PRODUCTIVITY CLASSIFICATION OF SOILS UNDER RUBBER (*Hevea brasiliensis* Muell. Arg.) IN KERALA

By

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THESIS

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2000

DECLARATION

I hereby declare that the thesis entitled "***Productivity classification of soils under rubber (Hevea brasiliensis Muell. Arg.) in Kerala***" is a bonafied record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title of any other University or Society.

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TO MY PARENTS
WHOSE ASPIRATIONS INSTILLED
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INTRODUCTION

Soil is an important edaphic component influencing the establishment, growth and yield of hevea. An understanding of the numerous soil factors affecting soil fertility is a prerequisite to proper management of soils for better performance of rubber plant. Suitable agronomic inputs and practices can be devised, implemented and adopted only upon knowing the physical and chemical characteristics and limitations of a particular soil. Understanding of a soil with regard to a crop includes the study of not only the characteristics of the soils but also their influences on the performance of the given crop either directly or indirectly.

Man has a natural tendency and urge to sort out and classify the natural objects of his environment and soils are no exception. Soil classification, as integral part of effective agricultural planning, enables us to assemble knowledge about the soils, to see their relationship to one another and to develop definite principles that help us to present their behaviour and response to various treatments. It is rather a convenient tool for grouping a highly complex and diverse natural resource. Realisation of importance of classification of soils for site specific management, led to the developments in soil classification from time to time.

Early systems of soil classification were quite simple and highly practicable. But with increasing sophistication in agriculture, greater knowledge about soils as a collection of independent natural bodies, and greater complexity and diversity of soil uses, the classification of soils has become more scientific and organised. Soil taxonomy is a natural system of classification in which the knowledge is organised without any reference to a specific applied objective in such a way that each group has as many unique, natural properties as possible and its properties relate it to, yet separate it from others (Cline, 1949). Comprehensive soil taxonomy is a system of soil classification developed by the United States Department of Agriculture after several approximations (Soil Survey Staff, 1975).

Like in many other crops, in case of rubber growing soils also attempts were made to apply the soil taxonomy for grouping different soils of varying production potentials. The soil series common to rubber in peninsular Malaysia were classified at great group level according to the norms of Soil Taxonomy (Chan *et al.*, 1975). Attempts were made in India also to classify some soils under rubber. The Soil Survey Branch of Kerala, (1978) classified some laterite soils as Typic Eutrorthox and Tropeptic Eutrorthox and some forest loams as Typic Hapludoll and Ultic Tropudalf where rubber is grown. Krishnakumar (1989) classified some of the rubber growing soils of Kerala as Paleudalfs and Paleudults at great group level while characterising them. Some of the classifications had been revised by Krishnan *et al.* (1996) based on changes in Soil Taxonomy and additional data availability since some of the classifications were based on incomplete data like base saturation by sum of cations and weatherable minerals.

While describing the agronomic utility of soil taxonomy, Chan (1975) reported a general order of ranking in yield patterns of modern rubber clones as Typic Paleudults > Plinthic Haplorthox > Oxic Dystropepts > Typic Sulfaquepts / Typic Tropaquepts. He stated that the yield patterns were consistent with soil pedological properties and concluded that soil taxonomy also reflected the logic of agronomic utility. However, the information on test application of soil taxonomy to rubber growing soils of Kerala is nil either in terms of growth or yield

Soil Taxonomy of USDA, as the basis of soil interpretation has the best potential for identifying agricultural land and consequently for the transfer of agrotechnology (Beinroth *et al.*, 1980). In an attempt to facilitate technology transfer at global level, the soil units identified in Malaysia in the earlier non-parametric and parametric soil classification systems were described in terms of Soil Taxonomy by Chan *et al.* (1984). Very recently only NBSS & LUP had published the resource soil survey report on soils under rubber in Kerala and Tamil Nadu on 1:50000 scale (NBSS & LUP, 1999) which will help in technology transfer.

Soil Taxonomy, is a natural or scientific classification system and soils are grouped according to several soil properties, which are measured to depths up to 2 m. Many soil properties that may not be relevant for fertility purposes are used as classification criteria (Buol and Couto, 1982). According to Sanchez *et al.* (1982) the direct interpretation of natural systems for specific uses is difficult because criteria relevant to specific soil use are confounded with other criteria. Hence, a system called fertility capability classification (FCC) was designed to group those soils that have the same kind of limitations from the point of view of fertility management (Buol, 1972).

FCC system was developed as an attempt to convey fertility management information and several features related to other soil management problems were not included. Suggestions have been made for certain features to be included which would make the system more applicable to soil management limitations (Sanchez *et al.*, 1982; Buol and Couto, 1982). This flexibility to either add or modify the condition modifiers gives a chance to identify the important limitations for meeting the management requirements of a given crop in a given area.

In the case of rubber also, the FCC was test applied in Malaysia as reported by Chan, 1980). In India, recently NBSS & LUP classified the soils under rubber in Kerala and Tamil Nadu in terms of fertility capability classification. However, no information is available with reference to testing the FCC in terms of agronomic utility.

Numerical taxonomy is described as numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities (Sneath and Sokal, 1963). The other aim of the numerical classification is to test the validity of semi-quantitative or qualitative natural classification systems i.e. Soil Taxonomy. Many workers reported in India that Numerical Classification and Soil Taxonomy classified soils almost alike with a few exceptions (Kumar and Sharma 1987; 1990; 1993; Srivatsava *et al.*, 1995; Karmakar *et al.*, 1995 and Singh *et al.*, 1996). However, no work was reported with regard to application of numerical classification technique to rubber growing soils in Kerala, India.

A bird's eye view of large area is an easy access to information about a given terrain rather than obtaining information by moving across the land. Remote sensing provides such information and it is the science of deriving information about the objects at a distance, without being in physical contact. The potential of remote sensing technology in applications lies in the fact that the observations are synoptic, it provides repetitive coverage of large areas and that the data are quantifiable.

In recent years, a number of investigators have used remotely sensed data for mapping vegetation, land use, and wasteland and for preparing crop inventory. However, only little work has been done on specific themes like mapping specific crops. A very little information is available on mapping of rubber in Kerala and elsewhere.

The available information revealed that the spectral behaviour of rubber was studied in one time image only during mapping. No information is available about the temporal behaviour in reflectance in the electromagnetic spectrum particularly during and after wintering. This information assumes significance in delineating rubber from other types of vegetation particularly when interference comes from confusion crops.

Considering the present level and gaps in the information pertaining to soils under rubber and utility of application of remote sensing as mentioned above, a project was proposed with the following objectives:

1. To study the soil taxonomy of selected prominent soils under rubber in Kerala

2. To classify the selected soils under rubber according to the norms of fertility capability classification

3. To attempt an introduction of local modifiers into the FCC based on specific crop requirements of rubber plant

4. To group the selected soils by numerical classification technique using important soil properties

5. To test the direct and indirect effects of soil factors on the growth of hevea; and

6. To identify the spectral signature of rubber using multiband satellite imagery.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The rubber plantation industry in India, which is more than a century old, has a research support with regard to scientific and technical aspects of the crop only from the last four decades. The management practices adopted in India in initial stages were a first approximation depending on the data generated in other countries where the research began in the early 20's. There is a definite need for specific and specialized recommendation based on the prevailing agro-ecological and agro-climatological conditions. of the country.

The cultivation of rubber traditionally was confined to a narrow tract in the western side of the Western Ghats mainly in Kerala sate, a humid tropical region characterized by highly weathered and leached soils presenting a unique soil environment. The management practices, nutritional management in particular, of rubber are specific warranting a thorough study of the natural growth medium.

Soil classification enables us to assemble knowledge about the soils, to see their relationship to one another and to develop definite principles that help us to present their behaviour and response to various treatments. It is rather a convenient tool for grouping a highly complex and diverse natural resource. Realization of importance of classification of soils for site specific management, the core of the Soil Science, led to the developments in soil classification from time to time, in general and soils under rubber in particular.

An understanding of a soil with regard to a crop includes the study of not only the characteristics of the soils but also their influences on the performance of the given crop either directly or indirectly. In that direction a considerable lot of work was done both in India as well as in other rubber growing countries while understanding the soils under rubber.

Application of remote sensing technology in agriculture is a fast growing branch of applied science for both scientific as well as planning purposes. However, a very little information is available with regard to the application of remote sensing technology in the case of rubber.

This chapter of review of literature is arranged to cover the above mentioned aspects related to soils under rubber and the application of remote sensing technology in general and with special reference to rubber.

1. Soil classification

Man has a natural tendency and urge to sort out and classify the natural objects of his environment and soils are no exception. Early systems of soil classification were quite simple and highly practicable. But with increasing sophistication in agriculture, greater knowledge about soils as a collection of independent natural bodies, and greater complexity and diversity of soil uses, the classification of soils has become more scientific and organized. The classification for a specific, applied practical purpose is a technical classification. But in scientific or natural classification, the knowledge is organized without any reference to a specific applied objective in such a way that each group has as many unique, natural properties as possible and its name and its properties relate it to, yet separates it from others (Cline, 1949).

1.1. Technical grouping of soils under rubber

Considerable work related to technical grouping (Cline, 1949) for a specified, applied, practical purpose of soils under rubber was done since long time. Much of the work in this regard was done in Malaysia. So far, a total of four systems of soil suitability for rubber were proposed from time to time. A nonparametric Soil Suitability Classification called System 1 (Chan and Pusparajah, 1972), Soil Suitability Technical Grouping (System 2), a parametric and additive approach (Chan *et al.*, 1975), a multiplicative Soil Suitability Evaluation System called System 3 and another system of soil suitability called System 4 (Yew, 1982) were developed based on different parameters.

The System 1 considered desirable physical, environmental and physiographic features and chemical properties with minor, serious and very serious limitations and has five classes of suitability. In System 2, a total of 16 soil parameters considered and five technical groups were identified with different degrees of suitability. The multiplicative Soil Suitability Evaluation System (System 3) for rubber also considered the evaluation of climate in addition to land evaluation units. The land characteristics include slope, drainage, flooding, texture / structure, surface and subsurface stoniness, soil depth, weathering stage and organic carbon content. Another multiplicative system (System 4) of soil suitability for rubber used another set of land qualities viz. available foothold for roots, available nutrients, favourable soil pH, absence of salinity, availability of oxygen, availability of water, soil erosion hazard, accessibility / trafficability.

After a long gap of time with reference to the development of land suitability systems, a multiplicative system involving nine climatic and ten soil characteristics was proposed in Vietnam after five years of testing and trails by Thinh *et al.* (1998). However, no information on such soil or land suitability systems for rubber evolved in India.

1. 2. Taxonomy of soils under rubber

Soil taxonomy is a natural system of classification in which the knowledge is organized without any reference to a specific applied objective in such a way that each group has as many unique, natural properties as possible and its properties relate it to, yet separate it from others (Cline 1949). A classification undergoes a revision as the body of knowledge on which it is based expands and classification succession is a phenomenon common to all disciplines.

In Soil Taxonomy (Soil Survey Staff, 1975), soils are grouped according to several properties, which are measured to depths up to 2 m. Soil taxonomy as a natural classification, attempts to organize all the features that can be measured in a soil. Some of the properties used as criteria in soil taxonomy perhaps may not have relevance to soil fertility as it is a natural classification without any reference to any specific purpose (Buol and Couto, 1982). Beinroth *et al.* (1980) stated that soils and climate are interrelated, both can be combined in one system of classification as has been done in Soil Taxonomy. They also opined that soil taxonomy, as the basis of soil interpretation has the best potential for identifying agricultural land and consequently for the transfer of agrotechnology. It is as implicit rationale of soil survey interpretation that soils classified in same taxa have a common response to management practices.

The soil series common to rubber in peninsular Malaysia were classified at great group level into Quartzipsamments, Sulfaquepts, Tropaquepts, Fluvaquepts, Dystropepts, Tropudults, Paleudults and Haplorthoxes according to Soil Taxonomy (Chan *et al.*, 1975). The soil units classified in the Soil Taxonomy are well substantiated in their relationships by the logic of soil formation and genesis. The Soil Taxonomy is found to be relatively easy-to-use when keying the soils and the strength of this system lies in the intrinsic ability of classifying disturbed profiles, especially of man-made nature and does not depend heavily on virgin profiles which many other local systems do (Chan, 1975). To facilitate technology transfer at global level, the soil units identified in the earlier nonparametric and parametric soil classification systems were described in terms of Soil Taxonomy by Chan *et al.* (1984).

In Kerala, the rubber cultivation is confined to lateritic, forest, red and alluvial soils (George, 1961). In this traditional region of rubber cultivation, the soil is mostly laterite and lateritic (Koshy and Varghese, 1972). The Soil Survey Branch of Kerala, (1978) classified some laterite soils as Typic Eutrorthox and Tropeptic Eutrorthox and some forest loams as Typic Hapludoll and Ultic Tropudalf where rubber is grown. Krishnakumar (1989) classified some of the rubber growing soils of Kerala as Paleudalfs and Paleudults at great group level while characterising them.

1. 3. Test applications of soil classification systems in rubber

The available literature on the test applications of both technical and natural soil classification systems in rubber and the yield performance of rubber in different soils is presented in this section.

1. 3.1. Technical classification of soils under rubber

The evaluation of technical grouping in terms of yield performance of rubber in Malaysia indicated that Munchong series, a Class I soil recorded higher yields when compared to Selangor series, a Class V soil. The soils of Munchong are shale derived and those of Selangor are marine alluvial in nature (Chan, 1972). Another study of technical grouping system by Chan *et al.* (1975) showed that soils with higher technical group ratings were generally related to higher yield in the field. The soils with balanced particle distribution, friability, strong and moderately strong medium and fine subangular blocky structure and good drainage such as Munchong, Selangor and Kuantan series scored highest. On the other hand, soil units with a shallow depth, unbalanced particle size distribution, very firm or very loose consistency, high compaction, poor structure and poor drainage as Briah, Selangor and Linau series scored very low while peat scored lowest.

The land indices according to land evaluation systems have the yield predictive values. High land indices are related to higher yields of rubber. The study of Chan *et al.* (1984) revealed that the rubber yield could be predicted from the land grouping by the systems developed for land evaluation having agronomic logic. In another study by Yew and Chan (1992) in which all the four systems of soil suitability classification were tested in 13 common series, it was observed that all systems correctly classified the very suitable and unsuitable soils for rubber. The decreasing ability of the classification systems to predict rubber yield performance was System 4 > System 3 > System 2 > System 1. Regression analysis for the soil indices obtained by the three parametric systems viz. System 2,

System 3 and System 4 with yield confirmed that the highest correlation was obtained for System 4 (Yew, 1992).
However, in India, the information on testing of any of the land evaluation systems in terms of rubber plant growth and yield is totally lacking.

1. 3. 2. Soil taxonomy

A general order of ranking in yield patterns of modern clones GT 1, PB 5/51, RRIM 605 and RRIM 623 is given (Chan, 1975). From this study it is understood that the yield patterns were consistent with soil pedological properties and concluded that soil taxonomy also reflected the logic of agronomic utility.

Though there is some information on the soil taxonomy of some of the rubber growing soils of India, there is no information as far as testing of soil taxonomy with reference to plant performance of hevea in India.

1. 4 Fertility capability classification

Soil management research is site specific. Several factors interact to define a given management site. These factors include soil type, ambient weather and fertility level of the soil as related to the past management, as well as several other parameters. Soil fertility management is mainly concerned with manipulation of the characteristics of plough-layer, simply because the present techniques have limited ability to change subsoil characteristics. In Soil taxonomy (Soil Survey Staff, 1975) soils are grouped according to several soil properties which are measured to depths of up to 2 m and many soil properties that may not be relevant for fertility purposes are used as classification criteria (Buol and Couto, 1982). To focus attention on significant properties of the soils that may be used to interpret and extrapolate the results of soil-fertility management experiments, a system called Fertility Capability Classification (FCC) was designed by Buol (1972). This system is also meant for grouping those soils that have the same kind of limitations from the point of view of fertility management.

FCC is also a technical system of classification (Cline, 1949) designed to emphasize only one soil use. Soil individuals in one FC class may belong to different classes for taxonomic purposes and the result is that the number of soil units in the FC classification is much smaller than that in Soil Taxonomy (Buol *et al.*, 1975). A FCC will essentially have type (surface texture), substrata type (subsurface texture) and condition modifiers. The name of the FC class is collectively constituted by type, substrata type (presented in capital letters) and the condition modifiers (presented in small letters) (Buol and Couto, 1982).

The system of FCC is flexible and enables the modifications as per the requirement. For example, if the soils are to be classified for suitability for a specific crop like rubber, it is possible to incorporate the condition modifiers, which are nothing but the crop requirements. Sanchez *et al.* (1982) summarised the first five years of testing and evaluation of the fertility capability classification and presented and improved version, examples of interpretation and its applicability with addition of two condition modifiers.

A report on the test application of FCC concept to the case of rubber was given by Chan (1980) and suggested that the critical C/N ratio for rubber available in Malaysia to be included as a condition modifier. Considering the tolerance limits of the cover crops grown in rubber plantations in Malaysia, he also

also stressed the necessity to introduce a condition modifier 'a', related to Al-saturation, where 'a' is defined as >80 % Al saturation of the ECEC.

Mathan (1990) applied the FCC concept to the acid soils of Nilgiris of Tamilnadu and introduced a condition modifier 'm' using the critical limit of 2.3 cmol kg^{-1} of magnesium in the top soil and used as a classifier. Mathan *et al.* (1994) classified 21 soils of Kamarajar district of Tamilnadu into eight FC classes.

The information on application of FCC concept and testing of FCC in rubber growing soils in India is however, lacking.

1.5 Numerical classification of soils

The concept of the universe as a continuum had led to the experiments in arranging or ordinating soil taxa on a numerical basis (Buol *et al.*, 1973). Numerical taxonomy is a numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities (Sneath and Sokal, 1973).

$\sqrt{\Sigma[x_i j - x_i k]^2}$ is euclidean distance between two soil profiles say j and k where $x_i j$ is the i^{th} character of the j^{th} profile, there being 'n' characters for each profile. This measure is probably most appropriate for soils because of its sensitivity to magnitude, being metric and that it provides a model that can be readily visualised (Moor and Russell, 1967). According to Kumar and Sharma (1987), numerical classification is useful in studying quantitative relationships among the complex groups of soils and is testing the validity of semi-quantitative or qualitative natural classification system.

In the beginning, the application of numerical taxonomy to soils in India was reported by Seth and Talati (1968), Gaikwad *et al.* (1977) and Sharma and Sharma (1979) on smaller number of soils and on a very limited scale. Subsequently a large number of soils have been studied and classified according to USDA Soil Taxonomy and numerical taxonomy. It is observed from the available literature that the numerical classification of many soils in general is in conformity with their USDA taxonomic classification with a very few exceptions (Kumar and Sharma 1987; 1990; 1993; Srivatsava *et al.*, 1995; Karmakar *et al.*, 1995 and Singh *et al.*, 1996). Kumar while applying the numerical classification technique to the bench mark soils of India, found that the differences at order, suborder, great group, subgroup and family level were clearly established by 'd_{jk}' (Euclidean distance coefficient) values at which they joined together.

However, the information on the application of numerical classification on the soils of Kerala in general and on the soils under rubber in particular is not available at present.

2 Influence of soil properties on the performance of hevea

The crop management practices, nutritional management in particular for any crop is specific and rubber is no exception warranting a thorough study of the natural growth medium, the soil.

2.1 Physiographic features

Physiographic features such as soil depth, slope, aspect rockiness etc. have been reported to have profound influence on growth and yield of rubber (Chan *et al.*, 1972).

Soil depth is to be an important parameter influencing growth and yield of the perennial crop, rubber. Shallow soils restrict development of taproot affecting anchorage of trees.

Deep soils with large quantities of clay, which serve as a reservoir of moisture, help to tide over drought situation (Krishnakumar and Potty, 1992). Depth of more than 125 cm increased growth, yield and leaf nutrient content (Chan *et al.*, 1974). Soil depth is included as a component of soil productivity after it was evaluated in 13 soils on the dry matter production (Yew and Pusparajah, 1991).

The Malaysian experience about the influence of slope on the performance of hevea revealed that there was an increase in growth, nutrient status and yield up to a slope of 26 per cent (Chan *et al.*, 1974). However, Krishnakumar and Potty (1992) stated that nevertheless, rubber is grown satisfactorily in much steeper slopes.

Aspect is found to influence growth and performance of rubber significantly. Jiang (1981) reported that in China, rubber trees on the leeward slopes suffered less damage due to cold. Studies on the microclimate conducted in China revealed that the trees on south and west slopes suffer less cold damage. Aspect coupled with soil properties also influence growth of rubber trees. Saseendran *et al.* (1993) observed that the girth of rubber trees on south facing slope was significantly higher than on the north facing slope, while studying the effect of aspect on soil temperature and growth of hevea on hills of North East India. This was because of increase in soil temperature during winter season in the south-facing slope.

2. 2. Physical properties

Apart from its role in pre-assortment as selection of site, the physical properties influence uptake of nutrients and water, root growth etc. (Hartge, 1982). Physical properties are generally considered more important in assessing the merits of the soil with respect to hevea (Chan and Pusparajah, 1972). Bin (1977) reported that mean girth and yield measured in 100 trees on soil mapping units indicated that the better performance of hevea in Malaysia was related more to the physical properties. The over-riding importance of a good soil physical condition over that of a high soil fertility status in encouraging the dry matter production was demonstrated by Yew and Pusparajah (1991).

A wide range of textures had been reported in the soils under hevea (Krishnakumar and Potty, 1992). In Malaysia, lack of adequate clay has been found to affect the growth of rubber in some soil series due to poor nutrient retention and this has warranted rescheduling of fertiliser application (Sivanadyan, 1972). Clay content and physiography are reported to influence the performance of rubber. Bin (1977) reported that higher clay content in the down slope area in granite soils favours the growth of rubber.

High amount of clay has been reported to inhibit growth of hevea. However, high clay content coupled with high organic matter content and sesquioxides has been reported to offset this situation and favour growth of hevea (Soong, 1976). He reported that feeder root development of rubber is directly related to texture. A correlation study on the effect of soil texture on root development showed that root development has positive correlation with sand and negative correlation with clay (Soong, 1971; Samarappuli, 1996).

Other physical parameters like bulk density and porosity also affect the growth of rubber indirectly through their influence on soil erosion and consequent root development (Krishnakumar and Potty, 1992).

The productive potential of a soil is influenced by its moisture holding capacity and rubber being rainfed crop, this assumes greater importance (Krishnakumar, 1989). The moisture retained at various tensions was also found to vary depending on the nature and content of clay (Ali *et al.*, 1966; Abrol *et al.*, 1968). At field capacity, 19.5 % to 37.8% soil moisture was found to be retained in the surface soils of the west coast of India (Krishnakumar, 1989). Aina and Periasamy (1985) stated that soil physical properties could be used to estimate the available moisture storage capacity of the soils.

2.3 Soil physico-chemical properties

Hevea being primarily grown in the humid tropics in highly weathered soils low in pH and cations on the exchange complex, toxic concentration of aluminium can be a limiting factor in optimising growth and production of rubber (Krishnakumar, 1989). In acid soils cations such as Ca, Mg and K are frequently the growth limiting factors (Tanaka, 1981). Giving a short account of rubber growing soils of India, George (1961) reported that the pH of the rubber growing soils of India vary between 4.5 and 6.7. In acid soil at a pH of less than 4 it is not the low pH *per se* but the toxicity and / or deficiency of mineral nutrients that limit the crop production (Marschner, 1995).

One of the most important physico-chemical properties of a soil, which regulates the nutrient supply potential of a soil, is the cation exchange capacity (CEC). The CEC of any soil depends on the pH, organic matter, nature and content of soil colloids. The quantum of the CEC indicates the capability of a soil to adsorb and desorb the nutrient ions. The dynamics of nutrients like Ca, Mg and K is determined by the CEC of soils, and for a crop like rubber these nutrients are intimately associated with the yield of rubber (Krishmakumar, 1989). Rubber is grown in soils with a wide range of CEC. The range of CEC found in the rubber growing soils of Malaysia was 2.05 to 15.96 cmol (+) kg^{-1} (Soong and Lau, 1977) and it ranges from 3.55 to 18.02 cmol (+) kg^{-1} in soils under rubber in India (Krishnakumar and Potty, 1992).

2.4 Nutrient elements

The role of Ca in the mineral nutrition of rubber is important. However, it has been noted that the tree is adaptable to survive in a low Ca environment (Bolton, 1960). Ca/total cation ratio is reported to be important for root growth. In acid mineral soil a ratio lower than 0.15 may inhibit root growth. This is particularly important for subsoil penetration of roots (Howard and Adams, 1965). Calcium being phloem immobile roots should get the required Ca from soil itself.

Magnesium is another element of major importance to rubber. Applied Mg is reported to increase Mg status of trees. Excess magnesium in soils however, produces imbalance like pre-coagulation (Rubber Research Institute of Malaysia, 1969).

The role of potassium in cell water regulation is well known. As far as rubber is concerned, the available literature indicate that better growth resulted with the combination of more water and less potassium or less water and more potassium (Samarappuli *et al.*, 1993). According to Samarappuli (1996) significant differences were noticed in the development of feeder roots of rubber with different soil moisture levels and potassium levels.

In acid soils with pH below 5.5, Al, where it replaces other cations and simultaneously acts as a P fixer, occupies an increasing proportion of the cation exchange sites of clay minerals. A close correlation exists between the exchangeable Al, soil pH and inhibition of growth in most plant species (Adams and Moore, 1985). Aluminium in excess is found to affect the root growth of crops. Ulrich *et al.* (1984) noted an increasing damage in the fine roots of spruce trees with a decreasing ratio of Ca: Al.

Excess Mn has been reported to affect rubber as it affects the uptake of Mg. Excess application of Ca/Mg is reported to enhance Mn deficiency (Bolle-Jones, 1957).

3. Application of remote sensing

Remote sensing is a science of deriving information about an object from measurements made at a distance from the object by a sensor without being in physical contact. The observation is made on the reflected/scattered or self-emitted electromagnetic energy from the earth's surface in different wavelength bands. The reflectance / emittance patterns under different spectral / polarisation / temporal conditions provide signatures specific to a land cover class, which forms the basis for data interpretation (Deekshatulu and Joseph, 1991). Remote sensing applications cover diverse fields such as agricultural crop acreage and yield estimation, drought warning and assessment, flood control and damage assessment, land use / land cover mapping for agroclimatic planning, wasteland management, water resources management, ocean / marine resource survey and management, urban development, mineral prospecting, forest resources survey and management etc., thus touching almost all facets of national development (Rao, 1991).

A large volume of literature is available regarding the applications of remote sensing and digital image processing techniques. In this section, the literature with reference to identification of some forest tree species, some of the digital image processing techniques and application of remotely sensed data to the case of rubber is reviewed and presented

3.1. Identification of crop species and mapping

Crop species identification and discrimination is based on the fact that each crop has a unique spectral signature. The identification and acreage estimation broadly consists of identifying representative sites of various crop / land cover classes on the images based on the ground truth collected, generation of signatures for different sites and classifying the image using training statistics (Parihar and Navalgund, 1992).

Identification of teak forests / plantations was reported by Jadhav (1992), Menon and Ranganath (1992) using Indian remote sensing satellite (IRS) LISS-II data in Sonbhadra district of Uttar Pradesh and IRS LISS-I data in the Silent Valley of Kerala respectively. The sal forests were identified using IRS LISS-II data in South Forest Division of Sikkim (Jadhav, 1992), Midnapore Forest Divisions (West and East) (Sudhakar *et al.,* 1992) and Rajaji National Park in Uttar Pradesh (Tiwari *et al.*, 1992). Similarly, oak was identified in South Forest Division of Sikkim by Jadhav (1992) and in Western Himalayas by Tiwari *et al.* (1992) by using the IRS LISS-II data. The conifer forests were identified in Sikkim as reported by Jadhav (1992) and in Western Himalayas (Tiwari *et al.*, 1992). Tiwari *et al.* (1992) identified deodar forests in Western Himalayas using the IRS LISS-II data.

The other forest types namely moist and dry deciduous forests, evergreen, subtropical hill forests, semi-evergreen, mixed deciduous forests were identified and reported by different workers (Jadhav, 1992; Menon and Ranganath, 1992; Tiwari *et al.*, 1992) all by using the IRS data. Among the monocultures, Sinha and Karale (1992) using both LISS-I and LISS-II of IRS mapped the orange plantations in Maharashtra. Cashew, eucalyptus, causurina and *Acasia arabica* were identified by Sudhakar *et al.* (1992) and the delineation of tea plantations was reported by Menon and Ranganath (1992)

Perhaps, Gopinath and Samad (1985) while evaluating the Landsat-TM data for mapping the rubber area under smallholdings in Kerala reported the first report on the identification of rubber in India. The identification of three classes of rubber plantations was reported in Thailand using SPOT 1 data by Bruneau *et al.* (1988). Similarly in Liberia also the distribution of rubber was investigated by Jeanjean *et al.*, (1991) using the SPOT data. Menon (1991) reported that the rubber plantations were identified in Thrissur region using IRS data. Menon and Ranganath (1992) located rubber plantations in the Silent Valley region of Kerala using LISS-I data while mapping the vegetation types.

3. 2. Classification techniques

Classification is of two types; supervised and unsupervised. The supervised classification used the priori probabilities, derived from ground truth information, whereas the latter does not make prior use of the ground truth information but generates spectral signatures by using various kinds of clustering techniques. Decision rules are then applied based on ground information or otherwise using the spectral statistics generated after clustering on the entire image to derive a classified map (Radhakrishnan *et al.*, 1992).

The use of supervised classification technique which is an automatic decision making process based on the priori probabilities using maximum likelihood classifier is reported by several authors while trying to identify different vegetation types (Jadhav, 1992; Tiwari *et al.*, 1992; Menon and Ranganath, 1992; Sudhakar *et al.*, 1992; Tiweari *et al.*, 1992; Katoh, 1993; Franklin *et al.*, 1994; Nair and Menon, 1998).

There are reports of using unsupervised classification techniques in identifying the vegetation types using clustering algorithm. Jadhav (1992) used this technique and delineated five forest vegetation types and two tree savannah types after ground truth and merging of different spectral classes. Jusoff and Rasol (1995) studied the deforestation rate in peninsular Malaysia using unsupervised classification technique. They reported that the accuracy of classification was 90%.

3. 3. Vegetation Indices

It is possible to characterize the spectral response characteristics of healthy vegetation, dead or senescent vegetation and the dry soil in different parts of the electromagnetic spectrum. Healthy vegetation reflects 40 to 50 per cent of the incident NIR (0.7 to 1.1 μm) energy with chlorophyll absorption being 80 to 90 per cent of the incident energy in the visible band (0.4 to 0.7 μm) (Jensen, 1986). Making use of these phenomena different vegetation indices were developed. The normalised vegetation difference index (NDVI) is one such and is being used round the globe in agriculture and forestry in interpreting the health of the green biomass (Radhakrishnan *et al.*, 1992).

Jagdeesh *et al.* (1992) employed the NDVI for forest stratification in Maharashtra while using the IRS, LISS-II data and found that the forest density classes broadly showed good agreement between NDVI classes and forest stock. Closer observation revealed that variations in NDVI were resulting from deferring moisture conditions.

MATERIALS AND METHODS

MATERIALS AND METHODS

Various methods were adopted in conducting the soil survey and classification, field survey and in the application of remote sensing techniques to identify rubber. The materials and methods were described under each experiment.

Experiment 1. Taxonomic classification of soils under rubber

Hevea is grown in Kerala in soils varying from relatively undeveloped Entisols to highly weathered Ultisols. For practical fertility management, information on different soils of given area is essential. In this context, a study was undertaken to characterise and classify some major soils under rubber, according to the norms of Soil Taxonomy (Soil Survey Staff, 1975). The *modus operadi* of this experiment is described below.

1.1 Selection of profile sites

The selection of the sites for profile excavations was based on the soil resource map of Kerala prepared and published by the National Bureau of Soil Survey and Land Use Planning (1993).

The physiographic base map of Kerala State had 38 physiographic units defined by shape of the land, crop cover and photometric characteristics such as colour tone, texture and pattern of the features observed in the Landsat imageries. Out of the 38 units, 6 units predominantly under rubber were selected for the present study. The details are given in Table 1.

In each physiographic unit, three soil profiles were cut one each from the top, middle and bottom of the catena of a hill under rubber to ascertain the impact of the slope on the soils properties. The details of the profile sites are given in Table 2. The soil profiles were cut to a depth of 180 cm or up to the parent material whichever was shallower. The cut profiles were exposed for 48 hours before taking the observations on the soil morphology.

1.2 Morphological features

The morphology of all the profiles were described based on the criteria established by the Soil Survey Staff (1975). The colour of the soils was noted using colour chart (Munsell, 1975). The taxonomic classification of the soils was done as per the Keys to Soil Taxonomy (1992).

1.3 Soil sample collection and preparation

The soil samples were drawn in sufficient quantities from the pedogenic horizons after the morphological study of the soil profiles. Soil samples were air dried and passed through 2mm sieve and preserved in labelled polythene bags for analysis.

1.4 Soil analysis

Soils collected in the above experiment were analysed for physical, physicochemical and chemical properties as detailed below.

Particle size analysis was done for all the samples collected in Experiment 1 by International pipette method. Soil pH was measured in both soil-water and soil-KCl (1*N*) suspensions (1:2.5 ratio) using glass pH electrode (Jackson, 1958) in the all soil

Table 1. General characteristics of physiographic units selected

Physiographic unit	Map symbol	Name of the Physiographic unit	Geology
PU1	K18	Gently and moderately sloping uplands of Wayanad Plateau in Hills and Uplands	Gneisses
PU2	K29	Very gently and gently sloping uplands with valleys in Hills and uplands	Precambrian archaean charnokites
PU3	K11	Very gently to moderately sloping laterites of Central Kerala (midlands)	Precambrian archaean charnokites
PU4	K07	Lowland laterites of coastal plains	Tertiary pleistocene laterite
PU5	K09	Laterite mounds in the midland plains	Precambrian archaean charnokites
PU6	K12	Very gently to moderately sloping midland laterites with valleys of South Kerala (midlands)	Precambrian archaean charnokites

samples collected in the above experiment. Cation exchange capacity in all the soil samples was determined by ammonium acetate method (Jackson, 1958) and by summation of the cations displaced by $BaCl_2$-TEA (Black (1965).

Organic carbon was estimated in the soil samples by Walkley and Black method of wet oxidation as described by Nelson and Sommers (1996). Total nitrogen was estimated in the soil samples collected from the field studies by Kjeldahl method as outlined by Bremner (1996).

The extractable acidity in all the samples was measured by $BaCl_2$-TEA method as detailed by Black (1965). Exchangeable Al (1:10 soil, 1*N* KCl ratio) was estimated by colorimetry using aluminon (Hsu, 1963 and Jayman and Sivasubramaniam, 1974). The exchangeable cations were determined in the soils samples by ammonium acetate method (1: 10 soil and ammonium acetate (1*N*) shaken for 5 minutes). Exchangeable Ca and Mg were estimated by AAS and exchangeable K and Na by flamephotometry.

Effective cation exchange capacity (ECEC) was determined by summation of ammonium acetate extractable bases viz. Ca, Mg, K and Na and 1*N* KCl extracted Al as described by Sumner and Miller (1996).

Experiment 2:

2.1 Fertility Capability Classification

Soil Taxonomy considers all measurable characteristics of soils up to a depth of 2 m for classification. But all characteristics may not be relevant for fertility purposes. Hence a system called fertility capability sification was developed which is designed to group those soils that have same kind of limitations from the fertility management point of view. Hence an attempt was made to study the FC classification of some major rubber soils

2.1.1 Soil sample collection

Four small pits of 50 X 50 X 50cm dimensions were dug in and around the soil profiles cut in Experiment 1, in all the locations. Soil samples were drawn from all the four pits as well as the profile from 0 - 20 and 20 - 50 cm layers separately for establishing the FC classes. Soil samples were air dried, processed and preserved for the analysis.

Table 2. Details of soil profiles sites

Physio-graphic unit	Reach of slope	Location	District	Profile ID
PU1	Upper	Kammana village	Wayanad	PU1A
PU1	Middle	Kammana village	Wayanad	PU1B
PU1	Bottom	Kammana village	Wayanad	PU1C
PU2	Upper	Pullangode Rubber Estate	Malappuram	PU2A
PU2	Middle	Pullangode Rubber Estate	Malappuram	PU2B
PU2	Bottom	Pullangode Rubber Estate	Malappuram	PU2C
PU3	Upper	Panamkutty village	Thrissur	PU3A
PU3	Middle	Panamkutty village	Thrissur	PU3B
PU3	Bottom	Panamkutty village	Thrissur	PU3C
PU4	Upper	RRII farm	Kottayam	PU4A
PU4	Middle	RRII farm	Kottayam	PU4B
PU4	Bottom	RRII farm	Kottayam	PU4C
PU5	Upper	Cheruvally Rubber Estate	Kottayam	PU5A
PU5	Middle	Cheruvally Rubber Estate	Kottayam	PU5B
PU5	Bottom	Cheruvally Rubber Estate	Kottayam	PU5C
PU6	Upper	Central Experiment Station of RRII, Ranny	Pathanamthitta	PU6A
PU6	Middle	Central Experiment Station of RRII, Ranny	Pathanamthitta	PU6B
PU6	Bottom	Central Experiment Station of RRII, Ranny	Pathanamthitta	PU6C

2. 1. 2. Soil analysis

Soil texture in the soil samples collected for FC classification was determined by the method followed in section 1.4. Similarly the soil pH was measured using glass electrode in 1:1 soil water suspension. KCl (1*N*) extractable Al was estimated colorimetrically as mentioned above (section 1.4). Exchangeable Ca, Mg, K and Na were determined by the method as mentioned in section 1.4 and the ECEC was calculated. In addition to that Morgan reagent extracted K and Mg were determined by flamephotometry and AAS respectively.

2. 2. Numerical classification of soils

The numerical classification of the soils identified in the survey was attempted to bring out important relationships among the individuals as well as the groups of soils of the study areas. The other aim of the numerical classification is to test the validity of semi-quantitative or qualitative natural classification systems i.e. the Soil taxonomy.

2.2.1 Selection of soils

The soils identified in Experiment 1 were used as the operational taxonomic units (OTU) in the numerical taxonomy.

2. 2. 2. Selection of soil characteristics

Thirtyfive soil characteristics including morphological, physical, physioco-chemical and chemical characteristics as suggested by Arkley (1976), were considered for each soil for comparison purpose.

2. 2. 3. Coding and standardisation of soil characteristics

The qualitative soil characteristics were coded as per the suggestions given by Kumar and Sharma (1987). Both quantitative and coded attributes were standardised by variance method. However, the binary attributes were not standardised as recommended by Sneath and Sokal (1973). All the standardised variables were made positive by adding a common constant value of 4 after verifying the largest negative value. The euclidean distance was calculated among all the soil pairs with all the soil properties and the cluster analysis was done by unweighted pair group method using averages (UPGMA) sorting strategy. The classification of soils is given as dendrogram in Fig 1 and is described subsequently.

2. 2. 4. Computation of taxonomic distance

The taxonomic distance between any two soils (OTUs) was computed in terms of average Euclidean distance coefficient (d_{jk}) suggested by Sneath and Sokal (1973) using appropriate computer software.

2. 2. 5. Presentation of taxonomic structure

The taxonomic structure worked out using Euclidean distance coefficient was presented by using the Unweighted Pair Group Method using Arithmetic averages (UPGMA) as described by Sneath and Sokal (1973) and given as a dendrogram.

Experiment 3. Relationship between soil properties and the growth of rubber

It is essential to understand the soil-plant relationships to device or to refine the crop management. Soil research is site specific research and soils do vary in nature thus evoking differential responses of plant in varying environments. It is a fact that soil, plant and atmosphere are in continuum and it is called soil-plant-atmospheric continuum (SPAC). It must be obvious to study the influence of weather not only on the plant performance but also on the soil environment as it influences several reactions taking place in soils because of changing temperature and soil moisture contents, the important reaction components. With this background an experiment was conducted to study the growth performance of rubber plants in different soils over one year corresponding to one annual cycle of weather as described below.

3. 1. Selection of sites

14 different fields belonging to the physiographic unit K11 (NBSS & LUP, 1993), spread over Thrissur district of Kerala were selected. These soils are planted with popular clone of rubber, RRII 105 in 1994 and maintained under common recommended management practices in general. Some of the details of the sites are given in Table 3.

3. 2. Observations

The observations on plant parameters, the girth and the height and on soil characteristics were taken as detailed below.

3. 2.1 Plant parameters

In all the fourteen rubber plantations, the plant girth was measured on 25 plants at a height of 10 cm from the bud union. Plant

Table 3. Relevant details of the experimental sites

Site No.	Location	Slope	Plant density plants/ha
1	Chimini rubber estate	7°	468
2	Bharatha	1°	474
3	Bharatha	1°	400
4	Plackode	14°	538
5	Panamkutty	21°	694
6	Panamkutty	10°	769
7	Kundai estate, HML	3°	426
8	Chaippankuzhy	15°	492
9	Chaippankuzhy	10°	553
10	Payyankulam	3°	666
11	Ponnumkunnu	2°	558
12	Thiroor	10°	466
13	Chettikulam	2°	598
14	Perambra	1°	480

height was also measured from ground level to the tip of the plants. Both girth and height measurements were taken at bimonthly intervals starting from November 1996 to September 1997, covering one annual cycle of weather and growth.

3. 2. 2. Soil parameters

Various soil parameters to study soil-plant relationships were studied in the soils col

lected from experimental sites at different times as described below.

3. 2. 2.1. Soil samples collection

Soil samples from a depth of 0 - 30 cm in all the 14 fields under the study were collected at bimonthly intervals. A single composite sample, from five samplings from plant bases was used for chemical analysis. A total of six soil samplings were done simultaneously with plant parameter recordings in a span of one year. Soil samples were air dried and processed and preserved in polythene covers for analysis.

3. 2. 2. 2. Soil analysis

Soil texture was determined by International pipette method as mentioned in Section 1.4. The field capacity of the soils of experimental sites was determined by pressure plate apparatus at 1/3 bar pressure. Soil pH in 1:2.5 soil water suspension was measured in all the samples collected at bimonthly intervals from the experimental sites(section 1.4).

Organic carbon, total N were estimated in these soil samples by Walkley and Black and Kjeldahl methods as described above. Exchangeable bases viz. Ca, Mg, K and Na were determined by ammonium acetate method as stated earlier. Exchangeable Al was determined by colorimetry using aluminon reagent as referred earlier. DTPA extractable Fe, Mn, Zn and Cu were estimated by AAS (section 1.4).

3. 3. Soil taxonomy in experimental sites

Soil profiles were cut in all the 14 fields under the above study to a depth of 180 cm or upto the parent material or which ever was the shallower. The cut profiles were exposed for 48 hours before taking the morphological observations and soil samples. Morphology was studied in the field and the soil samples were drawn from all the pedogenic horizons separately. Soils were processed and preserved for laboratory characterisation in well-labelled polythene bags.

3. 3. 1. Soil chemical analysis

The relevant soil analysis was done as mentioned in section 1.4 meant for soil characterisation for classification purposes.

3. 4. Fertility capability classification in the experimental sites

Four small pits of 50 x 50 x 50cm dimensions were dug in the sites of profiles spread over the area. From these pits as well as soil profiles, soil samples were taken from the depths of 0-20 and 20-50 cm to establish the FC Classes for the soils. Soil samples were air dried, processed and preserved for analysis.

3. 4.1. Soil chemical analysis

All the soil samples collected from different fields in different localities meant for FC classification were analysed for physical, physico-chemical and chemical properties by standard methods as described earlier (2.2).

3.5 Statistical analysis

The entire data generated in the above sections was subjected to statistical tests using appropriate statistical tools and the results are tabulated and discussed subsequently.

Experiment 4. Establishment of spectral signature to rubber using satellite imagery

Application of satellite remote sensing technology in agriculture is a fast growing filed in applied sciences. Digital image processing is a highly advantageous technique as it provides flexibility in enhancing the image qualities for better interpretability compared to the visual interpretation. Spectral signature, a unique characteristic of a given species, for example, rubber in the present study, is a presentation of spectral reflectance in different regions of EMS at different times. Various steps involved in the establishment of spectral signature of rubber for identification using satellite remote sensing data are described below.

4.1. Study area

To establish the spectral signature, two study areas were selected. Both these areas are under the rubber estates owned by M/s Harrison Malayalam Limited, one being in Kottayam district (Cheruvally estate) and the other in Trichur (Kundai estate).

Cheruvally Rubber Estate

Cheruvally rubber estate is located in Kanjirappally taluk of Kottayam district. Geographically this estate is between longitudes 76.79° & 76.83° E and latitudes 9.46° & 9.49° N. Cheruvally estate has a rubber area of 800 ha with different clones having different ages and extents. Teak plantations, mixed forest and smallholdings of rubber surround this estate.

Kundai Rubber Estate

Kundai rubber estate is located in Mukundapuram taluk of Trichur district. Geographically this estate is located between the longitudes 76.39° and 76.46° E and the latitudes 10.37° and 10.42° N. This estate has an extent of 950 ha under rubber with different popular clones of different ages and extents. Mixed forest, teak plantations and small rubber holdings surround this rubber estate.

4. 2. Acquisition of satellite data

The digital data pertaining to the study areas was purchased from the National Remote Sensing Agency (NRSA), Hyderabad, the authorised distributors of satellite data in India. With the help of the reference maps for IRS-1B (LISS II) and 1C (LISS III) the paths and rows to which the study areas belong to were identified after referring the orbital calendars for IRS-1B and 1C and making use of the digital browsing facility, suitable dates of data acquisition were selected. The information about the path and row of the study areas

Study area	Path	Row	Date of pass	Satellite
Cheruvally Estate	25	62	30 Jan 97	IRS-1B
	25	62	14 Mar 97	IRS-1B
	100	67	26 Feb 97	IRS-1C
Kundai Estate	26	61	29 Jan 97	IRS-1B
	26	61	26 Feb 97	IRS-1B
	99	66	21 Feb 97	IRS-1C

dates of pass of the satellite(s) and the satellite used are given.

The ground resolutions of the sensors LISS II of IRS-B and LISS III of IRS-1C are 36.25 m and 23 m respectively. The bands 2, 3 and 4 of IRS - 1B and 1C used in the present study represent green (0.52 - 0.59 µm), red (0.62 - 0.68 µm) and near infrared (0.77 - 0.86 µm) regions of EMS. The digital data on the dates of pass 29 Jan 97 and 30 Jan 97 pertaining to Cheruvally estate and Kundai estate respectively was given as geocoded product and the others were supplied as standard products.

4. 3. Digital image processing

The digital data acquired by both IRS-1B and 1C pertaining to the study areas and above mentioned dates of pass was processed by using the digital image processing software IDRISI for Windows 2.0. The various steps of image processing of the digital data are described below.

4. 3.1. Conversion of digital data

The first step was the splitting of the digital data into individual band data namely band 1, band 2, band 3 and band 4 using the BILIDRIS option. BILIDRIS is used to pull apart a byte-format band-interleaved by line (BIL) image file into a series of band sequential (BSQ) images in IDRISI for Windows format. After this only three bands namely 2,3 and 4 were used in the study.

4. 3. 2. Geometric correction

The satellite data for both the study areas were supplied as geocoded product only one time and the other two times as standard product. For change detection and comparison it is required to have all the data in geocoded form. Hence, the other standard products were geocoded using the RESAMPLE option in the REFORMAT menu for image resampling and geometric correction. In this, the geocoded product was taken as reference to correct the other images using thirty points of reference covering entire area. In the digital processing of images of Cheruvally estate area, during the geocoding of 1B image (14-03-97) and 1C image (26-02-97) using 1B image of 29-01-97 as reference, the overall root mean square error (RMS) was kept at 0.5461 and 0.7905 (below 1.0) by deleting certain control points having high RMS. Similarly in case of Kundai estate also the overall RMS value was 0.7552 geocoding 1C (21-02-97) image using 1B (30-01-97) image as reference. The entire geocoding process was done individually for all the bands of interest viz. band 2, 3 and 4 in case of IRS 1-B and 1C.

4. 3. 3. False colour composites (FCC)

False colour composites were made with band 2, 3 and 4 data of 1B and 1C. The composites were made with linear stretching with 1% saturation for better interpretability.

4. 3. 4 Normalised difference vegetation index (NDVI)

The normalised difference vegetation indices which indicate the greenness of a given vegetation, were calculated for all the images using the SCALAR option in the ANALYSIS menu using bands 3 and 4 data of 1B and 1C. The NDVI is calculated by the formula

NDVI = (Infrared-Red)/(Infrared + Red)

4. 3. 5. Supervised classification

A supervised classification was attempted in 1C image pertaining to Cheruvally estate area and in 1B image of Kundai estate area. Signatures of all the known features were made using MAKESIG option of ANALYSIS menu. MAKESIG created signatures from information contained in remotely sensed images for training site polygons. These signatures were used to perform a supervised classification using the MAXLIKE module. The training site polygons had been previously defined as a vector file of polygons. This vector file was created using the on-screen digitising feature. Using the same identifier for all polygons of the same class many training site polygons were drawn for a single class. MAXLIKE undertook a maximum likelihood classification of remotely sensed data based on information contained in a set of signature files. The maximum likelihood classification is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the probability that it belongs to each of the signatures being considered.

4. 3. 6. Change detection

A combined image created with both FCCs and NDVI images to see the change in rubber estates over time, during and after wintering. In this exercise, the boundaries of both the rubber estates were digitised using on-screen digitiser and the vector polygons were rasterised using INITIAL and POLYRAS options. These vectors were superimposed and the FCC and NDVI images were extracted by masking technique. This was done in both the study areas separately.

4. 3.7. Spectral and temporal variations

An exercise on spectral and temporal variations from different vegetation types namely, rubber, teak and mixed forest and river was done. In this exercise, the vector maps were created for each class with on-screen digitising feature, and the vector polygons were rasterised using INITIAL and POLYRAS options. These vector maps were used in querying using QUERY option in ANALYSIS menu to obtain mean digital numbers from each class. The querying was done with each vector in all bands, in all three times and in both the study areas. The mean reflectance was calculated by the formulae as given below:

Mean reflectance % (1B) = (Digital Number x 100)/128

Mean reflectance % (1C) = (Digital Number x 100)/256

4. 4. Interpretation of data

The resulting images from the digital image processing pertaining to the two study areas, at different times were studied and the interpretations regarding the establishment of a spectral signature for rubber, were given in the chapter on Results and Discussion

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of different experiments conducted as mentioned in the previous chapter are presented experimentwise and discussed.

Experiment I. Taxonomic classification of soils under rubber

1. 1. Properties of soils under rubber

As described under Materials and Methods, profile pits were taken at six locations representing six physiographic units. In each physiographic unit, profiles were excavated from upper, middle and bottom reach to study the influence of slope. Considering the overwhelming influence of topography on soil characteristics, the results are compared topographywise. The taxonomical grouping of the soils is attempted as per the Keys to Soil Taxonomy (Soil Survey Staff, 1992).

1.1.1. Soil of upper reaches of slope

1.1.1.1. Morphology of soil profiles

The soil profiles cut in the upper reach of slope in all the six physiographic units (PU1 to PU6) located in five districts are described for the morphology in Table 4. The description indicates that the soils on the upper reaches are moderately deep (75-100 cm) as found in PU5 to deep (101-150 cm) in other areas except in profile in PU1 where the depth class is very deep (>150 cm). The moist colour showed that all the surface horizons are dark coloured as indicated by the hue 10 YR. This is because of enrichment of soils by organic matter as a result of recycling of leaf litter added by the deciduous rubber tree. In soil from RRII (PU4), Cheruvally Estate (PU5) and Central Experiment Station (PU6), the subsurface horizons were also dark because of the prolonged incorporatien of organic matter since these plantations were in second cycle of planting. The hue of the lower horizons varied from 7.5 YR to redder hue of 2.5 YR. There were variations in value and chroma (Table 4).

Boundaries between horizons were found varying from clear smooth to diffuse wavy in different profiles and horizons, which would have resulted from the pedogenic processes. The texture in the surface horizons was sandy clay in all profiles except in Cheruvally Estate (PU5) where it was sandy clay loam. In the subsurface, the texture was sandy clay, sandy clay loam and clay. This is because of differential migration of clay from surface to subsurface. Gombeer (1977) reported that mobilisation, migration and subsequent immobilisation of clay colloid in tropical soils were major pedogenic processes. The low clay content in the surface horizons could be attributed to the loss of clay by run off.

The structure was seen varying from crumb to subangular blocky and that all the structures were medium in size and weak to moderate in strength. The structural changes in different profiles and horizons were due to the particle size composition as well the content and influence of organic matter. The influence of organic matter on soil structure in surface was clearly seen in the second cycle plantations which resulted in crumb structure. The structure in subsurface horizons was medium and moderate subangular blocky.

The consistence in surface horizons was once again the result of clay and organic matter. In second cycle rubber plantations the dry consistence was dry soft and it was moist friable. In the subsurface horizons the consistence was dry hard and moist firm In general, which might be as a result of decreasing

Table 4. Morphological characteristics of profiles on the upper reach of slope

Horizon	Depth (cm)	Colour (moist)	Boundary	Texture	Structure	Consistence
	1. PU1A (Kammana village, Mananthawadi taluk, Wayanad district)					
Ap	0-24	7.5 YR 4/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	24-52	7.5 YR 5/4	gw	c	m2sbk	dh, mfi, ws, wp
Bt2	52-75	7.5 YR 5/4	gw	c	m2sbk	dh, mfi, ws, wp
Bt3	75-95	7.5 YR 5/6	gw	c	m2sbk	dh, mfi, ws, wp
Bt4	95-127	7.5 YR 5/6	gw	c	m2sbk	dh, mfi, ws, wp
Bt5	127-160	7.5 YR 5/6		c	m2sbk	dh, mfi, ws, wp
	2. PU2A (Pullangode Rubber Estata, Nilambur, Malappuram district)					
Ap	0-12	5 YR 5/4	cs	sc	m2sbk	dh, mfi, wss, wps
Bt1	12- 34	5 YR 5/6	gw	c	m2sbk	dh, mfi, ws, wp
Bt2	34-65	5 YR 5/6	gw	c	m2sbk	dh, mfi, ws, wp
Bt3	65-90	5 YR 5/6	gw	sc	m2sbk	dsh,mfi wss, wps
Bt4	90-120	2.5 YR 4/4		sc	m2sbk	dh, mfi, ws, wp
	3. PU3A (Plackode village, Chelakkara taluk, Thrissur distrcict)					
Ap	0-22	10 YR 4/3	cs	sc	m1cr	ds, mfr, wss, wps
Bt1	22-45	7.5 YR 4/4	cs	c	m2sbk	dsh, mfi, ws, wp
Bt2	45-61	7.5 YR 4/4	dw	c	m2sbk	dh, mfi, ws, wp
Bt3	61-79	5 YR 5/4	dw	c	m2sbk	dh, mfi, ws, wp
Bt4	79-130	5 YR 4/4		sc	m2sbk	dh, mfi, ws, wp
	4. PU4A (Rubber Research Institute of India, Kottayam district)					
Ap	0-13	10 YR 5/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	13-27	10 YR 5/4	gw	c	m2sbk	dh, mfi, ws, wp
Bt2	27-60	10 YR 5/4	gw	c	m2sbk	dh, mfi, ws, wp
Bt3	60-87	7.5 YR 5/8	cs	c	m2sbk	dh, mfi, ws, wp
Bt4	87-120	5 YR 5/4		c	m2sbk	dh, mfi, ws, wp
	5. PU5A (Cheruvally Rubber Estate, Kottayam district)					
Ap	0-13	10 YR 3/3	cs	scl	m1cr	ds, mfr, wss, wps
AB	13-27	10 YR 3/3	cs	scl	m2sbk	dsh, mfi, wss, wps
Bt1	27-42	7.5 YR 4/4	gw	sc	m2sbk	dh, mfi, wss, wps
Bt2	42-65	7.5 YR 5/4	cs	c	m2sbk	dh, mfi, ws, wp
Bt3	65-80	5 YR 5/6		c	m2sbk	dh, mfi, ws, wp
	6. PU6A (Central Experiment Station, RRII, Pathanamthitta district					
Ap	0-16	10 YR 3/3	cs	sc	m1cr	ds, mfr, wss, wps
Bt1	16-28	10 YR 3/3	cs	sc	m1cr	ds, mfr, wss, wps
Bt2	28-42	5 YR 4/4	gw	sc	m2sbk	dh, mfi, wss, wps
Bt3	42-84	5 YR 5/6	cs	c	m2sbk	dh, mfi, ws, wp
Bt4	84-105	2.5 YR 4/6		sc	m2sbk	dh, mfi, ws, wp

organic matter and increasing clay content. However, the wet consistence was slightly sticky and slightly plastic in the surface horizons, which might be because of clay-humus formation thus moderating the stickiness and plastic nature of clay. In the subsurface horizons, the wet consistence was sticky and plastic because of higher quantity of clay and decreasing quantity of organic matter and the effect of the combination of these factors.

Table 5. Particle size analysis, OC, pH and ΔpH of profiles of upper reach

Profile	Horizon	Depth (cm)	Particle size (%)			Gravel (%)	OC %	pH	ΔpH
			Sand	Silt	Clay				
PU1A	Ap	0-24	49.6	9.6	40.8	20.5	2.07	4.8	-0.8
	Bt1	24-52	42.4	6.4	51.2	23.2	1.80	3.7	-1.2
	Bt2	52-75	42.4	6.4	51.2	15.6	1.41	4.2	-0.8
	Bt3	75-95	26.4	19.2	54.4	18.5	0.93	4.3	-0.4
	Bt4	95-127	29.6	16.0	54.4	30.4	0.78	4.0	-0.9
	Bt5	127-160	23.2	22.4	54.4	32.7	0.51	4.6	-0.8
PU2A	Ap	0-12	48.8	6.4	44.8	37.8	1.95	5.2	-0.9
	Bt1	12-34	42.4	6.4	51.2	41.2	0.96	4.8	-0.9
	Bt2	34-65	39.2	6.4	54.4	31.5	1.17	5.0	-1.0
	Bt3	65-90	52.0	6.4	41.6	23.7	0.63	5.2	-1.0
	BC	90-120	71.2	3.2	25.6	40.6	0.42	5.2	-0.9
PU3A	Ap	0-22	45.6	9.6	44.8	18.4	1.83	5.4	-0.5
	Bt1	22-45	42.4	9.6	48.0	31.5	1.16	5.3	-1.0
	Bt2	45-61	36.0	9.6	54.4	33.2	0.92	5.2	-0.9
	Bt3	61-79	32.8	9.6	57.6	12.4	0.83	5.2	-0.6
	Bt4	79-130	48.8	6.4	44.8	16.2	0.76	5.6	-0.9
PU4A	Ap	0-13	52.8	6.4	40.8	37.6	1.41	6.0	-1.0
	Bt1	13-27	36.0	6.4	57.6	32.1	1.09	4.2	-0.3
	Bt2	27-60	36.0	6.4	57.6	26.1	1.09	4.7	-0.7
	Bt3	60-87	42.4	6.4	51.2	25.4	0.55	4.6	-0.6
	Bt4	87-120	42.4	3.2	54.4	22.5	0.21	4.6	-0.6
PU5A	Ap	0-13	55.2	12.8	32.0	41.4	2.63	4.5	-0.6
	AB	13-27	58.4	9.6	32.0	46.0	1.99	4.4	-0.2
	Bt1	27-42	48.8	6.4	44.8	34.7	1.27	4.6	-0.3
	Bt2	42-65	36.0	6.4	57.6	30.9	0.86	5.7	-1.2
	Bt3	65-80	42.4	6.4	51.2	34.1	0.72	5.7	-1.3
PU6A	Ap	0-16	52.0	6.4	41.6	45.1	2.24	4.7	-0.6
	Bt1	16-28	52.0	3.2	44.8	48.2	1.18	4.6	-0.6
	Bt2	28-42	48.8	3.2	48.0	50.4	0.83	4.4	-0.5
	Bt3	42-84	42.4	3.2	54.4	42.6	0.51	4.3	-0.3
	Bt4	84-105	45.6	3.2	51.2	34.2	0.39	4.7	-0.2

1.1.1.2. Physical, physico-chemical and chemical properties

The data on particle size, textural classification, organic carbon content and pH in water as well as 1 *N* KCl are given in Table 5. The weighted averages of different soil properties are also given in Table 7. In general,, there is an increase in clay content with depth up to certain depth, which then turns inconsistent.

Table 6. Chemical and physicochemical properties of profiles on upper reach

Profile	Horizon	BaCl2-TEA extracted acidity, cmol kg^{-1}	1N KCl extracted Al, cmol kg^{-1}	Exchangeable bases ppm				CEC (cmol kg^{-1})		
				Ca	Mg	K	Na	Sum of cations	NH_4AoC clay	ECEC clay
PU1A	Ap	*8.9*	*0.10*	*0.90*	*0.61*	*0.24*	*0.15*	*10.8*	*12.7*	*4.9*
	Bt1	9.2	0.13	0.77	0.40	0.11	0.13	10.6	10.0	3.0
	Bt2	9.3	0.15	0.57	0.28	0.06	0.14	10.3	9.82	2.4
	Bt3	9.1	0.07	0.51	0.31	0.05	0.14	10.1	9.08	2.0
	Bt4	9.1	0.03	0.52	0.33	0.03	0.12	10.1	9.08	1.9
	Bt5	8.9	0.00	0.59	0.39	0.04	0.14	10.1	9.08	2.1
PU2A	Ap	9.1	0.04	0.84	0.86	0.08	0.16	11.0	11.8	4.4
	Bt1	9.3	0.15	0.62	0.29	0.05	0.13	10.4	9.88	2.4
	Bt2	9.3	0.10	0.50	0.21	0.03	0.12	10.1	9.09	1.8
	Bt3	9.1	0.02	0.57	0.28	0.03	0.11	10.1	11.9	2.4
	BC	9.0	0.01	0.64	0.45	0.03	0.13	10.3	19.6	4.9
PU3A	Ap	8.7	0.01	0.53	0.49	0.03	0.21	9.9	10.9	2.8
	Bt1	9.1	0.19	0.74	0.36	0.09	0.18	10.5	10.6	3.3
	Bt2	9.2	0.21	0.46	0.18	0.06	0.17	10.1	9.07	2.0
	Bt3	9.4	0.21	0.39	0.12	0.05	0.15	10.1	8.55	1.6
	Bt4	9.4	0.21	0.56	0.19	0.04	0.15	10.3	11.2	2.6
PU4A	Ap	9.3	0.21	0.79	0.41	0.05	0.17	10.7	12.6	4.0
	Bt1	9.0	0.09	0.42	0.20	0.11	0.14	9.9	8.44	1.7
	Bt2	9.5	0.24	0.29	0.14	0.10	0.13	10.2	8.61	1.6
	Bt3	9.3	0.21	0.38	0.18	0.09	0.16	10.1	9.63	2.0
	Bt4	9.1	0.15	0.55	0.33	0.08	0.17	10.2	9.16	2.4
PU5A	Ap	9.0	0.08	0.61	0.33	0.08	0.16	10.1	15.5	3.9
	AB	9.4	0.20	0.50	0.35	0.08	0.15	10.5	15.9	4.0
	Bt1	9.0	0.21	0.56	0.28	0.23	0.17	10.2	11.1	3.3
	Bt2	9.3	0.24	0.21	0.12	0.16	0.16	9.9	8.45	1.5
	Bt3	9.0	0.22	0.64	0.24	0.28	0.16	10.3	9.78	3.0
PU6A	Ap	8.7	0.22	0.32	0.18	0.24	0.23	9.7	11.5	2.8
	Bt1	8.8	0.21	1.28	0.59	0.35	0.17	11.2	11.9	5.8
	Bt2	9.4	0.20	0.40	0.28	0.19	0.11	10.4	10.5	2.5
	Bt3	8.9	0.18	0.80	0.50	0.17	0.19	10.6	9.44	3.4
	Bt4	9.1	0.21	0.91	0.54	0.14	0.19	10.8	10.2	3.9

Corresponding changes in the other fractions are also obvious.

The highest content of organic carbon is 2.63 per cent in the surface horizon of PU5 and the lowest is 0.21 per cent in the last horizon in soil profile PU6. As expected organic carbon is seen decreasing with depth in all soil profiles on the upper reaches of slope. Since the addition of organic matter in the form of crop residues takes place only in surface only its content generally decreases with the depth of the profile. Similar observations were made by Krishnakumar (1989) while describing the distribution of organic carbon down the profiles in some rubber growing soils.

It is seen that pH did not show any definite pattern with the depth of the profiles. A decrease followed by an increase in the lower layers in almost all the profiles could be due to enrichment of electrolytes leached down from the upper soil layers (Krishnakumar, 1989). The weighted means of the Δ pH (pH_{KCl} - pH_{water}) are given in Table 7. It is seen that mean values for the soil profiles

Table 7. Weighted averages of soil properties

Physio-graphic unit	Reach	BaCl2-TEA acidity, cmol kg⁻¹	1 *N* KCl Al, cmol kg⁻¹	Exchnageable, ppm				CEC (summation)	CEC (clay) (NH_4OAc)	ECEC (clay)	Δ pH
				Ca	Mg	K	Na	cmol kg⁻¹			
PU1	Upper	9.1	0.08	0.64	0.39	0.08	0.14	10.3	9.9	2.7	-0.8
	Middle	9.2	0.10	1.16	1.37	0.11	0.20	12.0	11.2	5.8	-0.3
	Bottom	9.1	0.17	0.19	0.08	0.12	0.16	9.7	12.0	1.8	-0.1
PU2	Upper	9.2	0.07	0.60	0.36	0.04	0.13	10.3	12.7	3.1	-1.0
	Middle	9.2	0.13	1.33	1.75	0.33	0.19	12.8	12.7	8.0	-0.9
	Bottom	9.2	0.20	0.07	0.03	0.11	0.15	9.6	12.1	1.5	-0.7
PU3	Upper	9.2	0.17	0.55	0.26	0.05	0.17	10.2	10.4	2.5	-1.0
	Middle	9.1	0.02	1.21	1.65	0.15	0.18	12.3	12.9	7.2	-0.6
	Bottom	9.3	0.19	0.19	0.10	0.09	0.15	9.8	14.2	2.1	-1.1
PU4	Upper	9.2	0.19	0.45	0.24	0.09	0.15	10.2	9.4	2.1	-0.6
	Middle	9.2	0.18	0.44	0.52	0.12	0.13	10.5	9.4	2.8	-0.5
	Bottom	9.4	0.21	0.15	0.06	0.05	0.15	9.8	9.2	1.2	-0.5
PU5	Upper	9.1	0.20	0.47	0.25	0.17	0.16	10.2	11.6	2.9	-0.6
	Middle	8.6	0.17	0.08	0.04	0.07	0.13	8.9	11.5	1.3	-0.4
	Bottom	9.3	0.19	0.16	0.14	0.14	0.13	9.9	11.7	1.8	-0.3
PU6	Upper	9.0	0.20	0.75	0.44	0.20	0.18	10.5	10.3	3.6	-0.6
	Middle	8.9	0.13	0.09	0.03	0.09	0.18	9.3	9.3	1.1	-0.4
	Bottom	9.4	0.23	0.14	0.08	0.09	0.14	9.9	10.9	1.5	-0.4

on upper reach are -0.84, -0.95, -1.02, -0.63, -0.55 and -0.61. The negative values suggest net negatively charged colloidal complex (Mekaru and Uehara, 1972; Adhikari *et al.*, 1993). The lower values of Δ pH values indicate that these soils are closer to their zero point of charge and indicates the pH-dependent charge minerals as evident by the mineralogical studies (Krishnakumar (1989).

The data on $BaCl_2$-TEA extracted acidity, 1*N* KCl extracted aluminium, exchangeable bases, CEC (by summation of cations and ammonium acetate method) and ECEC are given in Table 6. It is seen that there is not much variability in the $BaCl_2$-TEA extracted acidity among soil profiles as well as the horizons. The values for mean extractable acidity were 9.1, 9.2, 9.2, 9.2, 9.1 and 9.0 cmol kg^{-1} in the soil profiles of upper reach (Table 7).

Considerable variability is seen in 1*N* KCl extracted Al among these profiles and layers. The weighted mean values of exchangeable Al were 0.08, 0.07, 0.17, 0.19, 0.20 and 0.20

The weighted mean values of exchangeable Al were 0.08, 0.07, 0.17, 0.19, 0.20 and 0.20 cmol kg^{-1} soil indicating a definite pattern of increasing acidity as one moves from north to south of the State within the extent of area selected for the study. The role of high and well-distributed rainfall is well established in the release of exchangeable Al from the soil micelle.

There is a trend of increasing content of exchangeable Al with depth in all profiles with a few exceptions which might be due to the migration of clay over which the coatings of oxides of aluminium might be present

The exchangeable Ca appeared to be dominant over other bases in surface horizons. The weighted means of different profiles also indicated that Ca is dominant over other elements (Table 7). The mean values of Ca in different profiles were 0.64, 0.60, 0.55, 0.45, 0.47 and 0.75 cmol kg^{-1} in the soil profiles of upper reach (PU1 to PU6). It was observed that there was a general decrease in Ca down the profile and an increase in the last horizon in all the profiles except in the profile PU6 where is there is a continuous increase in Ca with depth. This accumulation in the last layer could be due to leaching of Ca from the above and accumulation in the last horizon. The higher content of Ca in surface is obviously due to application of rock phosphate which contains substantial amounts of Ca and retention by binding sites on exchange surface including that of organic matter.

Magnesium occupied second place in content after Ca in all surface layers and the weighted means also indicated the same. The mean values of Mg contents in these profiles on upper reach were 0.39, 0.36, 0.26, 0.24 0.25 and 0.44. It is noticed that the concentration of Mg also decreased with depth except in the last layer where an accumulation is seen. This could be because of leaching down and accumulation of Mg in the last horizon.
The mean values of exchangeable K in different soil profiles were 0.08, 0.04, 0.05, 0.09, 0.17 and 0.20 cmol kg^{-1} (Table 7). In majority of profiles, subsoil enrichment of K is noticed because of its high solubility and leaching down of K to bottom layers.

The exchangeable Na occupied fourth place in some profiles after Ca, Mg, and Al and in PU1, PU2, PU3 and PU4 it dominated over K and in PU5 and PU6 it stood after K. A further study is needed to look into the dominance of Na over K in acid soils, though Na is known to be more soluble than K and that the activation energy is less for Na compared to K. It is also seen that the differences in Na content among horizons was not much indicating the uniformity in the distribution of Na in a given soil profile. However, the last horizon had a slightly high accumulation of Na in all soil profiles indicating the leaching down and accumulation of Na to lower horizons.

The mean values of cation exchange capacity (estimated by summation and ammonium acetate method) and the calculated ECEC are given in Table 7. The CEC by ammonium acetate and ECEC are expressed as cmol (+) kg^{-1} clay. The CEC by summation method did not vary much among soil profiles as in the case of $BaCl_2$-TEA extractable acidity. The mean CEC (summation method) for the profiles were 10.3, 10.3, 10.2, 10.2, 10.2 and 10.5 cmol (+) kg^{-1} soil.
The CEC (ammonium acetate method) showed variability among profiles as well as horizons. The weighted average values for these profiles on upper reach of slope were 9.9, 12.7, 10.4, 9.4 11.6 and 10.3 cmol (+) kg^{-1} clay. Almost in all profiles there is a de-

creasing trend initially in values of CEC with depth and a slight increase again. This type of distribution is resultant of combined effect of organic matter and clay. It might be noted that there is an increase in clay content with concomitant decrease in organic matter. It appears that the contribution of organic matter in CEC is high as evident from higher CEC values in surface layer where OC content is high and clay is less (Table 6). Krishnakumar (1989) also reported the positive role of organic matter in CEC as evident by a significant correlation. The decrease with depth is substantial as a result of decreasing OC content rather than increase in clay.

The weighted average values of ECEC in the soil profiles on the upper reach were 2.7, 3.1, 2.5, 2.1, 2.9 and 3.6 cmol (+) kg^{-1} clay (Table 7). In general,, the depthwise distribution indicates that there is a decrease in ECEC with depth up to certain extent and then varies inconsistently in deeper layers. This is because the bases decreased down the depth except in last horizons which quantitatively contributed much to ECEC. However, in some cases, exchangeable Al increased in subsurface horizons, which might have caused variation accordingly in ECEC.

1.1.2. Soil of middle reach of slope

1.1.2.1. Morphology of soil profiles

The soil profiles cut in the middle reach of slope in all the six physiographic units located in Wayanad, Malappuram, Thrissur, Kottayam and Pathanamthitta districts (PU1 to PU6) are described for the morphology in Table 8. The description indicates that the soils on the middle reaches are moderately deep (75-100 cm) in Pullangode Rubber Estate (PU2) and RRII farm (PU4), deep (101-150 cm) as found in profiles of Panamkutty village(PU3), Cheruvally Rubber Estate (PU5) and Central Experiment Station of RRII (PU6). The soil profile on the middle reach of slope in Kammana village (PU1) yielded a very deep soil (>150 cm).

When moist, all the surface horizons were dark coloured as indicated by the hue 10YR except in a profile at Panamkutty (PU3) where the surface horizon showed a red colour of hue 7.5 YR. In fact,, this area was newly brought under rubber after making the terraces and other operations. The dark colour in other profiles was due to the enrichment of soils by organic matter through leaf litter added by rubber tree. In soils from Pullangode Rubber Estate (PU2), RRII (PU3), and Cheruvally Rubber Estate (PU5), the subsurface horizons were also dark coloured because of the same reason. As stated in the soils of upper reach, here also these plantations are in second cycle of rubber. The hue of the subjoining horizons varied from 7.5YR to 2.5 YR indicating more redness due to iron oxides.

Boundaries between horizons were found varying from clear smooth to diffuse wavy in different profiles and horizons, which might have resulted from the pedogenic processes. The texture in the surface horizons was sandy clay in all profiles except in Cheruvally Rubber Estate (PU5) and Central Experiment Station (PU6) where it was sandy clay loam. In the subsurface, the texture was sandy clay, sandy clay loam and clay as could be seen from Table 8. This is due to differential migration of clay from surface to subsurface. However, the texture in subsurface horizons of CES was sandy clay down the profile. The soil structure was crumb to subangular blocky in shape, medium in size and weak to moderate in strength. The structural changes in different profiles and horizons are due to

Table 8. Morphological characteristics of profiles in the middle reach of slope

Horizon	Depth (cm)	Colour (moist)	Boundary	Texture	Structure	Consistence
1. PU1B (Kammana village, Mananthawadi taluk, Wayanad district)						
Ap	0-14	7.5 YR 4/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	14-34	7.5 YR 5/4	dw	c	m2sbk	dh, mfi, ws, wp
Bt2	34-56	7.5 YR 5/4	dw	c	m2sbk	dh, mfi, ws, wp
Bt3	56-78	7.5 YR 5/6	dw	c	m2sbk	dh, mfi, ws, wp
Bt4	78-118	7.5 YR 5/6	dw	c	m2sbk	dh, mfi, ws, wp
Bt5	118-160	5 YR 5/8	-	c	m2sbk	dh, mfi, ws, wp
2. PU2B (Pullangode Rubber Estate, Nilambur, Malappuram district)						
Ap	0-17	10 YR 3/3	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	17-34	10 YR 3/3	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt2	34-62	7.5 YR 4/4	dw	sc	m2sbk	dsh, mfi, wss, wps
Bt3	62-96	7.5 YR 4/4	-	c	m2sbk	dsh, mfi, wss, wps
3. PU3B (Panamkutty village, Chelakkara taluk, Thrissur distrcict)						
Ap	0-18	7.5 YR 5/6	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	18-41	7.5 YR 4/4	dw	sc	m2sbk	dsh, mfi, ws, wp
Bt2	41-56	7.5 YR 4/4	cs	sc	m2sbk	dh, mfi, ws, wp
Bt3	56-79	5 YR 5/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt4	79-110	5 YR 4/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt5	110-125	5 YR 5/6	-	c	m2sbk	dh, mfi, ws, wp
4. PU4B (Rubber Research Institute of India, Kottayam district)						
Ap	0-10	10 YR 4/3	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	30-Oct	10 YR 4/3	gs	c	m2sbk	dh, mfi, ws, wp
Bt2	30-50	10 YR 4/3	cs	c	m2sbk	dh, mfi, ws, wp
Bt3	50-72	7.5 YR 5/8	cs	c	m2sbk	dh, mfi, ws, wp
Bt4	72-95	7.5 YR 5/4	-	c	m2sbk	dh, mfi, ws, wp
5. PU5B (Cheruvally Rubber Estate, Kottayam district)						
Ap	0-12	10 YR 4/3	cs	scl	m1cr	ds, mfr, wss, wps
Bt1	12- 23	10 YR 4/3	cs	scl	m2sbk	dsh, mfi, wss, wps
Bt2	23-44	7.5 YR 5/4	gs	sc	m2sbk	dh, mfi, wss, wps
Bt3	44-63	7.5 YR 5/4	cs	sc	m2sbk	dh, mfi, ws, wp
Bt4	63-106	5 YR 5/6	gs	sc	m2sbk	dh, mfi, ws, wp
Bt5	106-125	5 YR 5/6	-	sc	m2sbk	dh, mfi, ws, wp
6. PU6B (Central Experiment Station, RRII, Pathanamthitta district)						
Ap	0-26	10 YR 3/3	cs	scl	m1cr	ds, mfr, wss, wps
Bt1	26-40	7.5 YR 3/3	cs	sc	m1cr	ds, mfr, wss, wps
Bt2	40-58	5 YR 5/6	gs	sc	m2sbk	dh, mfi, wss, wps
Bt3	58-76	5 YR 5/8	gs	c	m2sbk	dh, mfi, ws, wp
Bt4	76-105	2.5 YR 4/6	-	sc	m2sbk	dh, mfi, ws, wp

the particle size composition as well the content and influence of organic matter.

The crumb structure in the surface and subsurface horizons in Cheruvally Estate and CES might be due to the influence of organic matter. The structure in subsurface horizons was medium and moderate subangular blocky.

As described in the soils on upper reach of slope, the consistence in all horizons varied from dry soft to slightly hard. The impact of organic matter on consistence is

Table 9. Particle size analysis, OC, pH and ΔpH of profiles of middle reach

Profile	Horizon	Depth	Particle size (%)			Gravel	OC	pH	ΔpH
		(cm)	Sand	Silt	Clay	(%)	%		
PU1B	Ap	0-14	54.4	6.4	39.2	25.8	1.74	4.3	-0.9
	Bt1	14-34	39.2	6.4	54.4	20.7	1.65	4.4	-0.7
	Bt2	34-56	36.0	3.2	60.8	16.1	1.20	4.5	-0.6
	Bt3	56-78	39.2	16.0	44.8	16.8	0.93	5.4	0.1
	Bt4	78-118	36.0	3.2	60.8	38.4	0.51	5.6	0.0
	Bt5	118-160	29.6	25.6	44.8	41.0	0.45	5.3	-1.0
PU2B	Ap	0-17	55.2	6.4	38.4	49.2	1.83	5.0	-0.8
	Bt1	17-34	48.8	6.4	44.8	45.7	1.65	4.8	-0.8
	Bt2	34-62	45.6	9.6	44.8	40.1	1.29	5.1	-1.1
	Bt3	62-96	36.0	6.4	57.6	42.6	0.78	5.0	-1.0
PU3B	Ap	0-18	55.2	6.4	38.4	23.6	0.72	5.2	-1.1
	Bt1	18-41	48.8	9.6	41.6	21.1	0.69	5.0	-1.0
	Bt2	41-56	52.0	9.6	38.4	25.0	0.72	5.1	-1.0
	Bt3	56-79	42.4	9.6	48.0	29.0	0.74	5.3	-1.0
	Bt4	79-110	32.8	12.8	54.4	38.7	0.51	5.5	-1.0
	Bt5	110-125	42.4	12.8	44.8	25.0	0.39	5.7	-1.0
PU4B	Ap	0-10	53.4	3.2	43.3	42.5	2.80	4.3	-0.3
	Bt1	10-30	39.2	9.6	51.2	32.1	2.19	4.3	-0.3
	Bt2	30-50	36.0	6.4	57.6	34.6	1.27	4.5	-0.4
	Bt3	50-72	32.8	3.2	64.0	24.3	0.72	4.8	-0.5
	Bt4	72-95	42.4	3.2	54.4	20.1	0.55	4.9	-0.9
PU5B	Ap	0-12	64.8	9.6	25.6	45.7	2.29	4.7	-0.3
	Bt1	12-23	61.6	9.6	28.8	401.0	1.66	4.6	-0.3
	Bt2	23-44	52.0	6.4	41.6	46.3	1.27	4.7	-0.4
	Bt3	44-63	52.0	6.4	41.6	34.2	0.81	4.7	-0.5
	Bt4	63-106	52.0	6.4	41.6	26.1	0.60	4.8	-0.6
	Bt5	106-125	45.6	6.4	48.0	24.6	0.53	4.9	-0.6
PU6B	Ap	0-26	61.6	9.6	28.8	42.8	2.36	4.6	-0.6
	Bt1	26-40	52.0	9.6	38.4	46.2	1.36	4.3	-0.3
	Bt2	40-58	48.8	6.4	44.8	57.1	1.09	4.6	0.0
	Bt3	58-76	42.4	6.4	51.2	35.6	0.65	4.8	-0.3
	Bt4	76-105	48.8	6.4	44.8	24.6	0.55	4.9	-0.5

reflected by dry soft consistence, which might have resulted from the moderating effect on the plastic nature of clay. Similarly the moist consistence in all the horizons varied from moist friable to firm, perhaps as a result of organic matter as well the of clay. The wet consistence varied from slightly sticky and slightly plastic to sticky and plastic in all the horizons, which is due to the combined effect of clay and organic matter.

1.1.2.2. Physical, physico-chemical and chemical properties

The data on particle sizes, textural classification, organic carbon content and pH in water as well as 1 *N* KCl are given in Table 9. The weighted averages of different soil properties are also given in Table 7. In general,, there is an increase in clay content with depth up to cer -tain extent. Corresponding changes in the other fractions are also seen. The variations in texture are discussed (Table 8).

Table10. Chemical and physicochemical properties of profiles on middle reach

Profile	Horizon	BaCl2-TEA extracted acidity, cmol kg^{-1}	1N KCl Al, cmol kg^{-1}	Exchangeable bases ppm				CEC (cmol kg^{-1})		
				Ca	Mg	K	Na	Sum of cations	NH_4AoC clay	ECEC clay
PU1B	Ap	9.0	0.18	0.73	0.40	0.10	0.19	10.5	12.9	4.1
	Bt1	9.0	0.02	0.85	0.68	0.13	0.12	10.8	9.57	3.3
	Bt2	8.9	0.12	0.96	0.66	0.11	0.19	10.9	8.59	3.4
	Bt3	9.0	0.13	1.02	0.69	0.11	0.19	11.0	11.8	4.8
	Bt4	9.7	0.15	1.37	2.26	0.11	0.21	13.6	10.3	6.7
	Bt5	9.0	0.04	1.44	1.89	0.12	0.23	12.7	13.2	8.3
PU2B	Ap	8.9	0.16	1.59	1.12	0.13	0.23	11.9	14.7	8.4
	Bt1	9.6	0.19	1.77	2.93	0.47	0.19	15.0	15.1	12.4
	Bt2	9.4	0.17	1.10	1.73	0.37	0.15	12.8	13.3	7.8
	Bt3	8.8	0.06	1.13	1.46	0.32	0.20	11.9	9.74	5.5
PU3B	Ap	9.3	0.03	1.09	2.09	0.33	0.16	12.9	15.6	9.6
	Bt1	8.7	0.03	1.12	1.11	0.25	0.19	11.3	13.0	6.5
	Bt2	8.8	0.01	1.28	1.61	0.10	0.23	12.1	14.8	8.4
	Bt3	9.7	0.00	1.33	2.42	0.08	0.17	13.7	13.1	8.3
	Bt4	9.0	0.00	1.21	1.30	0.07	0.18	11.7	10.2	5.1
	Bt5	9.2	0.02	1.27	1.58	0.09	0.17	12.3	12.9	7.0
PU4B	Ap	9.1	0.01	1.30	1.81	0.10	0.20	12.5	13.5	7.9
	Bt1	9.4	0.20	1.25	1.39	0.11	0.20	12.4	11.3	6.1
	Bt2	9.2	0.19	0.10	0.08	0.12	0.16	9.7	8.29	1.1
	Bt3	9.0	0.21	0.04	0.04	0.13	0.19	9.4	7.34	1.0
	Bt4	9.4	0.22	0.03	0.03	0.11	0.15	9.7	8.79	1.0
PU5B	Ap	9.3	0.17	0.07	0.03	0.09	0.13	9.6	18.6	1.9
	Bt1	9.4	0.19	0.08	0.04	0.09	0.13	9.7	16.7	1.8
	Bt2	9.3	0.22	0.09	0.07	0.12	0.16	9.7	11.5	1.6
	Bt3	9.2	0.21	0.07	0.04	0.08	0.17	9.6	11.4	1.4
	Bt4	9.4	0.18	0.08	0.04	0.07	0.12	9.7	11.5	1.2
	Bt5	9.2	0.17	0.14	0.04	0.07	0.16	9.6	9.91	1.2
PU6B	Ap	9.3	0.21	0.14	0.04	0.07	0.16	9.7	16.7	2.2
	Bt1	9.1	0.18	0.04	0.04	0.18	0.15	9.5	12.3	1.5
	Bt2	9.2	0.20	0.03	0.03	0.10	0.16	9.6	10.6	1.1
	Bt3	9.3	0.19	0.04	0.03	0.11	0.14	9.6	9.30	1.0
	Bt4	9.2	0.20	0.06	0.02	0.12	0.17	9.5	10.6	1.3

The highest content of organic matter is 2.80 per cent in the surface horizon of PU4 and the lowest is 0.39 per cent in the last horizon in soil profile PU3. The pattern of distribution of organic carbon down the profile is the same as that was found in soils of upper reach i.e. decreasing with depth. It is dur to the retention of higher organic matter or decomposed products in the surface horizon rather than the adjoining or subjoining horizons. Similar observations were made by Krishnakumar (1989) in some rubber growing soils regarding the distribution of organic carbon down the profiles.

It is seen from the data that pH did not show any definite pattern in the profiles. A de crease followed by an increase in the lower layers in almost all the profiles could be due to enrichment of electrolytes leached down from the upper soil layers (Krishnakumar, 1989).

The Δ pH (pH_{KCl} - pH_{water}) is measured and

Table 11. Morphological characteristics of profiles at the bottom reach of slope

Horizon	Depth (cm)	Colour (moist)	Boundary	Texture	Structure	Consistence
1. PU1C (Kammana village, Mananthawadi taluk, Wayanad district)						
Ap	0-14	10 YR 5/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	14-31	10 YR 5/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt2	31-62	10 YR 5/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt3	62-110	10 YR 5/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt4	110-140	10 YR 5/6	-	c	m2sbk	dh, mfi, ws, wp
2. PU2C (Pullangode Rubber Estate, Nilambur, Malappuram district)						
Ap	0-19	5 YR 4/4	cs	scl	m2sbk	dsh, mfi, wss, wps
AB	19-37	5 YR 4/4	gs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	37-58	5 YR 4/4	as	sc	m2sbk	dsh, mfi, wss, wps
Bt2	58-100	2.5 YR 4/4	gs	sc	m2sbk	dsh, mfi, wss, wps
Bt3	100-128	2.5 YR 4/4	gs	sc	m2sbk	dh, mfi, ws, wp
Bt4	128-158	2.5 YR 4/4	-	sc	m2sbk	dh, mfi, ws, wp
3. PU3C (Panamkutty village, Chelakkara taluk, Thrissur district)						
Ap	0-15	7.5 YR 5/4	cs	sc	m2sbk	dsh, mfi, wss, wps
BW1	15-28	5 YR 5/4	cs	c	m2sbk	dh, mfi, ws, wp
BW2	28-46	5 YR 4/4	cs	sc	m2sbk	dh, mfi, ws, wp
BW3	46-62	5 YR 4/4	gs	c	m2sbk	dh, mfi, ws, wp
BW4	62-90	5 YR 5/6	gs	c	m2sbk	dh, mfi, ws, wp
BW5	90-110	5 YR 5/6	-	sc	m2sbk	dh, mfi, ws, wp
4. PU4C (Rubber Research Institute of India, Kottayam district)						
Ap	0-13	7.5 YR 5/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt1	13-25	7.5 YR 5/4	gs	c	m2sbk	dh, mfi, ws, wp
Bt2	25-43	7.5 YR 5/8	gs	c	m2sbk	dh, mfi, ws, wp
Bt3	43-72	7.5 YR 5/8	gs	c	m2sbk	dh, mfi, ws, wp
Bt4	72-105	7.5 YR 5/8	-	c	m2sbk	dh, mfi, ws, wp
5. PU5C (Cheruvally Rubber Estate, Kottayam district)						
Ap	0-14	10 YR 4/4	cs	scl	m1cr	ds, mfr, wss, wps
Bt1	14-29	10 YR 4/4	cs	sc	m2sbk	dsh, mfi, wss, wps
Bt2	29-43	7.5 YR 5/4	gs	sc	m2sbk	dsh, mfi, wss, wps
Bt3	43-60	7.5 YR 5/4	cs	sc	m2sbk	dh, mfi, ws, wp
Bt4	60-88	5 YR 5/6	gs	sc	m2sbk	dh, mfi, ws, wp
Bt5	88-110	5 YR 5/6	-	sc	m2sbk	dh, mfi, ws, wp
6. PU6C (Central Experiment Station, RRII, Pathanamthitta district)						
Ap	0-14	10 YR 3/3	cs	sc	m2sbk	dsh, mfr, wss, wps
AB	14-25	10 YR 3/3	cs	sc	m2sbk	dh, mfi, wss, wps
Bt1	25-69	7.5 YR 4/4	gs	sc	m2sbk	dh, mfi, wss, wps
Bt2	69-104	7.5 YR 4/4	gs	sc	m2sbk	dh, mfi, ws, wp
Bt3	104-130	5 YR 4/4	gs	sc	m2sbk	dh, mfi, ws, wp
Bt4	130-150	5 YR 4/4	-	sc	m2sbk	dh, mfi, ws, wp

the weighted means are given in Table 7. It is seen that mean values for profiles on middle reach are -0.27, -0.94, 0.63, 0.51,-0.44 and -0.38. The negative values suggest net negatively charged colloidal complex (Mekaru and Uehara, 1972; Adhikari *et al.*,

Table 12. Particle size analysis, OC, pH and ΔpH of profiles of bottom reach

Profile	Horizon	Depth (cm)	Particle size (%) Sand	Silt	Clay	Gravel (%)	OC %	pH	ΔpH
PU1C	Ap	0-14	52.0	6.4	41.6	14.2	1.05	5.2	-0.9
	Bt1	14-31	39.2	9.6	51.2	12.6	1.02	5.3	-0.6
	Bt2	31-62	32.8	12.8	54.4	19.5	0.93	5.2	-0.9
	Bt3	62-110	39.2	12.8	48.0	9.4	0.75	4.9	-0.8
	Bt4	110-140	32.8	12.8	54.4	4.1	0.42	5.3	-0.3
PU2C	Ap	0-19	48.8	22.4	28.8	20.7	1.59	5.0	-0.8
	AB	19-37	48.8	19.2	32.0	18.6	1.17	4.9	-0.8
	Bt1	37-58	48.8	16.0	35.2	11.5	0.63	5.0	-0.9
	Bt2	58-100	52.0	3.2	44.8	14.3	0.48	5.0	-0.9
	Bt3	100-128	48.8	3.2	48.0	24.6	0.36	4.9	-0.8
	Bt4	128-158	48.8	3.2	48.0	20.6	0.30	4.7	-0.7
PU3C	Ap	0-17	48.8	9.6	41.6	7.2	0.99	5.8	-0.9
	BW1	17-36	55.2	12.8	32.0	7.6	0.67	6.1	-1.1
	BW2	36-52	61.6	6.4	32.0	8.6	0.53	6.2	-1.2
	BW3	52-86	58.4	6.4	35.2	8.3	0.44	6.2	-1.2
	BW4	86-112	61.6	6.4	32.0	10.2	0.39	6.2	-1.1
PU4C	Ap	0-13	54.4	6.4	39.2	38.4	0.32	4.9	-0.9
	Bt1	13-25	36.0	6.4	57.6	28.7	1.64	4.2	-0.3
	Bt2	25-43	36.0	6.4	57.6	34.6	1.22	4.1	-0.2
	Bt3	43-72	36.0	6.4	57.6	25.4	0.67	4.3	-0.4
	Bt4	72-105	42.4	6.4	51.2	21.8	0.44	4.6	-0.7
PU5C	Ap	0-14	61.6	3.2	35.2	34.1	1.64	5.0	-0.6
	Bt1	14-29	55.2	6.4	38.4	24.6	1.48	4.4	-0.7
	Bt2	29-43	55.2	6.4	38.4	28.1	1.16	4.5	-0.2
	Bt3	43-60	52.0	3.2	44.8	16.4	0.79	4.6	-0.2
	Bt4	60-88	52.0	3.2	44.8	18.2	0.60	4.5	-0.4
	Bt5	88-110	52.0	3.2	44.8	10.4	0.46	4.8	-0.3
PU6C	Ap	0-14	52.0	6.4	41.6	27.6	1.76	5.0	-0.7
	AB	14-25	55.2	3.2	41.6	25.7	1.25	4.2	-0.6
	Bt1	25-69	52.0	3.2	44.8	20.7	0.76	4.3	-0.2
	Bt2	69-104	48.8	6.4	44.8	14.2	0.53	4.7	-0.3
	Bt3	104-130	52.0	3.2	44.8	18.4	0.49	4.8	-0.7
	Bt4	130-150	45.6	6.4	48.0	14.8	0.44	5.0	-0.8

1993). The lower values of Δ pH their zero point of charge and points to the presence of pH dependent charge minerals as evident by the mineralogical studies conducted by Krishnakumar (1989)).

The data on $BaCl_2$-TEA extracted acidity, 1 *N* KCl extracted AL, exchangeable bases, CEC by summation of cations, ammonium acetate method and ECEC are given in Table 10. It is seen that there is not much variability in the $BaCl_2$-TEA extracted acidity among soil profiles and the horizons like in upper reach of slope. Values of mean extractable acidity were 9.2, .2, 9.1, 9.2, 8.6 and 8.9 cmol kg^{-1} in soil pro files of the middle reach (Table 7). Considerable variability is seen in 1 *N* KCl extractable Al among these profiles and layers. The weighted mean of exchangeable Al is 0.10, 0.13, 0.02, 0.18, 0.17 and 0.13 cmol kg^{-1} soil. Though the pattern of the content of Al on exchange surface does not follow that of the soils of upper reach, it is seen that higher exchangeable Al is noticed in high and well distributed rainfall area i.e., in Kottayam and Pathanamthitta regions which can be attributed to the influence of weather elements on weathering of rock and ultimate release of Al onto the exchange surface. The values of exchangeable Al in the present study however, are lesser and such occurrences of low exchangeable Al are also reported by NBSS & LUP (1999). while describing the soils under rubber in Kerala and Tamilnadu in some soil series. In these soils also accumulation of more Al in subsoil horizons might be due to the migration of clay along with the coatings of aluminium oxides. The weighted means of Ca in different pro-

Table 13. Chemical and physicochemical properties of soil profiles at bottom reach

Profile	Horizon	BaCl2-TEA extracted acidity	1N KCl ex-tracted Al	Exchangeable bases ppm				CEC (cmol kg^{-1})		
				Ca	Mg	K	Na	Sum of cations	NH_4AoC clay	ECEC clay
PU1C	Ap	8.9	0.17	0.12	0.03	0.11	0.19	9.4	11.2	1.5
	Bt1	8.9	0.16	0.06	0.06	0.13	0.18	9.4	9.13	1.2
	Bt2	9.0	0.13	0.08	0.04	0.09	0.17	9.4	8.60	0.9
	Bt3	8.9	0.14	0.06	0.03	0.10	0.18	9.3	9.67	1.1
	Bt4	8.9	0.10	0.13	0.03	0.05	0.18	9.3	8.50	0.9
PU2C	Ap	9.1	0.16	0.16	0.03	0.05	0.17	9.5	16.4	2.0
	AB	8.9	0.17	0.36	0.15	0.21	0.17	9.8	15.1	3.3
	Bt1	9.2	0.22	0.16	0.08	0.14	0.16	9.8	13.7	2.2
	Bt2	9.1	0.17	0.15	0.06	0.11	0.16	9.6	10.6	1.5
	Bt3	9.1	0.15	0.16	0.06	0.10	0.15	9.6	9.91	1.3
	Bt4	9.1	0.15	0.21	0.14	0.09	0.17	9.7	10.0	1.6
PU3C	Ap	9.1	0.18	0.21	0.13	0.08	0.17	9.7	11.6	1.9
	BW1	9.0	0.17	0.45	0.23	0.17	0.17	10.0	15.4	3.7
	BW2	9.4	0.24	0.11	0.06	0.09	0.16	9.8	15.1	2.1
	BW3	9.4	0.19	0.11	0.06	0.07	0.14	9.7	13.7	1.6
	BW4	9.4	0.16	0.15	0.06	0.05	0.13	9.8	15.0	1.7
PU4C	Ap	9.5	0.17	0.11	0.05	0.06	0.10	9.8	12.3	1.3
	Bt1	9.2	0.24	0.16	0.09	0.09	0.19	9.7	8.33	1.3
	Bt2	9.3	0.18	0.09	0.06	0.06	0.16	9.6	8.28	0.9
	Bt3	9.4	0.24	0.18	0.06	0.04	0.17	9.8	8.40	1.2
	Bt4	9.4	0.22	0.18	0.05	0.04	0.15	9.9	9.47	1.2
PU5C	Ap	9.4	0.17	0.13	0.04	0.04	0.13	9.7	13.6	1.5
	Bt1	9.1	0.17	0.11	0.10	0.28	0.12	9.7	12.5	2.0
	Bt2	9.0	0.15	0.06	0.05	0.18	0.16	9.4	12.2	1.6
	Bt3	9.3	0.22	0.17	0.11	0.16	0.14	9.9	10.9	1.8
	Bt4	9.6	0.22	0.20	0.18	0.12	0.10	10.2	11.2	1.8
	Bt5	9.3	0.16	0.23	0.24	0.11	0.14	10.0	11.0	2.0
PU6C	Ap	9.6	0.24	0.22	0.28	0.13	0.13	10.3	12.1	2.4
	AB	9.2	0.21	0.20	0.09	0.13	0.16	9.8	11.6	1.9
	Bt1	9.6	0.24	0.11	0.06	0.08	0.12	10.0	10.9	1.4
	Bt2	9.3	0.21	0.11	0.05	0.09	0.15	9.7	10.7	1.3
	Bt3	9.4	0.24	0.15	0.06	0.07	0.16	9.8	10.8	1.5
	Bt4	9.5	0.22	0.14	0.05	0.07	0.13	9.9	10.1	1.3

Table 14. Coefficients of correlation among soil properties

Correlation	r
Sand vs silt	-0.353**
Sand vs clay	-0.870**
Silt vs Al	-0.361**
Clay vs OC	-0.283**
Clay vs pH	-0.221*
OC vs pH	-0.333**
pH vs Delta pH	0.509**
ΔpH vs Al	-0.240*
ΔpH vs ECEC	0.224*
Al vs Ca	-0.520**
Al vs Mg	-0.512**
Ca vs Mg	0.888**
Ca vs K	0.364**
Ca vs Na	0.497**
Ca vs ECEC	0.927**
Mg vs K	0.423**
Mg vs Na	0.455**
Mg vs ECEC	0.946**
K vs ECEC	0.490**
Na vs ECEC	0.488**

*, ** for 5 % and 1% level of significance respectively

files were 1.16, 1.33, 1.21, 0.44 0.08 and 0.09 cmol kg^{-1}. It is observed that there is a general increase in Ca content down the profile unlike what was seen in upper reach or at least an accumulation in the last layer. This accumulation in the lower or the last layer could be due to leaching of Ca from the surface soil. Perhaps the influence of slope could be a reason so that the run off water carrying Ca might have settled in the middle reach and leached down to bottom layer.

The mean values of exchangeable Mg in six profiles were 1.16, 1.33, 1.21, 0.44, 0.08 and 0.09 cmol kg^{-1} and in the first four profiles the values were higher than those for exchangeable calcium. There was no definite trend observed in the depthwise distribution of exchangeable Mg in the profiles.

The mean contents of exchangeable K in the profiles on middle reach were 0.11, 0.33, 0.15, 0.12, 0.07 and 0.09 cmol kg^{-1} soil. As in the case of exchangeable Mg, the depthwise distribution of exchangeable K was not consistent. The addition of K and Mg to the soil is mainly by the decomposition of organic matter and being highly mobile these elements would have got distributed to the exchange sites at random without following any definite trend in distribution.

The mean values of exchangeable Na were 0.2, 0.19, 0.18, 0.18 0.13 and 0.18 cmol kg^{-1} in the profiles on middle reach of slope. In case of exchangeable Na also no definite pattern of depthwise distribution is seen in the profiles. A comparison of the magnitude of exchangeable cations reveals that Na stands third dominating over K among the exchangeable ions. A relatively higher level of exchangeable Na was seen in the last horizon of the profiles.

The CEC by summation method showed some variation unlike that of upper reach soil profiles. The profile mean values were 12.0, 12.8, 12.3, 10.5, 8.9 and 9.3 cmol (+) kg^{-1}. The conspicuously lower values are recorded in PU5 and PU6. The distribution of CEC (summation) in the profiles followed an increasing trend up to certain depth and then varied inconsistently.

The CEC (ammonium acetate method) had shown variability among profiles as well as horizons. The weighted average values for these profiles on middle reach of slope were 11.2, 12.7, 12.9, 9.4, 11.5 and 9.3 cmol (+)kg^{-1} clay. There is no definite trend in distribution of CEC down the profiles.

Though the content of organic matter decreased with depth the clay content increased up to a particular depth thus contributing little change in the values of CEC.

The weighted average value of ECEC in the soil profiles on the middle reach were 5.8, 8.0, 7.2, 2.8, 1.3 and 1.1 cmol (+) kg^{-1} clay (Table 7). It might be seen that there is distinct increase in ECEC values from upper reach to middle reach profiles except in PU5 and PU6 where a decrease is registered. There was no definite trend in the depthwise distribution of ECEC in the profiles.

Table 15. Taxonomic classification of soils

Soil profile	Classification
Wayanad (PU1)	
Upper reach	Clayey, kaolinitic, isphyperthermic Ustic Kandihumults
Middle reach	Calyey, kaolinitic, isohyperthermic Ustic Kandihumults
Bottom reach	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults
Malappuram (PU2)	
Upper reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Middle reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Bottom reach	Clayey, kaolinitic, isohyperhtermic Typic Kandiustults
Thrissur (PU3)	
Upper reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Middle reach	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
Bottom reach	Fine loamy, mixed, isohyperthermic Ustoxic Dystropepts
Kottayam (PU4)	
Upper reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Middle reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Bottom reach	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Kottayam (PU5)	
Upper reach	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Middle reach	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Bottom reach	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Pathanamthitta (PU6)	
Upper reach	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Middle reach	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
Bottom reach	Clayey, kaolinitic, isohyperthermic Typic Kandiustults

1.1.3 Soil of bottom reach of slope

1.1.3.1. Morphology of soil profiles

The soil profiles cut at the bottom reach of slope in all the six physiographic units located in Wayanad, Malappuram, Thrissur, Kottayam and Pathanamthitta districts are described for the morphology in Table 11. All the soils were deep (101-150 cm) except that of Pullangode Rubber Estate (PU2) which was very deep (>150 cm).

When moist, all the surface horizons were dark coloured as indicated by the hue 10 YR except in a profile in RRII farm (PU4) where the surface horizon showed a red colour of hue 7.5 YR. In fact, this area was actually a disturbed one because of construction activity. The dark colour in surface horizons is due to enrichment of soils by organic matter as a result of annual fall of leaf litter from rubber trees. In soils of bottom slope in Wayanad area (PU1), all the subsurface horizons were dark coloured as could be seen from the data. In subsurface horizons of Cheruvally Rubber Estate (PU5) and CES (PU6) were dark coloured due to enrichment of organic matter. As stated earlier while describing the soils of upper reach and middle reach, here also these plantations are in second cycle of rubber. The hue of the subjoining horizons varied from 7.5YR to 2.5 YR indicating more redness.

Boundaries between horizons were found to vary from clear to gradual smooth in different profiles and horizons, which might have resulted from the pedogenic processes. The texture of the surface horizons was sandy clay and sandy clay loam and in subsurface, it was sandy clay and clay. It is known that the differential migration of fine earth material would result in textural variations. However, a specific observation in PU2, PU5 and PU6, the texture of subsurface horizons was sandy clay down the profile.

The soil structure varied from crumb to subangular blocky and was medium in size and weak to moderate in strength. The structural changes in different profiles and horizons are due to the particle size composition as well as the content and influence of organic matter. The crumb structure in the surface in Cheruvally Rubber Estate (PU5) might be due to the influence of organic matter. The structure in subsurface horizons is otherwise medium and moderate subangular blocky.

As described in the soils on upper and middle reaches of slope, the dry consistence in all horizons varied from soft to slightly hard. The impact of organic matter on consistence is reflected by soft consistence, which might have resulted from the moderating effect on the plastic nature of clay. Similarly the moist consistence in all the horizons varied from friable to firm, perhaps under the influence of organic matter and clay. The wet consistence varied from slightly sticky and slightly plastic to sticky and plastic in all the horizons.

1.1.3.2. Physical, physico-chemical and chemical properties

The physical, physicochemical and chemical properties are presented in Table 12 and 13. The weighted averages of different soil properties are also given in Table 7. Variations are found in proportions of particle sizes viz., sand, silt and clay in different profiles and horizons. In general, there is an increase in clay content with depth up to certain extent, except in PU3 where the surface soil registered higher content of clay than other profiles. As compared to the soils of upper and middle reach, the soils of bottom reach registered higher values for clay probably due to transportation of finer fractions of soil down the slope due to run off.

As in the case of the profiles of the upper and middle reaches, here also the content of organic matter decreased with depth. But it is seen that content of organic carbon in the surface horizons of the profiles of the bottom reach was relatively lower as compared to the surface horizons of other reaches. The highest content of organic carbon was 1.76 % in the surface horizon of PU6 and the content was 0.30 % in the last horizon of PU2. The profiles of the bottom reach are mostly from plantations of first cycle rubber and this may be the reason for the relatively low level of organic carbon observed in profiles from bottom reaches.

It is seen from the data that pH did not show any definite pattern of variation with depth. There was a definite increase in pH in surface horizon compared to the profiles in upper and middle reaches. It can be due to the upper reach of the slope and also due to relatively low content of organic matter. The Δ pH (pH_{KCl} - pH_{water}) was measured and the weighted means are given in Table 7. The mean values for the profiles were -0.06, -0.72, -1.11, -0.51, -0.31 and -0.40. The reason for the low negative values of ΔpH has already been explained

The data on $BaCl_2$-TEA extracted acidity, 1 *N* KCl extracted Al, exchangeable bases, CEC (by summation of cations and ammonium acetate method) and ECEC are given in Table 13. It is seen that there is not much variability in the $BaCl_2$-TEA extracted acidity among soil profiles as well as the horizons like in upper and middle reaches of slope. The mean values $BaCl_2$-TEA extractable acidity were 9.1, 9.2, 9.3, 9.4, 9.3 and 9.4 in soil profiles of the bottom reach (Table 7).

It is noticed that the exchangeable Al content is high in the profiles at bottom reach than other reaches as evident from the weighted averages (Table 7). It occupied the highest proportion of exchange surface in almost all the profiles as evident from the mean profile values. The mean values were 0.17, 0.20, 0.21, 0.19 and 0.23 cmol kg^{-1}. It is also seen that there is an accumulation of Al on exchange surface in some subsurface layer(s) though there is no definite pattern of distribution. The increase in exchangeable Al in subsurface layer(s) might be ascribed to the relatively high content of clay.

The exchangeable Ca content in some profiles was lower than that of the profiles on upper and middle reaches (Table 7). The weighted means of Ca in different profiles were 0.19, 0.07, 0.19, 0.15, 0.16 and 0.14 cmol kg^{-1}. Different trends are seen in the distribution of exchangeable Ca down the profiles. However, there is an increase in the last layer than its adjoining upper layer suggesting an accumulation, as there is no further leaching.

In case of exchangeable Mg also, the mean values are for the profiles were lower than the values for upper and middle reaches of slope. The mean values were 0.08, 0.03, 0.10, 0.06, 0.14 and 0.08 cmol kg^{-1} soil. It is observed that accumulation of exchangeable Mg is high in the middle layers in almost all the profiles.

The mean contents of exchangeable K in the profiles at the bottom reach were 0.12, 0.11, 0.09, 0.05, 0.14 and 0.09 cmol kg^{-1} soil. In this case the highest concentration of exhangeable K is seen in the second horizon and there is a decrease with depth. The sub soil enrichment of K is because of run off water settling at mild slopes as seen in the middle reach and leaching of K to the lower layers. It might also be due to the presence of illite in clay fraction, second to kaolinite in content, which fixes K in considerable quantities, as reported by Krishnakumar (1989) in some rubber growing soils of Kerala.

The exchangeable Na had occupied in almost all the profiles the third position on exchange surface after Al and Ca. The mean contents were 0.16, 0.15, 0.15, 0.15 0.13 and 0.14 cmol kg^{-1} soil. It appears from the data that the distribution of exchangeable Na is almost uniform in entire profile with some exceptions.

The CEC by summation method showed no much variation unlike that of middle reach soil profiles. It is also seen that the profile mean values are lower than the other profiles on upper and middle reaches except in PU5 and PU6 where a little higher CEC is observed. The profile mean values are 9.7, 9.6, 9.8, 9.8, 9.9 and 9.9 cmol (+) kg^{-1} soil and there is no definite pattern of depth-wise distribution of CEC among horizons.

The CEC (ammonium acetate method) had shown variability among profiles as well as horizons. The weighted average values for these profiles at bottom reach of slope were 12.0,12.1, 14.2, 9.2, 11.7 and 10.9 cmol (+) kg^{-1} clay. The individual highest CEC value was 16.4 cmol (+) kg^{-1} clay in surface layer of PU2 and the lowest recorded was 8.28 cmol (+) kg^{-1} clay in middle layer of PU4. In this property also, there is no definite trend in distribution down the profiles. However, this type of distribution might be a resultant of combined effect of organic matter and clay. It is seen that the contribution of organic matter in CEC is high as evident from the data. Krishnakumar (1989) also reported the positive role of organic matter in CEC as evidenced by a significant correlation.

The values of weighted average value of ECEC in the soil profiles at the bottom reach were 1.8, 1.5, 2.1, 1.2, 1.8 and 1.5 cmol (+) kg^{-1} clay (Table 7). An increase in ECEC in adjoining subsurface is noticed in all soil profiles except PU1 and PU6. This may be beause of the translocation of bases to the subsurface layers.

1.2 General relationship among soil properties of edaphalogical importance

The correlation among soil properties of edaphalogical importance is worked out and presented in Table 14. A negative and significant correlation existed between clay and pH (-0.221^{*}). In an acid soil, the reserve acidity is contributed by the hydrogen ions of the exchange sites and therefore the positive correlation between acidity and the clay content is well explained. Because of the same reason, the negative correlation between OC and pH (-0.333^{**}) is justified.

It is seen that Δ pH is negatively related to soil pH. In other words, ΔpH increase with acidity. Since ΔpH is due to suppression of the ionisation of H ions in 1*N* KCl which would have otherwise ionised in water, normally the values of ΔpH should be proportional to the total acidity for a given soils and hence the correlation.

A positive relationship is observed between ΔpH and ECEC (-0.224^{*}, to be read as 0.224^{*}) clearly meaning increasing net negative charges results in increased ECEC. It is also seen that the components of ECEC, namely bases and Al had established clear relationship among themselves and with ECEC. Al exhibited a significant and negative impact on ECEC (-0.467**) while all bases are positively related (0.927**, 0.946**, 0.490** and 0.488** for Ca, Mg, K and Na respectively). As already seen, the effect of Al on ECEC might be by decreasing the net negative charge by means of occupation of charge sites by H^+.

Al^{+3} showed a significant and negative correlation with bases namely Ca and Mg (-0.520** and -0.512** respectively). As expected, exchangeable bases had positive correlation among themselves. Ca registered correlation with Mg (0.888**), K (0.364**) and Na (0.497**). Similarly, Mg had a positive correlation with K (0.423**) and Na (0.455**).

1.3 Soil classification

The classification of soils pertaining to the present study area (Soil Taxonomy, 1975) was done and presented in Table 15.

The soils on upper, middle and bottom reach in the physiographic unit selected in Wayanad area (PU1) are clayey, kaolinitic, isohyperthermic Ustic Kandihumults. Because of the presence of an argillic horizon and a base saturation of 35 per cent or less (by sum of cations) these soils were in the order, Ultisols. Because of the content of organic carbon 0.9 or more in argillic horizon, the soils are further put in Suborder, Humults. The other diagnostic criteria for further classification included a depth of > 150 cm and a CEC (by 1 *N* Ammonium acetate, pH 7.0) of less than 16 cmol (+) kg^{-1} clay and an ECEC of 12 cmol (+) kg^{-1} clay [(sum of bases extracted with 1 *N* NH4OAc (pH 7.0), plus 1 *N* KCl extractable Al)] to qualify the soils for Kandihumults.

It is stated that entire Kerala comes under Ustic moisture regime (NBSS & LUP, 1993) which In fact, is used as diagnostic criterion at Subgroup level. According to NBSS & LUP (1993), the clay mineralogical studies indicated that kaolinite is the most dominant in mineral clay-size fraction of soils. Family level differentiae viz., particle size classes, mineralogy classes and soil temperature classes are applied and the soils in Wayanad area are classified as clayey, kaolinitic, isohyperthermic Ustic Kandihumults.

The classification of soils on the upper and middle reaches of slope in Malappuram (PU2) is clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults and of bottom reach is clayey, kaolinitic, isohyperthermic Typic Kandiustults.

The soils at the bottom reach had the diagnostic criteria, which had put them under Typic Kandiustults. These criteria are; the argillic horizon and base saturation of 35 per cent or less (by sum of cations) to classify them as Ultisols. It could be seen that the soils did not qualify to be Humults because of lesser OC content in the argillic horizon.

The soil moisture regime is considered next as a diagnostic criterion and the soils ultimately are put in the Suborder, Ustults. The characteristics that put the soils in Great group, Kandiustults are that a depth of more than 150 cm, a CEC of 16 cmol (+) kg^{-1} clay or less (by 1 *N* NH4OAc, pH 7.0) and an ECEC of 12 cmol (+) kg^{-1} clay or less. The other characteristics of soils are such that the soils did not qualify to be in any Subgroup under Kandiustults but in Typic Kandiustults.

The other family differentiae used in other classes earlier remained essentially the same.

In the physiographic unit selected for study in Thrissur district (PU3), the soils on the upper reach are classified as clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults which is described above.

The soils of middle reach are classified as clayey, kaolinitic, isohyperthermic Typic Kanhaplustults. These soils do have argillic horizon and a base saturation of 35 per cent or less (1 *N* NH_4OAc, pH 7.0) to be qualified as Ultisols. Since the OC content is less than 0.9 per cent in the argillic horizon, it did not qualify to be Humults and as the soil moisture regime is ustic the soils are in Ustults. As the depth is less than 150 cm and the criteria of CEC (by 1 *N* NH_4OAc, pH 7.0) of 16 cmol (+) kg^{-1} clay and an ECEC of 12 cmol (+) kg^{-1} clay are satisfied, the soils are put in Great group, Kanhaplustults. The rest of Family differentiae are the same and the classification is clayey, kaolinitic, isohyperthermic Typic Kanhaplustults.

The soils at the bottom reach are classified as fine loamy, mixed, isohyperthermic Ustoxic Dystropepts, which is different from the soils so far classified. Basically this soil is in valley area and adjoining a paddy field. The textural features put these soils in the order Inceptisols. Since these soils are in warmer *iso* temperature regime the soils are placed in sub order, Tropepts.

The soils are subsequently put in great group, Dystropepts as the soil characteristics did not qualify for any other great group. As these soils are in ustic soil moisture regime and have a CEC (by 1 *N* NH_4OAc, pH 7.0) of less than 24 cmol (+) kg^{-1} clay in 50 per cent or more volume between a depth of 25 cm from the mineral soil surface and either a depth of 100 cm, or a lithic or paralithic contact if shallower, they are placed in subgroup Ustoxic Dystropepts. The differentiating characterstistics at family level are soil textural classes, mineralogical classes and soil temperature classes finally resulted in a soil taxon; fine loamy, mixed, isohyperthermic Ustoxic Dystropepts.

The soils in the selected physiographic unit (K07) (NBSS & LUP, 1993) in Kottayam region which is designated as (PU4), on upper, middle and at bottom reach are classified into one class; clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults. The description and classification criteria of these soils are already discussed earlier in soils of Malappuram and Thrissur area.

The soils of other physiographic unit in the same Kottayam region (K09) (NBSS & LUP, 1993) designated as PU5, on upper, middle and bottom reaches of slope are classified again into one class i.e., clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults. The soil properties are essentially same as found in clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults except the variation in the textural class, as Family criteria. The clayey-skeletal class is defined as to have 35 per cent or more (by volume) rock fragments; 10 per cent or more (by volume) particles less than 2.0 mm in diameter (fine-earth fraction), including 35 per cent or more (by weight) clay (Soil Survey Staff, 1992).

The soils studied in Pathanamthitta region (PU6) are classified into clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults in both upper and middle reach of the slope. The description of these soils is given in the above paragraph. The soils at the bottom reach of the slope are classified as clayey, kaolinitic, isohyperthermic Typic

Kandiustults the description of which is given while describing the soils at the bottom reach of Malappuram area.

A careful observation of the taxonomy of soils on upper, middle and bottom reaches of slope in different physiographic units selected in different regions indicated that there are differences in soil properties as influenced by the topography. These variable soils might be a result of catenary sequence of soil development. According to Brady (1990), soil catena is the close association of soils in the same region, formed from the same parent material and climate but having differences in relief or drainage conditions.

Venugopal and Deshpande (1993) in their study on catenary sequence of soil development, concluded that the soils on the upper, middle, lower reaches and valleys had decreasing order of development, based on the micromorphology. However, in some units the soils essentially are the same on all reaches as seen in the present study while in some units different soils are encountered. This indicates that in some places the conditions for soil development might be the same irrespective of the reach of the slope. According to Buol *et al.* (1973), though the role of relief is a real factor in the development of soil, its exact role is however, difficult to evaluate with examples of a generalised nature. However, it is important to study the catenary sequence of soil development so as to know the nature of the soils, which is of edaphalogical signifcance.

Experiment II: Fertility capability and numerical classification of soils

2.1. *Fertility Capability Classification*

Soil management research is site specific and several factors interact to define a given management site. These factors include soil type, ambient weather, fertility level of the soils as related to the past management and several other parameters. Soil fertility management is mainly concerned with manipulation of the characteristics of plough-layer, simply because the present techniques have limited ability to change subsoil characteristics.

In soil taxonomy, soils are grouped according to several properties measured in a depth up to 2 m some of which may not be relevant for fertility purposes, measured in a depth up to 2m are used as classification criteria (Buol and Couto, 1982). According to Sanchez *et al.* (1982), natural soil classification systems place more emphasis on subsurface than the topsoil properties, whereas most soil management practices are largely limited to the ploughed layer. To focus attention on significant properties of the soils that may be used to interpret and extrapolate the results of soil-fertility management experiments, a system called fertility capability classification (FCC) was designed by Buol (1972). This system essentially groups those soils that have the same kind of limitations from the point of view of fertility management.

The system of FCC focuses on the upper 20 cm of soil. Texture is examined and capital letter, L, C or O is assigned according to textural classes or organic matter content. The letter S indicates sandy or loamy sand topsoil; L indicates loamy topsoil; C for clayey topsoil and O for organic soils (>30 % OM to a depth of 50 cm). If a marked change in texture is observed within a 50 cm depth, a second capital letter (S, L, C or R where R stand for rock or other hard root restricting layer) is assigned to identify substrata texture.

Soil properties other than texture, are called 'condition modifiers' identified by lower case letters. Various condition modifiers are defined for FC classification. Gley horizon if present within 60 cm of the surface which is saturated for >60 days in an year is designated by a letter 'a'.

The ustic or xeric environment is indicated by 'd' and low CEC by 'e' when the CEC by summation of exchangeable bases and 1 *N* KCl extracted Al is <4 cmol kg^{-1}. Toxicity of aluminium is anticipated when the soil pH in 1:1 ratio is less than 5 and is designated 'a'. Similarly, when pH in 1:1 soil water suspension is between 5.0 and 6.0 it is said to be acidic and is indicated by 'h'.

P fixation by iron is used as a condition modifier which is indicated by 'i' when % free Fe_2O_3 / % clay is >0.15 or when the hue of 7.5 or redder. A condition modifier 'k' is used to indicate the deficiency when the exchangeable K is <0.20 cmol kg^{-1}.

Other condition modifiers indicating x-ray amorphous materials ('x'), vertisols ('v'), basic reaction ('b'), salinity ('s'), natric horizon ('n') and catclay ('c') are also used

It is further suggested by Buol and Couto (1982) to add a prime (') to denote 15 to 35 per cent and two primes (") to denote more than 35 % of volume of gravel or coarser particle to any type or substrata type texture. The addition of two primes is considered to highlight the soils with higher volume of coarser materials in which case the soil is designated as gravely.

The resulting combination of capital letters (type and substrata type) and lower case letters (condition modifiers) constitutes the name of the FC class. Collectively it indicates limitations that are common to the

Table 16. Characteristics relevant to FCC of soils on upper reach of slope

Physio-graphic unit	Particle size (%)			Gravel (%)	Tex-ture	Colour (moist)	pH (1:1)	ECEC (cmol kg^{-1})	Morgan (cmol kg^{-1})	
	Clay	Silt	Sand						Mg	K
PU1A1	44.8	9.6	45.6	20.5	c	7.5 YR 5/6	5.3	2.77	0.12	0.15
2	51.2	6.4	42.4	23.2	c	7.5 YR 5/6	5.0	2.13	0.15	0.04
PU2A1	32.0	3.2	64.8	37.8	scl	7.5 YR 5/8	5.0	2.73	1.92	0.12
2	38.4	6.4	55.2	41.2	sc	5 YR 5/6	5.1	2.73	1.38	0.06
PU3A1	38.4	6.4	55.2	18.4	sc	10 YR 4/3	5.1	3.21	0.49	0.10
2	41.6	9.6	48.8	31.5	sc	7.5 YR 5/4	5.2	2.91	0.25	0.08
PU4A1	60.8	6.4	32.8	37.6	c	10 YR 6/4	4.3	1.33	0.23	0.10
2	57.6	6.4	36.0	32.1	c	10 YR 6/4	4.7	1.29	0.30	0.08
PU5A1	22.4	9.6	68.0	41.4	scl	10 YR 4/4	4.5	1.15	0.11	0.10
2	35.2	6.4	58.4	46.0	sc	10 YR 4/4	4.9	0.84	0.10	0.04
PU6A1	32.0	6.4	61.6	45.1	scl	10 YR 4/4	4.5	2.51	0.70	0.14
2	51.2	3.2	45.6	48.2	sc	10 YR 4/4	4.6	1.84	0.30	0.09

1 = surface (0-20 cm); 2 = subsurface (20-50 cm)

soil units in that class. Considering this nature, an attempt was made to classify the soils studied in Experiment 1 according to FCC norms.

The study of the relevant properties of acid soils in Experiment 1 suggested to include the condition modifiers 'd' (dry), 'e' (low CEC), 'h' (acid), 'a' (Al toxic), 'i' (Fe-P fixation), 'k' (K deficient) for FC classification. However, the condition modifier 'k' is defined in terms of Morgan reagent extracted K considering 0.13 cmol kg^{-1} soil as the critical limit that is followed in rubber research in India.

The relevant characteristics used as criteria for FC of soils of upper reach of slope are given in Table 16. The data indicated that the clay content varied between 32.0 to 60.8 per cent among different soils. The silt content ranged from a low of 3.2 to 9.6 per cent while sand fraction was between 32.8 to 68.0 per cent. The resultant texture was sandy clay loam, sandy clay and clay in different soils. The coarse fragments (>2 mm diameter) were varying from 18.4 to 48.2 per cent.

The moist colour of the soils was found becoming deep red in hue from 10YR to 5YR in the soils of upper reach. Soil pH (1:1 soil water ratio) varied from a low of 4.3 to a high of 5.3. The CEC in these soils was as low as 0.84 and as high as 3.21 cmol kg^{-1} soil.

Based on the type, substrata type and condition modifiers the FCC units were identified and described (Table 17).

It is seen in the table that there are differences in gravel content and texture in the surface soils (type) of the upper reach of slope. The type is changing between loam to clay and the substrata type always being clayey. All the soils appeared to be gravely except PU1A and PU3A. This gravelyness might be due to slope causing erosion of fine earth materials leaving behind the coarse fragments. It is noticed that the soils of the upper reach of slope are characterised by dry soil moisture. Selected physiographic units in Wayanad and Malappuram districts appear

Table 17. Description of FCC units in the soils of upper reaches

Soil profile ID	FCC unit	Description	Taxonomic classification
PU1A	Cdeihk	Clayey surface and subsurface soils. Dry soils with low CEC and high P fixation. Soils are acidic and deficient in K	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults
PU2A	L"C"deihk	Gravely loam surface over gravely clay subsurface. Dry soils with low CEC and high P fixation. Soils are acidic and deficient in K	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
PU3A	Cdehk	Clayey surface and subsurface. Dry soils with low CEC. Acidic soils associated. with K deficiency	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
PU4A	C"deak	Gravely clay surface and subsurface. Dry soil moisture regime with low CEC with excess Al. Soils are deficient in K	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults
PU5A	L"C"deak	Gravely loam surface over gravely clay subsurface. Dry regime and low CEC. Excess Al followed. by k deficiency.	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
PU6A	L"C"deak	Gravely loam surface over gravely clay subsurface. Dry soils with low CEC and excess Al. Soils are deficient in K	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults.

to fix more P as revealed by the condition modifier 'i'. The soils of upper reach in physiographic units PU1, 2 and 3 are acidic whereas the soils of PU4, 5 and 6 have excess Al as indicated by the soil pH of <5.0. In addition to the above condition modifiers, the soils are deficient in available K (Morgan) as indicated by ('k'). This might be due to the runoff and leaching loss of K caused by the slope, resulting in the deficiency. Soil taxonomy indicates that the soils belong to Ustic Kanhaplohumults except that of PU1A where it is Ustic Kandihumults.

Table 18 gives the characteristics relevant for

FC classification measured in the soils of middle reach of slope in the physiographic units PU1 to PU6. Clay content varied from a low of 16.0 to a high of 60.8 %. However, silt content was within a narrow range of 3.2 to 9.6 % and the sand content in a wide range from 36.0 to 74.4 per cent. The resultant texture of soils was sandy clay loam, sandy clay and clay in these soils. The coarse fragments varied from 20.7 to 49.2 per cent.

Table 18. Characteristics relevant to FCC of soils on middle reach of slope

Physio-graphic unit	Particle size (%)			Gravel (%)	Tex-ture	Colour (moist)	pH (1:1)	ECEC (cmol kg^{-1})	Morgan (cmol kg^{-1})	
	Clay	Silt	Sand						Mg	K
PU1B1	54.4	6.4	39.2	25.8	c	7.5 YR 5/4	5.3	2.16	0.06	0.04
2	54.4	6.4	39.2	20.7	c	7.5 YR 5/6	5.5	2.32	0.17	0.01
PU2B1	38.4	6.4	55.2	49.2	sc	10 YR 4/3	5.2	3.00	0.21	0.25
2	48.0	6.4	45.6	45.7	c	10 YR 4/4	5.3	1.65	0.09	0.17
PU3B1	48.0	9.6	42.4	23.6	c	7.5 YR 5/6	5.3	3.95	0.64	0.37
2	51.2	9.6	39.2	21.1	c	7.5 YR 5/6	5.7	3.55	0.91	0.25
PU4B1	60.8	3.2	36.0	42.5	c	10 YR 5/4	5.0	1.09	0.10	0.10
2	60.8	3.2	36.0	32.1	c	10 YR 5/4	5.1	1.16	0.14	0.07
PU5B1	16.0	9.6	74.4	45.7	sl	10 YR 4/4	4.5	1.56	0.08	0.19
2	41.6	6.4	52.0	40.1	sc	10 YR 5/4	4.9	1.06	0.05	0.09
PU6B1	22.4	6.4	71.2	42.8	scl	10 YR 5/3	4.5	2.58	0.73	0.18
2	35.2	6.4	58.4	46.2	sc	7.5 YR 6/4	4.8	2.41	0.32	0.12

1 = surface (0-20 cm); 2 = subsurface (20-50 cm)

The moist soil colour was varying from 10YR to 7.5 YR with differences in value and chroma. The soil pH varied from 4.5 to 5.7. The lowest CEC measured was 1.01 and the highest being 3.95 cmol kg^{-1}.

The FCC units identified in the soils of the middle reach with the taxonomic classification are given in Table 19.

It is seen that the soils on the middle reach of the slope had differences in gravel content and texture in the surface. The type changed between loam to clay while substrata texture was always clay. The soils of the middle reach were gravely in surface as well as subsurface except in PU1 and PU3, similar to that observed in upper reach in the same physiographic units. Since middle reach also is sloppy it might have caused washing down of the fine earth materials down the slope, leaving behind coarser fragments.

The soil moisture regime is dry as indicated by the condition modifier 'd'. The soils of all these physiographic units are low in cation exchange capacity as indicated by 'e'. The soils of PU1B and PU3B appeared to fix more P as indicated by the colour of the soils indicating higher free Fe content ('i'). It is noted that all the soils were acidic except PU5B and PU6B which were characterised by excess of Al. Deficiency of K was noticed in soils of middle reach PU1 & PU2.

Majority of the soils of the middle reach are Ustic Kanhaplohumults except that of PU1B and PU3B where it was Ustic Kandihumults and Typic Kanhaplustults respectively. The relevant data on type, substrata type and condition modifiers measured in the soils of bottom reach are given in Table 20. The clay content varied from 28.8 to 57.6 per cent. Silt content ranged from 6.4 to 12.8 per cent and the sand fraction was between 36.0 to

Table 19. Description of FCC units in the soils of middle reaches of slope

Soil profile ID	FCC unit	Description	Taxonomic classification
PU1B	Cdeihk	Clay surface and subsurface. Dry soil moisture regime with low CEC and high P fixation Soils are acidic and deficient in K	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults.
PU2B	C"deh	Clayey surface and subsurface. Dry soils with low CEC and acidity	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults
PU3B	Cdeih	Clayey surface and subsurface. Dry regime and low CEC with high P fixation. Soils are acidic.	Clayey, kaolinitic, isohyperthermic Typic Kanhaplustults
PU4B	C"dehk	Gravely clayey surface and subsurface. Soils are dry with low CEC. Soils are acidic and deficient in K	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults.
PU5B	L"C"dea	Gravely loam in surface over gravely clayey subsurface. Dry soil moisture regime with low CEC and excess of Al	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults.
PU6B	L"C"dea	Gravely loam in surface over gravely clayey subsurface. Dry soil moisture regime. Soils are low in CEC with excess Al	Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults.

64.8 per cent. The relative proportion of all these separates resulted in soil texture of sandy clay loam, sandy clay and clay. Gravel content varied from 7.2 to 38.4 %.

Moist colour of these soils was changing to redder hues from 10YR to 5 YR. Soil pH (1:1 soil water ratio) ranged from 4.3 to 6.1, lower value being observed in PU4C, PU5C and PU6C. The CEC values ranged from 1.06 to 3.42 cmol kg^{-1} in these soils. Morgan extracted K ranged from 0.02 to 0.28 cmol kg^{-1} of soil. Fertility capability classification units identified in these soils are given in Table 21 and described.

It is noticed that the texture is clayey in all surface soils except in PU5C and PU6C where it was a loam. The substrata type is clayey in all soils. Like on the other reach of slope, the soils are low in activity.

All the soils were characterised by ustic soil moisture regime as shown by 'd'. Even though the condition modifier 'd' is applied in general, based on the report of NBSS & LUP (1993) it is quite possible that the soils of lower reaches need not always under the ustic soil moisture regime due to topographic effects. The mapping units adopted by NBSS & LUP can not take into account of such microclimatic changes due to the scale limitations. P fixation appeared to be a potent problem in soils of PU2C, PU3C and PU4C. Excess Al was seen in all soils except those of PU2C and PU3C. K deficiency was noticed in PU1C, PU3C, PU4C and PU5C.

Table 20. Characteristics relevant to FCC of soils on bottom reach of slope

Physio-graphic unit	Particle size (%)			Gravel (%)	Tex-ture	Colour (moist)	pH (1:1)	ECEC ($cmol\ kg^{-1}$)	Morgan ($cmol\ kg^{-1}$)	
	Clay	Silt	Sand						Mg	K
PU1C1	41.6	6.4	52.0	14.2	sc	10 YR 6/4	5.2	2.57	0.20	0.07
2	51.2	9.6	39.2	12.6	c	10 YR 6/4	4.9	2.21	0.44	0.01
PU2C1	44.8	6.4	48.8	20.7	sc	5 YR 4/6	5.1	2.92	0.14	0.23
2	54.4	6.4	39.2	18.6	c	5 YR 4/4	5.0	2.74	0.14	0.13
PU3C1	38.4	12.8	48.8	7.2	sc	7.5 YR 5/4	5.6	3.42	0.30	0.02
2	32.0	9.6	58.4	7.6	sc	7.5 YR 5/6	6.1	3.41	0.42	0.07
PU4C1	51.2	6.4	42.4	38.4	c	7.5 YR 5/6	4.3	1.14	0.03	0.11
2	57.6	6.4	36.0	28.7	c	7.5 YR 5/6	4.5	1.06	0.06	0.08
PU5C1	28.8	6.4	64.8	34.1	scl	10 YR 4/4	4.5	1.40	0.02	0.09
2	38.4	6.4	55.2	24.6	sc	10 YR 4/4	4.8	1.21	0.07	0.06
PU6C1	35.2	9.6	55.2	27.6	scl	10 YR 5/3	4.4	2.65	0.27	0.28
2	44.8	9.6	45.6	25.7	c	10 YR 4/4	4.9	2.70	0.03	0.20

1 = surface (0-20 cm); 2 = subsurface (20-50 cm)

2.2. Introduction of local modifiers

According to Rubber Research Institute of India (1980), the critical limit for available Mg is 0.08 $cmol\ kg^{-1}$ soil, to classify a soil as low or medium. It is also stated that some soils under rubber in Kerala are deficient in Mg calling for an attention. Keeping this fact in mind, a local modifier called 'm', suggested by Mathan (1990) was introduced to classify the soils with reference to the status of the availability of Mg. The same critical limit of 0.08 $cmol\ kg^{-1}$ of Morgan reagent extracted Mg in the surface layer was used as a criterion to classify the soils.

The data given in Table 16 indicate that the Morgan's Mg ranged from a low of 0.10 to 1.92 $cmol\ kg^{-1}$ in the soils of upper reach of the slope. The Morgan's Mg varied between 0.06 to 0.91 $cmol\ kg^{-1}$ in the soils of middle reach (Table 18). The data on Morgan reagent extracted Mg showed that it ranged from a low of 0.02 to a high of 0.42 $cmol\ kg^{-1}$

Table 21. Description of FCC units in the soils of bottom reaches of slope

Soil profile ID	FCC unit	Description	Taxonomic classification
PU1C	Cdeak	Clayey surface and subsurface. Dry soils with low CEC associated with excess Al activity. K is deficient.	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults.
PU2C	Cdeih	Clayey surface and subsurface. Dry soils with low CEC. High P fixation is indicated along with acidity.	Clayey, kaolinitic, isohyperthermic Typic Kandiustults.
PU3C	Cdeihk	Clayey surface and subsurface. Dry moisture regime in soils with low CEC. Soils are acidic and fixing more P. Deficiecy of K is indicated.	Fine loamy, mixed, isohyperthermic Ustoxic Dystropepts.
PU4C	C"deiak	Gravely clay in surface and subsurface. Dry soil moisture regime with low CEC. Soils are acidic fixing high quantities of P. Soils are deficient in K.	Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults.
PU5C	LCdeak	Loamy surface over clayey subsurface. Soils are dry with low CEC. Excess activity of Al associated with deficiency of K.	Clayey, kaolinitic, isohyperthermic Kanhaplohumults.
PU6C	LCdea	Loamy surface over clayey subsurface. Dry soils with low CEC and excess Al	Clayey, kaolinitic, isohyperthermic Typic Kandiustults.

in the soils of bottom reach of the slope (Table 20). According to the criterion selected the soils having < 0.08 cmol kg^{-1} in the surface layer (0-20 cm) were classified as Mg deficient. These soils included PU1B, in the middle reach and PU4C & PU5C in the bottom reach of the slope. After the local modifier was introduced the FCC notation for PU1B, PU4C and PU5C became Ceihkm, C"eiakm and LCeakm respectively.

The differences among reaches of slope and physiographic units with reference to fertility capability classification were observed. The soils of upper and middle reach in the physiographic unit, PU1 were similar except that Mg deficiency is noticed in the soil of middle reach. Excess of Al is found in the soil of bottom reach. The soils of all the reaches are K deficient.

In the physiographic unit, PU2 also differences among the soils of these three reach were observed. The texture in upper reach was loam over clay in surface and subsurface respectively. It is seen that the soils of upper and middle reach are gravelly in nature. The soils of upper reach exhibited K deficiency and P fixation problem is identified in the soil of middle reach.

Deficiency of K is found in both upper and bottom reach soils in physiographic unit, PU3. P fixation is recognised in the soils of middle and bottom soils. In case of PU4, all soils are gravely. Soils of upper and bottom reach indicated excess Al activity. Bottom soil showed P fixation and deficiency of K.

As expected in general, the soils at bottom reach of slope had less gravel in PU5. All the

Table 21A. Rearrangement of FCC units

Sl. No.	FCC unit	Soil profile ID
1	Cdeihk	PU1A & PU3C
2	L"C"deihk	PU2A
3	Cdehk	PU3A
4	C"deak	PU4A
5	L"C"deak	PU5A & PU6A
6	Cdeihkm	PU1B
7	C"deh	PU2B
8	Cdeih	PU3B & PU2C
9	C"deahk	PU4C
10	L"C"dea	PU5C & PU6B
11	Cdeak	PU1C
12	C"deiakm	PU4C
13	LCdeakm	PU5C
14	LCdea	PU6C

soils are loam over clay in surface and subsurface respectively. Soils of upper and bottom reach are deficient in K. In addition to that, the bottom soils had deficiency of magnesium. All the soils are characterised by excess aluminium.

Similar to PU5, the soils in the physiographic unit, PU6 also are loam over clay in texture in surface and subsurface respectively. Gravel is less in bottom soil when compared to other reach. Similarly,, all the soils are characterised by excess of Al.

The differences in FCC of the same physiographic units might be mainly due to differences in topography in addition to other local variations. Among the physiographic units both similarities and differences were noticed. The similarities might be due to the fact that many of the condition modifiers were measured only in the surface soil and similarities in these properties cluster the soils into one group, though inherently there could be differences in several other features. The differences might be due to variations in slope, parent material or any other feature, which could influence the composition of surface soils.

The eighteen soils were rearranged FCC-wise and are presented in Table 21A. These soils belong to 14 FC classes.

According to Buol (1972), the fertility capability classification was designed to group those soils that have the same kind of limitations from the point of view of fertility management. Buol *et al.* (1975) stated that soil individuals in one FC class may belong to different classes for taxonomic purposes with resultant smaller number of FCC than that in Soil Taxonomy. Contrary to that, though only five taxa were identified among these eighteen soils on different reach of slope in the present study, there were fourteen FCCs depending upon criteria selected for classification. The local modifier 'm', for example, when introduced, the number of FC classes In fact, increased than the earlier list. It was apparent that in the same taxon there were different FC classes depending on the modifiers used

As a technical soil classification system, FCC focuses on a specific use of natural soil classification systems such as Soil Taxonomy, which is essentially a record of soil properties. The direct interpretation of natural systems for specific uses is difficult because criteria relevant to a specific use are confounded with other criteria (Cline, 1949). In such situations, the condition modifiers are to be introduced for classification of soils based on constraints. It is evident that the critical limits of certain properties incorporated for technical classification of soils i.e. FC classification, however, are not dealt with in the Soil Taxonomy. Hence addition of a local modifier may some times result in increased number of FC classes as seen in the present study.

However, the flexibility of FCC system is appreciable as it really looks into the management constraints with reference to certain nutrient elements. Hence it could be used in routine when large areas of rubber are to be handled however, after understanding the basic soil-plant relationships so as to identify the fertility constraints.

2.3. *Numerical classification of soils*

The numerical classification of the soils is done to bring out important relationships among the individuals as well as the groups of soils. The other aim of the numerical classification is to test the validity of semi-quantitative or qualitative natural classification systems i.e. Soil Taxonomy. Several numerical methods have been suggested to measure the differences in soil units and classify them into distinct groups or clusters (Sneath and Sokal, 1973; Arkley, 1976).

The method of Euclidean cluster analysis appears to be more appropriate for soils because it is sensitive to magnitude and provides a model that can be more readily visualised (Kumar and Sharma, 1987; Kumar and Sharma, 1990). An attempt was made to group the soils studied in Experiment I by cluster analysis technique using this Euclidean distance measure. All the soils of upper, middle and bottom reach of slope were selected as operational taxonomic units (OTUs) and the relevant characteristics were chosen (Arkley, 1976). The data matrix of the soil variables is given in Table 22. The soil variables, which did not vary between different soils, were not included in the analysis. The resultant classification is presented as a dendrogram in Fig.1.

From the figure it is understood that a first cluster was formed with PU5B and PU5C belonging to the same physiographic unit and taxon, *Ustic Kanhaplohumults*. The distance between these two soils was 3.51 (Appendix A), the lowest among all the pairs.

The next lowest distance was found between soils of PU4A and PU1C forming another cluster. (Appendix A). However, taxonomically the soils were Ustic Kanhaplohumults and Ustic Kandiustults respectively. The data given in Table 22 indicate that the differences between these two soils were not much. Perhaps this might be the effect of considering the weighted averages of soil properties of both A and B horizons where the differentiating characteristics might have got evened out, making both the soils similar.

Soils of PU2B and PU4B were clustered together (Fig 1) with the Euclidean distance of 4.89. Soil taxonomy indicates that both the soils belong to Ustic Kanhaplohumults. Numerical taxonomy also indicated that both the soils were similar.

It could be noticed from the figure that soils of PU4C were fused to the cluster of PU4A

Table 22. Soil properties used in numerical classification

Soil variables	PU1A	PU2A	PU3A	PU4A	PU5A	PU6A	PU1B	PU2B	PU3B	PU4B	PU5B	PU6B	PU1C	PU2C	PU3C	PU4C	PU5C	PU6C
Thickness of A horizon	0.24	0.12	0.22	0.13	0.27	0.16	0.14	0.17	0.18	0.1	0.12	0.26	0.14	0.37	0.15	0.13	0.14	0.25
pH of A horizon	4.8	5.20	5.40	6.00	4.45	4.70	4.30	5.00	5.20	4.30	4.70	4.60	5.20	4.95	5.80	4.90	5.00	4.65
CEC of A horizon	5.19	5.28	4.87	5.16	5.02	4.78	5.07	5.62	6.00	5.85	4.77	4.80	4.68	4.78	4.80	4.84	4.80	4.93
BSP in A horizon	36.4	36.7	25.6	27.5	23.6	20.2	28.1	54.8	61.0	58.2	6.70	8.59	9.72	8.66	12.4	6.71	7.13	15.0
Colour : Value	5	5	4	5	3	3	5	3	5	4	4	3	5	4	5	5	4	3
Chroma	4	4	3	4	3	3	4	3	6	3	3	3	4	4	4	4	4	3
Structure: Grade	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Size	2	2	1	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2
Clay in A horizon	40.8	44.8	44.8	40.8	32.0	41.6	39.2	38.4	38.4	43.3	25.6	28.8	41.6	30.3	41.6	39.2	35.2	41.6
Silt in A horizon	9.6	6.4	9.6	6.4	11.1	6.4	6.4	6.4	6.4	3.2	9.6	9.6	6.4	20.8	9.6	6.4	3.2	5.0
Mottles: Abundance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Contrast	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OM in A horizon	2.07	2.0	1.8	1.4	2.3	2.2	1.7	1.8	0.7	2.8	2.3	2.4	1.1	1.4	1.0	0.3	1.6	1.5
Thickness of B horizon	1.36	1.08	1.08	1.07	0.53	0.89	1.46	0.79	1.07	0.85	1.14	0.79	1.41	1.31	0.95	0.92	0.96	1.25
pH of B horizon	4.16	4.64	5.41	4.58	5.39	4.45	5.15	4.99	5.32	4.64	4.76	4.70	5.12	4.32	6.18	4.36	4.57	4.63
CEC of B horizon	4.99	4.57	5.00	4.95	4.94	5.16	5.71	5.98	5.72	5.00	4.79	4.74	4.65	4.20	4.83	4.82	4.87	4.85
BSP in B horizon	22.7	20.9	19.6	17.6	20.4	32.4	51.2	60.8	54.2	18.31	7.59	7.46	8.31	11.7	18.49	8.91	12.38	8.53
OM in B horizon	1.1	0.7	0.9	0.7	0.9	0.6	0.8	1.1	0.6	1.1	0.9	0.8	0.8	0.4	0.5	0.8	0.8	0.6
Clay in B horizon	53.2	38.2	49.0	55.0	52.2	51.3	52.9	50.3	46.7	56.9	41.4	45.1	51.5	39.3	32.7	55.3	42.9	45.3
Silt in B horizon	14.4	5.0	8.1	5.4	6.4	3.2	12.0	7.5	11.0	5.5	6.7	7.0	12.4	4.6	7.5	6.4	4.2	4.6
Colour: Value	5	5	4	5	5	4	5	4	4	4	5	5	5	4	4	5	5	4
Chroma	6	6	4	4	4	4	5	4	4	5	4	4	4	4	4	6	5	4
Structure: Grade	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Size	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Mottles: Abundance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Contrast	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth of solum	1.6	1.2	1.3	1.2	0.8	1.05	1.6	0.96	1.25	0.95	1.25	1.05	1.55	1.58	0.9	1.05	1.1	1.5

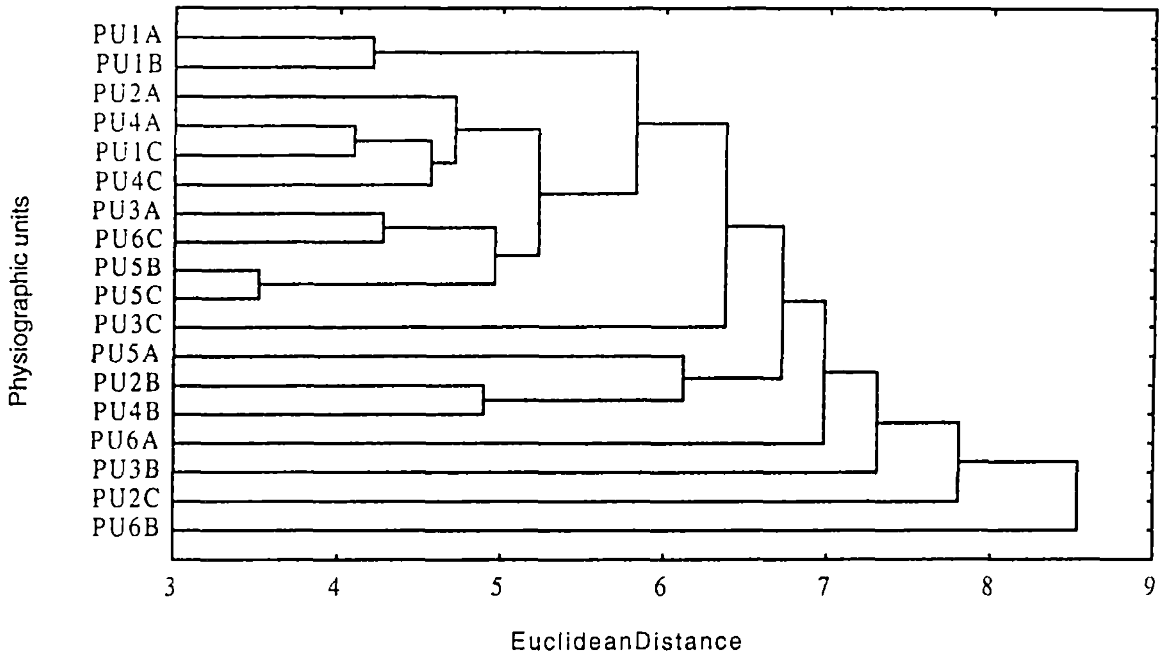

Fig.1 Numerical classification of soils

and PU1C. It is to note that the soils of PU4A, PU4C and PU1C were classified as Ustic Kanhaplohumults. In the next fusion, soil of PU2A was also merged to the above cluster of PU1C, PU4A and PU4C where the soil of PU2A was also Ustic Kanhaplohumults.

The clusters of PU3A & PU6C and that of PU5B & PU5C were merged as seen in the figure, clearly indicating the grouping of all soils of Ustic Kanhaplohumults with an exceptional inclusion of Typic Kandiustults of PU6C. In an another union, the soils of PU5A were merged with the cluster of PU2B and PU4B where all the members were classified as Ustic Kanhaplohumults.

The overall grouping as seen in figure showed that the soils of PU1A, 1B, 1C, 2A, 3A, 4A, 4C, 5B, 5C and 6C were closely associated however, with varying distances within the group. Taxonomically, these soils belong to Ustic Kandihumults and Ustic Kanhaplohumults which differ from each other only in one characteristic, the depth.

In is seen that the soils of PU3C, PU6A, PU3B, PU2C and PU6B were found forming individual groups (Fig 1). The soils of PU3C are Ustoxic Dystropepts and formed an individual cluster and of course, merged to the group of Ustic Kandihumults and Ustic Kanhaplohumults. In another observation, the soils of PU6A, again Ustic Kanhaplohumults, were seen forming another cluster. The data matrix indicates that the silt content in B horizon in this soil was the lowest and perhaps it might have increased the dissimilarity among the Ustic Kanhaplohumults.

The cluster with lone membership of PU3B was because of its dissimilarity from other soils encountered so far. The soil of this unit was classified as Typic Kanhaplustults. It could be noticed that the numerical taxonomy confirmed the separate identity of a different taxon as soil taxonomy did

Similar to the above observation, Typic Kandiustults of PU2C formed a different cluster because of its specific characteristics. However, there was an exception with the same taxon found in PU6C where it got merged with Ustic Kanhaplohumults of PU3A. It might be because of differences within the same taxon in thickness, base saturation percentage, clay content, silt content in A horizon as seen in the data matrix (Table 22), increasing the distance.

It is a fact that soil taxonomy has certain values of differentiae to classify different soils whereas the numerical taxonomy considers the numerical differences as such for calculating either similarity or dissimilarity. In addition to that, the weighted averaging of soil properties would have a definite influence on ironing out of differences when compared to soil taxonomy.

The soil of PU6B, an Ustic Kanhaplohumult also formed a different cluster. When compared to the soil of PU6A, same taxon in the same physiographic unit, there were conspicuous differences in thickness, BSP, clay content, silt content in A horizon, base saturation percentage, clay content and silt content in B horizon which might have added to the dissimilarity.

It could be seen in several instances that soil taxonomy and numerical taxonomy could distinguish and group different soils. However, similar taxa were grouped differently in numerical taxonomy. It was due to the quantitative differences in soil properties even in the same taxon, whereas in soil taxonomy certain fixed values of the attributes are used to classify the soils. It is however, a useful technique for grouping the soils based on the quantitative traits of edaphalogical importance as these numerical differences might certainly mean some thing in practical soil fertility management.

3 Experiment III. Relationship between soil properties and the growth of rubber

In any attempt either to devise or to refine a crop production technology for optimum yield of a crop, in given local situations, it is essential to understand the soil-plant relationships and rubber plant is no exception. Keeping this fact in mind, a study was conducted to understand the behaviour of hevea in different soils.

Though the entire state of Kerala is divided into several physiographic units for mapping of soils (Krishnan *et al.*, 1996), it is possible that there will be differences in soils within each physiographic unit because of the scale limitation while mapping. It is known that rubber is being grown in several types of soils in different physiographic units identified in Kerala. Out of six units studied in Experiment I, soils of the physiographic unit, K11 (Krishnan *et al.*, 1996), were selected for the present study. As the present study needed variability among the soils, fourteen different soils belonging to this physiographic unit, spread over Thrissur district were identified, the details of which are given in Table 3. These soils are planted with the popular clone of rubber, RRII 105 planted in 1994 and maintained under common recommended management practices.

Soil samples were drawn from profiles cut in these sites for characterisation and taxonomic classification. Measurements of plant characteristics i.e. girth of plant at 10 cm height from bud union and the height were taken at bimonthly intervals for one year. Surface soil samples were collected (0-30 cm) simultaneously for six times to cover one year, and analysed to study the influence of weather on soil properties which in turn are expected to influence the growth. Leaf samples from these sites were collected during September the sampling period recommended by the Rubber Research Institute of India and analysed for important nutrient elements as mentioned under Materials and Methods.

The data on growth and soil variables were analysed using different statistical techniques to understand the latent structure of variability and interrelationships between soil and plant properties as influenced by the weather.

3.1 Data generation

The soil samples collected from the profiles cut in all 14 sites were characterised for classification purposes. The data on these characteristics and taxonomic position of these experiment sites are given in Appendix B. The measurements of different soil variables and the volume of rubber plant recorded in all the fourteen sites at different intervals are given in Table 23 to 28. The soil variables included pH, available P, exchangeable Ca, Mg, K, Na, Al, DTPA extracted Fe, Mn, Cu, Zn, organic carbon and total N. The volume of the plant was calculated from girth and height by using the standard formula:

Volume = $(G/4)^2 / H$

where

G = Girth of plant at 10 cm height from bud union

H = Height of plant

3.2 Soil characteristics

The morphology, physical, chemical and physicochemical properties of the soil profiles cut in the all the 14 experimental sites are described in Appendix B1 to B5 including soil taxonomy and fertility capability classification.

Table 23. Tree volume and soil properties in November 96 .

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.8	1.17	0.16	12.5	149	46	40	38	12.5	171	321	52.4	2.5	15.8
2	4.4	0.81	0.12	49.0	86	20	45	35	28.7	474	130	9.3	4.5	23.8
3	5.2	0.30	0.10	15.0	250	78	73	38	10.2	112	178	4.1	1.5	14.2
4	4.6	0.66	0.10	10.0	320	199	154	51	11.6	43	201	2.6	2.0	15.7
5	5.5	1.50	0.14	11.2	448	143	166	39	3.6	137	293	4.0	3.5	12.7
6	5.5	0.51	0.09	16.6	388	159	101	53	1.7	116	258	18.9	2.5	17.8
7	4.9	1.71	0.22	8.3	395	46	148	39	10.4	160	65	38.5	3.0	22.2
8	4.8	0.57	0.11	41.7	106	24	81	33	24.2	95	48	3.1	13.0	31.0
9	5.3	1.05	0.11	21.6	230	83	83	36	12.5	182	44	4.7	1.5	21.7
10	5.5	0.78	0.11	12.5	286	110	38	41	2.9	333	305	6.1	2.5	17.2
11	5.9	0.66	0.07	12.5	356	136	78	40	0.2	184	255	27.5	3.5	16.2
12	5.3	0.78	0.10	13.3	176	69	51	35	11.2	87	228	4.2	18.0	14.5
13	5.0	0.78	0.12	12.5	78	26	52	34	21.7	124	234	22.2	4.0	22.2
14	4.8	0.75	0.09	17.4	58	15	60	34	22.9	79	151	14.7	4.0	18.5

Table 23 gives details of the soil variables measured during the month of November 96. Soil pH measured in the experimental sites during November ranged from 4.4 to 5.9. The organic carbon was found varying from 0.3 to 1.71 per cent. The total nitrogen content was varying between 0.09 to 0.22 per cent. Available P ranged between 8.3 to 49 ppm. Exchangeable Ca was observed to range from a low of 58 to a high of 448 ppm. The other bases were ranging between 15 to 199, 40 to 166, 33 to 53 ppm for Mg, K and Na respectively. KCl (1.0 *N*) extracted aluminium in all the sites measured between 0.2 to 28.7 ppm. DTPA extracted Fe was found in range of 43 to 474 ppm and Mn, between 44 to 321 ppm. DTPA extracted Cu and Zn were ranging between 2.6 to 52.4 and 1.5 to 18.0 ppm respectively.

Table 24 indicates the measurements recorded in the month of January 97 in all fourteen sites. Soil pH remained between 4.6 and 5.7. Organic carbon content varied from 0.24 to 2.31 per cent and the total nitrogen content ranged from 0.09 to 0.27 per cent. The available P measured during this time varied from 1.3 to 43.8 ppm. The exchangeable bases were between 48 to 609, 23 to 190, 36 to 265 and 29 to 45 ppm for Ca, Mg, K and Na respectively. KCl extracted Al had a minimum of 0.6 and a maximum of 23.2 ppm in these experimental sites. DTPA extracted elements namely Fe, Mn, Cu and Zn ranged from 33 to 304, 28 to 290, 2.7 to 20.2 and 1.0 to 7.5 ppm respectively.

The measurements on soil variables and plant volume in the experimental sites, taken in the month of March 97 are given in Table 25. Soil pH was between 4.6 and 5.6. Organic carbon content is at a minimum of 0.69 and at a maximum of 2.1 per cent. The total nitrogen content is at a minimum of 0.07 and at a maximum of 0.22 per cent. Available phosphorus varied between 6.7 to 83.3 ppm. Ammonium acetate extracted Ca, Mg, K and Na were ranging from 61 to 628, 15 to 222, 29 to 148 and 32 to 42 ppm respectively. Exchangeable Al was found to have a minimum of 0.1 and a maximum of 22.2 ppm. The DTPA extracted elements viz., Fe, Mn, Cu and Zn tested between 40 to 290, 28 to 289, 2.8 to 25.4 and 1.0 to 3.0 ppm respectively.

Table 24. Tree volume and soil properties in January 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.8	0.99	0.27	3.8	125	35	86	35	11.0	149	183	16.8	4.0	18.2
2	4.6	0.60	0.17	33.8	126	30	96	36	21.1	304	205	5.6	3.0	26.8
3	5.1	0.45	0.18	18.8	201	48	87	31	13.0	244	87	4.7	3.5	16.7
4	5.3	0.24	0.09	6.3	350	159	265	40	7.4	33	130	2.7	1.0	18.0
5	5.7	1.32	0.24	3.8	609	190	178	41	0.6	145	258	5.7	3.0	16.0
6	5.2	0.66	0.15	1.3	569	188	124	45	5.5	108	192	20.2	7.5	22.0
7	5.2	2.31	0.29	43.8	248	34	114	35	19.1	168	28	17.8	2.0	27.0
8	5.0	0.69	0.12	25.0	141	28	96	30	18.9	107	57	3.3	1.0	36.0
9	5.1	0.66	0.22	20.0	136	43	88	36	15.2	143	50	5.4	2.0	28.0
10	5.5	0.51	0.10	3.8	289	117	36	36	3.9	274	241	6.1	5.5	19.2
11	5.4	0.24	0.09	8.8	280	90	108	39	‹5.3	193	221	4.5	3.0	18.3
12	5.1	0.66	0.13	6.3	140	52	75	29	15.8	91	179	3.3	1.0	17.3
13	4.9	0.75	0.17	5.0	91	30	66	36	22.5	151	290	4.9	3.0	27.8
14	4.8	0.30	0.11	5.0	48	23	65	29	23.2	91	145	18.5	1.5	20.3

The data of the measurements taken in May 97 on soil parameters and plant volume are given in Table 26. The information on soil variables indicates that the soil pH varied between 4.6 and 5.8 almost like in other times of observation. The organic carbon content ranged from 0.21 to 1.5 per cent. The total nitrogen content this time varied from 0.05 to 0.26 per cent. Available P varied from 2.5 to 38.8 ppm. Exchangeable bases, Ca, Mg, K and Na were found to vary between 58 to 596, 20 to 159, 26 to 260 and 33 to 48 ppm respectively. Exchangeable Al in the experimental sites ranged from a low of trace to a high of 21.6 ppm. The micronutrients extracted by DTPA namely, Fe, Mn, Cu and Zn varied between 35 to 272, 24 to 217, 1.7 to 30.5 and 1.0 to 3.0 ppm respectively.

Table 27 gives the information on plant volume and soil variables measured during July 97 in all the experimental sites. It is observed from the data that soil pH varied from 4.5 to 6.0 and organic carbon from 0.49 to 1.25 per cent. Total N content was ranging from 0.04 to 0.22 per cent. Available soil P ranged between 8.4 to 142.0 ppm. Exchangeable bases Ca, Mg, K and Na varied from 41 to 560, 8 to 140, 35 to 258 and 34 to 49 ppm respectively. Exchangeable Al was found varying from to 0.4 to 23.1 ppm in the experimental sites. The contents of micronutrients viz. Fe, Mn, Cu and Zn varied between 21 to 370, 12 to 463, 1.8 to 34.7 and 1.0 to 5.5 ppm respectively.

Table 28 presents the data of plant volume and soil variables measured during September 97 in the experimental sites. It is seen that soil pH varied from 4.5 to 6.0 and the organic carbon was between 0.48 to 1.68 per cent. Total N ranged from 0.05 to 0.25 per cent. Available soil P ranged between 6.7 to 71.8 ppm. The contents of exchangeable bases Ca, Mg, K and Na varied from 51 to 676, 13 to 164, 24 to 340 and 30 to 49 ppm respectively. Exchangeable Al was varying from 0.4 to 22.1 ppm in these experimental sites. The content of micronutrients Fe, Mn, Cu and Zn varied between 40 to 566, 24 to 274, 2.3 to 43.0 and 1.0 to 4.5 ppm respectively.

Table 25. Tree volume and soil properties in March 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.7	1.53	0.16	6.7	93	34	79	33	17.9	150	196	22.0	2.0	20.8
2	4.9	1.05	0.09	25.8	123	30	61	36	19.5	290	166	5.7	2.0	30.5
3	5.0	0.96	0.09	9.2	123	37	29	36	20.0	103	158	3.4	1.0	16.7
4	5.2	0.87	0.10	6.7	446	222	148	41	10.5	40	77	2.8	1.5	19.2
5	5.5	1.56	0.19	9.2	500	148	92	39	0.1	83	222	5.0	3.0	18.3
6	5.4	1.44	0.15	15.8	628	162	76	42	0.9	86	289	25.4	3.0	23.2
7	5.2	2.10	0.22	83.3	249	38	108	38	13.0	153	28	23.2	2.0	29.8
8	4.8	1.44	0.18	66.6	179	37	118	36	17.6	154	54	3.9	3.0	40.8
9	5.1	1.05	0.11	21.7	175	38	124	34	14.2	125	44	3.9	2.0	27.0
10	5.4	0.84	0.10	10.0	321	124	43	44	2.1	231	209	5.3	2.0	20.7
11	5.6	0.69	0.07	10.8	349	115	67	39	0.5	174	181	4.3	2.0	20.0
12	5.2	1.17	0.12	10.0	205	67	90	39	13.6	90	197	3.2	2.0	18.5
13	4.9	1.26	0.13	10.8	86	25	52	39	22.2	129	195	5.3	3.0	29.5
14	4.6	0.84	0.09	16.0	61	15	36	32	22.0	81	146	21.6	1.0	21.5

The data of the mean soil properties between November 96 to September 97, measured in the experimental sites are given in Table 29. The information on soil variables indicates that the soil pH varied between 4.7 and 5.6. The organic carbon content ranged from 0.45 to 1.76 per cent. The mean total nitrogen content varied from 0.07 to 0.20 per cent. The content of available P ranged between 8 to 65 ppm. Exchangeable bases, Ca, Mg, K and Na were found to vary between 53 to 554, 16 to 167, 41 to 204 and 32 to 46 ppm respectively. Exchangeable Al in the experimental sites ranged from a low of 1 to 22 ppm. The micronutrients extracted by DTPA namely, iron,, manganese , copper and zinc varied between 96 to 302, 33 to 213, 2 to 33 and 1 to 4 ppm respectively.

The data on soil pH measured in the experimental sites clearly indicate spatial variations. These variations among the sites might be due to a variety of reasons viz., contents of bases, exchangeable aluminium, organic matter and physiographic location (top of the hill or bottom of the hill and so on) of the sites etc. and / or the combination of all the above. Site 11 situated in a valley region is characterised by high soil pH of 5.9 among all sites which is because of high base content, low exchangeable aluminium and low organic matter. Contrary to that, Site 2 has low soil pH, which is because of low base content and high exchangeable aluminium content It is seen from the data given in Table 29 that

Table 26. Tree volume and soil properties in May 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.5	1.50	0.11	3.8	306	85	104	40	2.9	137	159	28.0	2.0	21.8
2	4.9	1.11	0.10	23.8	223	49	116	43	12.1	270	90	7.0	3.0	31.2
3	5.0	1.26	0.13	12.5	234	69	102	38	5.8	117	217	3.7	2.0	18.5
4	5.3	0.21	0.05	3.8	321	135	108	46	3.2	35	48	1.7	1.0	21.8
5	5.5	1.50	0.21	5.0	529	159	260	47	0.8	111	190	4.2	2.0	17.7
6	5.3	1.02	0.12	2.5	596	170	73	48	0.4	62	146	5.5	2.0	26.7
7	4.9	1.80	0.26	38.8	169	39	150	37	18.3	171	36	27.9	1.5	34.8
8	5.0	1.17	0.17	40.0	120	32	124	35	19.5	130	46	3.5	2.0	45.8
9	5.4	0.90	0.07	18.8	161	37	172	39	9.7	113	24	4.9	1.0	36.5
10	5.0	0.99	0.13	3.8	291	128	68	39	6.6	272	153	5.6	2.0	20.8
11	5.8	0.54	0.08	5.0	349	128	95	36	0.0	171	173	4.3	2.0	19.5
12	4.9	0.87	0.13	3.8	215	68	63	35	13.6	82	203	3.6	1.5	19.0
13	5.2	0.90	0.15	10.0	169	88	146	41	8.2	177	174	5.8	3.0	32.7
14	4.6	0.96	0.16	5.0	58	20	26	33	21.6	81	65	30.5	2.0	21.5

there are inter-site variations in mean soil pH (between Nov. 96 to Sep. 97). The mean pH is highest in Site 5 and 11 with pH value of 5.6 and the lowest is in Site 1, 2 and 14 with pH of 4.7. As saidearlier, the pH is a resultant of a combination of different factors affecting it.

It is seen in Fig 2 that there are variations in pH between different times of observation in certain sites. The t-test at different times of observation indicated that soil pH varied significantly from time to time (Appendix C). This is because of the addition of fertilisers, organic matter and soil chemical and microbiological reactions, which might have influenced by the weather. Though the soils buffer the pH (Brady, 1990), there would be temporary changes in pH as a result of fertiliser addition etc. and might have reflected in the measurement at different times.

Correlation analysis (Table 30) clearly showed the role of exchangeable bases and Al in influencing the soil pH. Exchangeable Ca showed a significant positive correlation with soil pH ($r = 0.570^{*}$, 0.747^{**}, 0.771^{**}, 0.844^{**} and 0.714^{**} in November 96, January, March, July and September 97 respectively). Similarly, exchangeable Mg is also positively and significantly related with soil pH the coefficients of correlation being 0.735^{**}, 0.671^{**}, 0.570^{*}, 0.698^{**} and 0.796^{**} observed in January, March, May, July and September 97, respectively.

Exchangeable K is not having any relation with soil pH though it is a base forming element. Exchangeable Na is significantly and positively correlated with soil pH however, only in two times of observations ($r = 0.733^{**}$ and 0.587^{*} in March and July 97). A clear negative role played by exchangeable Al (Brady, 1990) is evident with 'r' values of --0.817**, -0.790^{**}, -0.898^{**}, -0.579^{*}, -0.845^{**} and -0.895^{**} observed in all the six times of observation (Table 30).

It is seen that organic carbon content varied considerably among the experimental sites. In

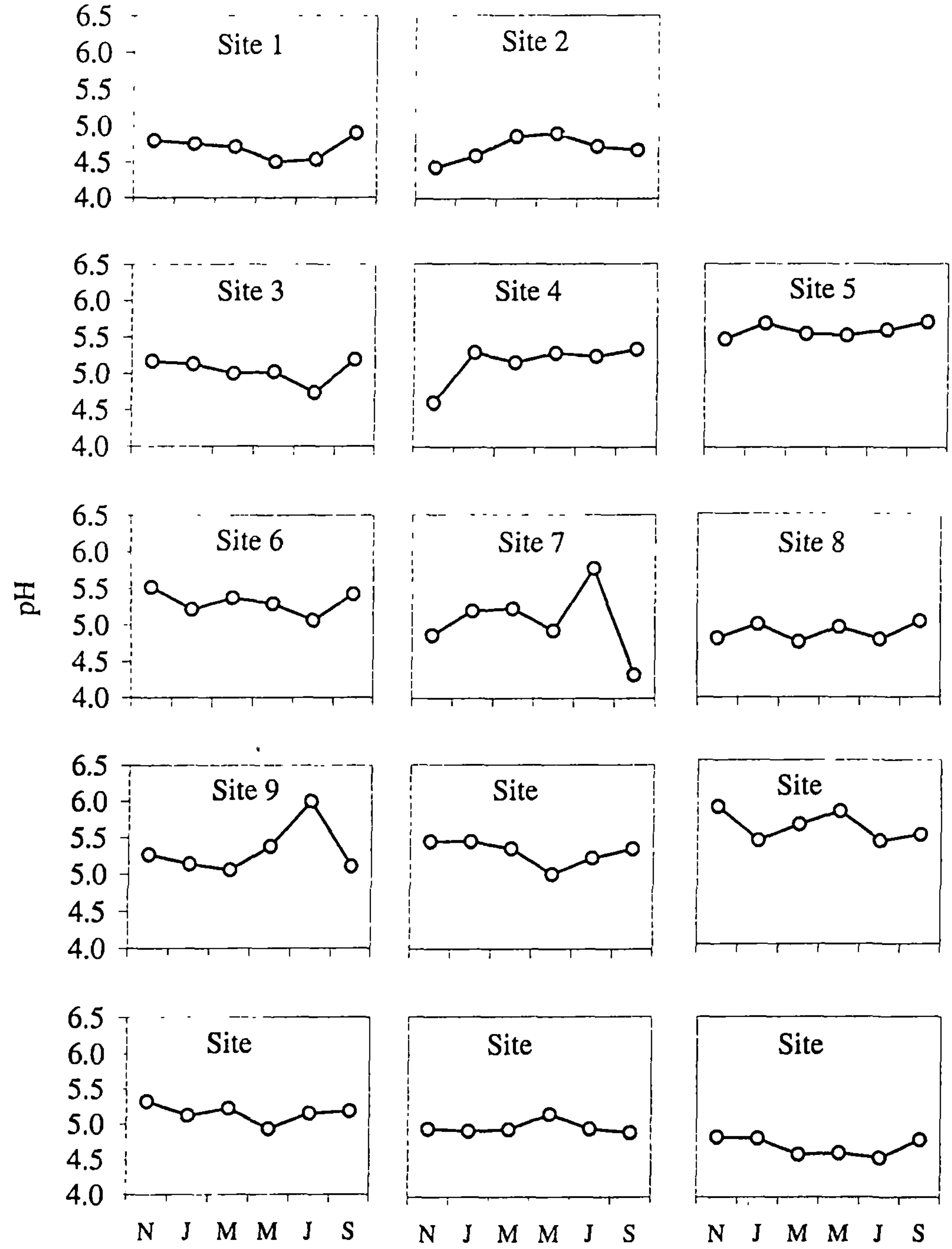

Fig 2. Seasonal changes in soil pH

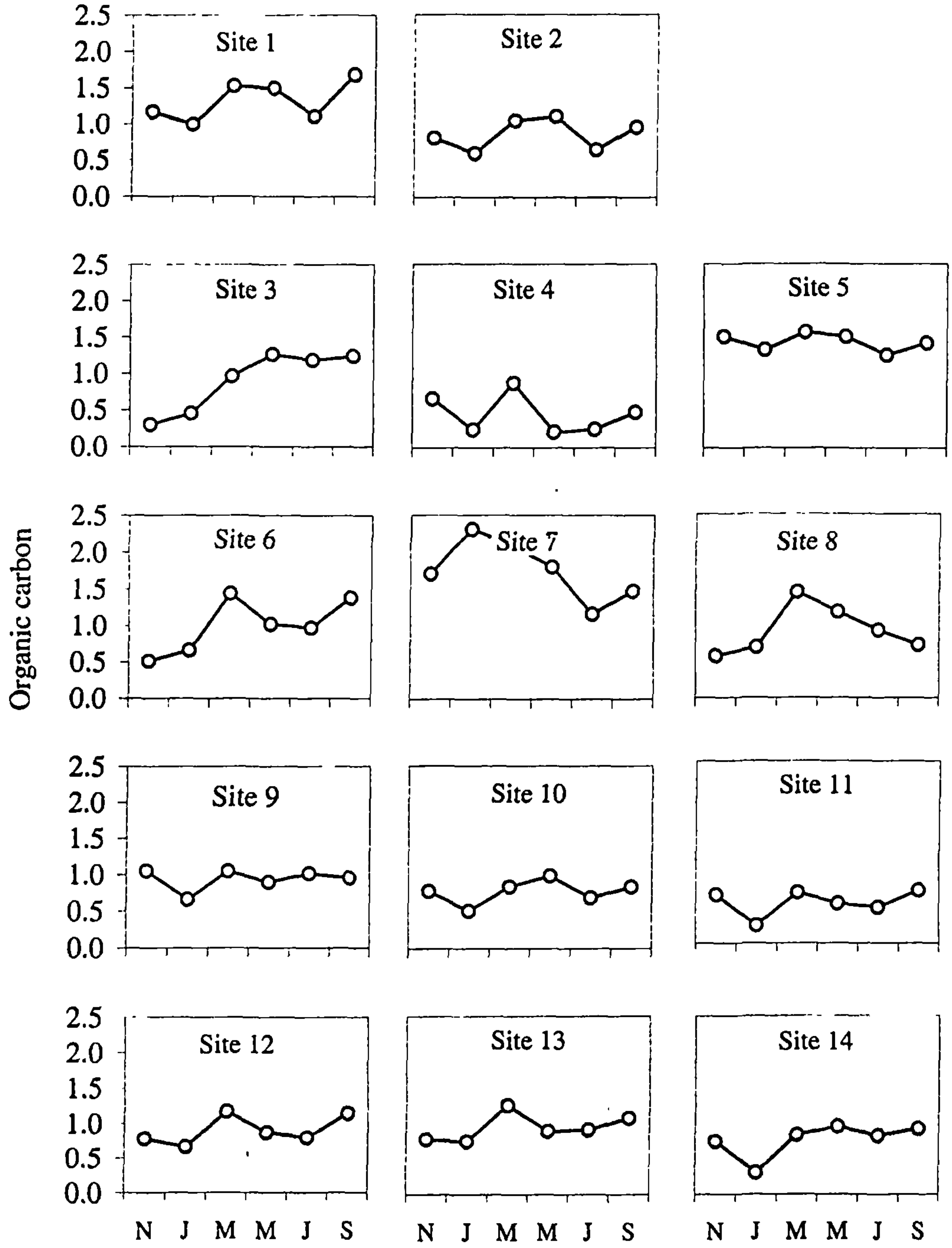

Fig 3. Seasonal changes in organic carbon

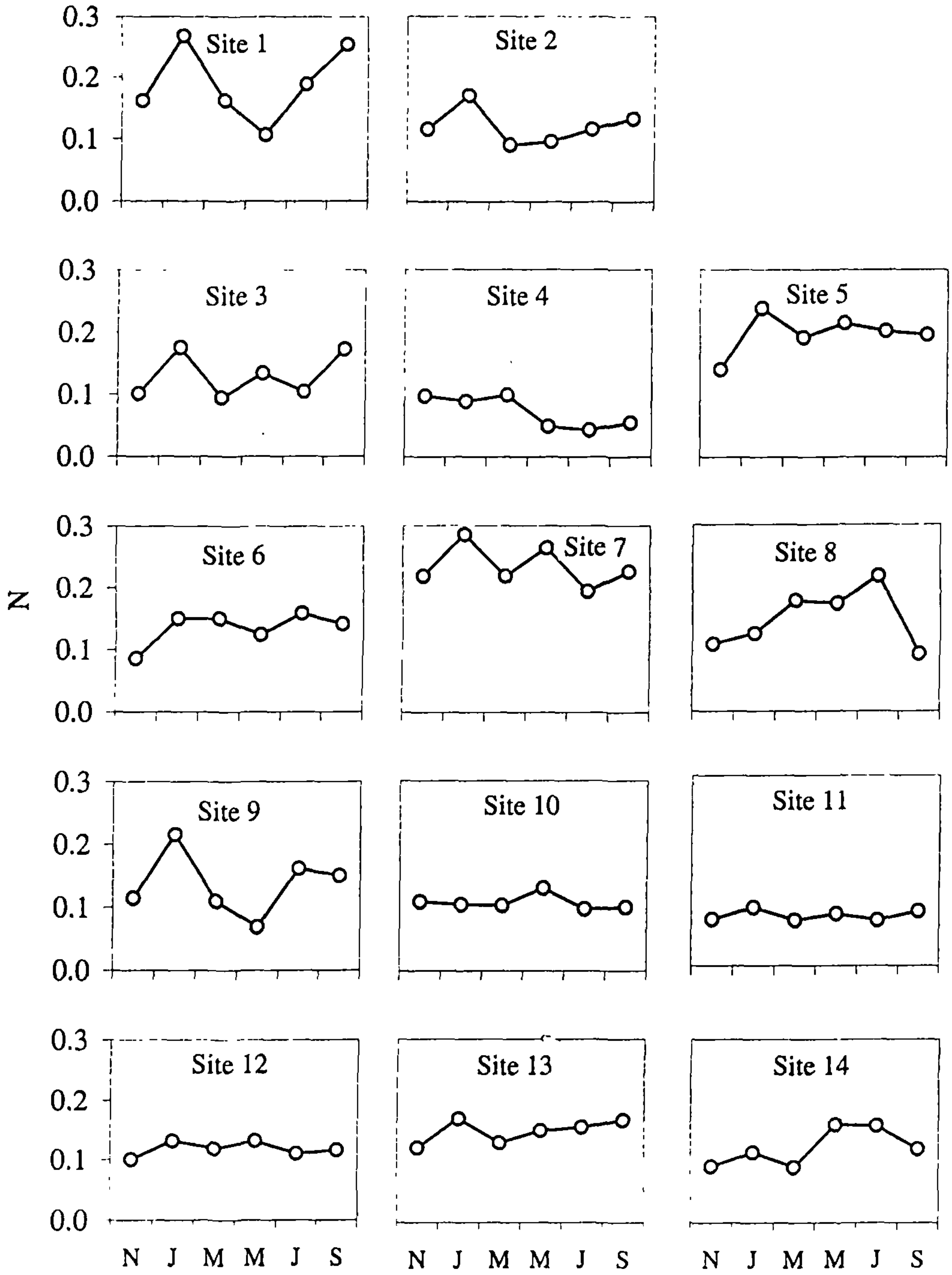

Fig 4. Seasonal changes in soil nitrogen

general, Site 1, 5 and 7 recorded high organic carbon content than other sites at any time of observation. The Site 1 and 7 had well maintained covercrop, which would add organic matter to the soil. The Site 5 in fact, is under rubber for long period, which must have resulted in build up of organic matter over time, as a result of leaf fall and recycling.

Table 27. Tree volume and soil properties in July 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.5	1.11	0.19	10.0	135	44	104	36	11.8	120	99	34.7	2.0	28.2
2	4.7	0.65	0.12	90.2	120	23	61	37	15.1	346	150	7.8	2.5	38.0
3	4.7	1.18	0.10	117.0	150	42	172	36	17.0	370	463	5.1	5.5	30.5
4	5.2	0.25	0.04	15.0	278	124	258	44	6.6	21	37	1.8	1.0	31.7
5	5.6	1.25	0.20	8.4	440	140	186	41	0.6	97	102	4.6	1.5	21.7
6	5.1	0.97	0.16	8.4	469	117	140	44	14.4	82	119	30.4	1.5	32.8
7	5.8	1.16	0.19	142.0	560	70	148	49	0.8	190	16	29.1	3.0	39.5
8	4.8	0.92	0.22	51.8	155	44	106	40	17.1	140	37	4.3	3.0	56.5
9	6.0	1.02	0.16	31.7	430	108	182	40	0.7	117	12	4.8	2.5	46.3
10	5.2	0.69	0.10	8.4	295	109	57	37	4.2	261	143	6.0	2.0	23.7
11	5.4	0.49	0.07	10.0	315	85	112	37	0.4	181	148	4.9	2.5	23.3
12	5.2	0.79	0.11	11.7	176	54	98	36	14.8	76	111	3.6	2.0	23.7
13	5.0	0.92	0.16	10.0	123	29	50	35	21.0	158	93	6.9	3.0	43.0
14	4.6	0.83	0.16	10.0	41	8	35	34	23.1	101	56	33.4	2.0	26.8

Mean soil organic carbon varied considerably among the experiment sites (Table 29). The highest mean organic carbon was noticed in Site 7 followed by Site 5 and 1. In other sites organic carbon ranged between these two. The high organic carbon content in Site 1 and 7 might be due to well-maintained cover crop and in Site 5, it might be due to long history of rubber cultivation.

From Fig 3 it is understood that there are different trends in dynamics of organic carbon. ANOVA of repeated measures showed that the difference in organic carbon among different times of observation is significant (Appendix D). In majority cases, the organic carbon content showed initially a decreasing trend followed by a dip and again a rise. These seasonal changes in organic carbon might be due to a combination of factors, which affect the decomposition like temperature, soil moisture and addition of organic matter by cover crop etc. The higher content of organic carbon in March 97 in many sites might be because of the addition of organic matter by the cover crop which usually dries during summer period. Organic carbon had a positive significant correlation with availablè P in March 97 (Table 30) indicating higher availability of P with increasing organic matter

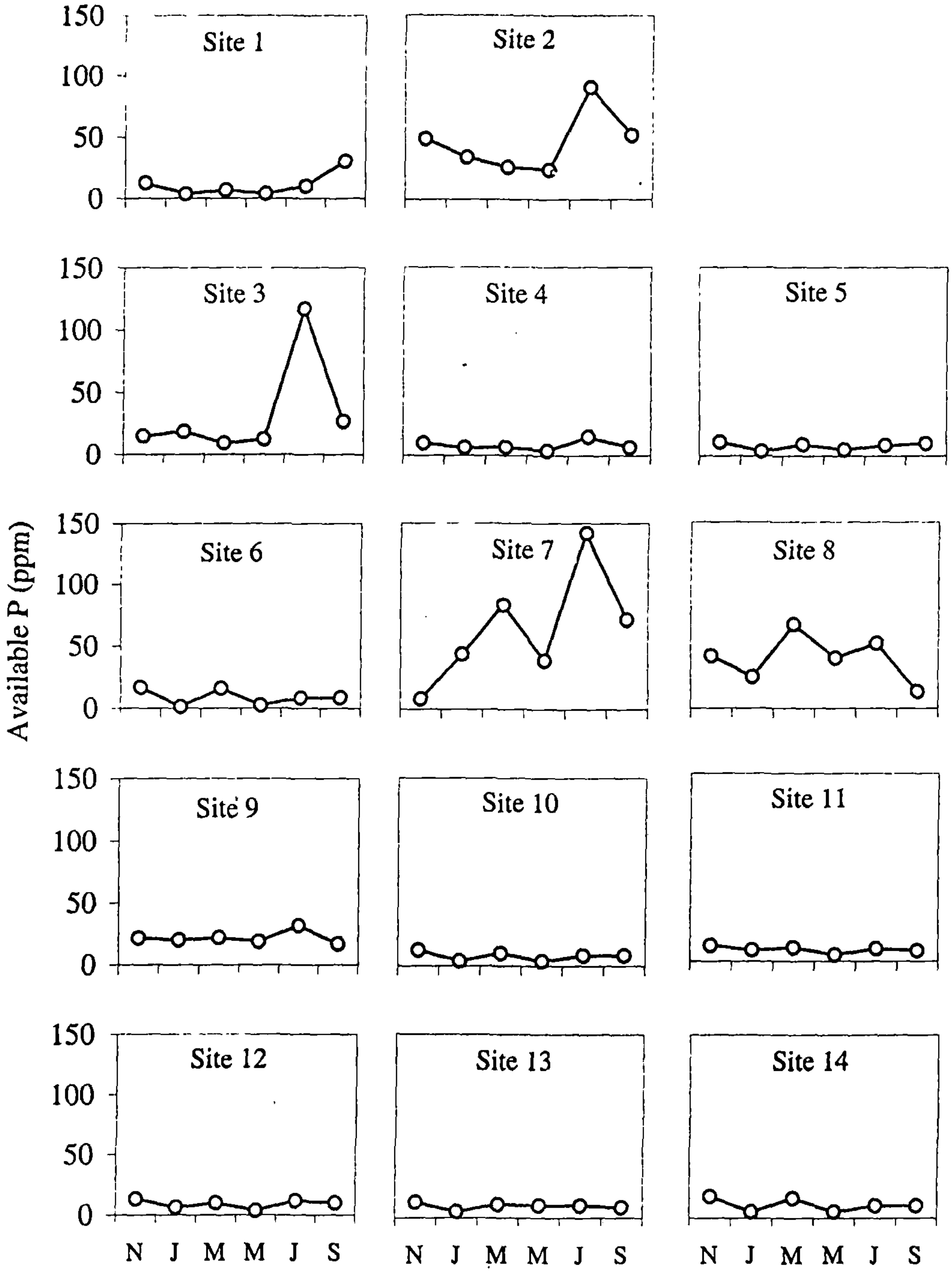

Fig 5. Seasonal changes in soil available P

Table 28. Tree volume and soil properties in September 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm				Volume
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn	dm^3
1	4.9	1.68	0.25	30.1	215	45	69	34	11.3	266	105	43.0	2.5	42.0
2	4.7	0.96	0.13	51.8	118	20	70	36	21.5	566	155	9.2	4.5	53.3
3	5.2	1.23	0.17	26.7	189	47	92	39	13.2	194	104	4.2	2.5	31.5
4	5.3	0.48	0.05	6.7	390	164	100	45	2.5	40	45	2.3	1.0	35.7
5	5.7	1.41	0.20	10.0	483	145	340	49	0.6	143	200	4.5	2.5	34.7
6	5.4	1.38	0.14	8.4	676	130	140	43	0.4	153	274	25.9	2.5	46.0
7	4.3	1.47	0.23	71.8	124	27	230	35	24.4	326	60	27.6	2.0	51.3
8	5.0	0.72	0.09	13.4	168	57	96	36	13.1	87	18	2.7	1.5	68.2
9	5.1	0.96	0.15	16.7	100	28	106	30	17.6	166	24	5.1	1.0	56.3
10	5.4	0.84	0.10	8.4	274	98	44	35	3.8	440	211	7.6	2.5	37.0
11	5.5	0.72	0.09	8.4	353	117	83	32	0.8	324	206	5.8	3.0	36.3
12	5.2	1.14	0.12	10.0	141	42	82	30	15.6	118	169	4.3	2.0	34.8
13	4.9	1.08	0.17	8.4	118	39	66	35	19.4	246	170	6.1	3.5	56.2
14	4.8	0.93	0.12	10.0	51	13	24	30	22.1	145	104	4.1	1.5	35.8

($r = 0.636^{*}$). It is a fact that the mineralisation of organic P is considered as a function of decomposition of organic residues (Gressel and McColl, 1997). In the other correlation, copper was positively related to the OC content during September 97 (0.738^{**}) which according to Stevenson (1986) is because of the metal-organic complexes involving different heavy metals including Cu which has highest stability. The correlation between organic carbon and nitrogen is discussed below where the dynamics of N are described

The nitrogen content appeared to vary among the experimental sites as evident from the data presented in the tables. It is noticed that Site 1, 5 and 7 had higher total N content In general, with exceptions during some times of observations where Site 8 and 9 also showed higher contents. The higher N percentage is seen in plantations where good cover crop is maintained and also in soils under rubber for longer period (Site 5).

The mean total nitrogen content among the soils of experimental sites varied from 0.07 to 0.23 per cent (Table 29). The highest value was recorded in Site 7 which In fact, is under estate sector and had well maintained cover crop also. The lowest total nitrogen content was seen in Site 4 (0.07 per cent).

Seasonal changes were noticed in N content in several sites (Fig 4). However, the ANOVA of repeated measures indicated that the variations in N content among different times of observation were insignificant (Appendix D).

Highly significant positive correlation was noticed between N and the organic carbon at all the times of observation (Table 30). The correlation coefficients were 0.845^{**}, 0.819^{**},

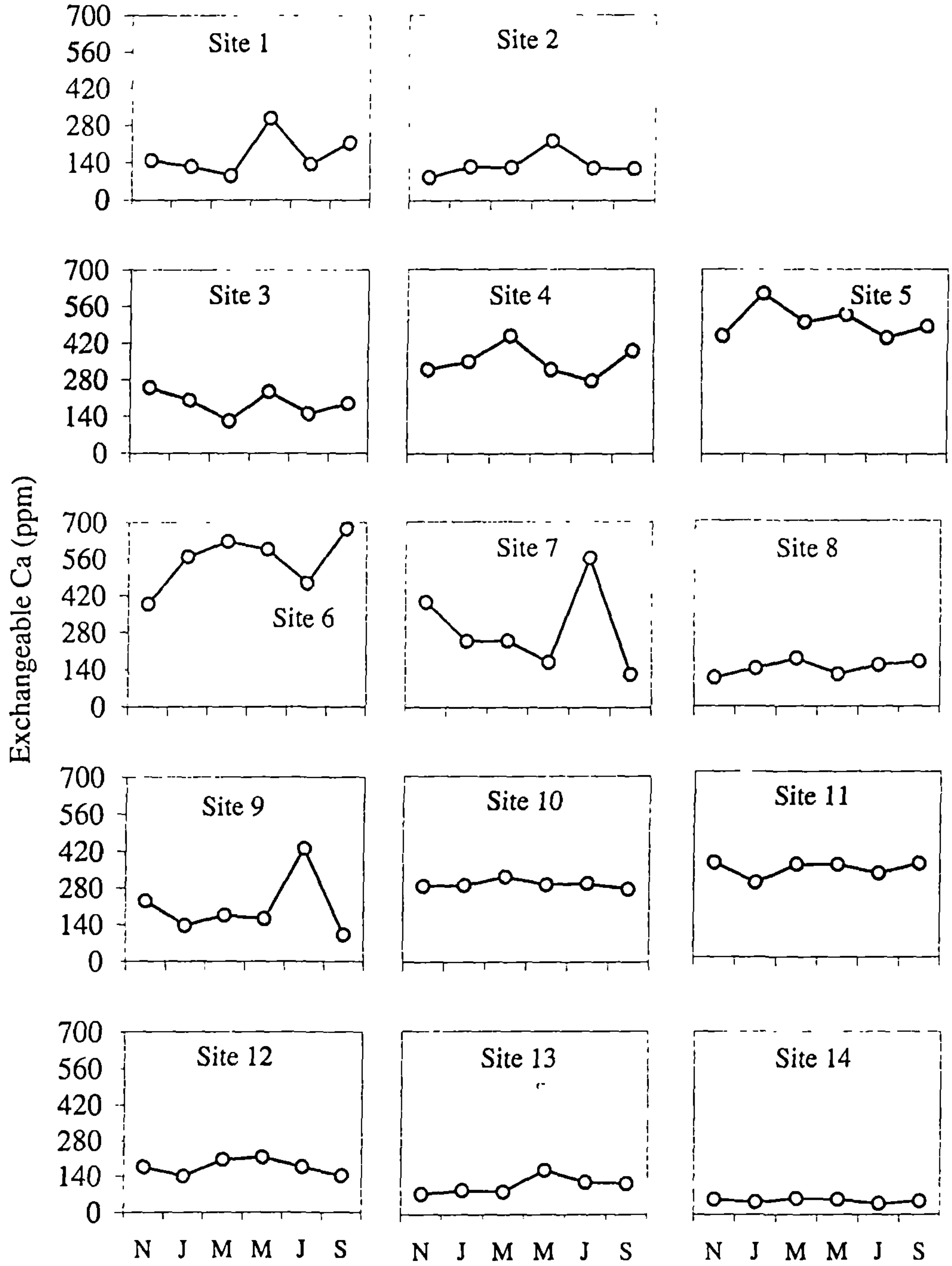

Fig 6. Seasonal changes in exchangeable Ca

0.960**, 0.766**, 0.787** and 0.925** seen in November 96, January, March, May, July and September 97 respectively. This is an obvious relation because of the fact that both C and N regulate each other to maintain a definite ratio in the OM at any time (Brady, 1990).

Table 29. Mean soil properties between November 96 and September 97

Site	pH	OC	N	Av.P	Exchangeable, ppm					DTPA extractable, ppm			
		%	%	ppm	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
1	4.7	1.33	0.19	11	170	48	80	36	11	165	177	33	3
2	4.7	0.86	0.12	46	133	29	75	37	20	375	149	7	3
3	5.0	0.90	0.13	33	191	53	93	36	13	190	201	4	3
4	5.1	0.45	0.07	8	351	167	172	45	7	35	90	2	1
5	5.6	1.42	0.20	8	501	154	204	43	1	119	211	5	3
6	5.3	1.00	0.13	9	554	154	109	46	4	101	213	21	3
7	5.0	1.76	0.23	65	291	42	150	39	14	194	39	27	2
8	4.9	0.92	0.15	40	145	37	104	35	18	119	43	3	4
9	5.3	0.94	0.14	22	205	56	126	36	12	141	33	5	2
10	5.3	0.78	0.11	8	293	114	48	39	4	302	210	6	3
11	5.6	0.56	0.08	9	334	112	91	37	1	204	197	9	3
12	5.2	0.90	0.12	9	176	58	77	34	14	90	181	4	4
13	5.0	0.95	0.15	9	111	40	72	37	19	164	193	9	3
14	4.7	0.77	0.12	11	53	16	41	32	22	96	111	20	2

Available P content, In general,, in Sites 2, 7, 8 and 9 appears to be high. Occasional higher values in other sites might be due to differences in time of application of fertilisers. The higher content of available P in the above sites might be because of higher native P.

The average available P also varied widely among the test sites from a low of 8 to a high of 65 ppm. Site 7 followed by sites 2, 8, 3 and 9 registered higher content of available P while the others had lower contents (Table 29).

Available P seemed to be limited by DTPA extractable Mn because of significant negative correlation with a coefficient of -0.565* (Table 29). It is possible because of formation of a complex of Mn and P thus inactivating the P for uptake. According to Kabata-Pendias and Pendias (1992), the interaction of Mn and P may be cross-linked with Fe and P antagonism or related to both the variation in Mn phosphate solubility in soils and the Mn influence on P metabolic reactions.

Fig 5 shows the seasonal variations in the contents of available P in these experimental sites. The ANOVA of repeated measures showed that the variations in the content at different times of observations are significant (Appendix D). Similar trend in the dynamics of P is noticed in several sites at different times of taking observation. The sudden rise in available P in Sites 2, 3 and 7 in July 97 mightbe because of fertiliser application.

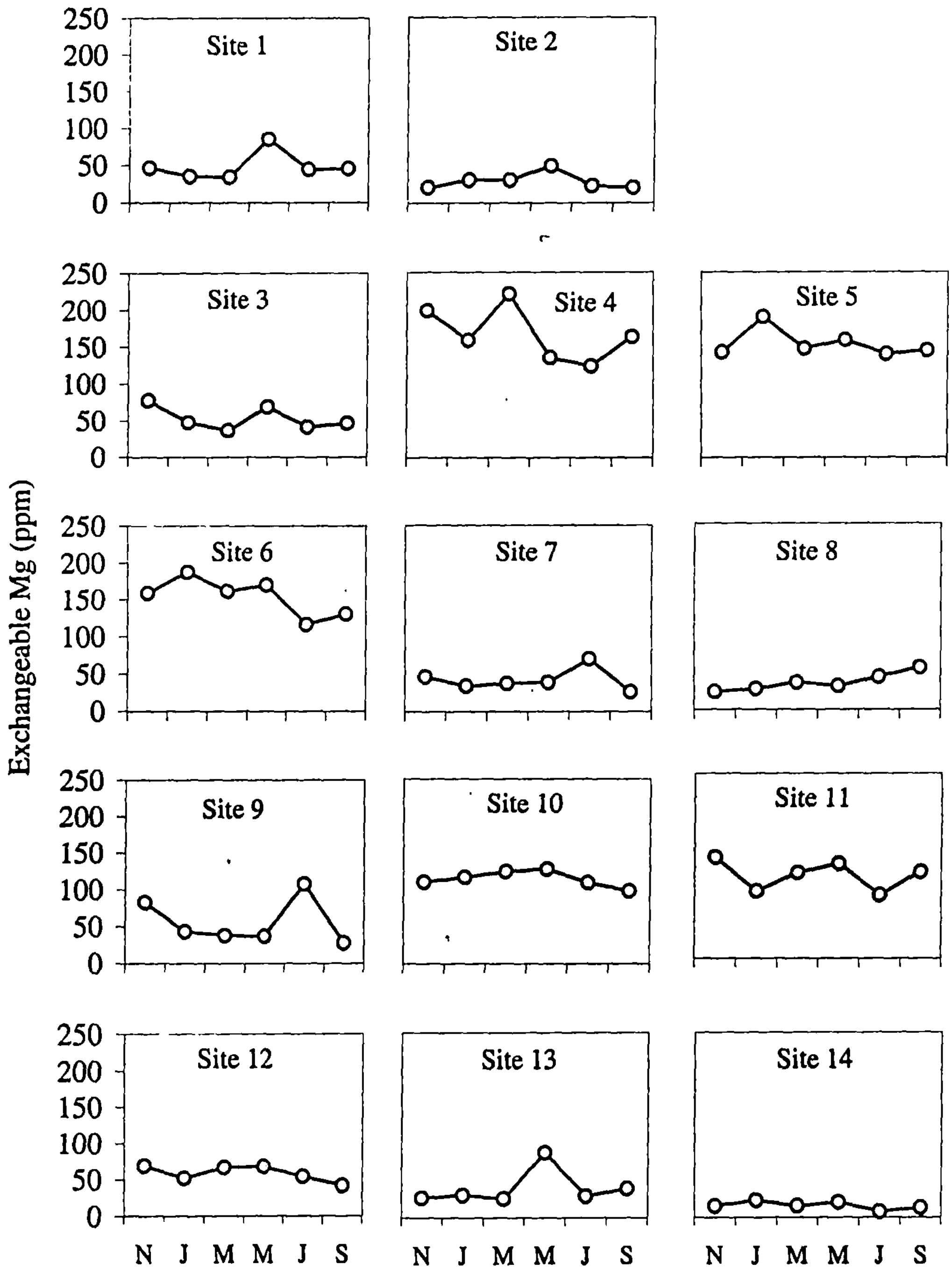

Fig 7. Seasonal changes in exchangeable Mg

Table 30. Correlation between soil properties and growth at different times

	Nov-96	Jan-97	Mar-97	May-97	Jul-97	Sep-97
Volume vs N	NS	NS	NS	NS	0.536 *	NS
Volume vs Av.P	0.701 **	0.568 *	0.746 **	0.797 **	NS	NS
Volume vs Mg	-0.578	NS	NS	NS	NS	NS
Volume vs Al	0.663 **	0.581 *	NS	NS	NS	NS
Volume vs Mn	-0.729 **	NS	-0.566 *	-0.620 *	NS	NS
pH vs Av.P	NS	NS	NS	NS	NS	-0.772 **
pH vs Ca	0.570 *	0.747 **	0.771 **	NS	0.844 **	0.714 **
pH vs Mg	NS	0.735 **	0.671 **	0.570 *	0.698 **	0.796 **
pH vs Na	NS	NS	0.733 **	NS	0.587 *	NS
pH vs Al	-0.817 **	-0.790 **	-0.898 **	-0.579 *	-0.845 **	-0.895 **
pH vs Cu	NS	NS	NS	-0.656 *	NS	NS
OC vs Av.P	NS	NS	0.636 *	NS	NS	NS
OC vs Cu	NS	NS	NS	NS	NS	0.738 **
N vs OC	0.845 **	0.819 **	0.960 **	0.766 **	0.787 **	0.925 **
N va Cu	0.546 *	NS	NS	NS	NS	0.699 **
N vs Zn	NS	NS	0.564 *	NS	NS	NS
Av.P vs Al	0.683 **	NS	NS	0.630 *	NS	NS
Av.P vs Mn	-0.548 *	-0.638 *	-0.652 *	-0.591 *	NS	NS
Av.P vs Fe	NS	NS	NS	NS	0.637 *	NS
Av.P vs Zn	NS	NS	NS	NS	0.679 **	0.679 **
Ca vs Mg	0.780 **	0.943 **	0.894 **	0.914 **	0.775 **	0.878 **
Ca vs K	0.732 **	0.566 *	NS	NS	0.541 *	NS
Ca vs Na	0.653 *	0.794 **	0.718 **	0.780 **	0.821 **	0.736 **
Ca vs Al	-0.856 **	-0.813 **	-0.878 **	-0.829 **	-0.787 **	-0.870 **
Mg vs K	0.564 *	0.618 *	NS	NS	0.672 **	NS
Mg vs Na	0.847 **	0.795 **	0.734 **	0.725 **	0.566 *	0.745 **
Mg vs Al	-0.763 **	-0.855 **	-0.772 **	-0.868 **	-0.751 **	-0.930 **
K vs Na	NS	NS	NS	NS	0.622 **	0.638 *
Na vs Al	-0.596 *	-0.665 **	-0.700 **	-0.667 **	-0.535 *	-0.591 *
Mn vs Ca	NS	NS	NS	NS	NS	0.583 *
Mn vs K	NS	NS	-0.579 *	NS	NS	NS
Mn vs Zn	NS	NS	NS	NS	0.705 **	0.590 *
Cu vs pH	NS	NS	NS	-0.656 **	NS	NS
Fe vs Mn	NS	NS	NS	NS	0.694 **	NS
Fe vs Zn	NS	NS	NS	0.586 *	0.726 **	0.755 **

The availability of P seemed to be influenced by certain soil parameters either always or at some specific times as revealed by the correlation analysis. Significant positive correlation was observed between exchangeable Al and available P during November 96 ($r = 0.683^{**}$) and May 97 ($r = 0.630^{*}$) as seen in Table 30. According to Kirk and Nye (1986b), the dissolution of phosphate rock is very sensitive to pH. It is also seen that the soil pH is always influenced by exchangeable Al and hence the positive relation between exchangeable Al and soil pH. Besides that, the dissolution of Al bound P also

Table 31. Nutrient composition of leaf during September 97

Site	N (%)	P (%)	K (%)	Ca ppm	Mg ppm	Na ppm	Al ppm	Fe ppm	Mn ppm	Cu ppm	Zn ppm
1	3.6	0.26	0.10	713	233	160	53.6	131	218	45.8	18.0
2	2.6	0.31	0.11	756	175	180	33.1	69	499	19.3	22.0
3	3.6	0.33	0.08	332	206	80	37.7	30	268	9.2	14.8
4	2.7	0.25	0.09	604	215	160	69.9	149	284	63.2	12.7
5	3.2	0.46	0.10	683	235	160	46.7	270	329	14.3	24.7
6	3.0	0.34	0.08	673	206	160	46.7	194	328	10.6	16.9
7	3.3	0.31	0.09	607	136	180	41.3	132	181	75.4	18.0
8	3.1	0.37	0.10	513	161	120	26.8	104	280	14.3	10.6
9	2.8	0.33	0.09	839	183	220	119.1	365	282	12.1	18.4
10	3.4	0.37	0.08	707	192	160	25.4	45	385	32.8	21.2
11	3.0	0.55	0.09	654	217	200	59.0	330	234	14.8	22.9
12	3.5	0.51	0.11	501	135	120	67.2	95	321	11.6	21.5
13	3.0	0.43	0.09	669	168	160	9.8	59	370	11.1	19.9
14	2.7	0.36	0.08	727	218	180	97.3	169	353	18.5	36.4

releases Al and thus leading to such positive correlation. It was shown by Amma *et al.* (1991) that Al bound P was positively correlated with available P in some rubber growing soils. The relationship between available P and soil pH is shown by a negative correlation ($r = -0.772^{**}$) in September 97 indicating that increasing acidity would increase the availability of P.

Bolan and Hedley (1990) observed that increased soil acidity could increase the P adsorptive capacity of soils with pH dependent charges. This can also increase the dissolution of rock phosphate by removing P released from the phosphate rock. This discussion is relevant here because of the application of split doses of fertilizer during October 96 and May 97 which might have a fall out on this observation in November and May 97.

DTPA extractable Mn showed significant negative correlation with available P in November 96, January, March and May 97 ($r = -0.548^{*}$, -0.638^{*}, -0.652^{*} and -0.591^{*} respectively), adding limitations to the availability of soil P. The negative interaction of Mn and P is already described by Kabata-Pendias and Pendias (1992).

Available P increased with DTPA extracted Fe during July 97 (Table 30). This perhaps might be because of temporary saturation of soil with water caused by heavy rainfall during this month (Appendix E) which in turn might have reduced the Fe^{3+} to Fe^{2+} form and also releasing P -from Fe bound P.

DTPA extracted Zn showed positive correlation with available P during July and September 97, which might be due to the dissolution

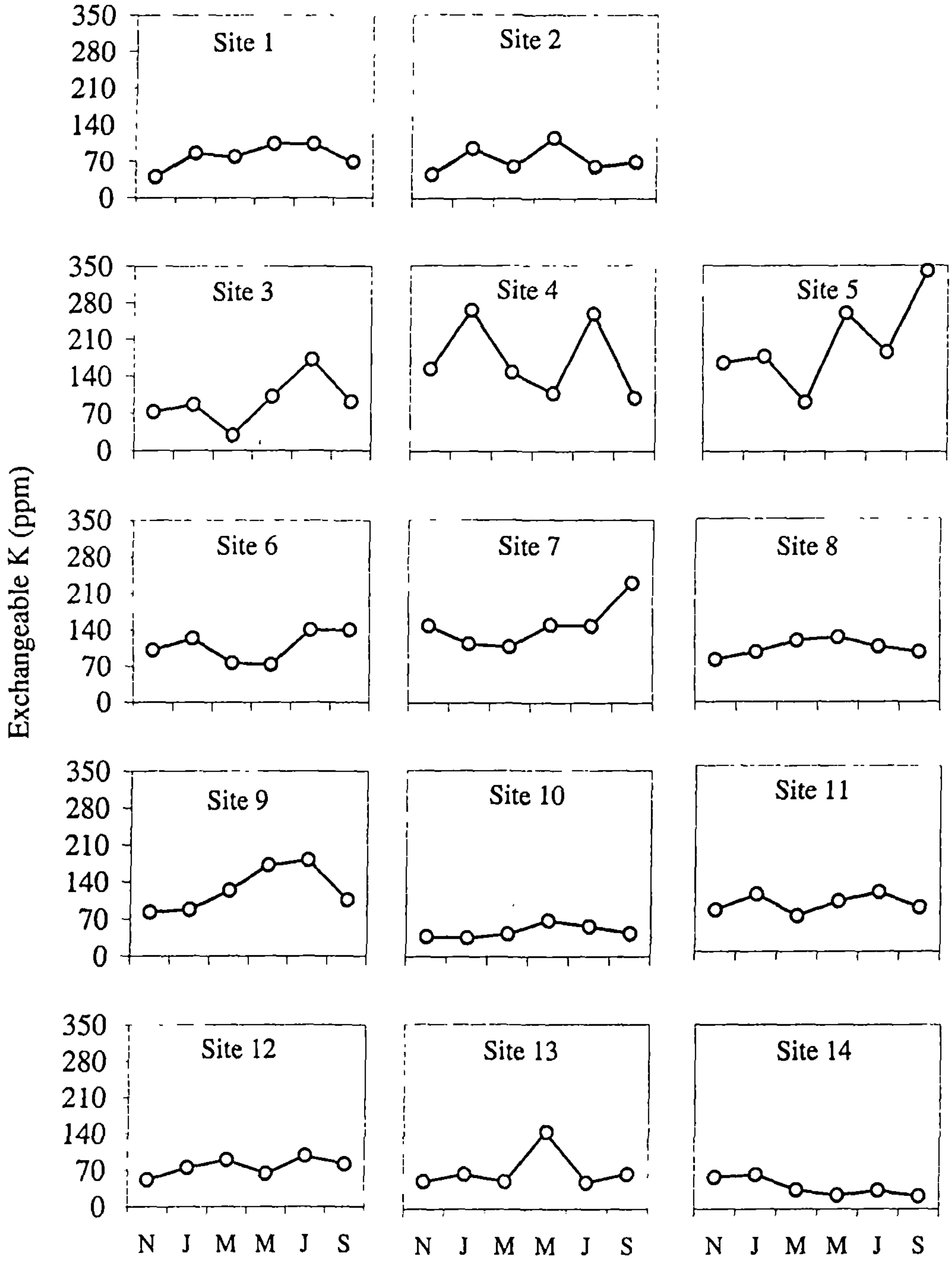

Fig 8. Seasonal changes in exchangeable K

Table 32. Correlation between growth (Sep 97) and leaf nutrients

	Correlation coefficient
Volume vs Mg	-0.545*
N vs Ca	-0.569*
N vs Na	-0.616*
P vs Cu	-0.550*
Ca vs Na	0.889**
Na vs Fe	0.676**
Al vs Fe	0.660**

*, ** for 5% and 1% level of significance respectively

of zinc phosphate releasing both Zn and P. It is to note that such relationship is seen

Table 33. Volume increment (%)

Site	1	2	3	4	5
1	13.2	12.5	4.6	22.7	32.9
2	11.2	12.1	2.2	17.9	28.7
3	15.0	0.0	9.7	39.3	3.2
4	12.8	6.3	11.9	31.2	11.2
5	20.6	12.6	-3.4	18.4	37.5
6	19.1	5.2	13.1	18.6	28.7
7	17.8	9.4	14.4	11.9	23.0
8	13.9	11.8	10.9	18.9	17.2
9	22.5	-3.7	26.0	21.2	17.8
10	10.4	7.2	0.5	12.2	35.9
11	11.5	8.5	-2.6	16.3	35.8
12	16.2	6.5	2.6	19.8	31.9
13	20.1	5.8	9.8	24.0	23.5
14	8.9	5.6	0.0	19.8	25.1

1 = Nov 96 to Jan 97; 2 = Jan to Mar 97; 3 = Mar to May 97; 4 = May to Jul 97; 5 = Jul to Sep 97

during July and September 97 only where soil moisture was high. According to Marschner (1995), with a fall in pH or in redox potential, the concentration of Fe, Mn and Zn increase to varying degrees which normally may occur during rainy period

Neutral normal ammonium acetate extracted calcium content varied widely among the experimental sites. High values are recorded in Site 5 and 6 In general, and some times in Site 7 also. Other sites registered different quantities of exchangeable Ca. The higher values in Site 7 were observed during November 96 and July 97 might be due to fertilizer application of second split dose of fertilisers including rock phosphate which contains Ca. The higher values noticed in Site 5 and 6 might be because of inherent presence of Ca in the soils. Higher exchangeable Ca in Site 11 might be because of accumulation of leached down bases as a result of its physiographic position. Soil of Site 14 recorded lowest exchangeable Ca at any time of observation.

The mean Ca extractable by ammonium acetate varied widely with different sites. It is seen that the highest exchangeable Ca registered in Site 6 followed by 5, 4 11 and 10. The lowest content was observed in Site 14 with a very low of 53 ppm (Table 29).

The seasonal variations in the contents of exchangeable Ca follow different patterns in different sites (Fig 6). In general,, higher values in exchangeable Ca were recorded either during May or July 97 which might be a result of fertiliser application. The ANOVA of repeated measures indicated that the changes in exchangeable Ca measured in different periods of observations are significant indicating its dynamic nature as regulated by the weather.

Exchangeable Ca has strong positive correlation always with exchangeable Mg (Table 30). The coefficients of simple correlation are, 0.780**, 0.943**, 0.894**, 0.914**, 0.775** and 0.878** observed during November 96, January, March, May, July and September 97 respectively. The correlation with exchangeable K was significant only during November 96 and January 97 (r =

0.732^{**} and 0.566^{*} respectively) whereas, exchangeable Na again had positive significant correlation with exchangeable Ca (r = 0.653^{*}, 0.794^{**}, 0.718^{**}, 0.780^{**}, 0.821^{**} and 0.736^{**} for November 96, January, March, May, July and September 97 respectively. Exchangeable Ca is also related to exchangeable Al but negatively. The correlation coefficients are, -0.856^{**}, -0.813^{**}, -0.878^{**}, -0.829^{**}, -0.787^{**} and -0.870^{**} respectively, for all the times of observations.

The exchangeable Mg content varied widely among the experimental sites. In general,, the Sites 4, 5 and 6 recorded higher exchangeable Mg content followed by Site 10 and 11 some times. The lowest content was noticed in Site 14 at any time of observation. The higher content of exchangeable Mg in the above sites and lower values in Site 14 appear to be inherent as such values were recorded all through the year.

The mean exchangeable Mg varied significantly among the experiment sites as seen in the Table 29. The highest exchangeable Mg was found in Site 4 followed by 5, 6, 10 and 11. The lowest value of exchangeable Mg is recorded in Site 14 (16 ppm).

Similar to calcium, exchangeable Mg also showed variations in content from time to time and according to the ANOVA of repeated measures, the variations are significant too. Fig 7 indicate that there is a rise in the content of exchangeable Mg during May or July 97 which coincide with the application of first split of fertiliser. In Site 14 however, the changes in exchangeable Mg appeared to be not varying much.

Exchangeable Mg exhibited a positive significant relation with that of exchangeable K. The correlation coefficients are 0.564^{*}, 0.618^{*}, 0.672^{**} and 0.745^{**} for November 96, January, July and September 97 respectively. Similarly there was positive significant correlation observed between exchangeable Mg and Na (0.847^{**}, 0.795^{**}, 0.734^{**}, 0.725^{**}, 0.566^{*} and 0.745^{**} for all the times of observations respectively). Highly significant and negative relationship was observed between exchangeable Mg and Al. The coefficients of simple correlation include, -0.763^{**}, -0.855^{**}, -0.772^{**}, -0.868^{**}, -0.751^{**} and -0.930^{**} for all the periods of observations.

The contents of exchangeable K varied widely from site to site and from time to time. These variations might be due to inherent K contents of the sites and seasonal changes imposed by weather. In general,, Sites 4, 5, 6 and 7 registered higher contents of exchangeable K which might be owing to high content of native K. However, the random increases in Site 8, 9, 11 and 13 etc. might be because of fertiliser application.

The mean exchangeable K varied among the sites from a low of 40 to a high of 204 ppm. The highest value observed in Site 5 followed by 4. The lowest value recorded was 41 ppm seen in Site 14 (Table 29).

Seasonal changes in the contents of exchangeable K are conspicuous as shown in Fig 8. ANOVA of repeated measures indicated that the differences among sites and

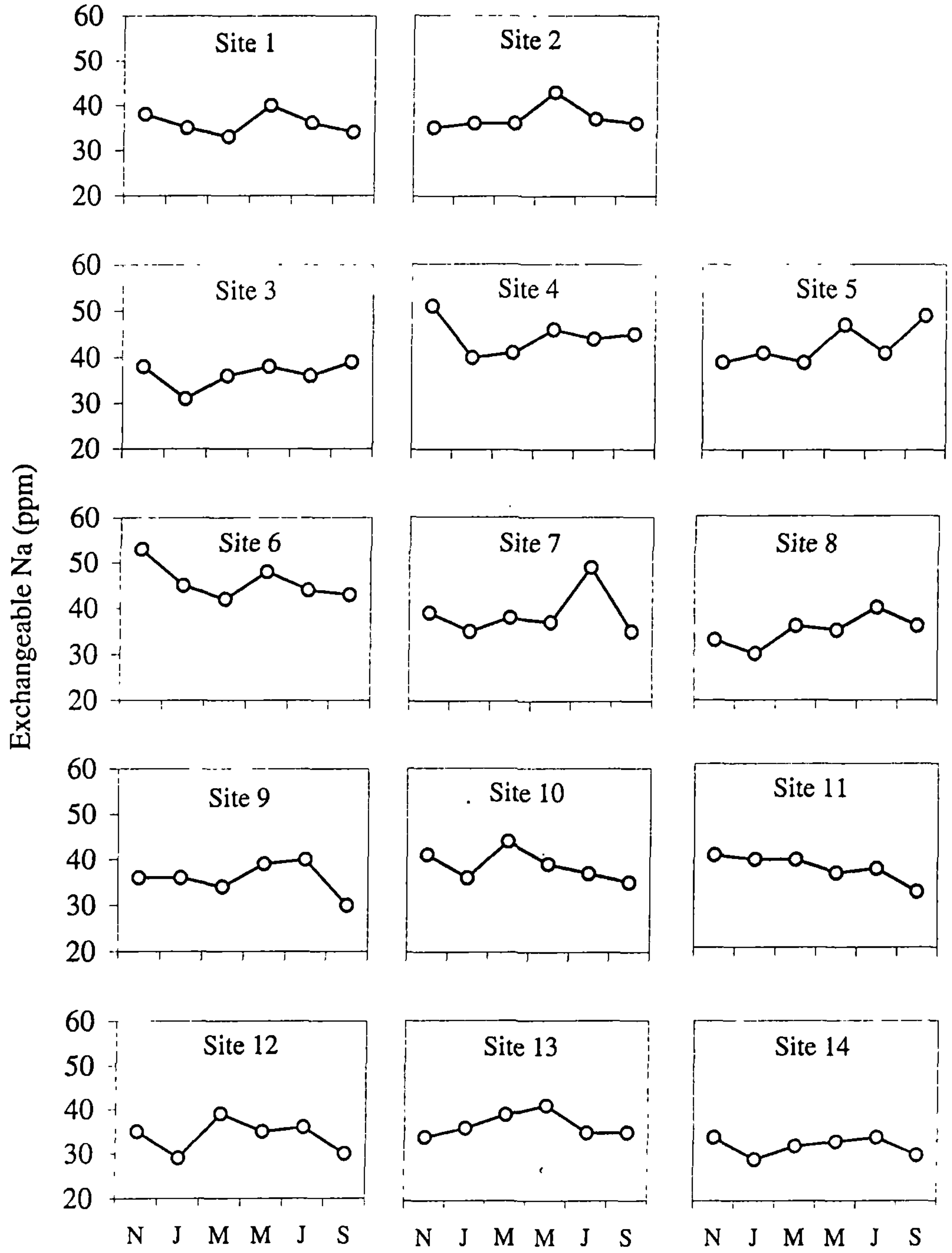

Fig 9. Seasonal changes in exchangeable Na

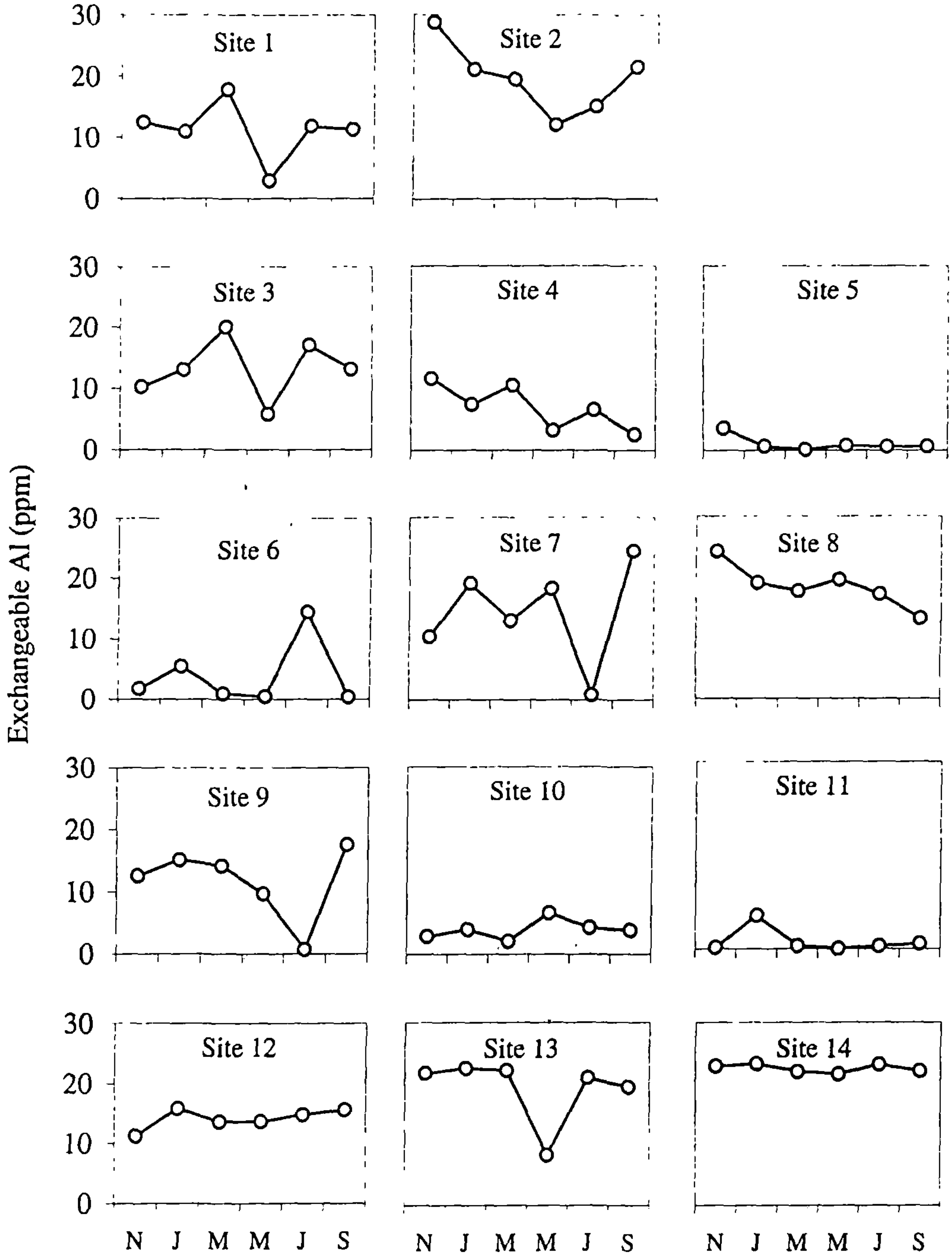

Fig 10. Seasonal changes in exchangeable Al

times are significant. Different trends are seen in different sites in the exchangeable K content which might be due to inherent differences in soils and increases during May or July are due to fertiliser application.

Exchangeable potassium showed a positive significant correlation with exchangeable Na during July and September 97 ($r = 0.622^{*}$ and 0.639^{*} respectively. It is to note that such relationship is observed during excess soil moisture regime in soil. This is because of the fact that both the cations are vulnerable to be washed out. Excess moisture might have brought both these elements into the soil solution, which must have been extracted easily by ammonium acetate. Since both are in the same solution, the resultant correlation might have been positive and significant.

It is seen from the data on exchangeable Na that apparently there are no much wider variations in the contents unlike other elements. Site 4, 5 and 6 In general, showed higher contents of exchangeable Na while other sites like that of 10 and 11 some times registering higher contents. The variations might be naturally occurring depending on the geology, soil forming processes etc.

The mean exchangeable Na appeared not to vary widely unlike other elements. The highest content of exchangeable Na was observed in Site 6 followed by 4. The lowest value recorded was in Site 14 with 32 ppm of exchangeable Na (Table 29).

ANOVA of repeated measures showed clearly that exchangeable Na varied significantly between different times of observations (Appendix D). Fig 9 depicts the seasonal variations over time in the contents of exchangeable Na. In majority cases, there is an increase in exchangeable Na during May or July 97 coinciding with high rainfall and fertiliser application which might have caused the hike in the content of exchangeable Na.

The relationship between exchangeable Na and other soil properties has already been presented. In addition to that there existed a significant negative relationship between exchangeable Na and Al at all the times of observation. The correlation coefficients are -0.596^{*}, -0.665^{**}, -0.700^{**}, -0.667^{**}, -0.535^{*} and -0.591^{*} for November 96, January, March, May, July and September 97 respectively. It is a fact that Na and Al are the most important elements, which influence the soil pH. It is obvious that the relationship between exchangeable Na and Al is negative.

Wider variation in the content of 1*N* KCl extracted aluminium among experimental sites is noticed Site 5, 6, 10 and 11 generally had lower contents of exchangeable Al. Site 13 and 14 generally and Site 2, 7 and 8 occasionally contained higher exchangeable Al contents. These variations might be the reflection of different chemical reactions taking place.

KCl (1 *N*) extractable mean Al content in different sites varied considerably (Table 29). The lowest value of exchangeable Al was seen in Site 5 and 11 and the highest in Site 14.

The seasonal changes in exchangeable Al in different sites and times of observation are given in Fig 10. The ANOVA of repeated measures indicated that the variation in exchangeable Al among different times of observations is significant (Appendix D). In several cases, it is seen that there is a dip in the content of exchangeable Al either during May or July 97 and in some cases even in September also. It is seen that soil pH and

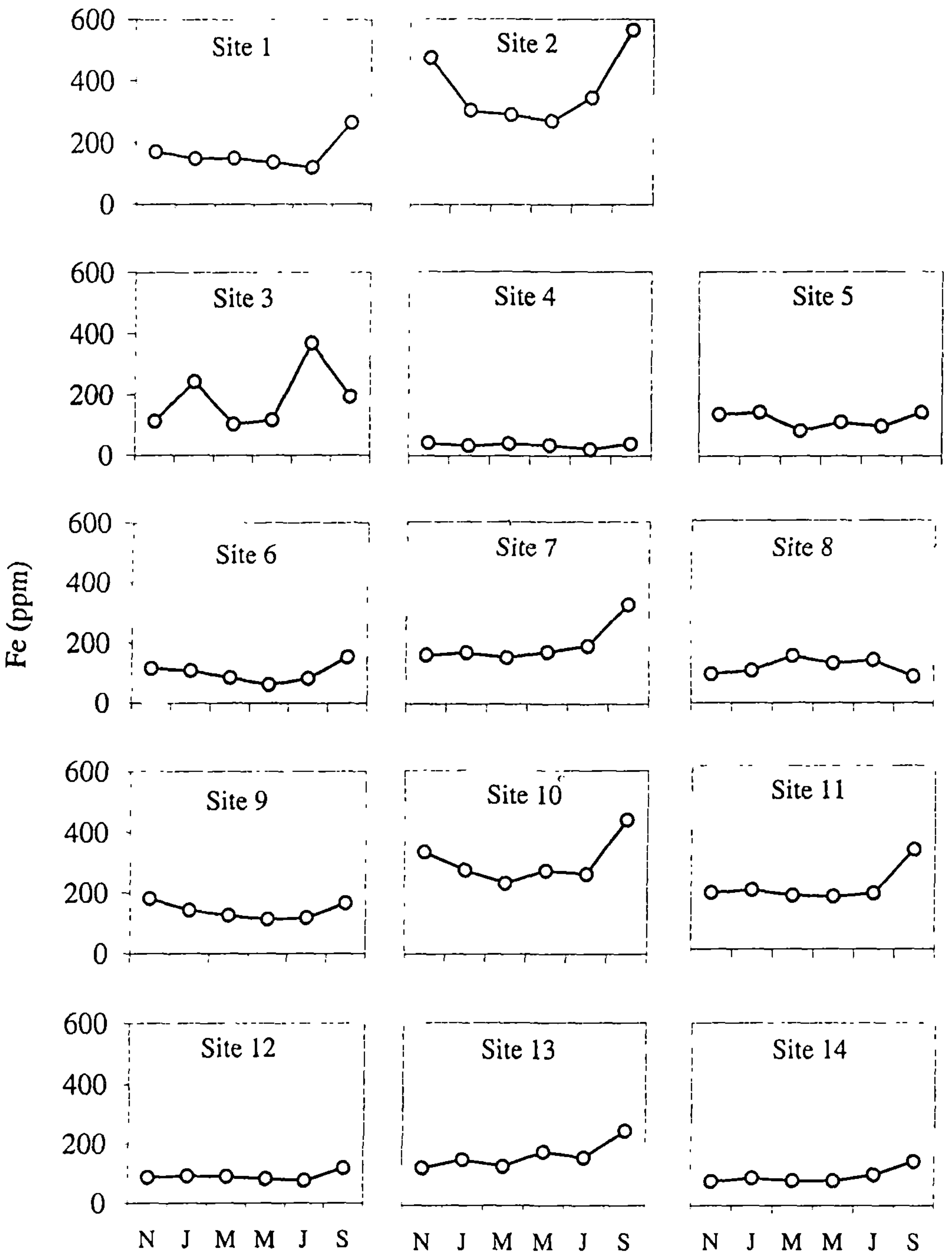

Fig 11. Seasonal changes in DTPA extractable Fe

exchangeable Al are negatively correlated. It is also noticed that the soil pH is found varying significantly from time to time which might have culminated into concurrent variations in exchangeable Al. According to Lindsay (1979), the activity of Al^{3+} in equilibrium with any of the aluminium minerals is pH dependent, decreasing 1000-fold for each unit increase in pH. In the present study also such relationship between exchangeable Al and pH phenomenon is understood by correlation study (Table 30).

It is seen from the data that sites 2, 10 and 11 had higher DTPA extractable Fe content at any time of observation. These variations might be a result of geological influence depending upon the degree of weathering, recombination of weathering products etc.. Site 3, 7, 9 and 13 contained higher quantities of DTPA-Fe at certain times. These occasional changes however, are a result of the influence of the factors that affect the solubilisation and release of Fe. Lowest DTPA-Fe content at any time of observation is recorded in Site 4.

The average DTPA extractable iron content varied between 35 to 375 ppm (Table 29). These variations might be inherent to the soils and in addition to that it is an average of varying Fe contents over time.

The trend of seasonal changes in DTPA extracted Fe is almost similar in all sites which is characterised by a rise during July or September 97 (Fig 11). Both these months must have had high soil moisture content, which might have led to temporary saturation of soils, solubilising Fe and thus increasing the content.

In addition to the correlation between DTPA-Fe and some soil properties described earlier, some relationships with other soil variables also were observed. DTPA extractable Fe has a positive and significant correlation with DTPA-Mn during July 97 ($r = 0.694^{**}$). DTPA-Fe also had positive and significant correlation with DTPA-Zn during May, July and September 97 ($r = 0.586^{*}, 0.726^{**}, 0.755^{**}$ respectively). Perhaps these relations might have a common reason that a fraction of Zn is associated with oxides of Mn and Fe and is likely to be most available to plants (Norrish, 1975; Zyrin *et al.*, 1976). Similarly, Abd-Elfattah and Wada (1980) found highest selective adsorption of Zn by Fe oxides, halloysites and allophane. All this imply that when Fe and Mn oxides are dissolved, simultaneously Zn also is released along with Fe and Mn.

DTPA extracted manganese showed wider variations in content among the experimental sites, as seen in the tables. Comparatively, Site 7, 8 and 9 In general, and occasionally in Site 4, lower DTPA-Mn content were recorded while others had higher DTPA-Mn content. It is possible that these inter-site variations might be natural.

Similar to the observations made on the content of DTPA extractable Mn earlier, Site 7, 8 and 9 had shown lower contents mean Mn extractable by DTPA while Sites 6, 5 and 10 showed higher values with intermediate values in other sites (Table 29).

Fig 12 depicts the variations in DTPA-Mn over time. The variations between different times of observations were significant according to the ANOVA of repeated measures (Appendix D). In general,, it is noticed that there is a decrease in DTPA-Mn content from November 96 to either July 97 and then followed by a rise during September 97 except for minor deviations in some sites. It is because of the role of soil moisture on the solubility of

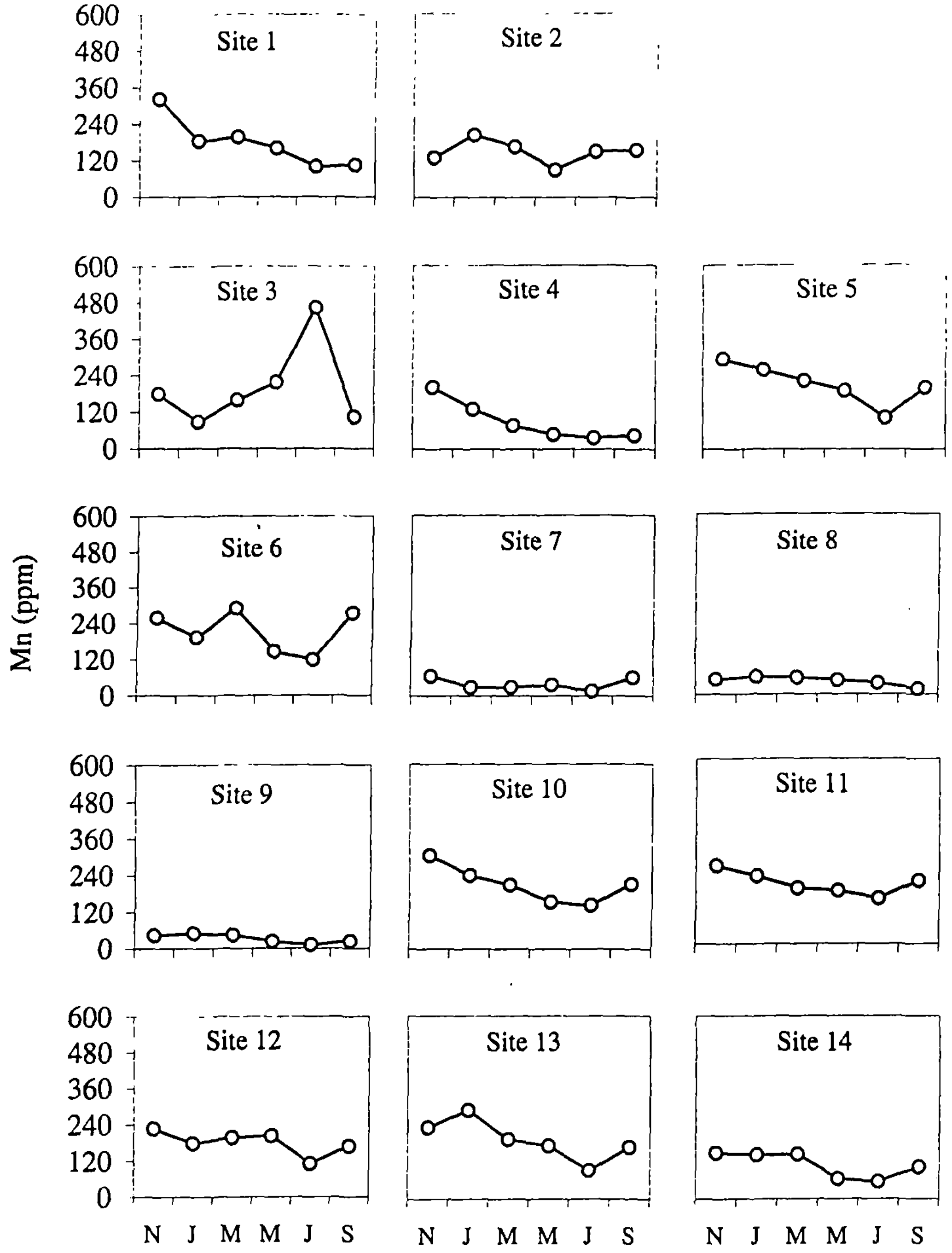

Fig 12. Seasonal changes in DTPA extractable Mn

manganese. The effect of wetting and drying on Mn mobility will be influenced by the state of oxidation / reduction to which the soil has been brought during the wet phase, since this will influence not only the concentration of Mn in solution at the commencement of drying but also the ensuing microbial activity. It was further stated that for Mn, under well drained conditions the effect of water content on Mn in solution is essentially an indirect effect of soil water on microbial activity (Nambiar, 1975).

Important relationships between DTPA-Mn and other soil properties mainly include that with DTPA-Zn during July ($r = 0.705^{**}$) and September 97 ($r = 0.590^{*}$). The explanation given earlier while describing the relationship between DTPA extracted Fe, Mn and Zn is applicable here also.

Considerable variations among sites are seen in DTPA extracted Cu also. It is observed that Site 1, 6, 7 and 14 recorded higher DTPA-Cu in majority times of recording of observations. These higher values are because of application of Bordeaux mixture to the plant as a protection measure and its subsequent entry into soil system and its recycling. Occasionally, Site 11 and 13 registered higher values, which might be due to the soil chemical reactions that solubilise copper. In other sites lower DTPA-Cu values limiting to single digit are seen.

In case of DTPA-Cu also a range of values from 2 to 33 ppm is recorded in the present experimental sites. The highest value noted is in Site 1 (33 ppm) followed by Site 7, 6 and 14 similar to the situation described above and the lowest value is found in Site 4 (2 ppm).

In Fig 13, the dynamics of DTPA extractable Cu are shown which indicate that in majority times, the curve did not show much variations over time in different sites. ANOVA of repeated measures indicated that the variations among sites over time are not significant (Appendix D).

DTPA extracted copper showed a significant negative correlation with soil pH in May 97 ($r = -0.656^{*}$) indicating higher solubility of Cu when soil reaction is acidic as shown by Brady (1990).

Variations in DTPA extractable Zn are seen among the experimental sites from the data given in tables. It is also seen that different sites recorded higher contents at different times of observation indicating no definite trend. These variations might be natural as well as influenced by the soil processes regulated by the weather or fertiliser application or organic matter addition etc.

There is not much variation in DTPA extractable Zn among experimental sites. The entire range of values lies between 1 and 4 ppm. The highest value is noted in Site 8 and the lowest in Site 4. However, mean Zn contents could indicate the trend unlike the values measured at different times.

Fig 14 shows the seasonal variations in DTPA-Zn contents in the experimental sites over the time between November 96 to September 97. The ANOVA of repeated measures also indicated that the variations at different times of observation are significant (Appendix D). Except in Site 8 and 12, the trend is almost similar in all the sites with dips and rises at varied times signifying the season's influence.

The important relations between DTPA extracted Zn and other soil variables particularly with available P, DTPA extractable Fe and Mn are already described earlier.

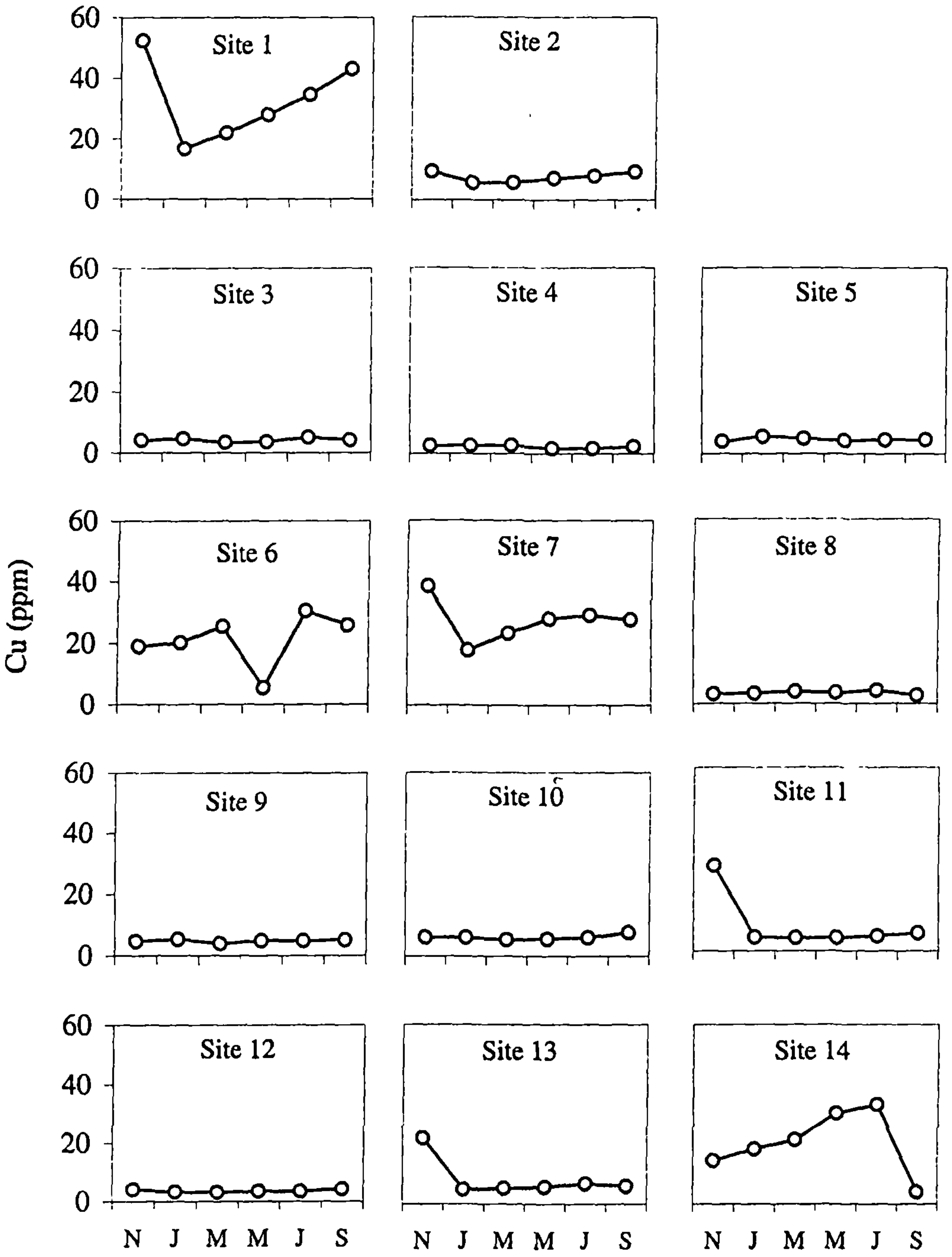

Fig 13. Seasonal changes in DTPA extractable Cu

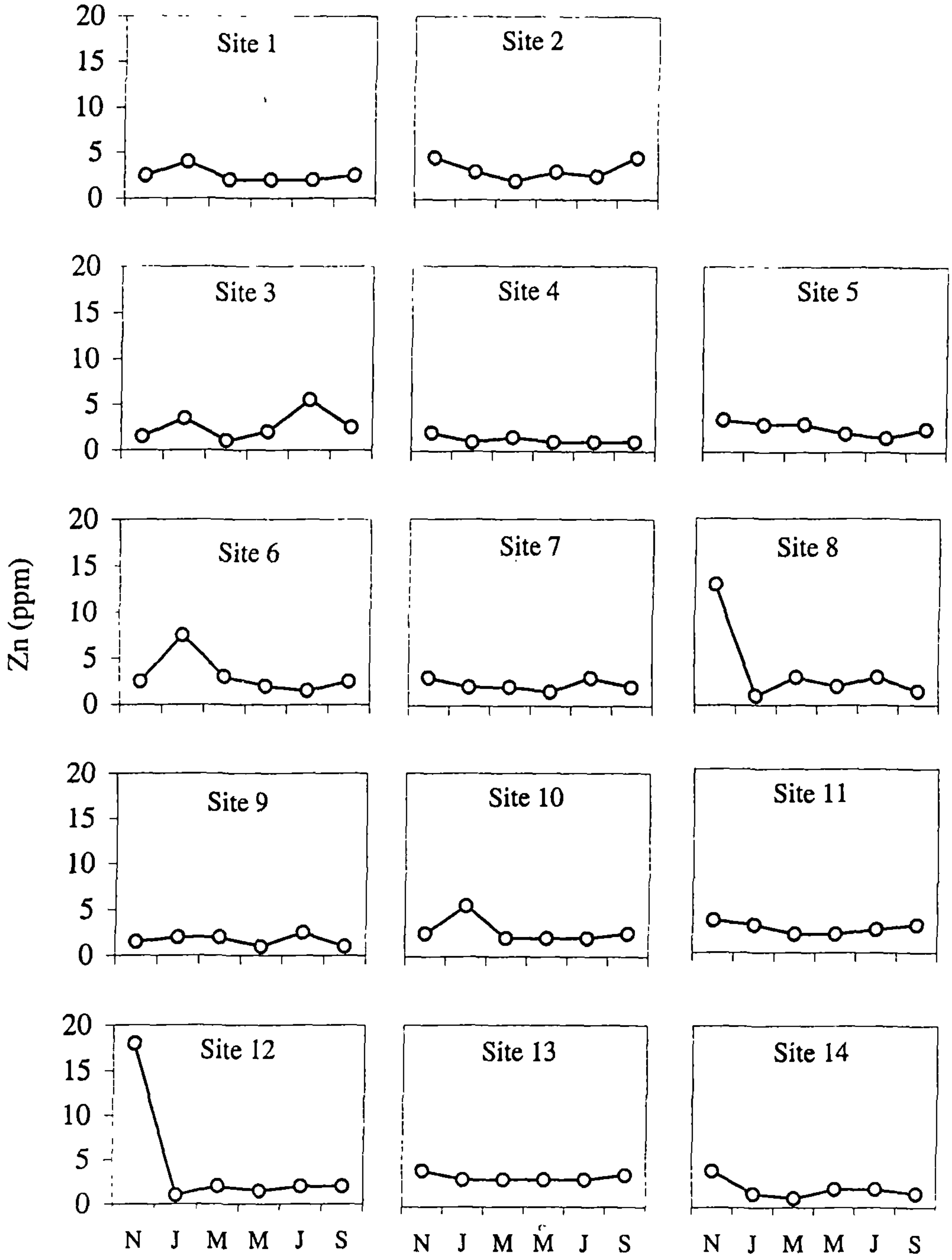

Fig 14. Seasonal changes in DTPA extractable Zn

The data on soil variables measured in different experimental sites at different times of observations covering one annual cycle of weather indicated clearly that sites varied in contents of different nutrient elements and other soil properties. Similarly there were seasonal changes in soil properties from time to time which were regulated by weather indicating differential availability of the nutrients to plants. The correlation analysis indicated that there were definite relations among certain soil properties at any time of observation. It is understood that soil temperature and soil moisture content were the most important parameters regulating the availability of elements particularly that of P and K as suggested by Rajan *et al.* (1996). The role of soil moisture was prominent in bringing out several relationships particularly among micronutrients which were observed during rainy season i.e. during July and September 97.

3.3 Leaf nutrients

The leaf analysis was done using the leaf samples collected during September 97 and the results are given in Table 31. From the data it is observed that nitrogen content varied from a low of 2.6 to 3.6 per cent. The highest content of N is recorded in Site 1 while the lowest being in Site 2. The other sites namely 2, 14 and 9 also had lower values when compared to other values.

Leaf P content varied among the experimental sites, from 0.26 to 0.55 per cent. The highest value was measured in Site 11 (0.55 %) followed by Site 12 (0.51 %) while the lowest value was found in Site 4 (0.25 %) followed by Site 1(0.26 %). The content of leaf K measured in different sites did not vary much and it ranged from 0.08 to 0.11 per cent only, the highest being in Site 2 and 12 and the lowest being in Site 3, 6, 10 and 14.

The calcium content in the leaf, measured during September 97, in all the sites varied widely from a low of 332 ppm (Site 3) to a high of 839 ppm (Site 9). Leaf Mg measured in all the experimental sites varied from 135 ppm in Site 12 to 235 ppm in Site 5. The sodium present in leaf also showed variations in content ranging from a low of 80 ppm (Site 3) to a high of 220 ppm (Site 9).

The aluminium content tested in leaf in the experimental sites ranged from a very low of 9.8 ppm to a very high of 119.1 ppm. The sites 13 and 9 presented these values respectively. Similarly, Fe also exhibited wider variation in the content among the sites. A low of 30 ppm Fe was recorded in Site 3 while there was a high of 365 ppm in the leaf from Site 9.

Leaf Mn varied considerably between 181 ppm (Site 7) and 499 ppm (Site 2) in the leaf. However, there is no wide variation in the content of Cu measured in the leaf in these sites. Site 3 registered a low Cu content of 9.2 ppm while Site 7 recorded a high of 75.4 ppm Cu. The high copper content might be because of application of Bordeaux mixture for protecting the plants from fungal diseases. For the same reason, Site 1, 4 also recorded higher Cu content in leaf. Leaf zinc among different sites recorded the content changing from a low of 10.6 ppm in Site 8 to a high of 36.4 ppm in Site 14.

A correlation analysis was done with the data on leaf nutrients and the results are presented in Table 32. It is seen that plant volume measured in September 97 is negatively correlated with leaf Mg ($r = -0.545^*$). Among the nutrients, leaf nitrogen is correlated negatively with Ca ($r = -0.569^*$) and Na (-0.616^*). Leaf P is found related negatively to copper with a coefficient of -0.550^*. A positive relationship is seen between Ca and

Na (r = 0.889**), between Na and Fe (r = 0.676**) and between Al and Fe (r = 0.660*)

As experienced in the soils of experimental sites, in leaf composition also variations were noticed among different sites. Such tendency is obvious, as leaf composition is dependent on the contents of available elements in soils. However, study of seasonal variations in leaf compistion was not done and perhaps such study would have added more to the present information.

3.4 Growth performance

The growth of hevea in terms of plant volume measured in different sites at bimonthly intervals over the period spanning between November 96 and September 97 is presented in different tables.

3.4.1 Site variations in growth performance

The plant growth measured in all the sites during November 96 had a range from 12.7 (Site 5) to 31.0 (Site 8) dm^3 (Table 23). The growth during January 97 increased from that measured in November 96 and it ranged from 16.04 (Site 5) to 36.0 (Site 8) dm^3 (Table 24). From the data it is found that the growth measured in March 97 had a range from 16.7 (Site 3) to 40.8 (Site 8) dm^3 (Table 25).

The data in Table 26 indicate that the growth had a range of 17.7 (Site 5) to 45.8 (Site 8) dm^3 during May 97. The plant growth as indicated by volume was between a low of 21.7 (Site 5) and a high of 46.3 (Site 9) dm^3 during July 97. The growth of plant ranged from a low of 31.5 (Site 3) and a high of 68.2 (Site 8) dm^3 during September 97.

It is seen from the data presented in all the tables that there were site variations in plant performance in terms of growth as indicated by plant volume. Site 5 and Site 8 registered lower and higher growth performance respectively. Further analysis might help in understanding the growth process influenced by the weather, as the very intention of this study is to know the soil-plant interrelationships under varying weather conditions.

3.4.2 Seasonal variations in growth

An attempt was made to assess the growth performance as influenced by the weather / season. The per cent increment in plant volume was calculated from the growth measurements recorded at all the observations and presented in Table 33. The volume increment between November 96 and January 97 in the experimental sites indicated that the highest growth increment is seen in Site 9 (22.5 %) followed by Site 5 (20.6 %) and Site 13 (20.1 %). The lowest growth increment was recorded in Site 14 with just 6.8 %.

The growth increment from January to March was measured in all the sites and presented in Table 33. It is observed that the volume increment in percentage was less than that was found from Nov. 96 to Jan 97. The highest increment was noticed in Site 5 with 12.6 % and the lowest in Site 9 with just -3.7 per cent. Such drastic reduction in volume increment between Jan to Mar 97 might be because of moisture limitation as there was no rainfall practically.

The growth between March and May 97 again showed increasing trend in volume increment. The highest increment in growth was observed in Site 9 with 26.0 % while a low value of -2.6 % was seen in Site 11. However, this raise in growth might be because of the increased soil moisture during summer showers. It may be noted that the rainfall received during April

97 was 8.2 mm and that in May was 63.0 mm when compared to January, February and March 97 where the rainfall was zero.

There is an overall increase in growth of rubber plants between May and July 97 as could be seen from the data given in Table 33. The highest increment in growth recorded was 39.3 % in Site 3 whereas the lowest observed was 11.9 in Site 7 This betterment in growth increment might be attributed to the availability of soil moisture with consequent favourable soil chemical reactions. The rainfall during June 97 was 720.5 mm and in July it was 979.2 mm (Appendix E).

The change in growth between July and September 97 appears to be the highest rate in many sites. The per cent increase in growth was ranging from 3.2 % in Site 3 to a high of 37.5 % in Site 5 in which a lowest growth increase was observed between May and July 97. This might be the positive effect of antecedent rainfall received during July to September 97 on soil chemical properties thus influencing the growth increment.

From the data, it is understood that there were seasonal changes in growth performance of rubber plants in different sites over one annual cycle of weather indicating the influence of weather. Different rates of growth in different sites were noticed in reponse to changes in weather from a dry season to a wet season.

3.5 Relationship of soil characteristics and leaf nutrients with plant growth

As mentioned above, it is essential to understand the soil-plant relationships for better management of crop culture for optimum yield. The data generated on soil variables and leaf nutrients in the filed experiment are handled accordingly to reveal the latent structure of relationship between the cause and effect i.e. growth.

3.5.1 Soil characteristics

The soil characteristics measured at different times of observations, the changes in soil properties over time and the mean soil properties were tested for their influence on plant growth in order to comprehensive understanding of the process.

3.5.1.1 Absolute measurements

Initially, simple correlation analysis was performed to examine the relationship between plant volume and the soil variables and the coefficients are given in Table 30. It is seen that, plant volume is directly related to total nitrogen with a coefficient of simple correlation of 0.536^{*} during July 97 indicating a limitation on nitrogen. Such relationship might be possible because of loss of mineral nitrogen by way of leaching in a situation of high rainfall, as the month of July was characterised by a high rainfall of 979.2 mm, thus posing a limitation.

Plant growth appeared to be highly influenced by the limitation of available P as seen in the correlation study (Table 30). It is seen that during Nov. 96, Jan, Mar and May 97, the plant volume is positively and significantly correlated with the availability of P ($r = 0.701^{**}$, 0.568^{*}, 0.746^{**} and 0.797^{**} respectively). However, during July and September 97, there was no such relation between available P and growth. Such positive correlation with P might be because of limitations on the availability of soil P owing to various soil factors as influenced by climate.

The pattern of rainfall indicates that there is a general decline in rainfall from November 96 onwards (with an exception in December 96) up to May 97 (Appendix E) thus reducing soil moisture availability. It is stated that the soil moisture is an important field variable because of the diffusion (Anderson and Sale, 1993; Weil *et al.,* 1994). According to Rajan *et al.* (1996) the rate limiting process in the dissolution of rock phosphate is the diffusion of the dissolved products (Ca, P and bases) away from the phosphate rock particles. Increased soil moisture levels increase the apparent diffusion coefficients of the ions by reducing the tortuosity of the diffusion path and increasing the cross sectional area of diffusion (Nye, 1979). Therefore reduced soil moisture obviously affects the solubility as well as the diffusion of soil P.

In an experiment to study the effects of deficit of water and phosphorus on the performance of soybean, Gutierrez-Boem and Thomas (1999) concluded that most effects of P and water stress on growth were additive, so that, In general,, effects of water stress were similar at each P level. In the present study also the limitation on the availability of P might be essentially because of reduced soil moisture.

In addition to the effect of soil moisture, the influence of temperature on the availability dissolved P may be of importance in tropical soils. An increase in temperature had been found experimentally to have an overall effect of increasing P adsorption by soils and decreasing P in soil solution (Rajan *et al.*, 1996). It could be seen in the weather data that mean monthly maximum temperature was increasing with corresponding decrease in rainfall reaching even zero during January to March 97 (Appendix E). This temporal increase in temperature coupled with decreasing soil moisture might have resulted in limitation on availability of P and hence a positive correlation with plant volume. The situation in July and September is different with high soil moisture and high temperature. However, the influence of soil moisture is such that the effect of soil temperature on P dissolution and diffusion might have been circumvented thus eliminating limitation on P.

A negative correlation between plant volume and exchangeable Mg was noticed during November 96 (-0.578^{*}). According to Lindsay *et al.* (1962) and Taylor *et al.* (1963), magnesium phosphates have been found as initial reaction products of phosphate fertilisers in soils, but they later disappear as more stable minerals are formed. They also stated that magnesium phosphates can be discounted as permanent fixation products of phosphorus in soils. However, this may add to already strained availability of P because of reduced soil moisture as seen in the present study. Perhaps a further study may be needed to understand the phenomenon of formation of magnesium phosphates rendering P unavailable at least temporarily.

The correlation study indicates that the growth increased with exchangeable Al during Nov. 96 and Jan 97 ($r = 0.663^{**}$ and 0.581^{*} respectively). This might be an indirect effect by enhancing the availability of P and there is a positive relationship between exchangeable Al and available P indicating that the available P of the soil is mainly contributed by the aluminium fraction in these soils. Besides that the availability P is also influenced by soil acidity as was seen during September 97, which is again controlled by exchangeable Al.

In another instance it is found that the plant growth is affected by DTPA extractable Mn with negative correlation during Nov. 96, Mar and May 97 adding to already impaired performance due to limitation of P. The coefficients of simple correlation are -0.729^{**},

-0.566* and -0.620* respectively for above periods. It might be because of the direct effect of Mn itself besides some indirect influences of excess Mn. However, at field level, no symptom of Mn toxicity was found

According to Marschner (1995), Mn toxicity can manifest into deficiency of Mg and Ca because of comparable ionic radius thereby it can substitute or compete in various reactions involving these cations which however, was not tested in the present study. There could be another way of interfering the plant growth i.e. inducing P deficiency. It is seen that the availability of P is affected by Mn during November 96, January, March and May 97 by negative correlation (Table 30) which might be because of precipitation of P as manganese phosphate thus inactivating P aggravating already suffered availability.

3.5.1.2 Changes in soil properties over time

An attempt was made to understand the influence of changing soil environment as indicated by the dynamics of nutrient elements on growth rate. In such a process, the differences in soil properties from time to time and the growth increment were taken as inputs and subjected to correlation analysis and the results are presented in Table 34

The changing soil environment as indicated by changes in soil properties between November 96 and January 97 did not change significantly the plant growth increment during the same period. However, among the soil variables some relationships were found Increasing organic carbon resulted in increasing available P (r = 0.571*). Regarding the role of organic matter in P availability, it is stated that the mineralisation of organic P is considered to be a function of decomposition of organic residues (Gressel and McColl, 1997) and it had an experimental support given by Dalal *et al.* (1976) which meant that higher organic matter releases higher content of P.

It is seen that the availability of P is influenced by both Ca and Al i.e. increasing Ca over time decreased available P and contrary to that increasing Al resulted in increasing P availability. It might be possible that the decrease in soil pH from Nov. 96 to Jan 97 as seen in many cases (Fig 2) would have increased the solubility of Al bound P with simultaneous release of Al resulting in such positive relationship. The relationship between Ca and Al is known to be negative and hence the relation of Ca versus P also might have become negative. It is because of the fact that calcium phosphates are less stable than aluminium phosphates (Lindsay, 1979) and in such a situation the assumption of formation calcium phosphate is unwarranted

Another positive significant relationship between increasing Ca and Mg is found during this period between Nov. 96 and Jan 97 (r = 0.760**). It is already seen that these two bases are always related positively. It is understood that any situation influencing a change in Ca also causes the same in Mg. It is stated that Ca and Mg are known to coexist and correlate positively as reported by Marschner (1995). Such positive relationship might be because of similarities between Ca^{2+} and Mg^{2+} including the binding strength for ligands based on oxygen donors (Hughes and Williams, 1988).

It is seen that there is a negative relation between increasing Al with K (r = -0.578*). It

Table 34. Coefficients of correlation among changes in growth and soil properties

	1	2	3	4	5
Volume vs Av.P	NS	-0.653 *	NS	NS	NS
Volume vs Mg	NS	NS	NS	-0.561 *	NS
pH vs Ca	NS	NS	NS	0.820 **	0.939 **
pH vs Mg	NS	NS	NS	0.763 **	0.745 **
pH vs Na	NS	NS	NS	0.573 *	0.736 **
pH vs Al	NS	NS	NS	-0.790 **	-0.923 **
OC vs N	NS	NS	NS	NS	0.625 *
OC vs Av.P	0.571 *	NS	NS	NS	NS
OC vs Ca	NS	NS	0.546 *	NS	NS
OC vs Fe	NS	NS	NS	NS	0.540 *
OC vs Zn	NS	NS	0.651 *	NS	0.588 *
Av.P vs Ca	-0.644 *	NS	NS	NS	NS
Av.P vs Al	0.636 *	NS	NS	NS	NS
Av.P vs Mn	NS	NS	NS	0.713 **	0.719 **
Av.P vs Fe	NS	NS	NS	0.742 **	NS
Av.P vs Zn	NS	NS	NS	0.656 *	0.632 *
Ca vs Mg	0.760 **	0.707 **	0.799 **	0.828 **	0.844 **
Ca vs Na	NS	NS	NS	0.803 **	0.757 **
Ca vs Al	NS	NS	-0.713 **	-0.864 **	-0.955 **
Mg vs Na	NS	NS	NS	0.628 *	0.620 *
Mg vs Al	NS	NS	NS	-0.821 **	-0.781 **
K vs Al	-0.578 *	NS	NS	NS	NS
Na vs Al	NS	NS	NS	-0.765 **	-0.687 **
Al vs Cu	0.606	NS	NS	NS	NS
Mn vs Zn	NS	NS	NS	0.707 **	0.717 *
Fe vs Mn	NS	NS	NS	0.953 **	0.667 *
Fe vs Zn	NS	NS	NS	0.727 **	0.782 **

* = 1% level 1 = Nov 96-Jan 97; 2 = Jan-Mar 97; 3 = Mar-May 97
** = 5% level 4 = May-Jul 97; 5 = Jul-Sep 97

was noticed earlier that the bases In general, are related negatively to exchangeable Al as both are opposite in their action in maintaining the soil reaction. In another observation, a positive correlation between increasing Al with Cu is noticed. It is because of increased Al release as a consequence of decreasing soil pH, which also renders Cu soluble resulting in such a relationship (Brady, 1990).

The relationship between growth increment and available P was found to be significantly negative (r = -0.653*) between January and March 97. It is to note that lack of soil moisture already hampered the dissolution as well as diffusion of P resulting in lesser growth rate during this period and it also might have left soil P in unavailable form. The Bray II extractant might have drawn the possible soil P, which might be high as it was not used up by the plant resulting into such correlation.

The correlation between changing Ca and Mg is same as that was explained earlier. The coefficients of simple correlation given in Table 34 indicated that increasing organic carbon also meant increased exchangeable Ca and Zn (r = 0.546* and 0.651* respectively). This might be due to fact that organic matter forms complexes with the metal cations, including Ca and hold them, of course, with different degrees of stability (Stevenson, 1986) and thus such positive relationship. Numerous studies have demonstrated a high correlation between organic matter and chemically extractable or available Zn (Lindsay, 1972).

The relationship between exchangeable Ca and Mg noticed between March and May 97 is similar to that was seen between Nov. 96 & Jan 97 and Jan & Mar 97. The correlation is significant and positive with r = 0.799**. In addition to that, increase in exchangeable Ca also resulted in decrease in exchangeable Al content (r = -0.713**) similar to that observed in correlation with absolute values.

It is seen from the coefficients of simple correlation (Table 34) that the increase in plant volume is inversely related to increase in exchangeable Mg between May and July 97. This negative effect of Mg might be by way of negating the effect of P on plant volume by forming magnesium phosphate, a temporary phase of inactivation (Lindsay, 1979) though there is no such direct relationship observed between available P and plant volume during this period

It is seen that increasing exchangeable bases increased soil pH and vice versa between pH and exchangeable Al as observed with absolute data. The correlation coefficients are 0.820**, 0.763**, 0.573* and -0.790** for Ca, Mg, Na and Al respectively.

The DTPA extractable Mn, Fe and Zn appeared to be related with the availability of P as indicated by their correlation. These elements had positive correlation with available P with 'r' values of 0.713**, 0.742** and 0.656* respectively. It might be because of the fact that during rainy period, when the soil moisture condition is favourable for dissolution and diffusion, P gets solubilised. Simultaneously, Fe, Mn and Zn also get solubilised because of fall in pH or redox potential as required by Mn.

As happened with absolute values, increasing Ca is found associated with increasing Mg with 'r' value of 0.828** and the reason remains the same as described. Similarly, changes in exchangeable Ca are associated with increasing Na and decreasing Al also (r = 0.803** and -0.864** respectively). Similar to exchangeable Ca, exchangeable Mg also is related positively with exchangeable Na and negatively with Al with coefficients of 0.628* and -0.821** respectively. Exchangeable Na has an inverse relationship with exchangeable Al (r = -0.765**).

It is observed that increasing DTPA-Mn resulted in increasing DTPA extractable Zn (r = 0.707**) indicating that solubility increased and hence the concentration of both. Similarly, increasing DTPA-Fe has resulted in increasing Mn and Zn with coefficients of 0.953** and 0.727**. According to Marschner (1995), with a fall in pH or in redox potential, the concentrations of Fe, Mn and Zn increase to varying degrees which normally may occur during rainy period. As mentioned earlier, dissolution of the oxides of Fe and Mn might have released Zn simultaneously during this period between May and July 97.

As noticed in the period between May and July 97, similar relationships existed between changes in soil pH and exchangeable Ca, Mg, Na and Al (r = 0.939**, 0.745**, 0.736** and

-0.923**), during the period between July and September 97 as a part of regulating the soil pH.

Increasing organic carbon increased the N content as evident by its correlation (r = 0.625*). It is known that C and N are in definite ratio and normally such relationship is possible. Increasing organic carbon also resulted in increasing Fe and Zn (r = 0.540* and 0.588* respectively). It is known that organic matter forms complexes (Stevenson, 1986) with metals including Fe and Zn and the decomposition of the same always leads to the release of these metals hence such relationship.

As noticed in the earlier period (May-July 97), the increasing available P appeared to be associated with increased DTPA-Mn (r = 0.719**) and DTPA-Zn (r = 0.632*). The reason for such relationships is already discussed above emphasising the role of soil pH coupled with soil moisture regime.

The increased exchangeable Ca resulted in increased Mg content as seen earlier as evident by a positive correlation (r = 0.844**). Similarly increased exchangeable Ca is associated with increased exchangeable Na and decreased exchangeable Al (r = 0.757** and -0.955** respectively). Increasing exchangeable Mg also increased exchangeable Na (r = 0.620*) and decreased exchangeable Al (-0.781**). The relationship between increasing exchangeable Na and Al is inverse as seen by its correlation (r = -0.687**). The relationship among changes in exchangeable bases and Al is as expected which regulate the soil pH from time to time.

DTPA extracted Mn changed positively with DTPA-Zn and Fe as seen earlier during May and July 97 (r = 0.717** and 0.667**). Similarly, increase in DTPA-Fe is associated with increase in Zn (r=0.782**). As stated earlier, the relationship among these three elements indicates that the dissolution of one element which is either because of change in soil pH or in redox potential, more or less results in increased concentration of the other elements.

Fróm the relationships among changes in soil variables over time, it is understood that soil moisture has a tremendous role in dissolution of elements as several relationships are noticed during the period from July to September 97 which received more rainfall when compared to the period from November 96 to may 97.

3.5.1.3 Mean soil properties

The correlation analysis to study the relationship between plant growth and mean soil properties also indicates that growth is hampered by excess DTPA extractable Mn (r = -0.572*) in same way as explained above.

3.5.2 Leaf nutrients

As indicated in Table 32, there is a negative relationship between leaf Mg and plant growth during September 97 (-0.545*) which hints the interaction effects in the plant system. Leaf analysis at one time may not always indicate the tendencies of different elements in the plant system and perhaps further probing is needed to look into such relationships.

3.5.3 Combined effects of soil properties on growth of hevea

To understand the role of soil, a multivariate system, on plant performance, the data were subjected to multivariate statistical tests. Factor analysis was attempted to study the latent structure and also to reduce the dimensionality of the data. The effects of various soil properties on growth performance were disentangled into direct and indirect effects in the path analysis. The effects of soil 'factors' derived after factor analysis, were tested either by multiple or simple regression analysis using factor scores and growth as inputs. Factor analysis and path analysis was done with absolute values measured from time to time. It is to note that the soil variables, which varied significantly from time to time, were used in these statistical analyses. These variables include pH, OC, available P, exchangeable Ca, Mg, K, Na, Al, DTPA extractable Fe, Mn and Zn.

3.5.3.1 Factor Analysis

The results of factor analysis of data collected in different times of observations are given in Appendix F1, G1, H1, I1, J1 and K1. It could be seen that factor analysis gave clear information on association of different variables with different factors when compared to simple correlation. It is observed that some of the factors were associated to the soil variables differently from time to time. However, it is clearly seen that the first factor was always associated with exchangeable Ca, Mg, Na, Al and pH also with occasional inclusion of K, characterised by higher factor loading, which are known to influence the soil reaction. It is also seen that DTPA-Zn was associated with Factor 1 during November 96. Similarly, DTPA-Mn is also associated with Factor 1 during May and September 97. Perhaps this first factor might be ruling the soil environment by regulating the soil pH, which determines the solubility of several minerals. This first factor hence might be called ' Soil Reaction Control Factor ' which In fact, explained highest variability among the soils .

In November 96, January, March and May 97 the availability of P was associated with Factor 2 with other soil variables either influencing it or being influenced. It could be noticed that soil pH and DTPA-Mn are associated with available P in November 96. Similarly, DTPA-Mn along with organic carbon is found associated with available P during January 97. DTPA-Mn with exchangeable K is again found associated with available P during March 97. However, during July and September 97, the availability of P is associated with Factor 3 along with organic carbon, exchangeable K and Na.. It would be appropriate to name this Factor 2 during November 96, January, March and May 97 and Factor 3 during July and September 97 as ' P Limiting Factor ' because of the fact that DTPA-Mn and increasing soil pH reduced the availability of P and also that increasing exchangeable Al has a positive role in enhancing the availability.

The other soil variables are seen to have higher factor loading on different factors from time to time depending on other conditions. Exchangeable K and organic carbon had higher loading on Factor 3 and DTPA-Fe and Mn are found associated with Factor 4 in November 96. In January 97 data it is seen that DTPA-Fe, Zn and exchangeable K had association with Factor 3. The factor analysis of March 97 data indicated that organic carbon and DTPA-Zn had higher factor loading on Factor 3 and DTPA-Fe alone contributed to Factor 4.

The results of factor analysis of May 97 data show that DTPA-Fe and Zn are related to Factor 3 whereas Factor 4 is closely related to organic carbon and soil pH. It is seen that the micronutrients gained importance during July and September as could be seen by the association of DTPA-Fe, Mn and Zn with Factor 2, describing the next highest variability in the data after first factor. It is prominent only during the period of high rainfall which might have resulted in the dissolution of these micronutrients.

Multiple or simple regression analysis of plant growth at different times and the factor scores derived after factor analysis was performed and the results are given in Appendix F2, G2, H2, I2, J2 and K2. It is observed that the availability of P had significant influence on the growth during November 96, March, May and July 97 as seen by means of regression coefficients given in appendices. The coefficient for Factor 2 obtained in regression analysis of factor scores and plant growth during November 96 indicated that the elimination of ' P Limitation Factor ' has a positive influence on the growth. The limitation posed by reduced soil moisture, increasing temperature and DTPA-Mn on the solubility and diffusion of P is already discussed earlier, which indicated that growth response was hindered because of reduced availability of P besides their other effects.

It is seen that no factor could be related to the growth response of rubber plants during January 97 as indicated by insignificant regression of factor scores. However, correlation analysis indicated that available P and exchangeable Al significantly influence plant growth.

It is interesting to note that plant growth has positive response to the availability of P as well as other elements namely, exchangeable K and Zn as regulated by organic matter during March 97. It is seen that Factor 2 indicated the availability of both P and exchangeable K. It is shown that available P, organic carbon and DTPA-Zn are closely associated to Factor 3 as indicated by higher factor loading. In the correlation analysis of March 97 data also it is seen that organic carbon and available P are directly related. In addition to that information, factor analysis revealed that DTPA-Zn was also related to organic carbon.

The regression analysis showed that plant growth responded positively to the availability of P, K as well as Zn. The role of soil moisture on the availability of nutrients is already known particularly in case of P, K and Zn where the access of these elements to roots is essentially by diffusion. Marschner (1995) stated that decreased soil moisture also hampered the diffusion of potassium to the root surface like P, which was clearly understood from this data. The weather data indicate that there was high temperature of 35.7 °C coupled with zero rainfall during March, which must have certainly hampered the dissolution and diffusion of P, K and Zn.

The regression analysis of factor scores and the plant growth during May 97 indicates that regression as well as regression coefficients of Factor 1 and 2 were significant. Factor 1 was associated with availability of P and that Factor 2 is associated with available P as well as exchangeable K. As mentioned earlier, the reduced soil moisture coupled with high temperature must have played the role in hindering the availability of P and K.

The simple regression analysis of factor scores and plant growth during July 97 also indicated that the availability of P as regulated by organic matter was important in plant growth. It is indicated that the regression and the partial regression coefficient of Factor 3 were significant ($p = 0.0376$ and 0.0376 respectively). The role of organic carbon in the availability of P could be seen in factor analysis, which was not revealed in the correlation analysis of July 97 data. As mentioned earlier, the decomposition of organic matter results in simultaneous increase in mineral P. It is noticed that no factor was significantly related to plant growth during September 97 perhaps indicating that there was no limitation on the availability of any nutrient element. This might be because of enhanced soil moisture and reduced temperature, which would have enhanced the dissolution and diffusion of the elements. It could be seen that even micronutrients contents were also high during the period of high soil moisture availability which again influence the availability of some elements, particularly P.

3.5.3.2 Path analysis

An attempt was made to disentangle the correlation into direct and indirect effects on the plant growth at different times of observation. The results of path analysis of data of different times of observation are given in Table 35 to 40. The following is the description of the results of path analysis presented in different tables.

The results of path analysis of November 96 indicate that 77 per cent of variability in plant volume is explained by this analysis (Table 35). The decomposition of the correlation between available P and plant growth indicate a direct effect of available P (0.434) followed by a prominent positive indirect effect of exchangeable Ca (0.980) and Mg (0.423) and negative indirect effect of exchangeable Al (-0.741) finally yielding a positive correlation coefficient of 0.701**. The direct effect of exchangeable Mg on plant growth appeared to be negative (-0.917) followed by a positive indirect effects of exchangeable K (0.672), Na (0.609) and Al (0.827) and prominent negative indirect effect via exchangeable Ca (-1.454) totalling to a significant correlation of -0.578*. There is a prominent negative direct effect of exchangeable Al on plant performance (-1.085) which was negated by positive and prominent indirect effects through exchangeable Ca (1.596) and Mg (0.699), finally resulting into a positive correlation between exchangeable Al and plant growth (0.663**). This might be because of the specific opposite reactions between exchangeable bases and Al. However, it is clear that exchangeable Al ultimately resulted in positive relation with growth. This might be due to the increased availability of P because of favourable soil reaction condition created by Al. In factor analysis, it was seen that any factor that hindered availability of P results in reduced plant growth. This might include chemical as well as weather parameters also. Path analysis also yields similar results emphasising the importance of available P.

The partitioning of correlation indicates a negative direct effect of DTPA-Mn (-0.478) on plant growth with positive direct effect via exchangeable Al (0.588) and negative indirect effects through exchangeable Ca (-0.473), Mg (-0.394) and also via available P (-0.220) yielding a net negative significant correlation of -0.729**. As seen earlier, the interactions among DTPA-Mn, available P, exchangeable bases and Al altogether might have resulted in such relationships. Factor analysis of November 96 data also indicates that Factor 2 which indicated limitations to the availability of P, is related negatively with growth as revealed by the regression analysis.

The path analysis done on the January 97 data (Table 36) indicates that only 43 per cent variability in data is explained by the analysis. However, there is a significant correlation of plant growth with available P and exchangeable Al. The disentanglement of correlation shows that there is a prominent positive direct effect of available P on growth of the plant (1.399) with a small negative indirect effect of DTPA-Fe (-0.332) finally summing up to a positive and significant

Table 35. Direct and indirect effects of soil properties on tree volume in November 96

	pH	OC	Av.P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	r
pH	0.414	-0.003	-0.197	-1.062	-0.442	0.050	0.152	0.886	-0.044	-0.203	-0.002	-0.450
OC	-0.031	0.040	-0.115	-0.625	0.096	0.525	-0.114	0.123	0.039	0.028	-0.011	-0.045
Av.P	-0.188	-0.010	0.434	0.980	0.423	-0.375	-0.267	-0.741	0.181	0.242	0.021	0.701**
Ca	0.236	0.013	-0.228	-1.865	-0.715	0.872	0.470	0.928	-0.047	-0.121	-0.026	-0.482
Mg	0.200	-0.004	-0.200	-1.454	-0.917	0.672	0.609	0.827	-0.082	-0.206	-0.023	-0.578*
K	0.017	0.017	-0.136	-1.364	-0.517	1.193	0.343	0.374	-0.142	0.070	-0.017	-0.162
Na	0.088	-0.006	-0.161	-1.218	-0.776	0.569	0.719	0.646	-0.067	-0.169	-0.030	-0.406
Al	-0.338	-0.004	0.296	1.596	0.699	-0.411	-0.428	-1.085	0.059	0.259	0.020	0.663**
Fe	-0.051	0.004	0.220	0.248	0.211	-0.477	-0.135	-0.181	0.356	-0.010	-0.015	0.171
Mn	0.176	-0.002	-0.220	-0.473	-0.394	-0.175	0.254	0.588	0.007	-0.478	-0.011	-0.729**
Zn	-0.009	-0.006	0.122	0.637	0.276	-0.270	-0.287	-0.287	-0.072	0.071	0.076	0.253

R^2 = 0.769; Residual = 0.480

Table 36. Direct and indirect effects of soil properties on tree volume in January 97

	pH	OC	Av.P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	r
pH	0.015	-0.050	-0.404	-0.002	0.050	-0.314	0.216	-0.025	0.097	0.045	-0.007	-0.379
OC	0.002	-0.419	0.726	-0.001	-0.005	-0.026	0.032	0.003	-0.038	-0.081	0.001	0.194
Av.P	-0.004	-0.218	1.399	0.001	-0.034	0.050	-0.121	0.016	-0.332	-0.203	0.014	0.568*
Ca	0.012	-0.076	-0.405	-0.003	0.064	-0.470	0.371	-0.026	0.109	0.083	-0.022	-0.363
Mg	0.011	0.031	-0.696	-0.003	0.068	-0.513	0.371	-0.028	0.199	0.116	-0.020	-0.462
K	0.006	-0.013	-0.085	-0.002	0.042	-0.831	0.248	-0.013	0.449	-0.028	0.009	-0.217
Na	0.007	-0.029	-0.363	-0.002	0.054	-0.441	0.467	-0.021	0.021	0.122	-0.025	-0.211
Al	-0.012	-0.039	0.697	0.002	-0.058	0.344	-0.311	0.032	0.011	-0.107	0.021	0.581*
Fe	-0.002	-0.017	0.500	0.000	-0.015	0.403	-0.010	0.000	-0.927	0.067	-0.017	-0.018
Mn	0.002	0.107	-0.892	-0.001	0.025	0.074	0.179	-0.011	-0.194	0.318	-0.018	-0.411
Zn	0.003	0.013	-0.467	-0.001	0.032	0.178	0.274	-0.016	-0.355	0.134	-0.043	-0.250

R^2 = 0.674; Residual = 0.571

correlation of 0.568*. Similarly, the impact of exchangeable Al on plant growth is because of a prominent indirect effect through available P (0.697) than any other path finally resulting in a significant positive correlation of 0.581*. Both indicated the role of availability of P on plant growth during this period which is characterised by zero rain fall and increasing temperature, posing limitation on the availability of P.

It is observed that 99 per cent of variability is explained by the path analysis of the data of March 97 (Table 36). During this period, both available P as well as DTPA-Mn significantly influenced the growth. The partitioning indicates that the direct effect of available P this time is not so prominent but positive (0.154). However, the indirect effects via exchangeable Mg, DTPA-Mn are prominent (0.344 and 0.379 respectively). Perhaps, this

Table 37. Direct and indirect effects of soil properties on tree volume in March 97

	pH	OC	Av.P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	r
pH	-0.491	0.006	-0.025	0.791	-0.671	0.012	0.238	-0.232	-0.010	-0.184	0.166	-0.401
OC	0.007	-0.417	0.098	0.107	0.174	0.031	-0.017	0.005	-0.010	0.087	0.288	0.353
Av.P	0.080	-0.265	0.154	-0.129	0.344	0.034	-0.046	0.046	0.033	0.379	0.117	0.746**
Ca	-0.378	-0.044	-0.019	1.026	-0.894	0.031	0.233	-0.227	-0.045	-0.200	0.232	-0.284
Mg	-0.329	0.072	-0.053	0.917	-1.000	0.035	0.238	-0.199	-0.052	-0.158	0.094	-0.435
K	-0.061	-0.136	0.055	0.340	-0.365	0.095	0.022	-0.042	-0.046	0.336	0.147	0.345
Na	-0.360	0.022	-0.022	0.737	-0.734	0.006	0.325	-0.181	0.001	-0.216	0.211	-0.210
Al	0.441	-0.008	0.027	-0.901	0.772	-0.015	-0.227	0.258	0.007	0.225	-0.200	0.379
Fe	0.034	0.028	0.034	-0.314	0.351	-0.029	0.003	0.012	0.148	-0.008	0.046	0.305
Mn	-0.156	0.062	-0.100	0.353	-0.273	-0.055	0.121	-0.100	0.002	-0.581	0.161	-0.566*
Zn	-0.138	-0.204	0.031	0.404	-0.161	0.024	0.116	-0.088	0.012	-0.159	0.589	0.425

$R^2 = 0.994$; Residual = 0.074

type of interaction needs further probing as this trend is very different than the one observed earlier. Contrary to this, the direct effect of DTPA-Mn itself is prominently negative on the plant growth (-0.581) with indirect effects positively via exchangeable Ca (0.353) and negatively via exchangeable Mg (-0.273) finally yielding a negative significant

Table 38. Direct and indirect effects of soil properties on tree volume in May 97

	pH	OC	Av.P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	r
pH	-0.012	0.048	-0.133	-0.148	0.128	0.040	-0.011	0.097	0.023	-0.051	-0.066	-0.084
OC	0.005	-0.116	0.338	0.002	-0.058	0.034	0.002	-0.041	-0.058	-0.022	0.078	0.164
Av.P	0.002	-0.052	0.761	0.144	-0.142	0.025	0.009	-0.107	-0.064	0.210	0.010	0.797**
Ca	-0.006	0.001	-0.374	-0.293	0.205	0.024	-0.023	0.139	0.043	-0.157	-0.005	-0.446
Mg	-0.007	0.030	-0.480	-0.268	0.225	0.015	-0.021	0.146	0.031	-0.174	-0.002	-0.505
K	-0.005	-0.043	0.209	-0.075	0.037	0.092	-0.013	0.041	-0.010	0.012	-0.009	0.235
Na	-0.004	0.007	-0.230	-0.228	0.163	0.040	-0.029	0.113	0.030	-0.041	0.030	-0.150
Al	0.007	-0.028	0.480	0.241	-0.194	-0.022	0.020	-0.169	-0.019	0.193	0.002	0.511
Fe	0.001	-0.029	0.209	0.055	-0.030	0.004	0.004	-0.014	-0.231	-0.026	0.226	0.169
Mn	-0.002	-0.007	-0.450	-0.130	0.110	-0.003	-0.003	0.092	-0.017	-0.355	0.145	-0.620*
Zn	0.002	-0.024	0.019	0.004	-0.001	-0.002	-0.002	-0.001	-0.135	-0.134	0.385	0.111

$R^2 = 0.769$; Residual = 0.481

correlation between DTPA-Mn and growth (-0.566*). Though there are no symptoms of excess Mn, there could be other interactions where for example, P could have been inactivated besides competing with Ca and Mg (Marschner, 1995).

Similar to that was noticed during March 97, there are relationships of plant growth with available P (positive) as well as DTPA-Mn (negative) in May 97 also. The results of the path analysis of this data are given in Table 38. It is observed that the direct effect of available P was very positive and prominent (0.761) with minor indirect effects of other nutrient elements ultimately resulting in significant positive correlation with plant growth (0.797**). It is understood from the path of the effect of DTPA-Mn on growth that there is a

Table 39. Direct and indirect effects of soil properties on tree volume in July 97

	pH	OC	N	Av.P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	r
pH	-0.057	-0.052	0.007	-0.036	0.605	-0.023	0.359	-0.105	-0.663	-0.226	0.505	-0.196	0.119
OC	-0.004	-0.685	0.575	-0.185	0.163	0.003	-0.002	-0.016	0.029	0.140	-0.261	0.435	0.191
N	-0.001	-0.540	0.730	-0.075	0.115	0.005	-0.121	-0.034	0.082	-0.157	0.478	0.053	0.536*
Av.P	-0.004	-0.221	0.095	-0.572	0.105	0.010	0.097	-0.065	-0.026	0.626	-0.462	0.722	0.306
Ca	-0.048	-0.156	0.117	-0.084	0.717	-0.025	0.385	-0.147	-0.619	-0.212	0.390	-0.247	0.069
Mg	-0.040	0.060	-0.112	0.171	0.556	-0.032	0.478	-0.102	-0.601	-0.370	0.269	-0.509	-0.231
K	-0.029	0.002	-0.124	-0.078	0.388	-0.022	0.712	-0.112	-0.414	-0.300	-0.021	-0.085	-0.082
Na	-0.033	-0.062	0.137	-0.207	0.588	-0.018	0.443	-0.179	-0.420	-0.269	0.539	-0.242	0.276
Al	0.047	-0.025	0.076	0.019	-0.560	0.025	-0.372	0.095	0.792	0.099	-0.338	0.275	0.133
Fe	0.013	-0.098	-0.117	-0.365	-0.155	0.012	-0.217	0.049	0.080	0.983	-0.975	0.772	-0.017
Mn	0.020	-0.127	-0.248	-0.188	-0.199	0.006	0.011	0.069	0.191	0.682	-1.405	0.750	-0.440
Zn	0.010	-0.280	0.037	-0.389	-0.167	0.015	-0.057	0.041	0.205	0.713	-0.991	1.064	0.202

$R^2 = 0.950$; Residual = 0.223

indirect effect via available P (-0.450). This type of interaction also is to be further studied as to what mechanism of occlusion takes place while Mn precipitating P or vice versa, finally resulting in such effects. From the factor analysis, it was seen that DTPA-Mn was associated with 'Soil Reaction Control Factor' in which the factor loading indicated that soil pH is directly related to DTPA-Mn. Perhaps, such relationship might have caused the path to deviate from that normally expected

The results of the path analysis of July 97 data are given in Table 39. The decomposition of correlation between plant growth and total nitrogen indicates a positive prominent direct of effect of nitrogen (0.730) with negative indirect effect through organic carbon (-0.540) and positive indirect effect via DTPA-Mn (0.478) finally yielding a significant correlation of 0.536*. The effect of nitrogen on plant growth itself was pronounced because of possible loss of mineralised nitrogen during this period of high rainfall hence limiting its availability. It is seen that path analysis could explain the variability to the extent of 77.7 %.

The correlation analysis of the data of September 97 showed that no soil variable is correlated with plant growth and hence the question of path analysis did not arise.

3.6. Agronomic utility of classification systems

An attempt was made to compare the agronomic utility of the soil classifications namely soil taxonomy and fertility capability classification. The growth measured as plant volume in September 97 was taken and ranked the experimental sites as given in Table 40. It could be noticed that the order of ranking based on plant growth indicated that Typic Kanhaplustults > Ustic Kandihumults > Ustoxic Dystropepts > Ustic Kanhaplohumults to which all the fourteen experimental sites belonged. It is understood that the depth did not pose any constraint in the plant growth as could be seen that Site 8 and 9, ranked first and second respectively, were in fact, shallow soils when compared to others. Perhaps, the impact of depth during early stages was not significant and that rooting depth might be sufficient.

Table 40. Ranking of sites in terms of growth

Rank	Site	Taxonomy	FCC
1	8	Typic Kan-haplustults	Cdihek
2	9	Typic Kan-haplustults	Ldhekm
3	13	Typic Kan-haplustults	Cdi-hekm
4	7	Ustic Kandihu-mults	Sdhek
5	2	Ustoxic Dystro-pepts	Ldae
6	6	Ustic Kanhaplo-humults	Cdihe
7	1	Ustic Kanhaplo-humults	Cdiaek
8	4	Typic Kan-haplustults	Cdihek
9	10	Typic Kan-haplustults	Ldhekm
10	14	Typic Kandius-tults	Cdi-hekm
11	12	Typic Kan-haplustults	Cdi-hekm
12	3	Typic Kan-haplustults	Cdae
13	11	Typic Kan-haplustults	Cdihek
14	5	Ustaic Kanhap-lohumults	Cdihek

Caution should however, be exerted while interpreting the agronomic utility of soil taxonomy as same Typic Kanhaplustults were ranked very low in Sites 4, 10, 12, 3 and 11. It is a fact that soil taxonomy is a scientific or natural classification and aimed at no specific purpose. There were earlier reports which stated that the yield patterns of modern rubber clones in Malaysia were consistent with soil pedological properties and concluded that soil taxonomy also reflected the logic of agronomic utility (Chan, 1975). In the present study on plant growth, a prerequisite for yield, it is observed that the soil taxonomy appeared to be not all that could explain the differential behaviuor in plant performance.

It was seen in Experiment 3 that the growth performance of rubber plants in these experimental sites was influenced by the 'Soil Reaction Control Factor' and 'P Limitation Factor' at different times of study during an annual cycle of weather between Novembner 96 to September 97. The growth during dry periods was affected by the availability of phosphorus, which in turn was influenced by soil pH, exchangeable Al and DTPA-Mn. Besides that, the availability of K was also found affected by limited soil moisture during the dry period. The combined effect of these limitations must have had a profound affect on the growth of rubber plants resulting in differential ranking of the experimental sites. Soil taxonomy, however, did not even contain any information about the local variations in the 'Soil Reaction Control Factor' and 'P Limitaion Factor' and thus could not explain the variations in plant performance within the same taxon.

Discrepancies were also found while studying the agronomic utility of the FCC concept. Interestingly, the soils ranked first, second and third (Sites 8, 9 and 13 respectively) were said to fix more P (Site 8 and 13) and deficient in available K. In addition to that Site 9 and 13 were classified as Mg deficient. Perhaps, there would be other important constraints posing problem in plant growth like 'P Limitation Factor' as was studied in Experiment 3. However, it is seen that the P fixation was included as one criterion for classification. But the impact of exchangeable Al (positive) and DTPA-Mn (negative) on P availability was seen earlier. There should be efforts to identify the constraints that affect the plant performance by further experimentation and to include them as condition modifiers to make the fertility capability classification more meaningful.

Experiment IV. Establishment of spectral signature to rubber using satellite imagery

Remote sensing technology is a tool for mapping and monitoring of natural resources on the earth's surface. However, a very little information is available with regard to application of remote sensing in case of rubber. Besides that the available information revealed that the spectral behaviour of rubber was studied in one time image only during mapping. No information is available about the temporal behaviour in reflectance in the electromagnetic spectrum particularly during and after wintering. This information assumes significance in delineating rubber from other types of vegetation particularly when interference comes from confusion crops. Considering these facts a study was taken up to study both the spectral as well as temporal variations in the reflectance of rubber vegetation. The results of this experiment to establish a spectral signature to rubber are discussed in this part.

4.1 Status of the study areas

The status of both the study areas with reference to predominant clones and the soil types is given below.

4.1.1 Cheruvally Rubber Estate

Predominant clones of rubber

Among different rubber clones available in the estate, GT 1, RRIM 600, PB 5/51, PB 217 and PB 28/59 occupy larger extent. The essential morphological characteristics of these clones as described by Paardekooper (1965) are given below (Table 41), which are expected to assume importance in the reflective behaviour

Table 41. Important rubber clones and their morphological features

Clone	Characteristics
GT 1	The stem is erect and slightly crooked. Medium heavy, narrow crown with dense canopy and glossy leaves. Wintering is generally late and only partial.
RRIM 600	Very straight stem, narrow, fan-shaped average crowns with yellowish canopy and average wintering.
PB 5/51	Stem straight, high and open crown, canopy variable, frequently light and small leaves. Usually complete and early wintering.
PB 217	Straight stem, light conical and average canopy. Late and prolonged wintering.
PB 28/59	Slightly curved stem with tendency to lean and bumpy. Broom shaped and high crown. Wintering is complete and early.

Soil types

According to Soil Taxonomy (Soil Survey Staff, 1992), the soils of the Cheruvally estate are classified as Ustic Kanhaplohumults, Ustic Kandihumults and Lithic Haplohumults. Among Ustic Kanhaplohumults varying depths between 50 to 150 cm are existing. Almost all the area is known to have clayey skeletal nature indicating more of gravelliness. The Ustic Kandihumults have a depth of more than 150 cm. The Lithic Haplohumults are shallow soils with a depth of less than 50 cm. The texture of surface soils is gravely sandy clay or gravely clay with coarse fragments up to 60 per cent. The subsoil layers have a texture of gravely sandy clay or gravely clay with coarse fragments as high as 80 per cent. The soils are strongly to very strongly acidic in reaction (NBSS & LUP, 1999).

4.1.2 Kundai Rubber Estate

Predominant clones of rubber

The clonal distribution of rubber in this estate is similar to that of the Cheruvally Rubber Estate as far as the extent of coverage is concerned

Soil types

The soils found in the Kundai estate area are an association of Ustic Kanhaplohumults, Ustic Kandihumults and Lithic Haplohumults. The depth of these soils varies between less than 50 cm to more than 150 cm. These soils have varying levels of gravelliness as indicated by clayey to clayey-skeletal character. The texture of surface soils is sandy clay loam, clay, gravely sandy clay or gravely clay, with coarse fragments up to 60 per cent. The texture of subsoils is gravely clay loam, gravely sandy clay and gravely clay with coarse fragments up to 80 per cent. These soils are strongly to very strongly acidic in reaction (NBSS & LUP, 1999).

4.2 Digital image processing

The results of various digital image-processing techniques as mentioned in the Materials and Methods are presented and discussed below.

4.2.1 Geometric correction

As mentioned in the materials and methods, geometric correction of standard products was done using geocoded products as reference images. A total of 30 ground control points (GCPs) having good spread over the entire image were selected to keep the overall root mean square of error (RMS) less than 1.0, some points were omitted and the geocoding was done for all the bands of all the standard products.

4.2.1.1 Cheruvally Rubber Estate area

Geocoding of 1B image

Bandwise geometric correction for the IRS 1B image (14 Mar 97) was done taking the geocoded 1B image (29 Jan 97) as reference. Out of the 30 GCPs, two were omitted to reduce the overall RMS to less than 1.0. Geocoding was done and the X and Y co-ordinates were put in the new reference system with corresponding latitude and longitude values as shown in Table 42.

Geocoding of 1C image

Bandwise geometric correction for the IRS 1C image (7 Feb 97) was done taking the geocoded 1B image (29 Jan 97) as the reference. Out of the 30 GCPs, three were omitted to reduce the overall RMS to less than 1.0. Geocoding was done and the X and Y co-ordinates were put in the new reference system with corresponding latitude and longitude values as shown in Table 43.

4.2.1.2 Kundai Rubber Estate area

Bandwise geometric correction for the IRS 1C image (26 Feb 97) was done taking the geocoded 1B image (21 Feb 97) as reference. Out of the 30 GCPs, five were omitted to reduce the overall RMS to less than 1.0. Geocoding was done and the X and Y co-ordinates were put in the new reference system with corresponding latitude and longitude values as shown in Table 44.

Table 42. Control points used for geocoding of 1B image of Cheruvally area

No.	Old X	Old Y	New X	New Y	Residual	No.	Old X	Old Y	New X	New Y	Residual
1.	251.0072	201.0723	76.79616	9.454731	0.226051	16.	386.796	225.2489	76.84287	9.455730	0.567804
2.	260.6612	180.0997	76.7985	9.447743	0.704450	17.	194.7157	210.193	76.77791	9.460244	0.030874
3.	251.0072	174.4404	76.79463	9.446344	0.825674	18.	456.6866	121.6112	76.86086	9.420445	0.420521
4.	272.7341	186.3187	76.80343	9.449570	omitted.	19.	272.1021	141.0444	76.79986	9.435583	0.906360
5.	213.1886	212.9389	76.78438	9.460306	0.506007	20.	428.3727	100.3542	76.85007	9.415319	0.092988
6.	256.9994	272.9785	76.80218	9.476473	0.086292	21.	211.9404	374.9511	76.79263	9.509790	0.272338
7.	261.1182	288.8275	76.80431	9.481016	0.495169	22.	245.0193	371.664	76.80271	9.507480	omitted.
8.	285.8319	291.0742	76.81276	9.480587	0.183797	23.	321.8102	263.0726	76.8235	9.470051	0.965585
9.	280.8393	347.9907	76.81417	9.498072	0.375579	24.	453.7427	397.8156	76.87468	9.504808	0.544014
10.	298.064	337.7557	76.81972	9.494346	0.972042	25.	498.6841	381.5036	76.88859	9.497743	0.238929
11.	309.0479	330.766	76.82261	9.491623	0.360074	26.	311.9071	366.815	76.82563	9.502502	0.394891
12.	494.276	284.0845	76.8819	9.468388	0.613973	27.	485.0396	135.3029	76.87093	9.423257	0.231075
13.	509.7533	277.0948	76.88703	9.465394	0.408497	28.	383.9551	387.7665	76.85051	9.505018	0.899831
14.	353.2485	304.7245	76.83621	9.481662	0.725162	29.	331.8659	174.2373	76.82159	9.442606	0.635419
15.	277.1083	209.2222	76.80552	9.456053	0.362082	30.	243.1652	266.9824	76.79729	9.475239	0.220552

Overall RMS = 0.546065

4.2.2 Reflectance characteristics of important features

The reflectance characteristics for the Cheruvally Rubber Estate area were studied for the image of 14 Mar 97 (IRS-1B) and for Kundai Rubber Estate area for the image of 26 Feb 97 (IRS-1C). These two dates are selected due to the presence of more or less complete development of canopy in rubber after leaf fall

Table 43. Control points used for geocoding of 1C image of Cheruvally area

No.	Old X	Old Y	New X	New Y	Residual	No.	Old X	Old Y	New X	New Y	Residual
1.	150.1729	533.2492	76.79616	9.454731	0.344322	16.	354.9527	569.5541	76.84287	9.45573	0.303337
2.	166.4887	502.2735	76.7985	9.447743	1.003613	17.	65.26423	547.9044	76.77791	9.460244	0.923094
3.	150.1729	492.9475	76.79463	9.446344	0.863880	18.	459.6951	413.8857	76.86086	9.420445	0.421087
4.	186.1343	513.2649	76.80343	9.44957	0.264339	19.	181.2819	444.109	76.79986	9.435583	0.213936
5.	94.23309	550.569	76.78438	9.460306	1.343887	20.	416.2642	382.2412	76.85007	9.415319	0.267235
6.	161.1611	640.8315	76.80218	9.476473	0.687976	21.	94.13734	794.7996	76.79263	9.50979	0.679011
7.	166.0503	664.9142	76.80431	9.481016	0.698397	22.	142.018	788.8585	76.80271	9.50748	omitted.
8.	205.0032	667.6617	76.81276	9.480587	1.055459	23.	258.938	625.6988	76.8235	9.470051	0.803701
9.	196.9472	753.6916	76.81417	9.498072	0.733357	24.	457.9472	826.7714	76.87468	9.504808	0.585809
10.	222.9137	738.7057	76.81972	9.494346	1.439439	25.	523.7712	802.7045	76.88859	9.497743	0.509643
11.	239.0928	726.9168	76.82261	9.491623	0.825454	26.	243.406	782.0541	76.82563	9.502502	0.850062
12.	517.6251	656.1719	76.8819	9.468388	omitted.	27.	501.6732	435.0404	76.87093	9.423257	0.309005
13.	540.3475	647.6794	76.88703	9.465394	0.716259	28.	352.1295	812.6645	76.85051	9.505018	1.374042
14.	306.2062	688.7527	76.83621	9.481662	0.517987	29.	277.0175	492.0538	76.82159	9.442606	omitted.
15.	191.2698	545.02	76.80552	9.456053	0.962031	30.	140.5531	631.7257	76.79729	9.475239	0.629651

Overall RMS = 0.790502

(wintering). The reflectance charactersitics of different land features identified in both the study areas in the bands 2, 3 and 4 are described below.

4.2.2.1 Cheruvally Rubber Estate area

The images for the above three bands are shown along with the boundary of the Cheruvally Rubber Estate in Plates 1,2 and 3 respectively. Important land features like Manimala river, power line, rubber and teak plantations and mixed forest are also marked on the image. The reflectance characteristics of rubber and teak plantations, mixed forest, water body, and power line in each band are as follows:

Band 2

This band corresponds to the wavelength between 0.52-0.59 µm of the electromagnetic spectrum. Rubber in this green band appeared in slight to dark grey levels. A teak plantation, triangular in shape, on the SW side of the estate is seen. The appearance of teak in this band is in lighter grey levels compared to rubber. A mixed forest adjoining the teak plantation is seen in the Plate. The reflectance from the mixed forest is found in grey levels from light to slightly dark. The Manimala river is seen as dark patches and present adjoining the boundary of Cheruvally estate. However, there is no clear appearance of river in this band. A power line at the bottom of the image, cutting across the mixed forest could be clearly seen. The power line appeared as a thin straight line characterised by higher reflectance.

Band 3

This band corresponds to the wavelength between 0.62-0.68 µm of the electro magnetic spectrum. In this red region, rubber appeared in black compared to the dark-grey that was noticed in band 2. Teak appeared bright as there is more reflectance in the red region. The reflectance from the mixed forest appeared in a mixture of lighter and darker grey levels. In this band, the river could not be clearly identified and it appeared as small strips with high reflectance. The power line is seen clearly as a thin linear feature with higher reflectance.

Table 44. Control points used for geocoding of 1C image of Cheruvally area

No.	Old X	Old Y	New X	New Y	Residual	No.	Old X	Old Y	New X	New Y	Residual
1.	150.1729	533.2492	76.79616	9.454731	0.344322	16.	354.9527	569.5541	76.84287	9.45573	0.303337
2.	166.4887	502.2735	76.7985	9.447743	1.003613	17.	65.26423	547.9044	76.77791	9.460244	0.923094
3.	150.1729	492.9475	76.79463	9.446344	0.863880	18.	459.6951	413.8857	76.86086	9.420445	0.421087
4.	186.1343	513.2649	76.80343	9.44957	0.264339	19.	181.2819	444.109	76.79986	9.435583	0.213936
5.	94.23309	550.569	76.78438	9.460306	1.343887	20.	416.2642	382.2412	76.85007	9.415319	0.267235
6.	161.1611	640.8315	76.80218	9.476473	0.687976	21.	94.13734	794.7996	76.79263	9.50979	0.679011
7.	166.0503	664.9142	76.80431	9.481016	0.698397	22.	142.018	788.8585	76.80271	9.50748	omitted
8.	205.0032	667.6617	76.81276	9.480587	1.055459	23.	258.938	625.6988	76.8235	9.470051	0.803701
9.	196.9472	753.6916	76.81417	9.498072	0.733357	24.	457.9472	826.7714	76.87468	9.504808	0.585809
10.	222.9137	738.7057	76.81972	9.494346	1.439439	25.	523.7712	802.7045	76.88859	9.497743	0.509643
11.	239.0928	726.9168	76.82261	9.491623	0.825454	26.	243.406	782.0541	76.82563	9.502502	0.850062
12.	517.6251	656.1719	76.8819	9.468388	omitted	27.	501.6732	435.0404	76.87093	9.423257	0.309005
13.	540.3475	647.6794	76.88703	9.465394	0.716259	28.	352.1295	812.6645	76.85051	9.505018	1.374042
14.	306.2062	688.7527	76.83621	9.481662	0.517987	29.	277.0175	492.0538	76.82159	9.442606	omitted
15.	191.2698	545.02	76.80552	9.456053	0.962031	30.	140.5531	631.7257	76.79729	9.475239	0.629651

Overall RMS = 0.755154

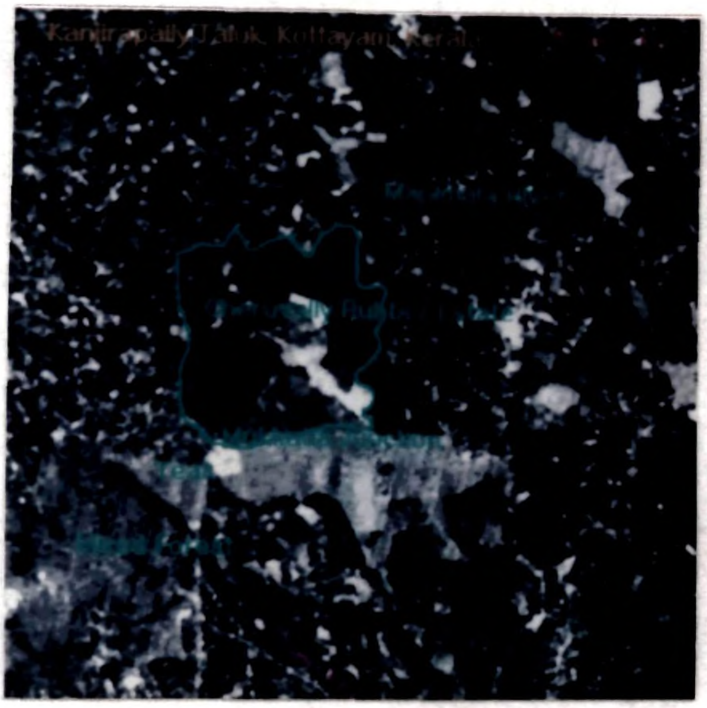

Plate 1. Band 2 image of Cheruvally Estate (linearly stretched with 1% saturation)

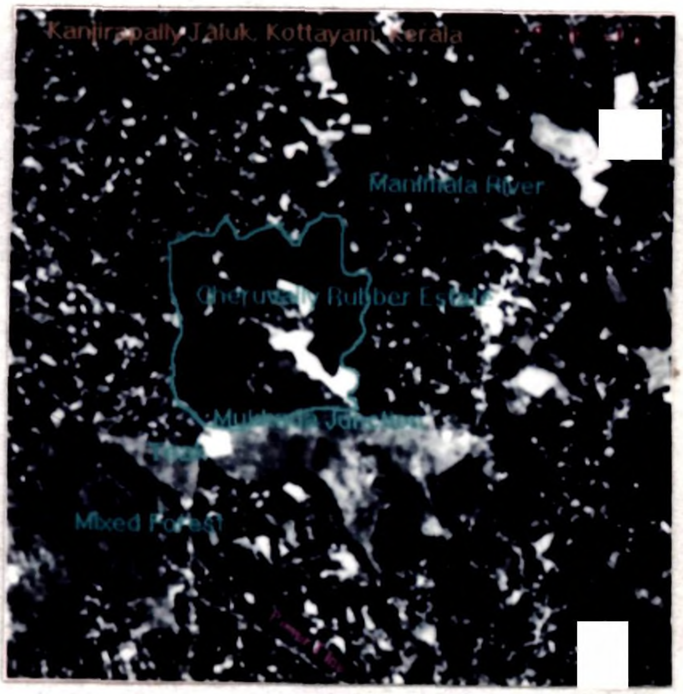

Plate 2. Band 3 image of Cheruvally Estate (linearly stretched with 1% saturation)

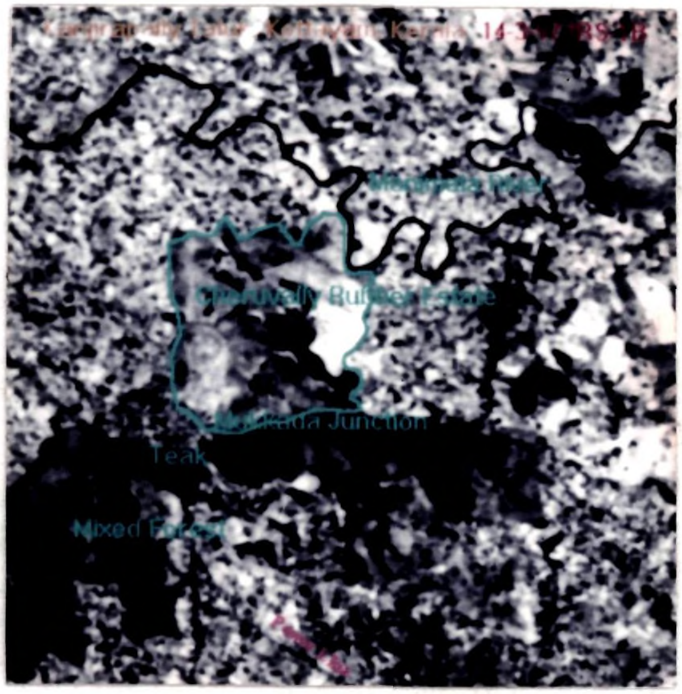

Plate 3. Band 4 image of Cheruvally Estate (linearly stretched with 1% saturation)

Band 4

This band corresponds to the wavelength between 0.77-0.86 μm of the EMS. In this near infrared region, rubber appeared very bright indicating higher reflectance compared to band 2 and 3. Teak plantation is seen as dark patch. The reflectance from mixed forest seemed to be a mixture of grey levels from light to dark. Manimala river is seen clearly in black. The power line appeared as a thin, straight and dark line indicating higher absorption.

The reflectance characteristics of rubber in all the three bands indicate that there is similar spectral behaviour in band 2 and 3 except for the little darker tone in band 3. This indicates higher absorption in the red band compared to the green band. On the other hand, it is noticed that in the near IR band there is high reflectance from rubber. This is a result of the presence of full canopy on the date of image acquisition. The spectral behaviour of teak is different from that of rubber, in all the bands, as there was no canopy. The ground truth survey conducted on 14 Mar 97 showed that the rubber had its full canopy and that teak had shed its leaves. In the case of mixed forest yet a different spectral behaviour is noticed which might be because of a mixture of various tree species.

The spectral behaviour of vegetation is quite distinct because of plant pigments and structure of leaf which influence the reflectance in the visible, and near IR regions. Low reflectance in red region corresponds to the absorption band of chlorophyll, centred at 0.65μm. Higher reflectance from the vegetation in near IR band is essentially controlled by the internal cellular structure of leaves, which in turn depends on the age and health of leaves (Deekshatulu and Joseph, 1991). The differential spectral behaviour of rubber, teak and mixed forest is because of morphology, chlorophyll content, age and health of canopy etc.

It is seen that though teak and bare land appeared black in band 4, it appeared strikingly darker compared to bare land in the other two bands. It is interesting to note that rubber has shown almost opposite spectral response.

The spectral behaviour of water bodies is also quite distinct. Water absorbs most of the radiation in the near IR and middle IR regions. This property enables easy delineation of even small water bodies (Dekshatulu and Joseph, 1991). Similar behaviour was noticed in this study wherein the river could be identified easily in the IR image.

Identification of the power line in the SW part of the images was relatively easy due to the absence of vegetation underneath and also of its linear nature.

4.2.2.2 Kundai Rubber Estate area

The images for the bands 2, 3 and 4 are shown along with the boundary of the Kundai Rubber Estate in Plates 4, 5 and 6 respectively. Important land features like Chiminipuzha, Kurumali and Muppili rivers, power line, rubber and teak plantations and mixed forest are also marked on the image. The reflectance characteristics of rubber and teak plantations, mixed forest, water body and power line in each band are as follows:

Band 2

Rubber in this green band appeared in slight to dark grey levels. A teak plantation, on the SW side of the estate is noticed. Teak appeared in lighter grey levels compared to rubber. A

Plate 4. Band 2 image of Kundai Estate (linearly stretched with 1% saturation)

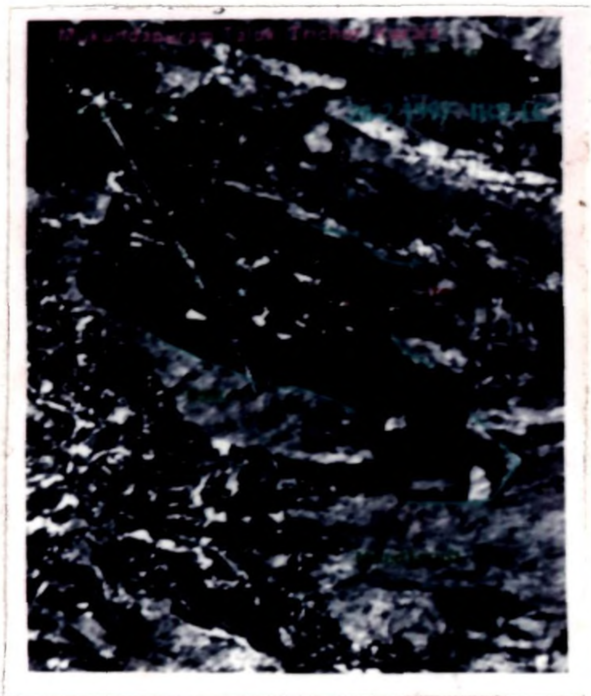

Plate 5. Band 3 image of Kundai Estate (linearly stretched with 1% saturation)

Plate 6. Band 4 image of Kundai Estate (linearly stretched with 1% saturation)

mixed forest adjoining the teak plantation is seen in the plate. The reflectance from the mixed forest is in light to slightly dark grey levels. The Chiminipuzha, Kurumali and Muppili rivers are not clearly seen and appeared like small dark patches. There is no clear appearance of river in this band. A power line on the western side of the estate, cutting across the estate and teak plantation is clearly seen as a thin straight line characterised by higher reflectance.

Band 3

In the red region of the EMS, rubber appeared in black compared to the dark-grey that was noticed in band 2. Teak appeared bright as there is more reflectance in the red region. The reflectance from the mixed forest appeared in a mixture of lighter and darker grey levels. In this band, the river could not be clearly identified and it appeared as small strips with high reflectance. The power line is seen clearly as a thin line with higher reflectance.

Band 4

In this near infrared region, rubber appeared very bright indicating higher reflectance compared to band 2 and 3. Teak plantation is seen as dark patch. The reflectance from mixed forest seemed to be a mixture of grey levels from light to dark. The Chiminipuzha, Kurumali and Muppili rivers are clearly seen in black. The power line appeared as a thin, straight and dark line indicating higher absorption.

The behaviour of various land features in these images is similar to the 1B images of Cheruvally area, but for the enhanced crispness in all the 1C images due to the higher spatial resolution.

4.2.3 False colour composite (FCC)

The false colour composite, a composite single band made out of the combination of green, red and near infrared bands with 1 % saturation for Cheruvally (IRS-1B image of 14 Mar 97) and Kundai (IRS-1C image of 26 Feb 97) are given in the Plates 7 and 8 respectively and the various features are described below.

4.2.3.1 Cheruvally Rubber Estate

Rubber appeared in different shades of red colour. Teak plantation appeared in varied shades of cyan and blue colours. Mixed forest is found to have a mixture of different shades of blue and red colours. Manimala river is identified as a black meandering curve, though broken at some places. The power line appeared as cyan coloured thin straight line. Known bare land in the estate appeared in very bright cyan.

4.2.3.2 Kundai Rubber Estate area

Rubber appeared in different shades of red colour as seen in the FCC of Cheruvally Estate. Varied shades of cyan and blue colours are seen in teak plantation. Mixed forest is found to have a mixture of different shades of blue and red colours similar to that found in Cheruvally Estate. The Chiminipuzha, Kurumali and Muppili rivers are clearly seen in black as meandering curves, though broken at some places. The power line present in this estate also appeared as cyan coloured thin straight line. Bare land, which is known to be present in the estate also, appeared in very bright cyan.

The study of the FCCs for the two estates clearly shows that the various land features could easily be identified in the FCC. In the individual bands, some of the features have similar spectral response thus making them difficult or even impossible to differentiate. Among different vegetation covers, it is possible to separate rubber from mixed forest because of variations in the colour and shades.

4.2.4 Normalised Difference Vegetation Index (NDVI)

The NDVI, calculated as (IR-R)/(IR+R) for Cheruvally (IRS-1B image of 14 Mar 97) and Kundai (IRS-1C image of 26 Feb 97) are given in the Plates 9 and 10 respectively.

4.2.4.1 Cheruvally Rubber Estate

The area under rubber appeared in different shades of green colour, while teak plantation appeared in different shades of brown colour. Mixed forest has both these colours. The Manimala river appeared in different shades of brown and yellow colours. The power line appeared as a thin and straight yellow line.

In the NDVI image, green indicates vegetation. Dark green is associated with higher ratios indicating good vigour and health of the vegetation. Since rubber has fully developed canopy it appeared in dark green. But the teak plantation appeared in brown colour as it shed its leaves at this time. Similarly in mixed forest, different shades of green and brown colours were seen indicating the presence of different species and greenness.

4.2.4.2 Kundai Rubber Estate area

Rubber, teak and mixed forest in this study area appeared similarly as seen in the NDVI image of Cheruvally estate area. The Chiminipuzha, Kurumali and Muppili rivers and the power line also appeared as seen in the above NDVI image. The NDVI images for the two estates indicate that this index is most suited for studying the vegetation vigour. Jagdeesh *et al.* (1992) employed the NDVI for forest stratification in Maharashtra while using the IRS, LISS-II data and found that the forest density classes broadly showed good agreement between NDVI classes and forest stock. Observation revealed that variations in NDVI were resulting from deferring moisture conditions.

4.2.5 Change detection

Temporal variations are the changes of reflectivity or emissivity with time. They can be diurnal and / or seasonal. The study of variations in reflectivity during the growing cycle distinguishes crops having similar spectral reflectance, but with different growing cycles.

Rubber has got a character called wintering, the term used to describe the annual shedding of senescent leaves which renders the trees wholly or partially leafless for a short period (Webster and Baulkwill, 1989). This wintering phenomenon can be seen in trees older than 3 or 4 years. There are marked differences between clones in wintering behaviour.

Change detection was carried out using temporal data of the study areas to record the changes in reflectance during defoliation and refoliation. Ground truth surveys were conducted during leaf fall and refoliation i.e.,, on the dates of acquisition of first and last images of three images. Images of FCC and NDVI for all the three dates were prepared for both the estates and the results are given .

4.2.5.1 Ground truth surveys

A ground truth survey was conducted in Cheruvally Rubber Estate on 29 Jan 97 and 14

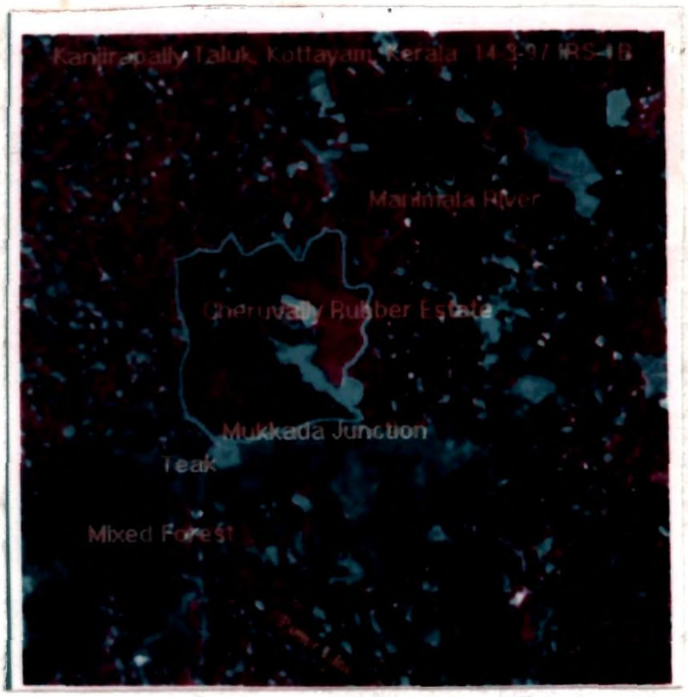

Plate 7. False colour composite of Cheryvally Estate Area

Plate 8. False colour composite of Kundai Estate Area

Mar 97 to get the information on the status of canopy coverage during and after wintering. The wintering was assessed based on visual observation, a common practice in rubber research. The status of the dominant clones on 29 Jan 97 is given below.

RRIM 600:Canopy was observed to be full with dull green coloured foliage

PB 235: Early stages of refoliation were noticed

PB 217: Refoliation with leaf stage seen in about 10 - 15 per cent area.

PB 28/59: Complete defoliation stage in many trees. Retention of some

GT 1:Refoliation started while senesced leaves are retained

Ground truth survey on 14 Mar 97 showed the complete development of leaf in all the clones and foliage seen in dark green colour.

Ground truth surveys for Kundai Rubber Estate were conducted on 30 Jan 97 and 26 Feb 97. The predominant clones in this estate are similar to those of Cheruvally estate and the wintering behaviour was also more or less similar to that of Cheruvally estate.

4.2.5.2 Change detection in FCC images

Plate 11 shows the three FCCs of Cheruvally, pertaining to the rubber estate area alone. Majority of the area was under wintering, however, some areas appear in red colour due to early reflushing. A progressive increase from 29 Jan 97 to 14 Mar 97 is seen in red area. In the FCC of 29 Jan 97 some areas could be seen in brick red colour with very little area in pink colour. After a gap of eight days (on 7 Feb 97) more area is seen with brick red as well as prominent pink colour. After five weeks i.e.,, by 14 Mar 97, all the vegetated area could be seen in bright brick red colour without any pink colour.

The observed trend clearly indicates that there were variations in wintering habits i.e.,, early or late wintering of different clones and progressive development of canopy after wintering. The more of pink colour in the FCC of 7 Feb 97 might be because of initial stages of the concentration of chlorophyll and it might have completed the process of maturation in five weeks of time (on 14 Mar 97) and appeared brick red

Plate 12 shows the three FCCs of Kundai, pertaining to the rubber estate area alone. As seen in Cheruvally estate, majority of the area was under wintering. However, some areas appear in red colour due to early reflushing. A progressive increase from 30 Jan 97 to 26 Feb 97 is seen in red area. In the FCC of 30 Jan 97 some areas could be seen in brick red colour with very little area in pink colour. After a gap of three weeks (on 21 Feb 97) more area is seen with brick red as well as prominent pink colour. After five dyas i.e.,, by 26 Feb 97, much of the vegetated area could be seen in bright brick red colour with less pink colour.

The observed trend in this case also clearly indicates that there were variations in wintering habits i.e.,, early or late wintering of different clones and progressive development of canopy after wintering. The more of pink colour in the FCC of 21 Feb 97 might be because of initial stages of the concentration of chlorophyll. The progress of chlorophyll concentration in the process of maturation could be seen by increasing brick red colour of with decreasing pink colour even in five days time (26 Feb 97).

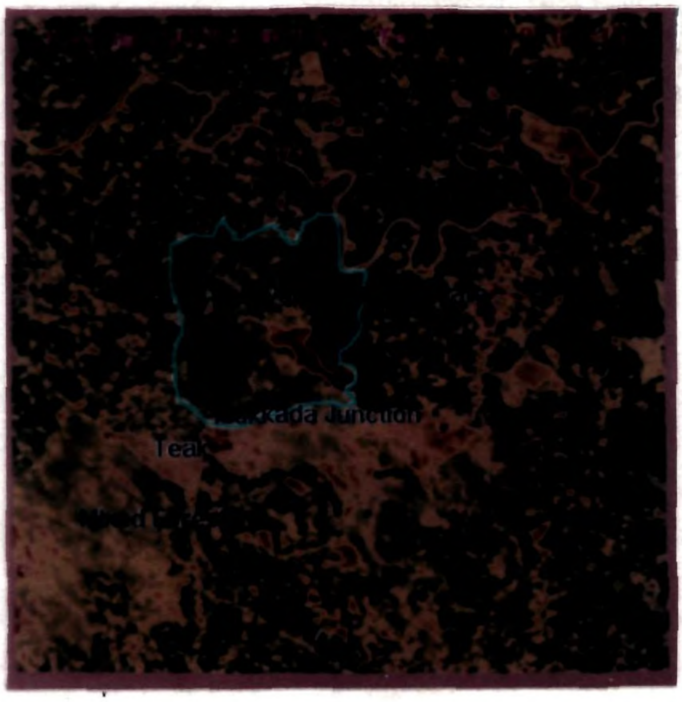

Plate 9. Normalised vegetation difference index image of Cheryvally Estate Area

Plate 10. Normalised vegetation difference index image of Kundai Estate Area

The inter-cellular air spaces in leaf increase as leaf expands, thus increasing the reflectance in near IR with age (Deekshatulu and Joseph, 1991). The temporal variations in reflectance as a result of increasing concentration of plant pigments, particularly chlorophyll, and change in structure following expansion, from January to February / March could be clearly understood from these FCCs.

4.2.5.3 Change detection in NDVI images

The three NDVI images showing only Cheruvally Rubber Estate are given in the Plate 13 to study the changes in vigour of the foliage in rubber. A 256 colour palette used in these NDVI images indicate the vegetation in green shades. It is seen that as time progresses, the area under green shades increased continuously, indicating foliage development after wintering. The NDVI clearly delineates the rubber areas with luxurious foliage from normal growth, as indicated by very dark green colour in the image of 14 Mar 97.

The three NDVI images showing Kundai Rubber Estate are given in the Plate 14 to study the changes in vigour of the foliage in rubber. Same palette used in Cheruvally images was used in these NDVI images also to indicate the vegetation in green shades. As seen earlier, the area under green shades increased continuously, indicating foliage development after wintering, as the time progressed. In this case also, the NDVI clearly delineates the rubber areas with luxurious foliage from normal growth, as indicated by very dark green colour in the image of 26 Feb 97.

The expansion of leaf and chlorophyll concentration with progressing time influence the reflectance properties with decreasing and increasing reflectance in red and near IR regions respectively (Deekshatulu and Joseph, 1991) and thus changes in NDVI. The temporal variations in reflectance as a result of increasing concentration of plant pigments, particularly chlorophyll, and change in structure following expansion, from January to February / March could be clearly understood from these NDVI images.

Jagdeesh *et al.* (1992) employed the NDVI for forest stratification in Maharashtra while using the IRS, LISS-II data and found that the forest density classes broadly showed good agreement between NDVI classes and forest stock. Closer observation revealed that variations in NDVI were resulting from deferring moisture conditions.

4.2.6 Spectral signatures

A systematic study of spectral and temporal variations in reflectance from rubber, teak, mixed forest and rivers in both the study areas was conducted to understand the spectral signatures. The per cent reflectance is calculated as the ratio of mean reflectance of each feature to the maximum number of levels given by the sensor, expressed as a per centage. The results are presented in Table 45 followed by discussion.

Rubber

In the Cheruvally image, there is an increasing trend in the reflectance for band 2 (15.5 to 18.7 %) and band 4 (35.2 to 60.9%) over time from January to March 97. A decreasing trend (18.8 to 14%) is seen for band 3. It is interesting to note that the highest temporal variation (35.2 to 60.9%) among the various land features and spectral bands is obtained for rubber. An examination of the inter-band variations indicated increasing trend (15.5, 18.8 and

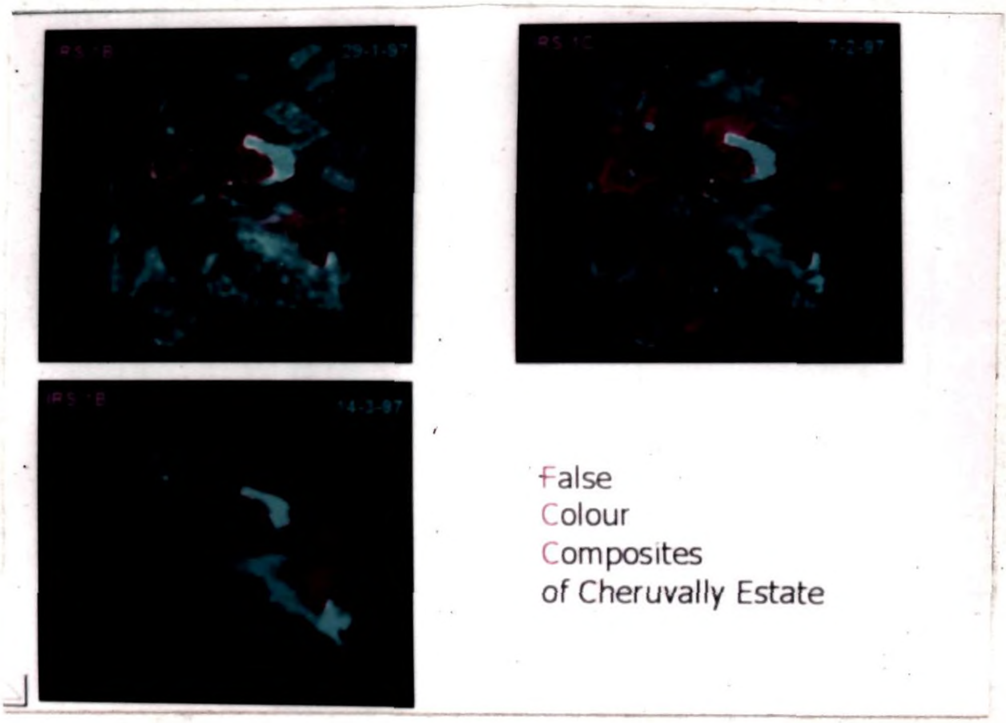

Plate 11. Change detection in FCCs of Cheryvally Estate

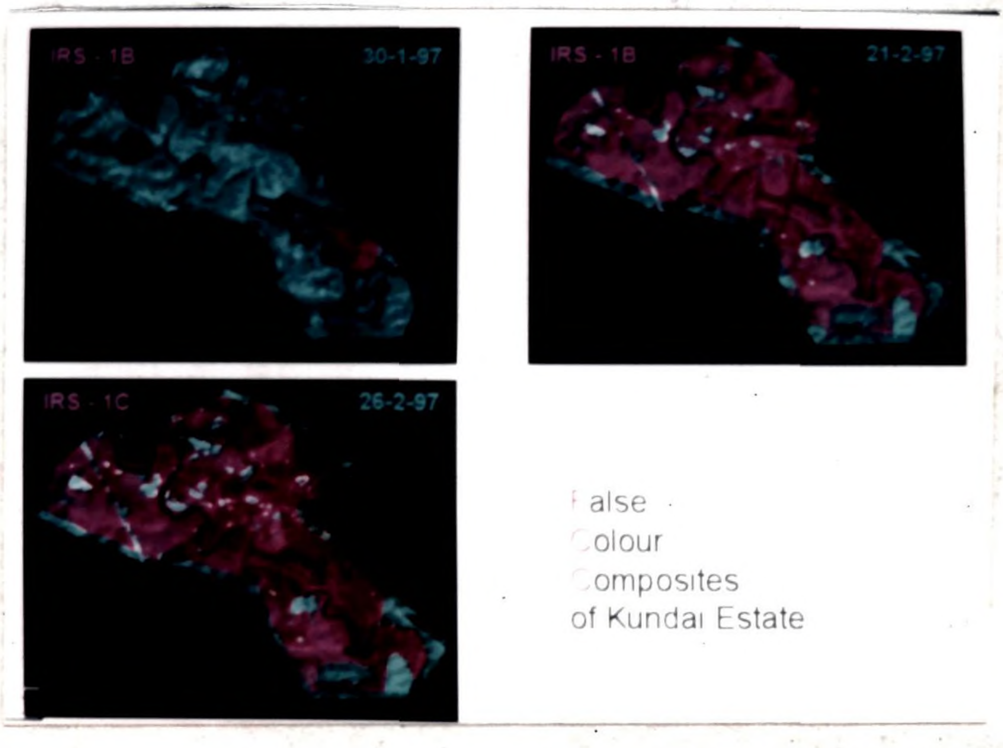

Plate 12. Chang? detection in FCCs of Kundai Estate

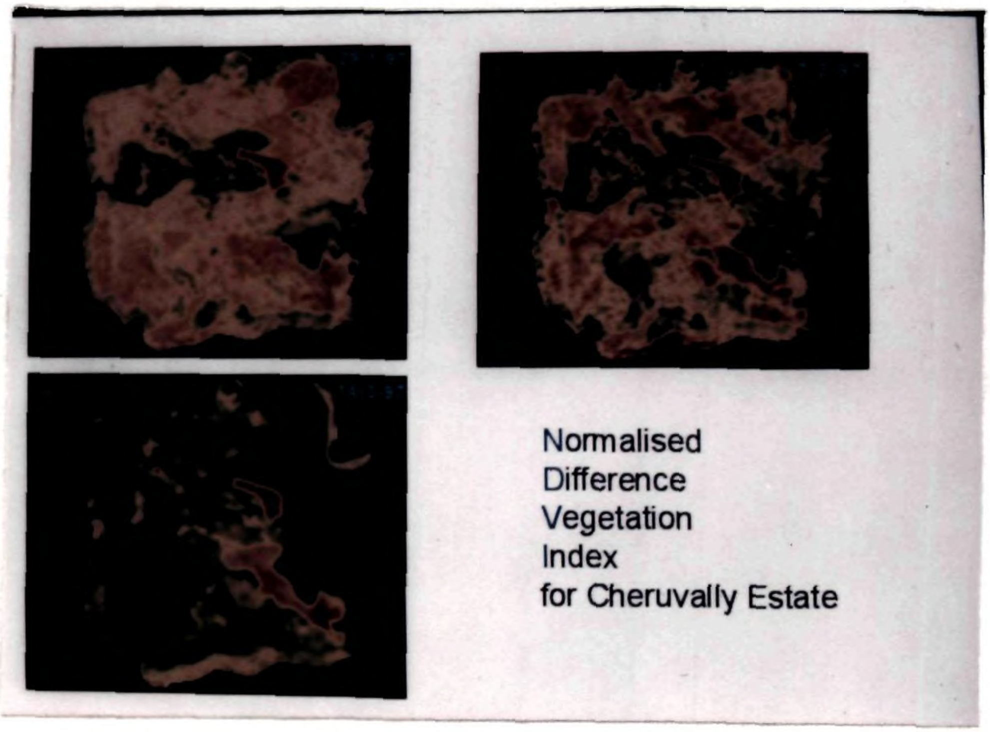

Plate 13. Change detection in NDVI images of Cheryvally Estate

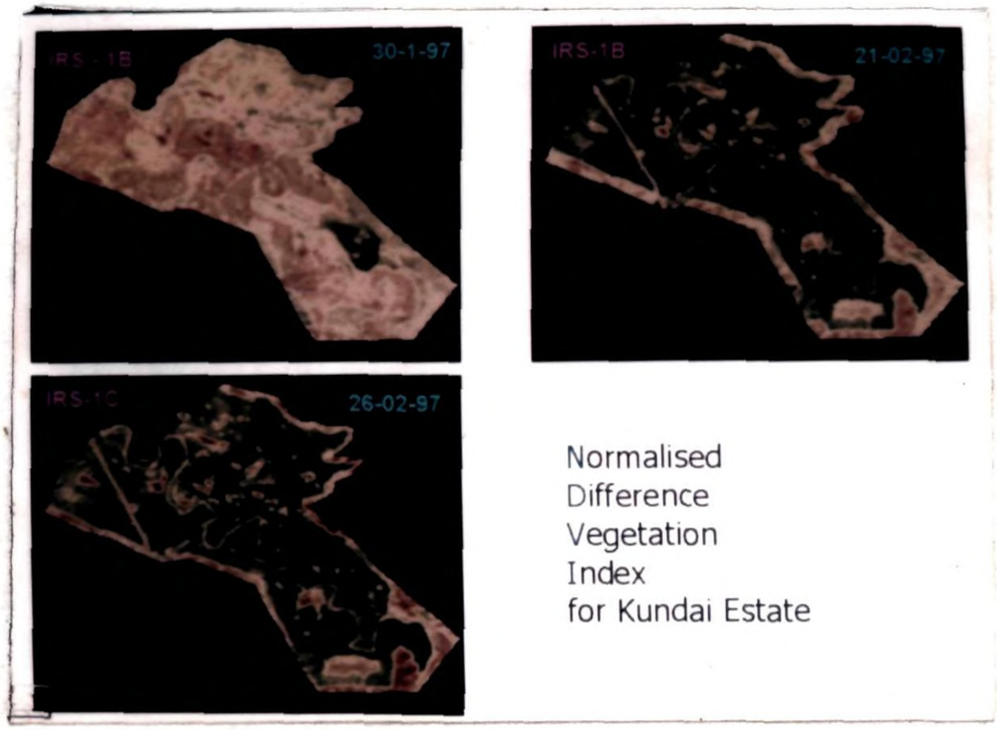

Plate 14. Change detection in NDVI images of Kundai Estate

Table 45. Per cent reflectance as influenced by spectral and temporal changes

Feature	Cheruvally estate area			Kundai estate area		
	Date 29-1-97	Date 7-2-97	Date 14-3-97	Date 30-1-97	Date 21-2-97	Date 26-2-97
Rubber						
Band 2	15.5	17.9	18.7	16.5	18.6	19.4
Band 3	18.8	15.7	14.1	18.2	14.5	11.6
Band 4	35.2	39.5	60.9	41.8	53.5	66.2
Teak						
Band 2	19.1	18.2	14.7	19.6	17.6	15.3
Band 3	14.8	15.0	19.6	15.2	15.9	18.0
Band 4	46.3	38.8	32.8	43.1	39.7	30.8
Mixed forest						
Band 2	18.5	17.2	14.3	16.4	15.6	14.8
Band 3	14.4	16.1	18.4	15.1	16.4	18.2
Band 4	39.3	32.5	30.7	45.0	42.9	37.2
River						
Band 2	25.8	26.1	27.2	27.1	28.4	28.9
Band 3	15.7	20.4	22.9	17.0	17.5	20.4
Band 4	12.0	18.0	18.5	13.0	16.2	18.6

35.2% in bands 2, 3 and 4 respectively) in reflectance for the image on 29 Jan 97, whereas, for the other two images, a dip in the red band is observed. Similar trend is observed images pertianing to Kundai Rubber Estate area..

The spectral response of vegetation in different wavelength regions is well understood and it is quite distinct. As mentioned earlier, plant pigments and leaf structure are the important factors which influence the reflectance in the visible and near IR regions. A relative lack of absorption in the green region allows normal vegetation to look green. Low reflectance in the red region corresponds to chlorophyll absorption band. In the near infrared region (also known as reflective IR band), there would be high reflectance from vegetation, which is actually controlled by the in internal cellular structure of the leaves. As the leaves grow, inter-cellular air spaces and the reflectance increase markedly (Deekshatulu and Joseph, 1991).

The distinct temporal variations of reflectance in the three bands are due to the leaf expansion and concentration of chlorophyll taking place from bud stage to maturation of leaf.

Teak

In the Cheruvally image, there is an decreasing trend in the reflectance for band 2 (19.1 to 14.7 %) and band 4 (46.3 to 32.8%) over time from January to March 97. An increasing trend (14.8 to 19.6%) is seen for band 3. The inter-band variations indicated that the reflectance is 19.1, 14.8 and 46.3% in bands 2, 3 and 4 respectively for the image on 29 Jan 97 whereas, for the other two images, a rise in the red band is observed which is just exactly opposite to the trend observed in rubber.

In Kundai image also similar trend is noticed with reference to the reflectance of teak.

The spectral response of teak over different bands and time is seen clearly. As mentioned earlier, plant pigments and leaf structure are the important factors which influence the reflectance in the visible and near IR regions.

The ground truth indicated that there was a decrease in canopy in teak as time progressed from January to March 97 which resulted in increasing and decreasing reflectance in red and near IR regions respectively subscribing to the behaviour of vegetation (as described by Deekshatulu and Joseph (1991).

Mixed forest

In the Cheruvally image, there is an decreasing trend in the reflectance for band 2 (18.5 to 14.3 %) and band 4 (39.3 to 30.7%) from January to March 97. Contrary to that an increasing trend (14.4 to 18.4%) is seen for band 3, which is similar to that of teak plantation. The inter-band variations indicated that the reflectance is 18.5, 14.4 and 39.3% in bands 2, 3 and 4 respectively for the image on 29 Jan 97, whereas, for the other two images, a rise in the red band is observed which is opposite to the trend observed in rubber and similar to that found in teak plantation.

In Kundai also similar trend is noticed with reference to the reflectance of mixed forest in different bands and between 30 Jan 97 and 26 Feb 97.

The trend in spectral response of mixed forest is similar to that of teak over different bands and time. However, the composition of the mixed forest is unknown as to describe the behaviour more clearly. It appears from the temporal study that the selected area in the mixed forest consists of deciduous trees and there was a decrease in the canopy with time from January to March 97. The observed trend of spectral as well as temporal variations in reflectance follows behaviour of vegetation.

River

In Cheruvally image, there is a increasing trend in the reflectance for band 2 (25.8 to 27.2 %), band 3 (15.7 to 22.9 %) and band 4 (12.0 to 18.5 %) over time from January to March 97. This is a specific pattern which is very different from that was seen in vegetation. The inter-band variations indicated a decreasing trend with per cent reflectance 25.8, 15.7 and 12.0% for band 2, 3 and 4 respectively for the image on 29 Jan 97. Similarly, in other two images also increasing trend is noticed from band 2 to band 4.

In Kundai image also similar trend is noticed with reference to the reflectance of water both spectrally as well as temporally (between 30 Jan 97 and 26 Feb 977).

The above data illustrate the spectral as well as the temporal variations in reflectance of water. The spectral as well as the temporal variations in reflectance from river are due to the reflectance characteristics of water as such and the influence of quantity of water or depth of the river. Deekshatulu and Joseph (1991) detailed that the spectral response of water in visible and near IR region is unique with decreasing absorbence in the spectrum from green to red region and highest absorbence in near IR region. In the present study also similar trend was noticed in the reflective characteristics of water.

The temporal variations are mainly due to change in the quantity of water as result of drying from January to February / March 97. In both the study areas, the water content was found to be more in January and decreased subsequently with time, resulting in changes. From the above study of spectral signatures, it is clear that rubber could be separated from other vegetation types owing to its specific spectral behaviour particularly in band 4.

It is also seen that studies on temporal changes in spectral behaviour of rubber might help in separating it from teak as well as mixed forest. It could be drawn from the data that mean reflectance of above 60 per cent in band 4 might indicate the vegetative cover of rubber. Similarly, the image pertaining to the period when complete canopy is developed would help in delineating rubber from teak and mixed forest in these study areas.

4.2.7 Supervised classification

A supervised classification with maximum likelihood algorithm was done in both Cheruvally (1B image of 14 Mar 97) and Kundai (1C image of 26 Feb 97) and the resultant are presented in Plate 15 and 16.

4.2.7.1 Cheruvally estate

Signatures were created considering several training sites containing representative pixels. Two signatures for rubber were created based on the reflectance as influenced by the nature of refoliation after leaf fall as early and late reflushing. One signature each for teak, mixed forest, river & shallow water and others (which include mainly bare lands) were also created The maximum likelihood classifier assigned six classes for all the pixels in the image, based on the above signatures. A colour palette for this image was specifically created keeping in mind the natural colours of the land features.

The accuracy of classification was assessed by visual interpretation of the classified image and comparing with the ground truth. It is seen that the classification was more or less correct. The classification indicates that the study area is mostly under rubber, which is generally true. Similarly, the classification for teak, mixed forest, river & shallow water, and "others" is satisfactory.
However, there were some discrepancies noticed. Some rubber areas in the estate are classified as water body while still others are classified under forest.

4.1.7.2 Kundai estate

Three signatures for rubber were created based on the reflectance as influenced by the nature of refoliation after leaf fall as early and late reflushing. One signature each for teak, mixed forest, river & shallow water and others (which include mainly bare lands) were also created

The maximum likelihood classifier assigned seven classes for all the pixels in the image, based on the above signatures. A specific palette for this image was created keeping in mind the natural colours of the land features.

The accuracy of classification was assessed by visual interpretation of the classified image and comparing with the ground truth. It is seen that the classification was more or less correct in this case also. The classification indicates that the study area is mostly under rubber, which is generally true. Similarly, the classification for teak, mixed forest, river & shallow water, and "others" is satisfactory.

However, there are some discrepancies noticed in this classified image also. Some rubber areas in the estate are classified as water body while still others are classified under forest.

In general, it can be stated that the classifications were satisfactory and could be used for delineation of different land covers. Menon (1991) used supervised classification with same algorithm of maximum likelihood and could separate rubber using LISS - 1 data of IRS-1A in Thrissur region with 90 per cent accuracy. Application of supervised classification techniques with accuracy assessments were reported in other vegetation types (Jadhav, 1992; Tiwari *et al.*, 1992;

Menon and Ranganath, 1992; Sudhakar *et al.*, 1992; Katoh, 1993, Franklin *et al.*, 1994 and Nair and Menon, 1998).

There are certain discrepancies in the classifications. These are seen when the classified image is critically compared with the ground truth. The discrepancies are the presence of non-existing water bodies in the estate, classification of rubber as forest, which could not be explained for want of large number of training sites and also due to the inherent complexity in the vegetative cover in a tropical area like Kerala.

However, it is felt that these small discrepancies do not seriously affect the utility of the classified images. As mentioned earlier, the classification was satisfactory and can be used for the delineation of rubber growing areas. The accuracy can be further enhanced by conducting vigorous ground truth surveys, using more sets of imageries pertaining to different seasons and applying advanced digital image processing techniques like divergence matrix analysis etc. in combinatiion with the use of high resolution data from PAN sensor along with LISS III data.

General discussion

In the study on taxonomy of soils under rubber in different prominent physiographic units, certain general relationships among different soil properties were established. The soil profiles in all the three reaches of slope in the selected physiographic units were characterised and classified according to Soil Taxonomy. A careful observation of the taxonomy of soils on upper, middle and bottom reaches of slope in different physiographic units indicated that there were differences in soil properties as influenced by the topography. These variations might be a result of catenary sequence of soil development, which indicates the close association of soils in the same region, formed from the same parent material and climate but having differences in relief or drainage conditions.

However, in some physiographic units, the taxonomic positions of the soils remained the same in spite of minor differences in soils characteristics. In the earlier reports it was stated that in some places the conditions for soil development might be the same irrespective of the reach of the slope resulting in same taxonomic position. However, it is seen that the slope caused changes in some soil properties in certain physiographic units. But the threshold values used for soil taxonomic classification may not be able to subdivide the soils further in the same group though distinct differences exist, for instance with respect to soil depth. It is certainly necessary to consider the role of the slope while evaluating the soils particularly in edaphalogical sense though soil taxanomy does not hint any thing about the role of the slope.

In another experiment, the norms of the fertility capability classification were applied to classify the soils. An attempt was also made to introduce one local modifier 'm' to separate Mg deficient soils from other lot. It was reported that some rubber growing soils are Mg deficient, which might be because of an interaction effect of excess Mn on the availability of Mg. There were differences among reaches of slope and physiographic units with reference to fertility capability classification. The differences in FCC within a given physiographic unit were due to the influence of varying topography. Among physiographic units however, both similarities and differences were observed

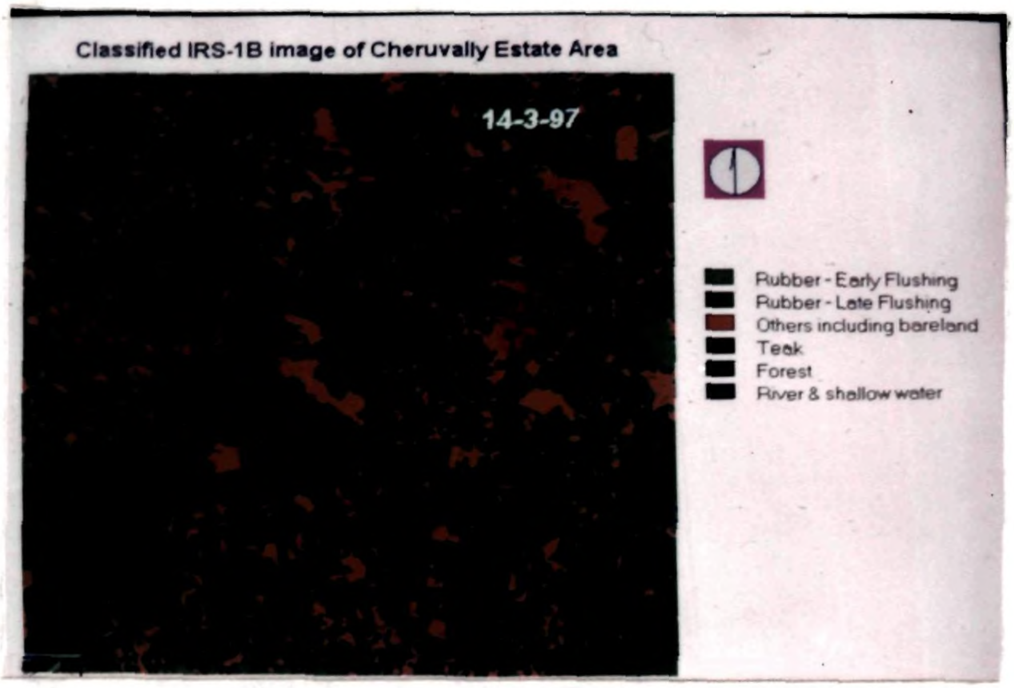

Plate 15. Classified image of Cheryvally Estate area

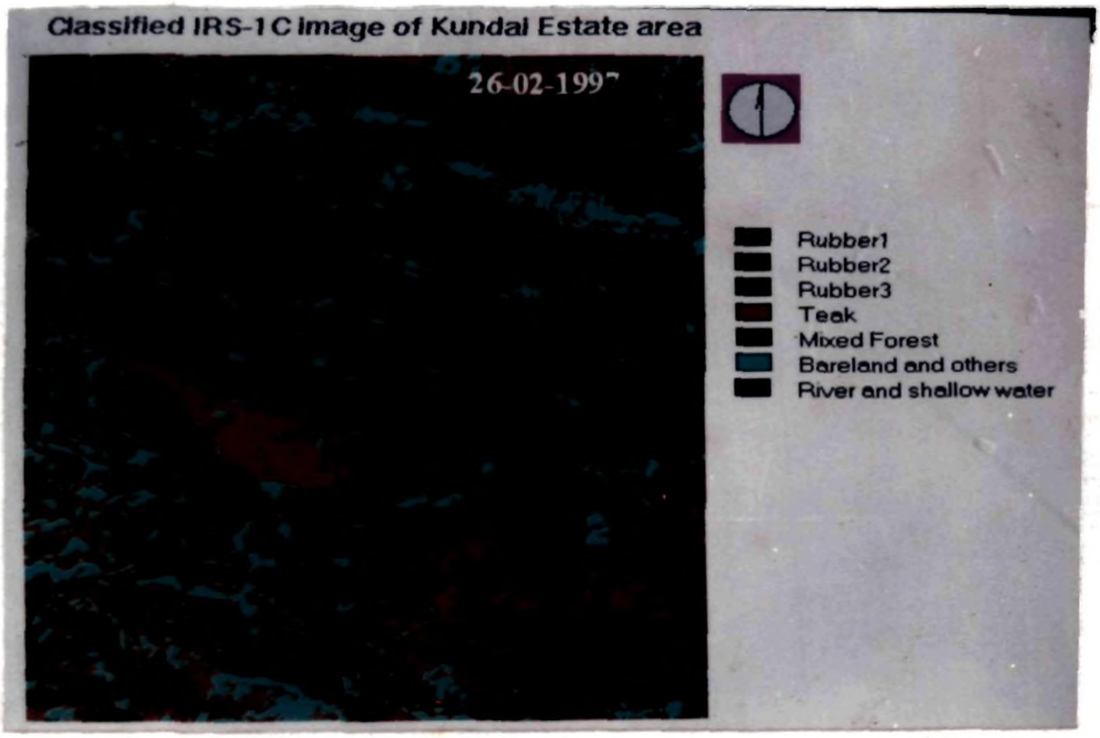

Plate 16. Classified image of Kundai Estate area

It could be seen in several instances that soil taxonomy and numerical taxonomy could distinguish and group different soils. However, similar taxa were grouped differently in numerical taxonomy. It was due to the quantitative differences in soil properties even in the same taxon, whereas in soil taxonomy certain fixed values of the attributes are used to classify the soils. It is however, a useful technique for grouping the soils based on the quantitative traits of edaphalogical importance as these numerical differences might certainly mean some thing in practical soil management.

In an experiment to understand the basic soil-plant relationships, the data on soil variables measured in different experimental sites at different times indicated clearly that sites varied in soil properties. Similarly there were seasonal changes in soil properties which were regulated by weather resulting in differential availability of nutrients.

The correlation analysis indicated that there were definite relations among certain soil properties. The role of soil pH, the resultant of acid-base balance, on the availability of P could be seen since it regulates the solubility of minerals containing phosphorus. It is understood that soil temperature and soil moisture content were the most important parameters regulating the availability of elements particularly that of P and K. From the data, it was understood that there were seasonal changes in growth performance of rubber plants in different sites indicating the influence of weather. Different rates of growth in different sites were noticed in response to changes in weather from a dry season to a wet season, which also manifested in differential availability of nutrient elements.
Factor analysis was attempted to study the latent structure and also to reduce the dimensionality of the data. This was done in all the sets of data collected at different times of observations. It could be seen that factor analysis gave clear information on association of different variables with various factors, which the simple correlation analysis could not unravel. It was observed that some of the factors were associated to the soil variables differently from time to time.

The factor analysis of the data on soil variables measured at different times of observation identified two important factors i.e.,, 'Soil Reaction Control Factor' and 'P Limitation Factor' which explained much of the variability in the data on soil properties. The regression analysis identified that the growth was associated with 'P Limitation Factor'. The limitation posed by reduced soil moisture, increasing temperature and DTPA-Mn on the solubility and diffusion of P was however, realised, which in turn might have hindered the growth response. Factor analysis also highlighted the role of K and Zn in the growth process, which the simple correlation analysis could not reveal. The role of soil moisture on the availability of nutrients was known, particularly in case of P, K and Zn where the access of these elements to roots is essentially by diffusion. The role of organic matter in the availability of P could be understood in the factor analysis of July 97 data.

The effects of various soil properties on growth performance were disentangled into direct and indirect effects in the path analysis. It was observed in general that the path model could explain variability in plant growth to a sufficiently larger extent emphasizing the role of soil parameters and also their interaction effects. In the path analysis direct and indirect effects of different soil parameters were observed at various times highlighting the correlation and factor analysis did not indicate.

An attempt was made to compare the agronomic utility of the soil classification namely soil taxonomy and fertility capability classification. It could be noticed that the Soil Taxonomy could give a general order of ranking based on plant growth among different taxa. It is felt that care should however, should be taken while interpreting the agronomic utility of soil taxonomy as same taxon was ranked low in some sites. It was seen earlier that the 'Soil Reaction Control Factor' and 'P Limitation Factor' influenced the growth performance of rubber plants. Soil taxonomy, however, could not provide any information about the local variations in these 'factors' and thus could not explain the variations in growth within the same taxon.

Discrepancies were found while studying the agronomic utility of the FCC concept also. Interestingly, soils deficient in available K and Mg besides with other known limitations were ranked high. It is felt that efforts should be on to include not only the limited soil variables but also the variables which limit the availability of the nutrient elements, to make the FCC system more meaningful. However, the flexibility of the system to include any soil parameter as a condition modifier is to be highly appreciated as it facilitates to identify such condition modifiers by detailed experimentation and to include into the system of classification.

Establishment of a spectral signature for rubber is felt necessary because it facilitates an easy mapping and monitoring of rubber plantations over a given large geographical area for varied purposes. From the study of spectral signatures, it was clear that rubber could easily be separated from other vegetation types owing to its specific spectral behaviour particularly in band 4.

It was also seen that studies on temporal changes in spectral behaviour of rubber might help in separating it from teak as well as mixed forest. It could be drawn from the data that mean reflectance of above 60 per cent in band 4 might indicate the vegetative cover of rubber. Similarly, the image pertaining to the period when canopy is developed would help in delineating rubber from teak and mixed forest in these study areas.

SUMMARY

SUMMARY

The present study had four experiments viz., 1. Taxonomic classification of soils under rubber; 2. Fertility capability and numerical classification; 3. Relationship between soil properties and the growth of rubber; and 4. Establishment of spectral signature to rubber using satellite imageries. In the first experiment, six prominent physiographic units, which have rubber, were selected for the study. In each physiographic unit, three soil profiles were cut one each from the top, middle and bottom of the catena of a hill under rubber to ascertain the impact of the slope on the soils properties. The soil profiles were cut to a depth of 180 cm or up to the parent material whichever was shallower. Morphology of the soil profiles was recorded and samples were drawn for laboratory analysis. Soil were characterised and classified according to the norms of soil taxonomy.

In the second experiment, the soil samples were drawn separately from the above soil profiles and surrounding places for characterisation for fertility capability classification of the soils. An attempt was made to introduce a lorganic carbonal modifier 'm' to denote the status of available Mg, using 0.08 cmol kg^{-1} in the FC classes identified. The soils studied for taxonomic classification were subjected to numerical classification in this experiment and different clusters were identified.

In the third experiment 14 sites were selected for studying the soil-plant relationships. Soil samples were collected at bimonthly intervals for one year so as to understand the influence of weather on the availability of different nutrients. Plant growth parameters i.e. girth and height were recorded simultaneously at bimonthly intervals.

In the fourth experiment, two rubber estate areas one in Thrissur and the other in Kottayam districts were selected for studying the spectral signature of rubber. Satellite data pertaining to different dates were prorganic carbonured for temporal study in the reflectance. The reflectance of rubber along with teak and mixed forest was in individual bands. A supervised classification was done in the images of the study areas.

Experiment I:Taxonomic classification of soils under rubber

1. The moist colour showed that all the surface horizons are dark coloured as indicated by the hue 10 YR because of enrichment of soils by organic matter as a result of recycling of leaf litter added by the deciduous rubber tree. In soil from RRII (PU4), Cheruvally Estate (PU5) and Central Experiment Station (PU6), the subsurface horizons are also dark because of the prolonged incorporation of organic matter since these plantations are in second cycle of planting.
2. The texture in the surface horizons was sandy clay in all profiles except in Cheruvally Estate (PU5) where it was sandy clay loam. In the subsurface, the texture was sandy clay, sandy clay loam and clay. This is because of differential migration of clay from surface to subsurface.
3. The influence of organic matter on soil structure in surface was clearly seen in the second cycle plantations which resulted in crumb structure.

4. Considerable variability is seen in 1*N* KCl extracted Al among these profiles of upper reach of the slope. There is a definite pattern of increasing acidity as one moves from north to south of the State within the extent of area selected for the study. The role of high and well-distributed rainfall is well established in the release of exchangeable Al from the soil micelle.
5. As seen in upper reach, in the surface soils of middle reach also, the darker hue is noticed which is because of recycling of organic matter and the rubber plantations are in second cycle.
6. The crumb structure in the surface and subsurface horizons in Cheruvally Estate and CES might be due to the influence of organic matter.
7. It is seen that higher exchangeable Al is noticed in high and well distributed rainfall area i.e. in Kottayam and Pathanamthitta regions which can be attributed to the influence of weather elements on weathering of rorganic carbonk and ultimate release of Al onto the exchange surface.
8. There was a definite increase in pH in surface horizon compared to the profiles in upper and middle reaches.
9. It is noticed that the exchangeable Al content is high in the profiles at bottom reach than other reaches. It organic carboncupied the highest proportion of exchange surface in almost all the profiles as evident from the mean profile values. The mean values were 0.17, 0.20, 0.21, 0.19 and 0.23 cmol kg^{-1}. The increase in exchangeable Al in subsurface layer(s) might be ascribed to the relatively high content of clay seen in these layers.
10. The soils of the upper, middle and bottom reach of the physiographic unit, PU1, belonged to clayey, kaolinitic, isohyperthermic Ustic Kandihumults respectively.
11. The soils in upper, middle and bottom reaches of PU2 are clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults, clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults and clayey, kaolinitic, isohyperthermic Typic Kandiustults respectively.
12. Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults, clayey, kaolinitic, isohyperthermic Typic Kanhaplustults and Fine loamy, mixed, isohyperthermic Ustoxic Dystropepts were found in upper, middle and bottom reaches of the physiographic unit, PU3.
13. Clayey, kaolinitic, isohyperthermic Ustic Kanhaplohumults were seen in all the three reaches of PU4.
14. Similarly, clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults were noticed in all the three reaches of PU5.
15. Clayey-skeletal, kaolinitic, isohyperthermic Ustic Kanhaplohumults were seen in the upper and middle reaches of PU6 and in the bottom reach, the soils were clayey, kaolinitic, isohyperthermic Typic Kandiustults.

Experiment II. Fertility capability and numerical classification

1. The soils studied for soil taxonomy were classified according to the norms of fertility capability classification. The soils of upper reach of the physiographic units PU1, PU2, PU3, PU4, PU5 and PU6 are classified into the FCC units Cdeihk, L"C"deihk, Cdehk, C"deak, L"C"deak, L"C"deak respectively.

2. The soils of the middle reach of PU1 to PU6 are classified into the FCC units

Cdeihk, C"deh, Cdeih, C"dehk, L"C"dea and L"C"dea respectively.

3. The soils of the bottom reach in these physiographic units PU1 to PU6 are classified as Cdeak, Cdeih, Cdeihk, C"deiak, Lcdeak and Lcdea respectively. After the lorganic carbonal modifier was introduced the FCC notation for PU1B, PU4C and PU5C became Ceihkm, C"eiakm and LCeakm respectively.
4. After the introduction of a lorganic carbonal modifier 'm' the FCC notation for PU1B, PU4C and PU5C became Ceihkm, C"eiakm and LCeakm respectively.
5. Differences among reach of slope and physiographic units with reference to fertility capability classification were observed. The differences in FCC of the same physiographic units might be mainly due to differences in topography in addition to other lorganic carbonal variations.
6. Among the physiographic units both similarities and differences were noticed. The similarities might be due to the fact that many of the condition modifiers were measured only in the surface soil and similarities in these properties cluster the soils into one group, though inherently there could be differences in several other features. The differences might be due to variations in slope, parent material or any other feature, which could influence the composition of surface soils.
7. Contrary to the idea of reducing the number of taxa as suggested by the author of FCC system, more FC classes were identified than those of soil taxa because of the use of specific lorganic carbonal modifiers.
8. The flexibility of FCC system however, is appreciable as it really looks into the management constraints with reference to certain nutrient elements. Hence it could be used in routine when large areas of rubber are to be handled after understanding the basic soil-plant relationships so as to identify the fertility constraints.
9. It is seen that a first cluster was formed with PU5B and PU5C both belonging to the same physiographic unit and taxon, Ustic Kanhaplohumults. The second cluster had the soils of PU4A and PU1C as members which are taxonomically Ustic Kanhaplohumults and Ustic Kandihumults respectively, where only the depth is the differentiating character between these two. Soils of PU1A and PU1B were clustered with next lowest distance 4.21. The members of this cluster were taxonomically similar i.e. Ustic Kandihumults
10. The next cluster joined the soils of PU3A and PU6C with a distance of 4.27 where the soils were different according to soil taxonomy i.e. Ustic Kanhaplohumults and Typic Kandiustults respectively.
11. Soils of PU2B and PU4B were clustered together with the Euclidean distance of 4.89. Both the soils belong to Ustic Kanhaplohumults.
12. The overall grouping showed that the soils of PU1A, 1B, 1C, 2A, 3A, 4A, 4C, 5B, 5C and 6C were closely assorganic carboniated with varying distances within the group. Taxonomically, these soils belong to Ustic Kandihumults and Ustic Kanhaplohumults.
13. In is seen that the soils of PU3C, PU6A, PU3B, PU2C and PU6B were found forming individual groups. The soils of PU3C are Ustoxic Dystropepts and formed an individual cluster and of course, merged to the group of Ustic

Kandihumults and Ustic Kanhaplohumults. In another observation, the soils of PU6A, again Ustic Kanhaplohumults, were seen forming another cluster.

14. The cluster with lone membership of PU3B, which is taxonomically, Typic Kanhaplustults was because of its dissimilarity from other soils encountered so far. It could be noticed that the numerical taxonomy confirmed the separate identity of a different taxon as soil taxonomy did
15. Similarly, Typic Kandiustults of PU2C formed a different cluster because of its specific characteristics. However, there was an exception with the same taxon found in PU6C where it got merged with Ustic Kanhaplohumults of PU3A.
16. In several instances soil taxonomy and numerical taxonomy could distinguish and group different soils. However, similar taxa were grouped differently in numerical taxonomy because of the numerical differences in soil properties even in the same taxon., whereas in soil taxonomy certain fixed values of the attributes are used to classify the soils.

Experiment III: Relationship between soil properties and the growth of rubber

1. The data on soil pH measured in the experimental sites clearly indicate spatial variations. It is seen from the data that there are inter-site variations in mean soil pH between Nov. 96 to Sep. 97. Significant seasonal variations were noticed in soil pH as revealed by t-test.
2. Correlation analysis clearly showed the role of exchangeable bases and Al in influencing the soil pH. Exchangeable Ca and Mg showed significant positive correlation with soil pH during different times of observations. The relationship between exchangeable Al and pH was negative as seen in all the observations.
3. ANOVA of repeated measures showed that the difference in ORGANIC CARBON among different times of observation is significant in all the sites indicating seasonal variations.
4. ORGANIC CARBON had a positive significant correlation with available P in March 97 indicating higher availability of P with increasing organic matter ($r = 0.636^{*}$).
5. The nitrogen content appeared to vary among the experimental sites as evident from the data. Seasonal changes were noticed in N content in several sites. However, the ANOVA of repeated measures indicated that the variations in N content among different times of observation are insignificant.
6. Significant positive correlation was noticed between N and the organic carbon at all the times of observation. The correlation coefficients were 0.845^{**}, 0.819^{**}, 0.960^{**}, 0.766^{**}, 0.787^{**} and 0.925^{**} seen in November 96, January, March, May, July and September 97 respectively.
7. There were inter-site and seasonal variations in the available P. ANOVA of repeated measures also indicated that the seasonal changes were significant.
8. The availability of P seemed to be influenced by certain soil parameters either always or at some specific times as revealed by the correlation analysis.
9. DTPA extractable Mn showed significant negative correlation with available P in November 96, January, March and May 97 ($r = -0.548^{*}$, -0.638^{*}, -0.652^{*} and -0.591^{*}.respectively), adding limitations to the availability of soil P.

10. DTPA extracted Zn showed positive correlation with available P during July and September 97, which might be because of the dissolution of zinc phosphate releasing both Zn as well as P. It is to note that such relationship is observed during July and September 97 only where soil moisture was high.
11. There were site and seasonal differences in exchangeable Ca, Mg, K and Na as shown by the data as well as the ANOVA of repeated measures.
12. Exchangeable bases had positive and significant correlation among themselves and negatively correlated with exchangeable aluminium.
13. The contents of exchangeable Al varied among sites and seasons as evidenced by the ANOVA of repeated measures.
14. Similar observations were made in DTPA extractable Fe, Mn and Zn where inter-site and seasonal variations were prominent while the DTPA-Cu did not change significantly among seasons.
15. The correlation among the micronutrients particularly DTPA-Fe, Mn and Zn were prominent during the periods of high soil moisture contents (July and September, 97) and were positively correlated indicating that the conditions of release of one leads to the release of other elements.
16. As experienced in the soils of experimental sites, in leaf composition also variations were noticed among different sites. Such tendency is obvious, as leaf composition is dependent on the contents of available elements in soils.
17. It is seen from the data presented in all the tables that there were site variations in plant performance in terms of growth as indicated by plant volume. Site 5 and Site 8 registered lower and higher growth performance respectively.
18. It is seen that there were seasonal changes in growth performance of rubber plants in different sites over one annual cycle of weather indicating the influence of weather. Different rates of growth in different sites were noticed in response to changes in weather from a dry season to a wet season.
19. It is seen that, plant volume is directly related to total nitrogen with a coefficient of simple correlation of 0.536^{*} during July 97 indicating a limitation on nitrogen.
20. Plant growth appeared to be highly influenced by the limitation of available P. It is seen during Nov. 96, Jan, Mar and May 97 that the plant volume is positively and significantly correlated with the availability of P ($r = 0.701^{**}$, 0.568^{*}, 0.746^{**} and 0.797^{**} respectively).
21. The correlation study indicates that the growth increased with exchangeable Al during Nov. 96 and Jan 97 ($r = 0.663^{**}$ and 0.581^{*} respectively). In another instance it is found that the plant growth is affected by DTPA extractable Mn with negative correlation during Nov. 96, Mar and May 97 adding to already impaired performance due to limitation of P.
22. From the relationships among changes in soil variables over time, it is understood that soil moisture has a tremendous role in dissolution of elements as several relationships are noticed during the period of July to September 97 characterised by high rainfall when compared to other periods from November 96 to May 97.
23. There is a negative relationship between leaf Mg and plant growth during September 97 (-0.545^{*}) which hints about the interaction effects in the plant system.
24. It could be seen that factor analysis gave clear information on assorganic carboniation of different variables with different factors when compared to simple

correlation. It is clearly seen that the first factor was always assorganic carboniated with exchangeable Ca, Mg, Na, Al and pH also with organic carboncasional inclusion of K influencing the soil reaction. This first factor hence might be called ' Soil Reaction Control Factor ' which in fact explained variability among the soils to a higher degree.

25. It would be appropriate to name Factor 2 during November 96, January, March and May 97 and Factor 3 during July and September 97 as ' P Limiting Factor ' because of the fact that DTPA-Mn and increasing soil pH reduced the availability of P and also that increasing exchangeable Al has a positive role in enhancing the availability.
26. Regression analysis of factor scores and the plant volume indicated that growth is influenced mainly by the availability of P during November 96, January, March and May 97 which was revealed by correlation analysis also. However, an additional information on the positive role of exchangeable K and Zn on growth was provided by the factor analysis, which the correlation analysis could not.
27. Path analysis of correlation between plant growth and soils properties at different times of observations indicated that the path models could explain much of the variability in the data indicating the prominent role of the soil properties on plant performance.

28. Discrepancies were also found while studying the agronomic utility of the FCC concept also. The soils ranked first, second and third in terms of growth were said to fix more P and deficient in available K. In addition to that there was Mg deficiency also in some sites. Perhaps, there would be other important constraints posing problem in plant growth like 'P Limitation Factor' as studied

Experiment IV: Establishment of spectral signature to rubber using satellite imageries

1. Rubber in green band appeared in slight to dark grey levels in both the study areas. Teak plantations appeared in lighter grey levels compared to rubber. The reflectance from the mixed forest is found in grey levels from light to slightly dark in both the study areas. The rivers are seen as dark patches. However, there is no clear appearance of rivers in this band. The power line in both the images appeared as a thin straight line characterised by higher reflectance.
2. In the red region of the visible spectrum rubber in both the study areas appeared in black compared to the dark-grey that was noticed in band 2. Teak appeared bright as there is more reflectance in the red region. The reflectance from the mixed forest appeared in a mixture of lighter and darker grey levels. In this band, the rivers could not be clearly identified and it appeared as small strips with high reflectance. The power line is seen as a thin line with higher reflectance.
3. In the near infrared region, rubber appeared very bright indicating higher reflectance compared to band 2 and 3, in both the study areas. Teak plantation is seen as dark patch. The reflectance from mixed forest seemed to be a mixture of grey levels from light to dark. Rivers are seen clearly in black. The power line appeared as a thin, straight and dark line indicating higher absorption.
4. In the false colour composite rubber in both the study areas appeared in different shades of red colour. Teak plantation

appeared in varied shades of cyan and blue colours. Mixed forest is found to have a mixture of different shades of blue and red colours. Rivers are identified as a black meandering curve, though broken at some places. The power line appeared as cyan coloured thin straight line. Known bare land in the estate appeared in cyan.

5. The study of the FCCs for the two estates shows that the various land features could be identified in the FCC. In the individual bands, some of the features have similar spectral response thus making them difficult or even impossible to differentiate. Among different vegetation covers, it is possible to separate rubber from mixed forest because of variations in the colour and shades.

6. In the NDVI images of both the study areas the area under rubber appeared in different shades of green colour, while teak plantation appeared in different shades of brown colour. Mixed forest has both these colours. The rivers appeared in different shades of brown and yellow colours. The power line appeared as a thin and straight yellow line.

7. From the study of spectral signatures, it is clear that rubber could easily be separated from other vegetation types owing to its specific spectral behaviour particularly in band 4. It is also seen that studies on temporal changes in spectral behaviour of rubber might help in separating it from teak as well as mixed forest. It could be drawn from the data that mean reflectance of above 60 per cent in band 4 might indicate the vegetative cover of rubber. Similarly, the image pertaining to the period when complete canopy is developed would help in delineating rubber from teak and mixed forest in these study areas.

8. In general, it can be stated that supervised classification was satisfactory and could be used for delineation of different land covers. Though there were discrepancies it is felt that these small discrepancies do not seriously affect the utility of the classified images. The accuracy can be further enhanced by conducting vigorous ground truth surveys, using more sets of imageries pertaining to different seasons and applying advanced digital image prorganic carbonessing techniques like divergence matrix analysis e

REFERENCES

REFERENCES

*Abrol, I.P., Khosla, B.K. and Bhumbla, DR. 1969. Relationships of texture to some important soil moisture constants. *Geoderma* 2: 33-39

Adams, F. and Moore, B.L. 1983. Chemical factors affecting root growth in subsoil horizons of coastal plain soils. *Soil Sci. Soc. Am. J.* 47: 99-102

Adhikari, M., Bandhopadhyay, S.K., Kundu, N. and Bhattacharya, S. 1993. Variation of charge characteristics of some soils of West Bengal. *Red and Lateritic Soils of India* (ed Sehgal, J. *et al.*), National Bureau of Soil Survey and Land use Planning, Nagpur, pp. 195-201

Aina, P.O. and Periaswamy, 1985. Estimating available water-holding capacity of western Nigerian soils from soil texture and bulk density, using core and seived samples. *Soil Sci.* 140: 55-58

Ali, M.H., Chatterjee, R.K. and Biswas, T.D 1966. Soil moisture tension relationships of some Indian soils. *J. Indian Soc. Soil Sci.* 14: 51-62

Amma, M.K., Nair, A.N.S., Krishnakumar, A.K., Potty, S.N. and Mathew, M. 1991. Important inorganic phosphorus fraction in rubber growing soils. Indian J. Nat. Rubb. Res. 4: 72-76

Arkely, R.J. 1976. Statistical methods in soil classification research. *Adv. Agron.* 28: 37-70

Beinroth, F.H., Uehara, G., Silva, J.A., Arnold, R.W. and Cady, F.B. 1980. Agrotechnology transfer in the tropics nased on soil taxonomy. *Adv. Agron.* 33: 303-339

Bin.W.C. 1977. A toposequence on granite and its influence on the performance of *Hevea brasiliensis. Proceedings of Conference on Classification and Management of Tropical Soils, 1977,* Kuala Lumpur. pp. 74-83

Black, C.A. 1965. *Methods of Soil Analysis-Part II.* American Society of Agronomy Inc., Madison, Wisconsin. p.1572

*Bolan, N.S. and Hedley, M.J. 1990. Dissolution of phosphate rocks in soils: II. Effects of pH on the dissolution and plant availability of phosphate rock in soil with pH dependent charge. *Fert. Res.* 24: 125-134

Boll-Jones, E.W. 1957. A magnesium-manganese inter-relationship in the mineral nutrition of *Hevea brasiliensis. J. Rubb. Res. Inst. Malaya* 15: 22-28

*Bolton, J. 1960. The effect of fertilizers on pH and the exchangeable cations of some Malaysian soils. *Proc. Natural Rubb. Res. Conf.*, Kula Lumpur, 1960. pp. 70

Brady, N.C. 1990. *The Nature of Properties of Soils.* Macmillan Publishing Company, New York. p.621

Bremner, J.M. 1996. Nitrogen - Total. *Methods of Soil Analysis - Part 3: Chemical Methods* (ed Sparks, DL. *et al.*). Soil Sci. Soc. Am., Inc., American Society of Agronomy, Inc., Madison, Wisconsin, USA. pp. 1085-1122

*Bruneau, M., Galtier, B, Kilian, J., Musigasan, W. and P.J. Roca. 1988. Agro-ecological mapping from SPOT 1 data in southern Thailand: New considerations for farming systems analysis. *SPOT 1: Utilisation des Images, Bilan, Resultats.* Toulouse, France, Cepadues Editions. pp. 463-470

*Buol, S.W. 1972. Fertility capability classification system. *Agronomic-Economic Research on Tropical Soils- Annual Report for 1971.* Soil Science Department, NC State University, Raleigh, North Carolina.

*Buol, S.W., Sanchez, Cate, R.B. Jr. and Granger, M.A. 1975. Soil fertility capability classification. *Soil Management in Tropical America* (ed Bornemisza, E. and Alvarado, A.). Soil Science Departmebnt, NC State University, Raliegh, North Carolina. pp. 126-141

Buol, S.W. and Couto, W. 1982. Soil fertility-capability assessment for use in the humid tropics. *Characterization of Soils in Relation to Their Classification and Management for Crop Production* (ed Greenland, DJ.). Clarendon Press, Oxford pp. 252-261

Buol, S.W., Hole, F.D and McCracken, R.J. 1973. *Soil Genesis and Classification.* The Iowa State University Press, Ames, Iowa. p.360

Chan, H.Y. 1975. Macro-pedogenetical relationships and classification of tropical soils under *Hevea* cultivation. *Proc. Intl. Rubb. Conf. 1975*, Kula Lumpur. pp. 3-22

Chan, H.Y. and Pusparajah, E. 1972. Productivity potentials of common clones on common rubber growing soils. *Proc. Rubb. Res. Inst. Malaya Plr's Conf.* Kuala Lumpur, 1972. p. 99

Chan, H.Y., Wong, C.B., Sivanadyan, K. and Pusparajah, E. 1974. Influence of soil morphology and physiography on leaf nutrient content and performance of *Hevea. Proc. Rubb. Res. Inst. Malaya Plr's Conf.*, Kual Lumpur. pp. 115-126

*Chan, H.Y., Pusparajah, E., Yew, K. and Zainol, E. 1975. A soil suitability technical grouping system for *Hevea. Proc. 3rd ASEAN Soil Conf.*, Kula Lumpur.

Chan H.Y., Yew, F.K. and Pusparajah, E. 1984. Approaches towards land evaluation systems for *Hevea brasiliensis* cultivation in peninsular Malaysia. *Proc. Intl. Rubb. Conf.*, Colombo, 1: 545-563.

Chan, H.Y. 1972. Soil and leaf nutrient surveys for discriminatory fertilizer use in west Malaysian rubber holdings. *Proc. Rubb. Res. Inst.*

Malaya Planter's Conf., 1971. pp.201-213.

*Chan, H.Y. 1980. Tropical tree crop requirement and land evaluation: A case experience of Malaysia. *Rubb. Res. Inst. Malaysia*, Kuala Lumpur.

*Chan, H.Y., Pusparajah, E. and Sivanadyan, K. 1972. A preliminary assessment of influence of soil morphology and physiography on the performance of *Hevea. Proc. Second ASEAN Conf.*, Djakartha

Cline, M.G. 1949. Basic principles of soil classification. *Soil Sci.* 67: 81-91

Dalal, R.C. 1979. Mineralisation of carbon and phosphorus from carbon-14 and phosphorus 32 labeled plant material added to soil. *Soil Sci. Soc. Am. J.* 43: 913-916

Deekshatulu, B.L. and Joseph, G. 1991. Science of remote sensing. *Current Sci.* 61: 129-135

*Franklin, S.E., Titus, B.D and Gillespie, R.T. 1994. Remote sensing of vegetation cover at forest regeneration sites. *Global Ecology and Biogeography Letters* 4: 40-46

Gaikwad, S.T., Goel, S.K. and Raghumohan, N.G. 1977. Numerical classification of some Indian soils. *J. Indian Soc. Soil Sci.* 25: 288-297

George, C.M. 1961. A short account of rubber soils in India. *Rubber Board Bull.* 5: 92-95

Gombeer, R. 1977. Potential and effective clay mobility in tropical soils. *Proc. Conf. on Classification and Management of Tropical Soils.* (ed Joseph, K.T.), Malaysian Soc. Soil Sci., Kuala Lumpur. pp. 9-19

*Gopinath, G. and Samad, A.K. 1985. Evaluation of thematic mapper data for mapping the rubber area under small holdings in Kerala. *Proc. Sixth ACRS Conf.*, Hyderabad

Gressel, N and J.G. Meloll. 1997. Phosphorus mineralisation and organic matter decomposition: A critical review. *Driven by Nature-Plant Litter Quality and Decomposition* (ed Cadisch, G and Giller, K.E.). CAB International, UK. p. 409

Gutierrez-Boem, F. and Thomas, G.W. 1999. Phosphorus nutrition and water deficits in field-grown soybean. *Pl. Soil* 207: 87-96

Hartge, K.H. 1984. The influence of soil physical properties on the growth and yield of cultivated plants. *J. Indian Soc. Soil Sci.* 32: 595-602

*Howard, DD and Adams, R. 1965. Calcium requirement for penetration of subsoil by primary cotton roots. *Soil Sci. Soc. Am. Proc.* 29: 550-562

Hsu, P.H. 1963. Effect of initial pH, phosphate and silicate on the determination of aluminum with aluminon. *Soil Sci.* 96: 230-238

*Hughes, N.P. and Williams, R.J.P. 1988. An introduction to manganese biological chemistry. *Manganese in Soils and Plants* (ed Graham, R.D, Hannam, R.J. and Uren, N.C.), Kluwer Academic, Dordrecht

Jackson, M.L. 1958. *Soil Chemical Analysis.* Reprint (1973) by Prentice-Hall of India (P) Ltd, New Delhi. p.498

Jadhav, R.N. 1992. Forest mapping and damage detection. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 295-303

Jagdeesh, K.M., Karale, R.M., Balasubramanian, R., Krishnamurthy, Y.V.N., Dabral, S.L. and Bahadur, S. 1992. Forest stock mapping and perparation of management plan using IRS, LISS-II data. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp.289-294

'Jayman, T.C.Z. and Sivasubramaniam, S. 1974. The use of ascorbic acid to eliminate interference from iron in the aluminon method for determining aluminium in plant and soil extracts. *Analyst* 99: 296-301

'Jeanjean, H. Serve, M.de la and De la Serve. M. 1991. The inventory of plantations by satellite (SPOT). *Revue-Generals-des-Caoutchoucs-et-Plastiques.* 702: 43-49

Jensen, J.R. 1986. *Introductory Digital Image Processing - A Remote Sensing Perspective.* Prentice-hall, Englewood Cliffs, NJ, USA. p.379

*Jiang, A. 1981. Temperature inversion and vegetation inversion in xishuangbanna. *Mountain Res. Dev.*1(3&4): 275-280

Kabata-Pendias, A. and Pendias, H. 1992. *Trace Elements in Soils and Plants.* CRC Press Inc., Florida, USA. P.365

*Kamaruzaman-Jusoff and Mohd-Rasil, A.M. 1995. Satellite remote sensing of deforestation in the Sungai Buloh forest reserve, Peninsular Malaysia. *Int. J. Rem. sen.* 16: 11-17

Karmakar, R.M., Rao, A.E.V. and Raghumohan, N.G. 1995. Numerical classification of some soils developed on different prhysiographic units in the northern Brahmaputra valley of Assam. *J. Indian Soc. Soil Sci.* 43: 136-138

*Katoh, M. 1993. Application of satellite remote sensing and geographic information system to stand-level databases of todomatsu plantations. *J. Jap. For. Soc.* 75: 154-158

Kirkby, G.J.D and Nye, P.H. 1986. A simple model for predicting the rates of dissolution of sparingly soluble calcium phosphates in soil: II. Applications of the model. *J. Soil Sci.* 37: 541-553

Koshy, M.M. and Varghese, T. 1972. *Soils of India.* The Fertiliser Association of India, New Delhi. pp. 144-157

Krishnakumar, A.K. 1989. *Soils under Hevea in India: A physical, chemical and mineralogical study with a reference to soil moisture-cation* *influence on yield of Hevea brasiliensis.* Ph.D thesis, Indian Institute of Technology, Kharagpur,

Krishnakumar, A.K. and Potty, S.N. 1992. Nutrition of Hevea. *Natural Rubber: Biology, cultivation and technology* (ed Sethuraj, M.R. and Mathew, N.M.), Elsevier, Amsterdam. pp. 240-261

Krsihnan, P., Venugopal, K.R. and Sehgal, J. 1996. Soil Resources of Kerala for land Use Planning. NBSS Publication 48b (Soils of India series), National Bureau of Soil Survey and land use Planning, Nagpur. pp. 54

Kumar, S. 1994. Bench mark soils of India - their clustering and similarities. *J. Indian Soc. Soil Sci.* 42: 286-292

Kumar, S. and Sharma, A.K. 1987. Numerical classification of some hill soils of Uttar Pradesh. *J. Indian Soc. Soil Sci.* 35: 465-473

Kumar, S. and Sharma, A.K. 1990. Numerical classification of some soils of Indian Tarai. *J. Indian Soc. Soil Sci.* 38: 265-271

Kumar, S. and Sharma, A.K. 1993. Cluster analysis of some soils of different regions of North-west India. *J. Indian Soc. Soil Sci.* 41: 598-600

Lindsay, W.L. 1972. Zinc in soils and plant nutrition. *Adv. Agron.* 24: 147-186

Lindsay, W.L. 1979. *Chemical Equilibria in Soils.* John Wiley & Sons, New York. p.449

*Lindsay, W.L., Frazier, A.W. and Stephenson, H.F. 1962. Identification of reaction products from phosphate fertilizers in soils. *Soil Sci. Soc. Am. Proc.* 26: 446-452

Marschner, H. 1995. *Mineral Nutrition of Higher Plants.* Academic Press, San Diego, CA. p.889

Mathan, K.K. 1990. Application of soil fertility capability classification to aid soils. *J. Indian Soc. Soil Sci.* 38: 469-473

Mathan, K.K., Natarajan, S.S. and Maheswran, P.P. 1994. Application of fertility capability classification concept in major soil groups of Kamarajar district, Tamilnadu. *J. Indian Soc. Soil Sci.* 42: 416-420

*Mekaru, I and Uehara, G. 1972. Anion adsorption in ferrugenous tropical soils. *Soil Sci. Soc. Am. Proc.* 30: 296-300

Menon, A.R.R. 1991. Digital mapping of rubber area using IRS data. *Indian J. natu. Rubb. Res.* 4(1): 68-71

Menon, A.R.R. and Ranganath. 1992. Vegetation mapping of the Silent Valley and its environs using IRS data. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 310-313

*Moor, A.W. and Russell, J.S. 1967. Comparison of coefficients and grouping procedures in numerical analysis of soils trace element data. *Geoderma* 1: 139-158

Nair, P.V. and Menon, A.R.R. 1998. Estimation of bamboo resources in Kerala by remote sensing techniques. *Current Sci.* 75: 209 - 210

Nambiar, E.K.S. 1975. Mobility and plant uptake of micronutrients in relation to soil water content. *Trace Eelements in Soil-Plant-Animal System.* Academic Press Inc., London. pp.151-164

NBSS & LUP, 1993. *Soil Resources of Kerala for Land-Use Planning.* National Bureau of Soil Survey and Land Use Planning, Nagpur. pp. 115

NBSS & LUP. 1999. Resource soil survey and mapping of rubber growing soils of Kerala and Tamilnadu on 1:50000 scale. Consultancy project for Rubber Research Institute of India, Rubber Board, Kottayam. National Bureau of Soil Survey and land Use Planning, Nagpur

Nelson, DW. and Sommers, L.E. 1996. Total carbon, organic carbon and organic matter. *Methods of Soil Analysis - Part 3: Chemical Methods* (ed Sparks, DL. *et al.*). Soil Sci. Soc. Am, Inc., American Society of agronomy, Inc., Madison, Wisconsin, USA. pp.961-1010

Norrish, K. 1975. The geochemistry and mineralogy of trace elements. *Trace Elements in Soil - Plant - Animal Systems* (ed Nicholas, DJ.D and Egan, A.R.). Academic Press, Inc., London. pp. 55-82

Nye, P.H. 1979. Diffusion of ions and uncharged solutes in soils and soil clays. *Adv. Agron.* 31: 225-272

Pardekooper, E.C. 1965. *RRIM Planting Manual No.11.* Rubb. Res. Inst. Malaya. p.135

Parihar, J.S. and Navalgund, R.R. 1992. Crop production forecasting. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 91-107

Radhakrsihnan, K., Varadan, G. and Diwakar, P.G. 1992. Digital image processing techniques-An overview. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 66-85

Rajan, S.S.S., Watkinson, J.H. and Sinclair, A.G. 1996. Phosphate rocks for direct applications to soils. *Adv. Agron.* 57: 77-159

Rao, U.R. 1991. Remote sensing for national development. *Current Sci.* 61: 121-128

*Rayner, J.H. 1966. Classification of soils by numerical methods. *J. Soil Sci.* 17: 79-92

*Rubber Research Institute of Malaysia. 1965. Magnesium: Its role in rubber cultivation. *Plr's Bull.* 102: 99

RRII, 1980. Handbook of Natural Rubber Production in India. Rubber Research Institute of India, Rubber Board, Kottayam. p.668

Samarappuli, L. 1996. Root development in *Hevea brasiliensis. Bull. Rubb. Res. Inst. Sri Lanka* 34:15-21

Samarappuli, L. Yogaratnam, N., Karunadasa, P., Mitrasena, U. and Hettiarachchi, R. 1993. Role of potassium on growth and water relations of rubber plants. *J.Rubb.Res.Inst. Sri Lanka* 73: 37-57

Sanchez, P.A., Couto, W. and Buol, S.W. 1982. The fertility capability soil classification system: Interpretation, applicability and modification. *Geoderma* 27: 283-309

Saseendran, S.A., Mandal, D, Sinha, R.R., Vijayakumar, K.R., Potty, S.N. and Sethuraj, M.R. 1993. Effect of aspect on soil temperature and growth of *Hevea* on hills of north east India. *Indian J. Natural Rubb. Res.* 6:105-110

Seth, S.P. and Talati, N.R. 1968. Rating morphological characteristics for classification of alluvial soils. *J. Indian Soc. Soil Sci.* 16: 277-284

Sharma, A.K. and Sharma, R.K. 1979. Comparison of two methods of numerical classification for some Tarai and Bhabar soils of Uttar Pradesh. *J. Indian Soc. Soil Sci.* 27: 434-440

Singh, K. Joorel, J.P.S., Bhandari, A.R. and Kumar, S. 1996. Numerical classification of some soils from upper transect of Sutlej river catchment in Himachal Pradesh. *J. Indian Soc. Soil Sci.* 44: 122-130

Sinha, A.K. and Karale, R.L. 1992. Preliminary investigation on area and health assessment of orange plantations using IRS data. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 274-279

*Sivanadyan, K. !972. Lysimeter studies on the efficiency of some potassium and nitrogen fertilisers on two common soils in West Malaysia. *Proc. Second ASEAN Conf.*, 1972, Djakartha

Sneath, P.H.A., Sokal, R.R. 1973. *Numerical Taxonomy.* Freeman & Co., San Fransisco. p.573

Soil Survey Branch. 1978. *Soils of Kerala.* Department of Agriculture, Kerala. p.33

Soil Survey Staff. (1975). *Soil Taxonomy.* Agric. Hb. 436, U.S. Department of Agriculture, Washington DC, USA. p.754

Soil Survey Staff. (1992). *Keys to Soil Taxonomy.* Sixth edition, 1994, United States Department of Agriculture, Soil Conservation Service, Washington DC. p.306

Soong, N.K. and Lau, C.H. 1977. Physical and chemical properties of soils. *Soils under* Hevea *in Peninsular Malaysia and their Management* (ed Pusparajah, E.), Rubber Research Institute of Malaysia, Kuala Lumpur. pp. 25-56

*Soong, N.K. 1971. *A study of the root distribution of* Hevea brasileinsis *in relation to its nutrition and growth of* *some typical Malysian soils*. M.Sc. thesis, University of Malaysia

Soong, N.K. 1976. Feeder root development of *Hevea brasiliensis* in relation to clones and environment. *J. Rubb. Res. Inst. Malaysia* 24(5): 283-298

Srivastava, R., Chatterji, S., Sarkar, D and Nayak, DC. 1995. Numerical taxonomy of some rice rowing soils of Bankura district, West Bengal. *J. Indian Soc. Soil Sci.* 43: 302-304

Stevenson, F.J. 1986. *Cycles of Soil Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients*. John Wiley & Sons, Inc., USA. p.380

Sudhakar, S., Krishnan, N., Das, P.K. and Raha, A.K. 1992. Forest cover mapping of Midnapur Forest Division (west & east) using IRS-1A, LISS-II data. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 314-319

Sumner, M.E. and Miller, W.P. 1996. Cation exchange capacity and exchange coefficients. *Methods of Soil Analysis - Part 3: Chemical Methods* (ed Sparks, DL. *et al.*), Soil Science Society of America, Inc., American Society of Agronomy, Inc., Madison, Wisconsin, USA. pp.1201-1230

*Tanaka, A. 1981. Nutritional problems of crops on highly weathered acid soils. *Phosphorus and Potassium In The Tropics* (ed Pusparajah, E. and Sharifuddin, A.H.), Malaysian Soc. Soil Sci.. pp. 237-251

*Taylor, A.W., Frazier, W.A. and Gurney, E.L. 1963b. Solubility products of magnesium ammonium and magnesium potassium phosphates. *Trans. Faraday Soc.* 59: 1580-1584

*Taylor, A.W., Ftazier, W.A., Gurney, E.L. and Smith, J.P. 1963a. Solubility products of di and trimagnesium phosphates and the dissociation of magnesium phosphate solutions. *Trans. Faraday Soc.* 59: 1585-1589

Thinh, T.V., Nam, T.V., An, V.V., Duc, N.V. and Nguyen, T.N. 1998. Land suitability classification system for *Hevea brasiliensis* cultivation in Vietnam. *Proc. Sym. nat. Rubb (Hevea brasiliensis)*: Vol. I - General, soils and fertilisation and breeding and selection sessions, Ho Chi Minh City, 14-15, Oct. 1997. pp.29-34

Tiwari, A.K., Kudrat, M. and Bhan, S.K. 1992. Vegetation classification for a part of western Himalayas using IRS, LISS-II digital data. *Natural Resources Management - A New Perspective* (ed Karale, R.L.), National Natural Resources Management System, Dept. of Space, Bangalore. pp. 304-309

*Ulrich, B., Pirovzpanah, D and Murach, D 1984. Relation between soil acidification and root development in Norway spruce with various degree of damage. *Forstarchir* 55: 127-134

Venugopal, K.R. and Deshpande, S.B. 1993. Micromorphological investigations of catenary sequence of ferrugenous soils. *Red and Lateritic Soils of India* (ed Sehgal, J. *et al.*), National Bureau of Soil Survey and Land Use Planning, Nagpur. pp. 121-133

Webster, C.C. and Baulkwill, W.J. 1989. *Rubber.* Longman Scientific & Technical, New York.

*Weil, S., Gregg, P.E.H. and Bolan, N.S. 1994. Influence of soils moisture on the dissolution of reactive phosphate rocks. *The Efficient Use of Fertilizer in a Changing Environment: Reconciling Productivity and Sustainability.* (ed Currie, L.D and Loganathan, P.), Fertilizer and Lime Research Center, Massey University, Palmerston North. pp.75-81

*Yew, F.K. 1982. *Contribution towards development of a land evaluation system for Hevea brasisliensis Muell. Arg. Cultivation in peninsular Malaysia.* DSc. Thesis, State University, Ghent, Belgium

Yew, F.K. 1992. Soil suitability evaluation for *Hevea brasiliensis* cultivation using land qualities. *Soil Sci. Conf. Malaysia*, Kuala Tregganu

Yew, F.K. and Chan H.Y. 1992. Soil suitability classification systems for *Hevea brasiliensis* cultivation. *J. natu. Rubb. Res.* 7: 290-302

Yew, F.K. and Pusparajah, E. 1991. Influence of soil conditions on growth of *Hevea*: Glasshouse evaluations. *J. natu. Rubb. Res.* 6: 62-73

Zyrin N.G., Rerich W.J. and Tikhomirov, F.A. 1976. Form of zinc compounds in soils and its supply to plants. *Agrochimiya*, 5: 124

- Originals are not seen

APPENDICES

Appendix A. Euclidean distance matrix

	PU1A	PU2A	PU3A	PU4A	PU5A	PU6A	PU1B	PU2B	PU3B	PU4B	PU5B	PU6B	PU1C	PU2C	PU3C	PU4C	PU5C	PU6C
PU1A	0.0	5.2	5.9	5.8	7.5	8.4	4.2	7.2	7.2	6.5	6.6	9.1	4.9	7.7	8.4	5.6	6.2	6.3
PU2A	5.2	0.0	5.5	4.3	7.0	7.2	5.8	7.0	6.8	5.8	5.9	8.8	5.3	7.5	5.7	4.6	4.2	5.4
PU3A	5.9	5.5	0.0	4.7	5.0	5.8	5.8	5.6	7.0	6.1	5.1	7.8	4.8	6.9	5.1	6.0	4.7	4.3
PU4A	5.8	4.3	4.7	0.0	6.6	6.9	5.8	6.4	6.2	6.4	5.8	8.6	4.1	7.4	5.6	4.3	4.5	5.3
PU5A	7.5	7.0	5.0	6.6	0.0	6.3	7.4	5.9	8.6	6.3	4.8	6.6	7.4	7.9	7.3	6.7	5.1	6.2
PU6A	8.4	7.2	5.8	6.9	6.3	0.0	7.8	6.9	8.9	7.0	6.5	8.6	7.8	8.5	8.0	7.4	5.9	5.9
PU1B	4.2	5.8	5.8	5.8	7.4	7.8	0.0	6.2	5.9	6.7	6.4	9.4	4.7	8.5	7.5	6.0	6.2	6.1
PU2B	7.2	7.0	5.6	6.4	5.9	6.9	6.2	0.0	6.1	4.9	7.3	9.1	7.9	9.6	7.7	7.5	6.8	6.6
PU3B	7.2	6.8	7.0	6.2	8.6	8.9	5.9	6.1	0.0	7.7	8.7	10.7	7.0	9.1	6.8	7.6	7.7	7.6
PU4B	6.5	5.8	6.1	6.4	6.3	7.0	6.7	4.9	7.7	0.0	7.1	9.1	7.7	9.9	8.6	6.7	6.4	6.4
PU5B	6.6	5.9	5.1	5.8	4.8	6.5	6.4	7.3	8.7	7.1	0.0	6.7	5.5	6.6	6.7	6.1	3.5	5.3
PU6B	9.1	8.8	7.8	8.6	6.6	8.6	9.4	9.1	10.7	9.1	6.7	0.0	8.8	8.8	9.3	8.7	7.2	7.8
PU1C	4.9	5.3	4.8	4.1	7.4	7.8	4.7	7.9	7.0	7.7	5.5	8.8	0.0	7.1	5.8	4.8	5.2	5.0
PU2C	7.7	7.5	6.9	7.4	7.9	8.5	8.5	9.6	9.1	9.9	6.6	8.8	7.1	0.0	7.4	7.8	7.4	5.6
PU3C	8.4	5.7	5.1	5.6	7.3	8.0	7.5	7.7	6.8	8.6	6.7	9.3	5.8	7.4	0.0	6.7	6.0	6.3
PU4C	5.6	4.6	6.0	4.3	6.7	7.4	6.0	7.5	7.6	6.7	6.1	8.7	4.8	7.8	6.7	0.0	4.1	5.8
PU5C	6.2	4.2	4.7	4.5	5.1	5.9	6.2	6.8	7.7	6.4	3.5	7.2	5.2	7.4	6.0	4.1	0.0	4.8
PU6C	6.3	5.4	4.3	5.3	6.2	5.9	6.1	6.6	7.6	6.4	5.3	7.8	5.0	5.6	6.3	5.8	4.8	0.0

Appendix B1. Texture, OC and pH of soils of experimental sites

Site	Horizon No.	Depth (cm)	Particle size (%)			Gravel (%)	Texture	OC (%)	pH water	pH KCl
			Sand	Silt	Clay					
1	1	0-12	64.8	9.6	25.6	31.2	scl	1.6	4.9	4.0
	2	12-36	48.8	12.8	38.4	33.3	sc	1.0	4.9	4.1
	3	36-60	36.0	6.4	57.6	19.7	c	0.6	4.8	4.0
	4	60-76	39.2	9.6	51.2	14.2	c	0.4	4.4	3.6
	5	76-98	52.0	6.4	41.6	17.1	sc	0.2	4.8	4.8
	6	98-127	55.2	9.6	35.2	14.2	scl	0.3	4.9	5.0
	7	127+	45.6	12.8	41.6	12.0	sc	0.2	5.1	5.5
2	1	0-18	58.4	9.6	32.0	13.6	scl	1.1	5.4	5.6
	2	18-40	61.6	9.6	28.8	19.1	scl	0.6	5.2	3.8
	3	40-64	68.0	6.4	25.6	18.4	scl	0.4	5.0	3.9
	4	64-100	64.8	6.4	28.8	28.3	scl	0.3	5.4	4.5
3	1	0-15	55.2	9.6	35.2	31.9	scl	1.0	5.6	4.7
	2	15-33	52.0	9.6	38.4	32.9	sc	0.9	5.3	4.1
	3	33-51	36.0	6.4	57.6	48.3	c	0.4	5.3	4.0
	4	51-85	36.0	9.6	54.4	19.1	c	0.4	5.1	4.0
	5	85-110	39.2	9.6	51.2	36.9	c	0.3	4.8	4.2
4	1	0-18	55.2	6.4	38.4	23.6	sc	0.7	5.2	4.1
	2	18-41	48.8	9.6	41.6	21.1	sc	0.7	5.0	4.0
	3	41-56	52.0	9.6	38.4	25.0	sc	0.7	5.1	4.1
	4	56-79	42.4	9.6	48.0	29.0	c	0.7	5.3	4.3
	5	79-110	32.8	12.8	54.4	38.7	c	0.5	5.5	4.5
	6	110-125	42.4	12.8	44.8	25.0	c	0.4	5.7	4.7
5	1	0-22	45.6	9.6	44.8	18.4	sc	1.8	5.4	4.9
	2	22-45	42.4	9.6	48.0	31.5	c	1.2	5.3	4:3
	3	45-61	36.0	9.6	54.4	33.2	c	0.9	5.2	4.3
	4	61-79	32.8	9.6	57.6	0.0	c	0.8	5.2	4.6
	5	79-130	48.8	6.4	44.8	0.0	sc	0.8	5.6	4.7
6	1	0-15	48.8	12.8	38.4	15.9	sc	0.9	5.4	4.8
	2	15-28	39.2	12.8	48.0	17.8	c	0.9	5.1	4.4
	3	28-46	32.8	12.8	54.4	16.3	c	0.7	5.3	4.4
	4	46-62	29.6	16.0	54.4	12.6	c	0.4	5.5	5.0
	5	62-90	36.0	12.8	51.2	17.6	c	0.4	5.7	4.9
	6	90-110	74.4	6.4	19.2	16.9	sl	0.1	5.7	4.9
7	1	0-20	58.4	12.8	28.8	0.0	scl	2.6	5.5	4.6
	2	20-65	61.6	12.8	25.6	9.3	scl	2.0	5.6	4.5
	3	65-116	52.0	12.8	35.2	7.7	scl	1.4	7.3	6.0
	4	116-150	58.4	9.6	32.0	10.0	scl	1.0	5.8	2.9

Appendix B1 contd....

Site	Horizon No.	Depth (cm)	Particle size (%) Sand	Silt	Clay	Gravel (%)	Texture	OC (%)	pH water	pH KCl
8	1	0-15	48.8	9.6	41.6	17.9	sc	0.5	5.2	3.8
	2	15-33	45.6	9.6	44.8	20.0	sc	0.3	4.6	3.5
	3	33-55	45.6	9.6	44.8	18.8	sc	0.2	4.5	3.9
	4	55-72	45.6	9.6	44.8	16.7	sc	0.2	4.4	3.9
	5	72+	55.2	6.4	38.4	25.0	sc	0.1	4.9	4.5
9	1	0-16	64.8	6.4	28.8	26.9	scl	1.2	6.1	5.2
	2	16-40	58.4	9.6	32.0	22.0	scl	0.9	6.3	5.0
	3	40-59	52.0	6.4	41.6	35.5	sc	0.7	5.8	4.3
	4	59+	58.4	6.4	35.2	45.1	scl	0.4	5.7	4.6
10	1	0-21	55.2	12.8	32.0	8.4	scl	0.5	5.9	5.0
	2	21-31	55.2	12.8	32.0	9.6	scl	0.4	6.2	4.9
	3	31-48	55.2	16.0	28.8	9.8	scl	0.4	6.4	5.0
	4	48-65	58.4	12.8	28.8	25.9	scl	0.2	6.5	5.1
	5	65-97	55.2	12.8	32.0	14.3	scl	0.2	6.4	4.9
	6	97-120	29.6	12.8	57.6	17.5	c	0.3	6.4	5.0
11	1	0-17	48.8	9.6	41.6	7.2	sc	1.0	5.8	4.9
	2	17-36	55.2	12.8	32.0	7.6	scl	0.7	6.1	5.0
	3	36-52	61.6	6.4	32.0	8.6	scl	0.5	6.2	5.0
	4	52-86	58.4	6.4	35.2	8.3	scl	0.4	6.2	5.0
	5	86-112	61.6	6.4	32.0	10.2	scl	0.4	6.2	5.1
12	1	0-16	52.0	6.4	41.6	25.4	sc	0.7	5.5	3.9
	2	16-32	42.4	9.6	48.0	19.4	c	0.5	5.7	4.3
	3	32-70	29.6	12.8	57.6	15.1	c	0.4	5.5	4.0
	4	70-94	32.8	9.6	57.6	12.8	c	0.3	5.7	4.8
	5	94-115	32.8	9.6	57.6	14.8	c	0.2	5.8	5.0
	6	115-135	36.0	12.8	51.2	52.2	c	0.2	5.9	5.2
13	1	0-13	48.8	9.6	41.6	25.0	sc	0.5	5.3	4.6
	2	13-33	58.4	6.4	35.2	23.0	sc	0.6	5.3	3.9
	3	33-58	45.6	6.4	48.0	23.9	sc	0.4	5.7	4.4
	4	58-91	45.6	3.2	51.2	49.6	c	0.1	5.5	4.0
	5	97-120	45.6	6.4	48.0	57.0	sc	0.2	5.5	4.2
14	1	0-15	55.2	6.4	38.4	0.0	sc	1.0	4.7	3.0
	2	15-35	48.8	6.4	44.8	0.0	sc	0.7	4.8	4.1
	3	35-60	45.6	6.4	48.0	0.0	sc	0.5	5.0	4.2
	4	60-86	42.4	6.4	51.2	0.0	c	0.5	5.1	4.2
	5	86-110	39.2	9.6	51.2	0.0	c	0.4	5.1	4.1
	6	110-160	42.4	6.4	51.2	0.0	c	0.3	5.2	4.2

Appendix B2. Extractable acidity, bases, CEC and BSP in experimental sites

Site	Depth	Acidity (cmol kg^{-1})			Exchangeable bases				CEC (cmolkg^{-1})			Base saturation	
		$BaCl_2$-TEA	1 *N* KCl Al	H	cmol kg^{-1} Ca	Mg	K	Na	Sum of Cations	Ammo. acetate	ECEC	percentage NH_4AoC	sum
1	0-12	12.9	0.87	0.63	0.14	0.06	0.08	0.14	14.8	6.7	1.3	6.2	2.8
	12-36	12.7	0.87	0,63	0.44	0.32	0.16	0.16	15.3	6.9	1.9	15.6	7.0
	36-60	13.5	0.92	0.70	0.20	0.12	0.11	0.12	15.7	7.0	1.5	7.8	3.5
	60-76	15.2	1.12	0.94	0.42	0.30	0.10	0.16	18.2	8.0	2.1	12.2	5.3
	76-98	13.2	0.92	0.70	0.45	0.40	0.09	0.16	15.9	7.1	2.0	15.4	6.9
	98-127	12.0	0.87	0.63	0.46	0.35	0.10	0.23	14.6	6.7	2.0	17.1	7.8
	127+	11.7	0.77	0.51	0.50	0.39	0.06	0.16	14.1	6.5	1.9	17.2	7.9
2	0-18	10.3	0.62	0.33	0.43	0.34	0.05	0.15	12.2	5.8	1.6	16.7	7.9
	18-40	11.2	0.72	0.45	0.25	0.13	0.30	0.16	13.2	6.1	1.6	13.6	6.3
	40-64	12.5	0.82	0.57	0.36	0.17	0.17	0.12	14.7	6.7	1.6	12.3	5.6
	64-100	10.1	0.62	0.33	0.59	0.22	0.14	0.17	12.2	5.8	1.7	19.4	9.2
3	0-15	9.3	0.52	0.21	0.73	0.37	0.17	0.15	11.4	5.5	1.9	25.9	12.4
	15-33	10.9	0.67	0.39	0.68	0.34	0.26	0.14	13.4	6.2	2.1	22.9	10.6
	33-51	10.5	0.67	0.39	0.66	0.28	0.24	0.17	13.0	6.0	2.0	22.5	10.5
	51-85	11.8	0.77	0.51	0.81	0.39	0.16	0.15	14.6	6.6	2.3	22.7	10.3
	85-110	13.1	0.92	0.70	0.97	0.53	0.13	0.17	16.5	7.4	2.7	24.3	10.8
4	0-18	11.5	0.72	0.45	0.85	0.68	0.13	0.12	14.5	6.6	2.5	27.0	12.3
	18-41	11.9	0.82	0.57	0.96	0.66	0.11	0.19	15.2	6.9	2.7	28.1	12.7
	41-56	11.4	0.77	0.51	1.02	0.69	0.11	0.19	14.7	6.7	2.8	30.1	13.7
	56-79	10.2	0.67	0.39	1.37	2.26	0.11	0.21	15.2	6.9	4.6	57.3	25.9
	79-110	9.0	0.57	0.27	1.44	1.89	0.12	0.23	13.5	6.2	4.3	59.1	27.3
	110-125	8.0	0.48	0.15	1.59	1.12	0.13	0.23	11.7	5.6	3.6	55.3	26.4
5	0-22	9.9	0.62	0.33	1.77	2.93	0.47	0.19	16.2	7.2	6.0	74.1	33.1
	22-45	10.8	0.67	0.39	1.10	1.73	0.37	0.15	15.2	6.9	4.0	48.7	22.0
	45-61	10.8	0.72	0.45	1.13	1.46	0.32	0.20	15.1	6.8	3.8	45.5	20.6
	61-79	11.2	0.72	0.45	1.09	2.09	0.33	0.16	16.0	7.2	4.4	51.0	22.8
	79-130	8.9	0.52	0.21	1.12	1.11	0.25	0.19	12.3	5.8	3.2	46.1	21.7
6	0-15	10.0	0.62	0.33	1.25	0.69	0.13	0.17	13.2	6.1	2.9	36.5	16.9
	15-28	11.4	0.77	0.51	1.34	1.72	0.22	0.19	16.1	7.2	4.2	48.2	21.5
	28-46	10.4	0.67	0.39	1.63	2.88	0.13	0.19	16.3	7.3	5.5	66.6	29.7
	46-62	9.4	0.57	0.27	1.56	2.82	0.13	0.19	14.9	6.8	5.3	69.4	31.5
	62-90	8.5	0.48	0.15	2.30	3.60	0.12	0.18	15.3	6.9	6.7	89.9	40.5
	90-110	8.4	0.48	0.15	1.51	5.46	0.09	0.19	16.3	7.3	7.7	99.9	44.6

Appendix B2 contd...

Site	Depth	Acidity (cmol kg^{-1})			Exchangeable bases				CEC (cmolkg^{-1})			Base saturation	
		$BaCl_2$-TEA	1 *N* KCl		cmol kg^{-1}				Sum of Cations	Ammo. acetate	ECEC	percentage	
			Al	H	Ca	Mg	K	Na				NH_4AoC	sum
7	0-20	9.0	0.57	0.27	1.07	0.65	0.05	0.23	11.8	5.6	2.6	35.6	16.9
	20-65	9.3	0.52	0.21	0.99	0.24	0.42	0.15	11.8	5.6	2.3	31.9	15.2
	65-116	3.7	-0.32	0.00	0.95	0.18	0.37	0.14	5.0	3.1	1.3	52.6	32.5
	116-150	7.9	0.43	0.09	1.18	0.29	0.34	0.19	10.4	5.1	2.4	39.2	19.2
8	0-15	11.2	0.72	0.45	1.13	0.34	0.30	0.16	14.3	6.5	2.6	29.4	13.5
	15-33	14.0	1.02	0.82	0.41	0.19	0.33	0.17	17.0	7.5	2.1	14.7	6.5
	33-55	14.8	1.07	0.88	0.36	0.21	0.18	0.15	17.6	7.8	2.0	11.7	5.1
	55-72	15.0	1.12	0.94	0.39	0.21	0.17	0.17	18.0	7.9	2.1	12.0	5.3
	72+	13.0	0.87	0.63	0.37	0.22	0.12	0.12	15.4	6.9	1.7	12.0	5.4
9	0-16	6.9	0.28	0.00	0.30	0.28	0.14	0.17	8.1	4.2	1.2	20.9	11.0
	16-40	6.5	0.18	0.00	0.95	0.46	0.30	0.15	8.5	4.4	2.0	42.0	21.7
	40-59	8.0	0.43	0.09	0.74	0.27	0.31	0.17	10.1	5.0	1.9	30.0	14.8
	59+	8.7	0.48	0.15	0.64	0.24	0.26	0.16	10.6	5.2	1.8	25.0	12.2
10	0-21	7.9	0.38	0.03	0.72	0.32	0.47	0.14	9.9	4.9	2.0	33.6	16.7
	21-31	7.0	0.23	0.00	0.88	0.97	0.11	0.13	9.3	4.7	2.3	44.5	22.4
	31-48	5.7	0.13	0.00	1.05	2.22	0.07	0.20	9.4	4.7	3.7	74.7	37.5
	48-65	5.5	0.08	0.00	1.20	2.64	0.09	0.20	9.7	4.8	4.2	85.6	42.7
	65-97	5.5	0.13	0.00	1.14	2.48	0.11	0.23	9.6	4.8	4.1	82.4	41.2
	97-120	5.5	0.13	0.00	1.17	3.32	0.12	0.23	10.5	5.1	5.0	94.6	46.2
11	0-17	7.5	0.43	0.09	1.28	1.61	0.10	0.23	11.2	5.4	3.6	59.7	28.7
	17-36	6.9	0.28	0.00	1.33	2.42	0.08	0.17	11.2	5.4	4.3	74.1	35.7
	36-52	6.5	0.23	0.00	1.21	1.30	0.07	0.18	9.5	4.7	3.0	58.0	29.1
	52-86	6.6	0.23	0.00	1.27	1.58	0.09	0.17	9.9	4.9	3.3	63.4	31.4
	86-112	6.3	0.23	0.00	1.30	1.81	0.10	0.20	10.0	4.9	3.6	69.1	34.2
12	0-16	8.6	0.57	0.27	1.23	2.55	0.20	0.28	13.7	6.3	4.8	67.5	31.1
	16-32	8.5	0.48	0.15	0.74	0.35	0.16	0.17	10.6	5.2	1.9	27.6	13.4
	32-70	9.6	0.57	0.27	1.00	0.53	0.17	0.17	12.4	5.8	2.5	32.3	15.2
	70-94	8.3	0.48	0.15	1.22	0.59	0.12	0.20	11.1	5.3	2.6	39.9	19.3
	94-115	7.8	0.43	0.09	1.31	0.65	0.12	0.20	10.6	5.2	2.7	44.2	21.5
	115-135	7.3	0.38	0.03	1.10	0.97	0.12	0.20	10.1	5.0	2.8	47.9	23.6
13	0-13	10.8	0.67	0.39	0.41	0.30	0.13	0.15	12.8	6.0	1.7	16.4	7.7
	13-33	10.7	0.67	0.39	0.37	0.17	0.07	0.16	12.5	5.9	1.4	13.1	6.1
	33-58	7.9	0.48	0.15	0.80	0.37	0.12	0.24	10.1	5.0	2.0	30.9	15.3
	58-91	9.5	0.57	0.27	0.83	0.63	0.14	0.18	12.1	5.7	2.4	31.1	14.7
	97-120	9.8	0.57	0.27	0.67	0.52	0.14	0.15	12.1	5.7	2.1	25.9	12.2
14	0-15	13.7	0.97	0.76	0.19	0.12	0.10	0.16	16.0	7.2	1.5	7.9	3.5
	15-35	13.4	0.92	0.70	0.12	0.04	0.05	0.13	15.4	6.9	1.3	4.9	2.2
	35-60	12.2	0.82	0.57	0.22	0.15	0.05	0.16	14.2	6.5	1.4	8.9	4.1
	60-86	11.8	0.77	0.51	0.23	0.15	0.06	0.15	13.7	6.3	1.4	9.3	4.3
	86-110	11.8	0.77	0.51	0.20	0.13	0.06	0.15	13.6	6.3	1.3	8.7	4.0
	110-160	11.2	0.72	0.45	0.19	0.09	0.06	0.16	12.9	6.0	1.2	8.3	3.9

Appendix B3. Taxonomy of soils of experimental sites

Site	Taxonomy
1	Clayey, kaolinitic isohyperthermic Ustic Kanhaplohumults
2	Fine loamy, mixed isohyperthermic Ustoxic Dystropepts
3	Clayey, kaolinitic isohyperthermic Typic Kanhaplustults
4	Clayey, kaolinitic isohyperthermic Typic Kanhaplustults
5	Clayey, kaolinitic, isohyperthermic Typic Kanhaplohumults
6	Clayey, kaolinitic, isohyperthermic Typic Kanhaplohumults
7	Clayey, kaolinitic, isohyperthermic Ustic Kandihumults
8	Clayey, kaolinitic isohyperthermic Typic Kanhaplustults
9	Clayey-skeletal, kaolinitic, isohyperthermic Typic Kanhaplustults
10	Fine loamy, mixed, isohyperthermic Typic Kanhaplustults
11	Fine loamy, mixed, isohyperthermic Typic Kanhaplustults
12	Clayey, kaolinitic isohyperthermic Typic Kanhaplustults
13	Clayey-skeletal, kaolinitic, isohyperthermic Typic Kanhaplustults
14	Clayey, kaolinitic, isohyerthermic Typic Kandiustults

Appendix B4. Physical properties of soils of experimental sites

Site	Sand (%)	Silt (%)	Clay (%)	Gravel (%)	FC (%)
1	56.8	11.2	32	32.3	25.4
2	60	9.6	30.4	16.4	20.4
3	53.6	9.6	36.8	32.4	21.1
4	52	8	40	22.4	27.3
5	44	9.6	46.4	25	22.7
6	44	12.8	43.2	16.9	27.5
7	60	12.8	27.2	4.7	28.8
8	47.2	9.6	43.2	19	18.7
9	61.6	8	30.4	24.5	18.9
10	55.2	12.8	32	9	20.4
11	52	11.2	36.8	7.4	17
12	47.2	8	44.8	22.4	20.5
13	53.6	8	38.4	24	19.1
14	52	6.4	41.6	0	18

Appendix B5. Fertility capability classification of experimental sites

Sl. No	FCC unit	Description
1	Cdiaek	Clayey surface and subsurface; dry soil moisture regime; P fixation is a problem; excess Al; low CEC and deficient in K
2	Ldae	Loamy surface and subsurface; dry soil moisture regime; excess Al and low CEC
3	Cdae	Clayey surface and subsurface; dry soil moisture regime; excess Al with low CEC
4	Cdihek	Clayey surface and subsurface; dry soil moisture regime; P fixation is a problem; acidic soils; low CEC and K deficient
5	Cdhek	Clayey surface and subsurface; dry soil moisture regime; acidic soils; low CEC and deficient in K
6	Cdihe	Clayey surface and subsurface; dry soil moisture regime; P fixation is a problem; acidic soils with low CEC
7	Sdhek	Sandy surface and subsurface; dry soil moisture regime; acidic soils; low CEC with K deficiency
8	Cdihek	Clayey surface and subsurface; dry soil moisture regime; P fixation is a problem; acidic soils; low CEC and K deficient
9	Ldhekm	Loamy surface and subsurface; dry soil moisture regime; acidic soils; low CEC with deficiency of K and Mg
10	Ldhekm	Loamy surface and subsurface; dry soil moisture regime; acidic soils; low CEC with deficiency of K and Mg
11	Cdihek	Clayey surface and subsurface; dry soil moisture regime; P fixation is a problem; acidic soils; low CEC and K deficient
12	Cdihekm	Clayey surface and subsurface; dry soil moisture regime; P fixations is a problem; acidic soils; low CEC with deficiency of K and Mg
13	Cdihekm	Clayey surface and subsurface; dry soil moisture regime; P fixations is a problem; acidic soils; low CEC with deficiency of K and Mg
14	Cdihekm	Clayey surface and subsurface; dry soil moisture regime; P fixations is a problem; acidic soils; low CEC with deficiency of K and Mg

Appendix C. Paired t-test between pH at different times of observations

Variable	No. of pairs	r	2- tail sig	t-value	df	2- tail Sig
pH (Nov 96) pH (Jan 97)	28	0.71	0.000	-0.46	27	0.649
pH (Jan 97) pH (Mar 97)	28	0.861	0.000	0.7	27	0.491
pH (Mar 97) pH (May 97)	28	0.795	0.000	0.24	27	0.815
pH (May 97) pH (Jul 97)	28	0.638	0.000	-0.45	27	0.657
pH (Jul 97) pH (Sep 97)	28	0.19	0.333	0.21	27	0.832

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Total N

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.31	14	14	0.02	
Site	0.24	13	13	0.02	0.618

Site by Total N

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	3.66259	2.94924	65	70	0.000
Hotellings	106.66224	13.78404	65	42	0.000
Wilks	0.00003	6.50178	65	51.2	0.000
Roys	0.98690				

Total N

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.96447	54.29627	5	10	0.000
Hotellings	27.14814	54.29627	5	10	0.000
Wilks	0.03553	54.29627	5	10	0.000
Roys	0.96447				

Tests involving Total N within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual		70			
Total N		5			
Site by Total N		65			

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Organic carbon

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.06	14	0		
Site	18.28	13	1.41	352.41	0.000

Site by Organic carbon

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.79816	25.60096	65	70	0.000
Hotellings	722.86973	93.41701	65	42	0.000
Wilks	0.00000	57.92982	65	51.2	0.000
Roys	0.99787				

Organic carbon

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.99862	1447.92	5	10	0.000
Hotellings	723.96004	1447.92	5	10	0.000
Wilks	0.00138	1447.92	5	10	0.000
Roys	0.99862				

Tests involving Organic carbon within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.13	70	0		
Organic carbon	4.12	5	0.82	444.27	0.000
Site by Organic carbon	6.44	65	0.1	53.49	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Available P

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.03	14	0		
Site	516.94	13	39.76	18479.73	0.000

Site by Available PCa

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.95421	116.5291	65	70	0.000
Hotellings	11523.92060	1489.245	65	42	0.000
Wilks	0.00000	662.0775	65	51.2	0.000
Roys	0.99988				

Available P

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.99971	6974.836	5	10	0.000
Hotellings	3487.41805	6974.836	5	10	0.000
Wilks	0.00029	6974.836	5	10	0.000
Roys	0.99971				

Tests involving Available P within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.22	70	0		
Available PCa	116.46	5	23.29	7410.16	0.000
Site by Avialbale PCa	385.82	65	5.94	1888.43	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Calcium

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.13	14	0.1		
Site	82.71	13	6.36	670.75	0.000

Site by Ca

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.77943	23.33542	65	72	0.000
Hotellings	417.8153	53.99459	65	42	0.000
Wilks	0.00000	38.95561	65	51.2	0.000
Roys	0.99656				

Ca

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	0.97415	75.36177	5	10	0.000
Hotellings	37.68089	75.36177	5	10	0.000
Wilks	0.02585	75.36177	5	10	0.000
Roys	0.97415				

Tests involving Ca within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.34	70	0		
Ca	0.56	5	0.11	23.23	0.000
Site by Ca	17.74	65	0.27	57.02	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Magnesium

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.5	14	0		
Site	28.51	13	2.19	559.57	0.000

Site by Mg

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.43982	8.53529	65	70	0.000
Hotellings	306.0209	39.54732	65	42	0.000
Wilks	0.00000	18.26756	65	51.2	0.000
Roys	0.99591				

Mg

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.93912	30.8537	5	10	0.000
Hotellings	15.42685	30.8537	5	10	0.000
Wilks	0.06088	30.8537	5	10	0.000
Roys	0.93912				

Tests involving Mg within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.27	70	0		
Mg	0.4	5	0.08	20.7	0.000
Site by Mg	3.54	65	0.05	14.18	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Potassium

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0	14 o			
Site	2.18	13	0.17	1498.75	0.000

Site by K

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.95686	123.7502	65	70	0.000
Hotellings	2136.64113	276.1198	65	42	0.000
Wilks	0.00000	244.1991	65	51.2	0.000
Roys	0.99921				

K

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.99689	640.8736	5	10	
Hotellings	320.43681	640.8736	5	10	
Wilks	0.00311	640.8736	5	10	
Roys	0.99689				

Tests involving K within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.01	70	0		
K	0.27	5	0.05	639.53	0.000
Site by K+A17	1.26	65	0.02	231.34	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Sodium

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0	14	0		
Site	0.05	13	0	18.92	0.000

Site by Na

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	3.44165	2.37842	65	70	0.000
Hotellings	17.92930	2.37842	65	42	0.002
Wilks	0.00115	2.37842	65	51.2	0.000
Roys	0.88845				

Na

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.84767	11.12933	5	10	0.001
Hotellings	5.56466	11.12933	5	10	0.001
Wilks	0.15233	11.12933	5	10	0.001
Roys	0.54767				

Tests involving Na within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.01	70	0		
Na	0.01	5	0	11.72	0.000
Site by Na	0.03	65	0	3.1	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Manganese

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.06	14	0		
Site	9.87	13	0.76	189.34	0.000

Site by Mn

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	4.03018	4.47526	65	70	0.000
Hotellings	330.33599	42.68957	65	42	0.000
Wilks	0.00000	12.73358	65	51.2	0.000
Roys	0.99658				

Mn

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.99181	242.3007	5	10	0.000
Hotellings	121.15033	242.3007	5	10	0.000
Wilks	0.00819	242.3007	5	10	0.000
Roys	0.99181				

Tests involving Mn within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.42	70	0.01		
Mn	1.63	5	0.33	53.89	0.000
Site by Mn	5.5	65	13.99	13.99	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Iron

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.14	14	0.01		
Site	3.92	13	0.3	30.27	0.000

Site by Fe

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	3.59439	2.75389	65	70	0.000
Hotellings	90.46542	11.69092	65	42	0.000
Wilks	0.00003	6.53498	65	51.2	0.000
Roys	0.98286				

Fe

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.97607	81.58127	5	10	0.000
Hotellings	40.79064	81.58127	5	10	0.000
Wilks	0.02393	81.58127	5	10	0.000
Roys	0.97607				

Tests involving Fe within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.39	70	0.01		
Fe	0.53	5	0.11	18.77	0.000
Site by Fe	0.98	65	0.02	2.69	0.000

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Copper

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.15	14	0.01		
Site	0.15	13	0.01	0.13	0.409

Site by Copper

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	2.34368	0.95017	65	70	0.582
Hotellings	6.83908	0.88382	65	42	0.678
Wilks	0.02558	0.92338	65	51.2	0.622
Roys	0.79939				

Cu

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.59750	2.96895	5	10	0.067
Hotellings	1.48447	2.96895	5	10	0.067
Wilks	0.40250	2.96895	5	10	0.067
Roys	0.59750				

Tests involving Cu within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0.05	70	0		
Cu	0.01	5	0	2.19	0.065
Site by Cu	0.05	65	0	0.95	0.576

Appendix D. ANOVA of repeated measures;

Tests of Between-subjects effects- Zinc

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual	0	14	0		
Site	0	13	0	0.82	0.641

Site by Zn

Test Name	Value	Approx. F	Hypoth.DF	Error DF	Sig of F
Pillais	3.63484	2.86739	65	70	0.000
Hotellings	43.50997	5.62283	65	42	0.000
Wilks	0.00012	4.54493	65	51.2	0.000
Roys	0.95740				

Zn

Test Name	Value	Approx. F	Hypoth. F	Error DF	Sig of F
Pillais	0.85569	11.85945	5	10	
Hotellings	5.92973	11.85945	5	10	0.021
Wilks	0.14431	11.85945	5	10	0.577
Roys	0.85569				

Tests involving Zn within-subject effect

Source of variation	SS	DF	MS	F value	Sig of F
Within + residual		70			
Zn		5			
Site by Zn		65			

Appendix E. Weather data of Vellanikkara during the study period

	Nov-96	Dec-96	Jan-97	Feb-97	Mar-97	Apr-97	May-97	Jun-97	Jul-97	Aug-97	Sep-97
Rainfall (mm)	23.1	60.8	0	0	0	8.2	63	720.5	979.2	636.8	164
Max temp (°C)	31.5	30.5	32	33.9	35.7	35.2	34.4	31.2	28.6	29	30.6
Min temp (°C)	23.6	21.8	22.9	21.8	24	24.5	24.5	23	21.8	22.8	23.4

Appendix F1. Factor analysis of November 96 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.93995	*	1	4.87639	44.3	44.3
Av.P	.72798	*	2	1.70403	15.5	59.8
Ca	.90040	*	3	1.34942	12.3	72.1
Fe	.88173	*	4	1.23246	11.2	83.3
K	.93524	*				
Mg	.91239	*				
Mn	.67704	*				
Na	.89348	*				
OC	.93668	*				
pH	.73963	*				
Zn	.61778	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3	Factor 4
Al	-.49259	-.81987	-.15111	.04771
Av.P	-.26198	-.67320	-.32460	.31745
Ca	.71695	.46573	.40880	-.04860
Fe	-.17807	-.09008	-.00307	.91755
K	.71243	-.11385	.54237	-.34723
Mg	.83559	.44153	-.08982	-.10565
Mn	.09084	.77762	-.17522	.18272
Na	.89746	.23173	-.18505	-.00982
OC	-.04959	.01701	.96052	.10644
pH	.10580	.84798	-.01186	-.09608
Zn	-.53841	-.05704	-.18816	-.53781

Appendix F2. Regression analysis of factor scores and growth during November 96

Multiple R	.70129
R Square	.49181
Adjusted R Square	.44946
Standard Error	.01456

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	.00246	.00246
Residual	12	.00254	.00021

F = 11.61310 Signif F = .0052

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
FACTOR 2	-.013762	.004039	-.701290	-3.408	.0052
(Constant)	.074571	.003892		19.162	.0000

Appendix G1. Factor analysis of January 97 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.83029	*	1	5.03622	45.8	45.8
Av.P	.90195	*	2	2.05030	18.6	64.4
Ca	.94741	*	3	1.65957	15.1	79.5
Fe	.78893	*				
K	.78825	*				
Mg	.96474	*				
Mn	.67668	*				
Na	.75114	*				
OC	.66756	*				
pH	.63539	*				
Zn	.79375	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3
Al	-.87263	.24532	-.09289
Av.P	-.31092	.89436	.07348
Ca	.97310	.01183	.01856
Fe	-.11376	.19193	.85974
K	.61299	.10152	-.63419
Mg	.94783	-.24425	-.08191
Mn	.27024	-.65511	.41770
Na	.85040	-.07215	.15086
OC	.17046	.79340	.09494
pH	.79065	.00170	-.10128
Zn	.47645	-.22907	.71713

Appendix G2. Regression analysis of factor scores and growth during January 97

Multiple R	.57910
R Square	.33535
Adjusted R Square	.13596
Standard Error	.02312

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	.00270	.00090
Residual	10	.00534	.00053

F = 1.68187 Signif F = .2333

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
FACTOR 1	-.009980	.006411	-.401313	-1.557	.1506
FACTOR 2	.010322	.006411	.415070	1.610	.1385
FACTOR 3	-.001117	.006411	-.044936	-.174	.8651
(Constant)	.088589	.006178		14.340	.0000

Appendix H1. Factor analysis of March 97 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.89268	*	1	4.58357	41.7	41.7
Av.P	.88307	*	2	2.45046	22.3	63.9
Ca	.93088	*	3	1.52900	13.9	77.8
Fe	.90562	*	4	1.01617	9.2	87.1
K	.84409	*				
Mg	.92577	*				
Mn	.96758	*				
Na	.77061	*				
OC	.85322	*				
pH	.81856	*				
Zn	.78711	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3	Factor 4
Al	-.93674	.09253	-.08103	-.00819
Av.P	-.17435	.71334	.48894	.32365
Ca	.90318	-.01863	.18803	-.28186
Fe	-.05575	-.03205	.01020	.94941
K	.25539	.76405	.20128	-.39316
Mg	.87856	.00363	-.13708	-.36755
Mn	.30615	-.92599	.12588	-.02358
Na	.85901	-.12713	.07574	.10402
OC	-.09170	.27447	.87496	-.06263
pH	.90000	-.06458	.04656	.04717
Zn	.31982	-.11787	.81803	.04187

Appendix H2. Regression analysis of factor scores and growth during March 97

Multiple R	.81871
R Square	.67028
Adjusted R Square	.52374
Standard Error	.01976

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	.00714	.00179
Residual	9	.00351	.00039

F = 4.57396 Signif F = .0273

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
FACTOR 1	-.009126	.005479	-.318782	-1.665	.1302
FACTOR 2	.014967	.005479	.522813	2.731	.0232
FACTOR 3	.012894	.005479	.450404	2.353	.0431
FACTOR 4	.008705	.005479	.304073	1.589	.1466
(Constant)	.094732	.005280		17.941	.0000

Appendix I1. Factor analysis of May 97 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.88291	*	1	4.55053	41.4	41.4
Av.P	.86951	*	2	1.95824	17.8	59.2
Ca	.90142	*	3	1.74818	15.9	75.1
Fe	.82636	*	4	1.00297	9.1	84.2
K	.82068	*				
Mg	.91493	*				
Mn	.74895	*				
Na	.71377	*				
OC	.93619	*				
pH	.84260	*				
Zn	.80262	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3	Factor 4
Al	-.90731	-.03770	-.02158	.24045
Av.P	-.68079	.60144	.11812	.17423
Ca	.93086	.16039	-.09553	-.00811
Fe	-.16815	.14417	.88156	-.01200
K	.25146	.86460	.02373	.09673
Mg	.92685	.01936	-.03200	-.23342
Mn	.65381	-.40064	.35480	.18731
Na	.75120	.37716	-.07226	-.04465
OC	-.07043	.36970	.18148	.87271
pH	.46098	.40718	-.03454	-.68052
Zn	.09179	-.09663	.86831	.17575

Appendix I2. Regression analysis of factor scores and growth during May 97

Multiple R	.78453
R Square	.61549
Adjusted R Square	.44460
Standard Error	.02642

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	.01006	.00251
Residual	9	.00628	.00070

F = 3.60159 Signif F = .0511

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
FACTOR 1	-.020663	.007328	-.582814	-2.820	.0201
FACTOR 2	.018212	.007328	.513679	2.485	.0347
FACTOR 3	.003646	.007328	.102837	.498	.6307
FACTOR 4	-.001315	.007328	-.037094	-.179	.8616
(Constant)	.104857	.007062		14.849	.0000

Appendix J1. Factor analysis of July 97 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.78959	*	1	4.84800	44.1	44.1
Av.P	.81276	*	2	2.78403	25.3	69.4
Ca	.91298	*	3	1.05583	9.6	79.0
Fe	.80279	*				
K	.60757	*				
Mg	.89995	*				
Mn	.86095	*				
Na	.79170	*				
OC	.55686	*				
pH	.77627	*				
Zn	.87645	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3
Al	-.88459	.04931	.06824
Av.P	.12704	.54178	.70930
Ca	.89389	-.19660	.27440
Fe	-.16665	.85529	.20856
K	.77561	.05594	-.05352
Mg	.87824	-.19150	-.30327
Mn	-.12974	.91494	-.08367
Na	.74094	-.27609	.40802
OC	.01029	.09504	.74008
pH	.85255	-.18226	.12733
Zn	-.19452	.80060	.44457

Appendix J2. Regression analysis of factor scores and growth during July 97

Multiple R	.55921
R Square	.31272
Adjusted R Square	.25544
Standard Error	.03713

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	.00753	.00753
Residual	12	.01654	.00138

F = 5.46002 Signif F = .0376

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
FAC3_1	.024062	.010298	.559210	2.337	.0376
(Constant)	.128768	.009923		12.977	.0000

Appendix K1. Factor analysis of September 97 data

Variable	Communality	*	Factor	Eigenvalue	Pct of Var	Cum Pct
		*				
Al	.91736	*	1	4.95295	45.0	45.0
Av.P	.84340	*	2	2.42191	22.0	67.0
Ca	.89897	*	3	1.79868	16.4	83.4
Fe	.81793	*				
K	.83783	*				
Mg	.90001	*				
Mn	.82840	*				
Na	.77032	*				
OC	.59924	*				
pH	.88447	*				
Zn	.87561	*				

Rotated Factor Matrix:

	Factor 1	Factor 2	Factor 3
Al	-.95711	-.00287	.03596
Av.P	-.65754	.24852	.59100
Ca	.90486	.06738	.27505
Fe	-.29900	.85333	.01891
K	.31324	-.16283	.84451
Mg	.93751	-.11361	.09041
Mn	.57520	.70533	.00766
Na	.68286	-.10020	.54220
OC	-.13546	.22975	.72671
pH	.91996	-.08396	-.17635
Zn	-.02564	.93022	.09824

Appendix K2. Regression analysis of factor scores and growth during September 97

Multiple R	.47673
R Square	.22727
Adjusted R Square	-.00455
Standard Error	.04502

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	.00596	.00199
Residual	10	.02027	.00203

F = .98036 Signif F = .4404

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
FAC1_1	-.019995	.012487	-.445140	-1.601	.1404
FAC2_1	-.007585	.012487	-.168849	-.607	.5571
FAC3_1	-.001107	.012487	-.024655	-.089	.9311
(Constant)	.165571	.012033		13.760	.0000

PRODUCTIVITY CLASSIFICATION OF SOILS UNDER RUBBER (*Hevea brasiliensis* Muell. Arg.) IN KERALA

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A project titled "Productivity classification of soils under rubber (*Hevea brasiliensis* Muell. Arg.) in Kerala was taken up in the College of Horticulture, Vellanikkara during 1996–1997. The objectives of the study were; (1). To study the soil taxonomy of selected prominent soils under rubber in Kerala, (2). To classify the soils according to the norms of fertility capability classification, (3). To attempt an introduction of local modifiers into the FCC based on specific crop requirements of rubber plant, (4). To group the soils by numerical classification technique using important soil properties, (5). To test the direct and indirect effects of relevant soil factors on the growth of hevea and (6). To identify the spectral signature of rubber using multiband satellite imagery. The entire study was conveniently divided into four experiments.

In the first experiment, six prominent physiographic units, present in Wayanad, Malappuram, Thrissur, Kottayam and Pathanamthitta districts were selected for the study. In each physiographic unit, three soil profiles were cut one each from the top, middle and bottom of the catena of a hill to ascertain the impact of the slope on the soil properties. Soils were characterised and classified according to the norms of soil taxonomy.

In the second experiment, the soils from the above soil profile were characterised for fertility capability classification. An attempt was made to introduce a local modifier 'm' to denote the status of available Mg, using 0.08 cmol kg^{-1} in the FC classes identified. In this experiment the soils studied for taxonomic classification were subjected to numerical classification using Euclidean distance measure.

In the third experiment 14 sites in Thrissur district were selected for studying the soil-plant relationships. Soil samples were collected at bimonthly intervals between November 96 and September 97 to understand the influence of weather on the availability of nutrients. Plant girth and height were recorded simultaneously while collecting soil samples. Soils were analysed pH, organic carbon, total nitrogen, exchangeable Ca, Mg, K, Na, Al and DTPA extractable Fe, Mn, Cu and Zn. An attempt was made to relate the dynamics of nutrient availability to the plant growth.

In the fourth experiment, two rubber estate areas, one in Thrissur and the other in Kottayam districts were selected for studying the spectral signature of rubber. Satellite data pertaining to different dates were procured studying temporal variations in reflectance. The reflectance of rubber along with teak and mixed forest was studied in individual bands, false colour composite and normalised difference vegetation index images. A supervised classification was performed in the images of both the study areas.

The soil taxonomy indicated that the soils of all the reaches in the selected physiographic units belong to Ustic Kandihumults, Ustic Kanhaplohumults, Typic Kandiustults, Ustoxic Dystropepts, Typic Kanhaplustults. Careful observation of the taxonomy of soils indicated that there are differences in soil properties caused by the topography resulting into a catenary sequence of soil development. However, in some physiographic units, there were no differences in the taxonomic position

among the reaches though there were known differences in certain soil properties, which might have been caused by the slope. The threshold values used for soil taxonomic classification were such that the soils with intragroup distance were not subdivided further into similar taxonomic position in all the three reaches.

There were differences among reaches of slope and physiographic units with reference to fertility capability classification. The differences in FCC of the same physiographic units might be mainly due to differences in topography in addition to other local variations. Among physiographic units however, both similarities and differences were observed. The similarities might be due to the fact that many of the condition modifiers were measured only in the surface soil and similarities in these properties cluster the soils into one group, though inherently there could be differences in several other features. The differences might be due to variations in slope, parent material or any other feature, which could influence the composition of surface soils. Inclusion of a condition modifier, 'm' could identify three FC classes with deficiency in available Mg.

In numerical classification of soils it was seen that all soils belonging to Ustic Kanhaplohumults were grouped with some members, however, forming individual clusters because of intragroup distance. Different soil taxa viz. Typic Kanhaplustults, Typic Kandihumults and Ustoxic Dystropepts formed individual clusters. However, Typic Kandihumults were merged to the cluster of Ustic Kanhaplohumults which might be because of weighted averaging of soil properties in A and B horizons. It is seen that similar taxa were grouped differently in numerical taxonomy because of the quantitative differences in soil properties within the same taxon, where in soil taxonomy certain fixed values of the attributes are used to classify the soils.

The data on soil variables measured in different experimental sites at different times of observations indicated clearly that sites varied in soil properties. Similarly there were seasonal changes in soil properties from time to time. Seasonal changes in plant growth were seen in all the experimental sites. Different rates of growth in the experimental sites were noticed in response to changes in weather from a dry season to a wet season, which also manifested in differential availability of nutrient elements.

The factor analysis of the data on soil variables measured at different times of observation identified two important factors i.e. 'Soil Reaction Control Factor' and 'P Limitation Factor' which explained much of the variability in the data on soil properties. The regression analysis identified that the growth was associated with 'P Limitation Factor'. It is understood that the soil temperature and soil moisture were the most important parameters regulating the availability of elements particularly that of P and K. The limitation posed by reduced soil moisture, increasing temperature and DTPA-Mn on the availability of P was realised. Factor analysis also highlighted the role of K and Zn in the growth .

The effects of various soil properties on growth performance were disentangled into direct and indirect effects in the path analysis. It was observed in general that the path model could explain variability in plant growth to a sufficiently larger extent emphasizing the role of soil parameters and also highlighting the interaction effects on plant growth.

While attempting to test the agronomic utility of soil taxonomy and fertility capability classification, it could be noticed that the soil taxonomy could give a general order of ranking based on plant growth among different taxa. However, it was also noticed that same taxon was ranked low in some experimental sites calling for attention while interpreting the agronomic utility of soil taxonomy. It was seen earlier that the 'Soil Reaction Control Factor' and 'P Limitation Factor' influenced the growth performance of rubber plants. Soil taxonomy, however, did not contain any information about the local variations in these 'factors' and thus could not explain the variations in plant performance within the same taxon.

Discrepancies were found while studying the agronomic utility of the FCC concept also. Soils deficient in available K and Mg besides other known limitations were ranked high. It is felt that efforts should be on to include not only the limited soil variables but also the variables which limit the availability of the nutrient elements, to make the FCC system more meaningful.

It was clear from the study of spectral signatures that rubber could easily be separated from other vegetation types owing to its specific spectral behaviour particularly in band 4 (0.77 – 0.86 μm). It was also seen that studies on temporal changes in spectral behaviour of rubber might help in separating it from teak as well as mixed forest. It could be drawn from the data that mean reflectance of above 60 per cent in band 4 might indicate the vegetative cover of rubber. Similarly, the image pertaining to the period when complete canopy is developed would help in delineating rubber from teak and mixed forest in these study areas.