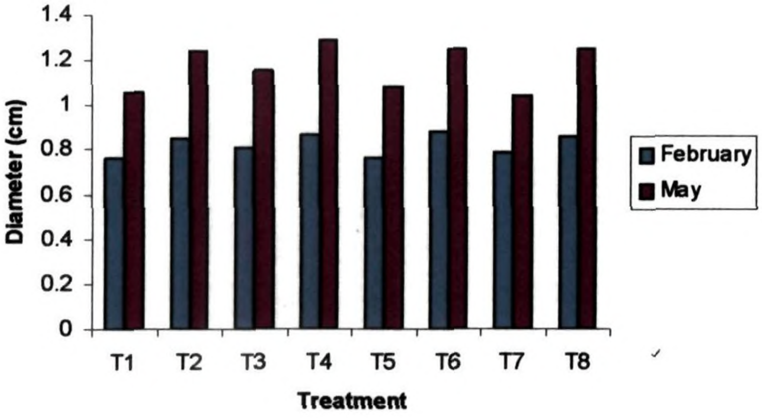
IV.6.5 Residual effect of liming materials on growth and nutrient availability

The diameter of plants which received application of fertilizer alone or in combination with various sources of lime was on par and was significantly superior to the control in the residual study (Table 44 and Fig. 29). Among the treatments highest diameter (1.29 cm) was recorded in quick lime @100% LR + NPK Mg followed by (1.25 cm) in phosphogypsum@100% LR + NPK Mg applied plots .

Table 44. Residual effect of liming materials on diameter of rubber seedlings

Treatment	Diameter(cm)	
	2004	
	February	May
Control	0.76	1.06
NPKMg	0.85	1.24
Quick lime* @100% LR	0.81	1.15
Quick lime @100% LR + NPKMg	0.87	1.29
Dolomite@100% LR	0.76	1.08
Dolomite@100% LR + NPKMg	0.88	1.25
Phosphogypsum@ 100% L.R.	0.79	1.04
Phosphogypsum@100% LR + NPKMg	0.86	1.25
SE	0.02	0.04
CD	0.06	0.10

LR - Lime requirement *** Powdered shell lime**



T1-No lime and no NPKMg T2-NPKMg T3- Quick lime@100% LR
T4- Quicklime@100% LR + NPKMg T5-Dolomite @100% LR T6- Dolomite @100% LR + NPKMg
T7- Phosphogypsum@100% LR T8-Phosphogypsum@100% LR+ NPKMg

Fig. 29 Residual effect of different liming materials on diameter of rubber seedlings

Phosphorus availability in the soil was significantly improved in plots received application of quick lime or dolomite along with fertilizer in the residual study (Table 45). In phosphogypsum applied plots available iron content was reduced significantly when compared to other treatments (Table 46). Application of different liming materials reduced the availability of copper.

Table 45. Residual effect of liming materials on soil nutrient status (0-30cm)

Treatment	OC (%)	Available nutrients(ppm)				pH
		P	K	Ca	Mg	
Control(no lime and no fertilizer)	1.51	47.8	40.1	105.8	15.0	4.29
NPKMg	1.43	72.8	55.1	82.3	25.8	4.27
Quick lime* @100%LR	1.47	52.8	37.4	210.3	10.9	4.14
Quick lime @100%LR + NPKMg	1.57	100.0	42.6	180.2	23.5	4.29
Dolomite100% LR	1.38	39.0	42.6	160.1	13.2	4.29
Dolomite100% LR + NPKMg	1.52	99.0	48.8	225.9	34.2	4.43
Phosphogypsum@!00% LR	1.52	60.0	42.6	151.9	12.8	4.20
Phosphogypsum@100%LR + NPKMg	1.52	65.0	40.0	55.9	13.0	4.09
SE	0.08	9.60	4.9	47.2	3.9	0.04
CD	NS	26.8	NS	NS	NS	0.12

LR - Lime requirement *** Powdered shell lime**

Table 46. Residual effect of liming materials on soil micronutrient status-(0-30cm)

Treatment	Available micronutrients(ppm)			
	Mn	Fe	Cu	Zn
Control	0.90	50.67	2.51	0.30
NPKMg	1.25	50.80	2.32	0.27
Quick lime* @100%LR	1.02	45.70	1.78	0.27
Quick lime @100%LR + NPKMg	1.08	52.02	2.18	0.25
Dolomite100% LR	1.26	51.66	1.80	0.26
Dolomite100% LR + NPKMg	1.27	54.08	2.54	0.28
Phosphogypsum@!00% LR	0.77	40.48	1.72	0.29
Phosphogypsum@100%LR + NPKMg	1.08	46.19	1.85	0.24
SE	0.14	2.43	0.25	0.03
CD	NS	7.29	NS	NS

LR - Lime requirement *** Powdered shell lime**

CHAPTER-V

SUMMARY AND CONCLUSIONS

In the traditional belt of rubber cultivation, plantations are in the second or third planting cycle. Continuous cultivation of rubber was reported to reduce the soil pH because of removal of bases like Ca and Mg and also increase in Al content. Hence, a need was felt to assess the extent of occurrence of soil acidity in these soils and its management for better growth of rubber plants. So the present investigation was carried out with the following studies viz., i) Collection of soil samples from the major soil series and characterization of the nature of soil acidity ii) estimate the lime requirement of these soils iii) an incubation experiment to study the changes in nutrient availability through liming (iv) a nursery experiment to study the effect of liming on growth of rubber seedlings (v) a pot culture experiment to understand the translocation of Ca in different plant parts upon liming and (vi) a nursery experiment to study the effectiveness of different liming materials on growth of rubber seedlings.

1. Characterization of soil acidity in rubber growing soils

1. Soils were strongly to moderately acidic. pH $_{(water)}$ ranged from 4.29 to 5.48. In general, pH of the profiles does not show any regular pattern. In the surface soil it ranged from 4.46 in Vijayapuram to 5.40 in Panachikkad series.

2. pH $_{(Cacl2)}$ represents more nearly pH of the soil solution under actual field conditions and reflect accurately the H^+ ion environment of the plant roots and soil microorganisms. pH $_{(CaCl2)}$ ranged from 3.76 to 4.80 in the surface soil. Similarly,

pH$_{(Kcl}$ ranged from 3.80 to 4.79 in the surface soil. (ΔpH), the difference in pH$_{(Kcl)}$ and pH$_{(water)}$ was negative indicating the presence of negative charges and variable charge colloids. Presence of significant amount of silicate clay minerals in these soils is also indicated. ΔpH values showed a gradual, though irregular increase with depth. ΔpH is less than one in Vijayapuram, Kanjirappally, Lahai, Kunnathur and Panachikkad series. Low values of ΔpH indicate that the pH of these soils was closer to their zero point charge, indicating the presence of pH dependent charge minerals. $pH_{(NaF)}$ values were very high indicating the presence of amorphous aluminosilicate minerals.

3. Lime potential of the soil ranged from 2.59 to 3.66. The surface soil showed higher lime potential than the lower horizons indicating greater lime buffering capacity in the subsurface contributed mainly by the high content of clay accumulated in the lower layers.

4. Organic carbon ranged from 0.68 to 2.0 per cent and the values showed decline with depth. High OC in the surface layer might be due to the organic matter additions through rubber litter and cover crops and the dense fine root system of rubber.

6. Cation exchange capacity was low in all the pedons and it decreased down the profile. In the surface soil, the values ranged from 4.20 to 8.66 cmol/kg. High organic matter might have contributed to the comparatively high values of CEC in the surface horizons. In general, the exchangeable Ca, Mg and K were low. Exchangeable Ca ranged from 0.06 to 1.50 cmol /kg. In the surface soil, the values ranged from 0.10 to 1.50 cmol/kg.

7. Base saturation percentage in the surface soil ranged from 4.42 per cent in Lahai series to 41.77 per cent in Kunnathur series. The base saturation in general is low due to the preponderance of Al^+ and H^+ in the exchange sites.

8. Clay content in general showed an increasing trend with depth and it ranged from 18.0 to 62.0 per cent Clay accumulation was highest in the third layer in most of

the series. Increase in clay content with increasing depth and the highest clay accumulation in the lower layers was recorded

9. Total potential acidity comprises pH dependent and exchangeable acidity and was estimated in the $BaCl_2$ – TEA extraction. In general, the surface soil showed higher total potential acidity. The total potential acidity of the surface soil ranged from 6.39 in Kunnathur series to 27.70 cmol /kg in Lahai series. High values of TPA in the surface layer could be due to the high organic matter status. Total potential acidity decreased down in the profiles except in Kunnathur series. Among the profiles, comparatively high values were noticed in Lahai followed by Kanjirappally and low values were recorded in Vazhoor, Thrikannamangal and Kunnathur series.

10. Exchangeable acidity includes the exchangeable H^+ and Al^+ held at the permanent charge sites of the soil exchange complex. The exchange acidity values ranged from 0.98 to 3.97 cmol /kg. Except Kunnathur and Vazhoor , all the other series had high values of exchangeable acidity. Contribution of exchangeable acidity to total potential acidity is relatively low and it ranged from 8.46 to 54.0 per cent.

11. pH dependent acidity due to variable charge (pH dependent) is the difference between TPA and EA and it varied from 0.14 (Kanjirappally) to 25.83 cmol/kg (Lahai). Lahai series had highest values of PA followed by Kanjirappally while comparatively lower values were recorded in Thrikannamangal. Lahai and Kanjirappally had high values of pH dependent acidity as observed in the case of total potential acidity. The decline in PA in the subsoil which contains relatively low OC might be an indication of possible role of organic matter in the development of variable charge. Total potential acidity and pH dependent acidity showed significant positive correlation with OC. The important soil factors which control significantly the different forms of soil acidities are pH, organic matter, exchangeable and extractable Al and clay.

12. No regular pattern was observed in the distribution of exchangeable Al. Exchangeable Al ranged from 0.55 to 3.33 cmol/kg. Exchangeable Al was high in Thiruvanchoor, followed by Thrikannamangal, Panachikkad and Kanjirappally and low in Vazhoor and Kunnathur series. Vazhoor series had very low values of exchangeable Al through out the profile. Among the exchangeable cations high contribution of exchangeable Al was in all the soils except for Vazhoor especially in the subsoil layers indicating the occurrence of subsoil acidity. Among the soils Vazhoor had lowest values of exchangeable Al and exchangeable acidity.

13. Soluble Al ranged from 0.75 ppm in Kunnathur series to 10.63 ppm in Thiruvanchoor series. Comparatively high values of soluble Al were noticed in Thiruvanchoor, Thrikkannamangal, Vijayapuram, Kanjirappally, Lahai and low values were found in Vazhoor, Panachikkad and Kunnathur series. Soluble Al was found to be high in the subsurface layers compared to the surface layer. Lower soluble Al in the surface layer might be due to the presence of organic matter. In acid soils, inhibition of root growth is closely related to soil solution Al and further studies are required in the direction to understand the root growth in relation to exchangeable Al.

14 Extractable Al values ranged from 1.36 to 8.33 cmol/kg. In Vijayapuram, Vazhoor, Kanjirappally, Thrikkannamangal and Kunnathur series in the lower horizons extractable Al content was higher than in the surface layer. Among the series low extractable Al was recorded in Vazhoor series.

15. In all the pedons the amount of Al extracted by IM NH_4OAc buffered at pH 4.8 was higher than the Al extracted by IM KCl, which indicate that extractable Al^{3+} includes exchangeable Al $^{3+}$ and soluble Al $(OH)_3$ and the hydioxy-Al monomers or polymers .

16. Non exchangeable Al is associated with organic matter, interlayer Al and hydroxy Al polymers. No regular pattern was observed in the distribution of non-exchangeable Al in the profiles. The values ranged from 0.18 cmol /kg in Panachikkad series to 7.01 cmol/kg in Kanjirappally series.

17. Wide variation in total Al was observed ranging from 1.6 to 9.8 per cent Total Fe ranged from 5.4 to 18.86 per cent in horizons of different profiles.

18. Wide variation in exchangeable, extractable and total Mn was recorded. Comparatively higher values of exchangeable and total Mn were noticed in Kunnathur series. In general, exchangeable, extractable and total Mn decreased down the profile in all the series.

19. Distribution of total, exchangeable and DTPA extractable Fe were estimated. Higher values of exchangeable Fe was recorded in the surface layer. Among the series, highest DTPA extractable Fe was recorded in Panachikkad series and lowest value was recorded in Kunnathur series.

20. Acid ammonium oxalate extracts Al and Fe from the amorphous, exchangeable and organically bound forms and little from crystalline forms. Acid ammonium oxalate extractable Al ranged from 1.39 to 8.33 cmol /kg. No regular pattern was observed in the distribution of oxalate extractable Fe and the values ranged from 0.34 to 1.85 per cent. Oxalate extractable Al and Fe were much less than the citrate extractable Al and Fe, indicating the dominance of crystalline forms of Al and Fe in these soils.

21. Dithionate citrate bicarbonate extractable Al and Fe were estimated and wide variation was noticed between soils. Values for Al ranged from 26.39 to 186.11 cmol /kg. Values for Fe ranged from 1.08 to 3.90 per cent. Higher values of dithionate citrate bicarbonate extractable Fe suggest that amorphous Fe had been transformed to

crystalline iron. The trend is reflected in active Fe ratio (Fe_o/Fe_d). The active iron ratio (Fe_o/Fe_d) was low indicating that the soils under study are highly aged soils.

22. Effective cation exchange capacity ranged from 1.41 cmol/kg in Vazhoor series to 4.31 cmol/kg in Panachikkad series in the surface soil. Aluminium saturation per cent was calculated from the ECEC. The surface layers had generally lower Al saturation per cent and the values increased with depth. Values ranged from 21.88 per cent in the surface horizon of Kunnathur to 89.45 per cent in the bottom layer of Kanjirappally series. Except in Vijayapuram, Lahai and Panachikkad series, subsurface horizons had high values of Al saturation than the surface horizons. pH and Al saturation per cent were significantly and indirectly correlated. Saturation of exchangeable complex with exchangeable Al was highest at pH 4.58 and lowest at pH 5.2. The higher the Al saturation the more the soils will be deficient in Ca, Mg and K. In Kunnathur, Vazhoor and Panachikkad series the Al saturation was less than 60.0 per cent in the surface and subsurface horizons, while in the rest of the profiles (Vijayapuram, Thiruvanchoor, Kanjirappally, Thrikkannamangal and Lahai) the Al saturation was high.

2. Lime requirement of the rubber growing soils

Lime requirement of eight soil series was estimated by four methods and wide variation was recorded between soils as well as between methods. Quantity of lime requirement by different methods varies in the order SMP>Peech>Adams and Evans>Exchangeable Al. Lahai series recorded the highest LR for all the methods which might be due to the high values of acidity, exchangeable Al, organic matter and clay content of this series. Kunnathur series with relatively high base saturation recorded the lowest LR. Lime requirement calculated by the exchangeable Al method recorded the lowest values which ranged from 0.90 to 4.3 t/ha between series.

All these methods showed highly significant positive correlation with different forms of acidity, forms of Al, OC, and clay and correlated negatively with pH. Hence all these methods are suitable for rubber growing soils. But liming should be cost effective by considering the nature of soil, crop to be grown, the quantity of liming material and also its availability. For tropical crops, adapted to acid soil environment acidity management through liming is not to change the pH *per se but* to bring down exchangeable Al to the required level and improve the availability of Ca and Mg. Hence, the exchangeable Al method even though it is not rapid for routine analysis is found to be more appropriate for the estimation of LR of rubber growing soils.

3. Effect of liming on pH and nutrient availability-Incubation experiment

Liming had positive and significant effect on soil pH, which increased progressively with increase in the rate of lime addition. pH was brought to neutrality in the 75 and 100 per cent LR treatments. Irrespective of the rate of application, pH decreased significantly with increase in incubation time, but the improvement in pH was maintained up to 90 days. Liming improved the availability of Ca, P, K and Zn and reduced the availability of Fe, Mn and Cu. At the higher levels of lime application availability of K and Mg was slightly reduced due to the antagonistic effect of excessive supply of Ca. Liming significantly reduced the exchangeable Al content in the soil and at the 100 per cent LR treatment the exchangeable Al was brought down to traces.

4. Effect of liming on availability of nutrients and growth of rubber seedlings in the nursery

Liming improved the pH of the soil and increased the availability of Ca. pH changes were significant in the initial phase and after one year the pH values were decreased indicating the strong buffering capacity of the soil. But significant gradation in pH was noticed between control and lime applied plots. Growth of plants which received application of fertilizer alone or in combination with various doses of lime were on par and were significantly superior to application of lime alone or control. Nutrient availability assessed after one year of plant growth indicated that lime in combination with fertilizer significantly increased the availability of P and K and Ca in the soil and is thus beneficial in maintaining /improving the soil fertility.

5. Effect of liming on translocation of Calcium to different plant parts

Incorporation of lime along with recommended fertilizer significantly increased the dry matter yield over fertilizer alone or lime alone application. Similarly, application of lime alone and fertilizer alone treatments were significantly superior to control indicating positive response to both lime and fertilizer. Liming significantly increased the Ca concentration in different plant parts and wide variation was recorded in the root and petiole concentration compared to stem and leaf. Petiole Ca concentration ranged from 2.99 to 4.71 per cent between control and 100 per cent LR+ fertilizer. Similarly, root Ca concentration ranged from 0.82 to 2.00 per cent between control and 100 per cent LR+ fertilizer. Highest Ca accumulation was recorded in petiole followed by stem.

6. Comparative evaluation of liming materials on growth of rubber seedlings

Liming effect of quick lime (shell lime), dolomite and phosphogypsum were compared alone and in combination with fertilizer through a nursery experiment. Application of quick lime and dolomite improved the pH of the soil significantly over control. Dolomite or shell lime in combination with fertilizer was found to be significantly superior in influencing the growth of seedlings in the nursery. One year after liming the pH of the soil was reverted back and the treatment effects were not significant. Availability of Ca and P in the soil was significantly improved with liming and the availability of Mg was slightly reduced.

Residual effect of the different liming materials were evaluated thorough a second experiment in the same field. Fertilizer alone or in combination with lime significantly improved the growth of seedlings, indicating residual effect of liming to the next crop. High content of available Ca was maintained even after two years of liming and the order of availability of Ca from different liming materials was shell lime>dolomite>phosphogypsum. Thus in the nutrient management of rubber growing soils liming is found to be beneficial in improving the soil fertility and growth of rubber plants.

Soils in the traditional rubber growing tract were found to be strongly to moderately acidic and the major factors responsible for acidity were different forms of aluminium together with organic matter and clay. Aluminium saturation of the exchange complex was found to be high especially in the subsoil layers indicating the possibility of subsoil acidity in these soils. Soluble Al content was found to increase with increase in Al saturation per cent. The inverse relation observed between exchangeable Al and exchangeable Ca points to the deleterious effect of soil acidity and Al toxicity on the availability of Ca. Low availability of Ca will reduce the root growth and in turn will reduce the uptake of nutrients and growth and yield. Hence, further studies are required to explore the influence of subsoil acidity on the growth and yield of rubber plant.

Lime requirement of the soils were estimated by different methods. Except exchangeable Al method, all the other methods estimated very high lime requirement for these soils. This might be due to the strong buffering capacity of the soil and may not be economical and may be deleterious to the plants. Exchangeable Al method was found to be more appropriate for rubber.

Application of lime along with fertilizer increased the growth, dry matter production and nutrient uptake of plants by increasing the availability of nutrients. Liming improved the pH of the soil significantly. pH improvement was for a short period of time and then pH was reverted back to the original indicating the strong buffering capacity of the soil. Among the liming materials dolomite or quick lime was found to be equally effective. Dolomite or quick lime along with regular dose of fertilizer significantly improved the growth of plants in the nursery. Residual effect of liming was observed in the second year of application and plant growth was improved significantly and the availability of Ca in the soil was also increased. Liming significantly increased the Ca concentration in different plant parts and highest Ca concentration was recorded in the petiole followed by stem. This indicates that rubber is a Ca loving plant and under conditions of higher availability rubber plants take up more Ca. Liming these soils should be with the objective of a pH change to the desired level for improving the availability of nutrients, for supplementing the Ca and Mg. and for increased microbial activity.

Continuous cycles of rubber plantation may lead to depletion of soil fertility and productivity. Adequate attention need to be given for pH control and Ca and Mg nutrition. Effective soil management techniques for maintaining the soil health will be highly essential for the sustained higher productivity of the rubber plantations.

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