GEOSPATIAL ANALYSIS AND SOIL NUTRIENT DYNAMICS OF RUBBER PLANTATIONS IN RELATION TO GROWING ENVIRONMENT

by

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(2009-21-105)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University, Thrissur

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KERALA, INDIA

2013

DECLARATION

I hereby declare that this thesis entitled "**Geospatial analysis and soil nutrient dynamics of rubber plantations in relation to growing environment**" is a bonafide record of research work done independently by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Geospatial analysis and soil nutrient dynamics of rubber plantations in relation to growing environment"** is a record of research work done independently by Mr. Shankar Meti (2009-21-105) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ACKNOWLEDGEMENT

First of all I admit the unbound love and blessings of god which is the prime factor that led to the successful completion of work.

I have ebullient and intense pleasure in expressing my heartfelt thankfulness to the chairperson of the advisory committee Dr. Meerabai, M. Professor, Department of Agronomy for her valuable guidance, kind treatment, whole hearted technical help, constructive and timely advice and constant encouragement rendered me in successful completion of this thesis work.

My heartfelt thanks are due to Dr. Geethakumari, V.L. Professor and Head, Department of Agronomy, for her timely support, co-operation rendered throughout the course of this research endeavour.

I am greatly thankful to Dr. James Jacob, Director of Research, RRII and member of Advisory committee, for his keen interst, immense help and constructive suggestion, timely support and co-operation rendered throughout the course of this research Endeavour.

My heartfelt thank to Dr. N. Saifudeen, Professor and Head and member of advisory committee, for keen interest, whole hearted help and valuable guidance rendered to me during the course of research work.

I have great pleasure in recording thanks to Dr. Vijayaraghavakumar, Professor and head, Department of Agricultural statistics, and member of advisory committee, for his expert opinion, valuable suggestion about the statistical analysis, *interpretation, and presentation of data as well as critical scrutiny of manuscript.*

I wish to express my sincere gratitude to Dr, M. Abdul Salam, Former Professor and Head, Department of Agronomy and present Vice Chancellor of University of Calicut, Kozhicode, for his valuable suggestion, encouragement and kind help in formulating research work.

I am greatly thankful to all the farmers and estate managers in Kanyakumari, Kasargod and Kottayam districts for their co-operation and help extended to me during sample collection and recording observations. My special thanks to Mr. Pradeep, Mr. Rajasekhar, Mr. Kumaran, Mr. Jose, Mr. Thomas, Mr. Baletan, and Mr. Velappan for providing local support and help during field work.

I express my sincere thanks to my beloved teachers of Department of Agronomy, Dr. R. Pushpakumari, Dr. K.R.Sheela, Dr. Sansamma George, Dr. P. Shalini Pillai, Dr. S. Chandini, Dr. O. Kumari Swadija, Shri. Jayakrishnakumar, Dr. S. Lakshmi, and Dr. Shahul Hameed for their expert teachings, whole hearted cooperation and help. I also express my sincere thanks to teachers of Department of Crop Physiology Dr. Roy Stephan and Dr. R. Manju and teachers of Department of Soil Science and agricultural chemistry Dr. P.B. Usha, Dr. Sudharmai Devi and Dr. Suman George for their valuable teaching and help.

I express my sincere gratitude to Deputy RPC's, Development officers, and Filed officers of Kanyakumari, Kasargod and Kottayam district for their help in identifying the small holdings. My special thanks to Mr. Anilkumar Field Officer, Kasargod for his local help and support extended during sample collection.

I express my sincere thanks to Dr. Jessy, M.D. Deputy Director, Agronomy/Soils Division, RRII, Rubber Board for her constructive help, cooperation and suggestion rendered during my laboratory analysis work at RRII. My sincere thanks to all scientist, technical staff and trainee particularly Ms Sreeja for extending full help and cooperation in timely completion of chemical analysis of samples. My heartfelt thanks to Mr. Pradeep, B. Junior Research Fellow, Agronomy/Soil division for his timely help in remote sensing and GIS work.

I am extremely thankful to Mr. Jhony, driver of RRII, for his valuable help in timely payment and getting admission for PhD.

I am deeply indebted to my father , mother and sisters for being a source of inspiration and for their constant encouragement, patience and sacrifice without which I would not have completed this endeavor. No words ever would entirely express my fervent indebtedness to my sisters for their help, love and support to pursue this Endeavour to complete.

I express my sincere thanks to chairman, Rubber Board for granting me study leave to perceive the endeavor to compete. I also thank Director of Research, RRII for the institutional support and help in successful completion of research work.

I wish to express my love, affection and indebtedness to my wife Mrs. Tanuja, Son Mr. Vishal and daughter Ms. Smitha for their support, sacrifice during this Endeavour.

Lastly but with utmost fullness of heart, let me humbly bow my head before the lotus feet of my beloved Goddess Saraswathi, my guru the almighty who provided me the strength, zealots to fulfill the task in satisfactory manner.

Vellayani

18-04-2013

Shankar Meti

DEDICATED TO MY BELOVED

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LIST OF ABBREVIATIONS

%	Per cent
m	Meter
cm	Centimeter
g	Gram
kg	Kilogram
^0C	Centigrade
M	Molar
N	Normal
g/cc	Gram per cubic meter
mm/m	Millimeter per meter
AWC	Available water content
FC	Field capacity
WP	Wilting point
MPa	Mega pascal
MAI	Moisture adequacy index
AET	Actual evapotranspiration
ET	Evapotranspiration
PET	Potential evapotranspiration
RF	Rainfall
TRMM	Tropical Rainfall Monitoring Mission
OC	Organic Carbon
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
Al	Aluminium

LIST OF ABBREVIATIONS CONTD....

NO_3	Nitrate
NH_4	Ammonium
Exch. Al	Exchangeable aluminium
Av.	Available
Avg.	Average
BD	Bulk density
CEC	Cation exchange capacity
cmol	Centimol
mg/kg	Milligram per kilogram
ha	Hectare
GI	Girth increment
TPD	Tapping Panel Dryness
g/t/t	Gram per tree per tap
CER	Certified Emission Reduction
meq	Mili equivalent
Ann.	Annual
SMU	Soil Management Unit
S.D	Standard deviation
S.Em	Standard error of mean
ANOVA	Analysis of variance
r	Correlation coefficient
DRIS	Diagnosis and Recommendation Integrated System
µm	Micromole
t/ha	Tons per hectare
T_{max}	Maximum temperature
T_{min}	Minimum temperature
i e	That is
et al	And others

LIST OF ABBREVIATIONS CONTD....

^0N	Degree North
^0E	Degree East
GPS	Global positioning system
GIS	Geographical information system
IRS	Indian remote sensing
DEM	Digital elevation model
NIR	Near infrared
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
LISS	Linear imaging and self-scanning sensor
NRE	Nutrient Resorption efficiency
CDM	Clean Development Mechanism

INTRODUCTION

1. INTRODUCTION

Para rubber (*Hevea brasiliensis* Muell. Arg.), indigenous to tropical rain forest of central and South America was introduced into India in 1873. The genus *Hevea* is a member of the *Euphorbiaceae* family which comprises10 species, of which the Para rubber tree, *Hevea brasiliensis*, is the only one commercially planted (Webster and Paardekooper, 1989). It is the major source of global natural rubber (NR). Natural Rubber is native to Amazon rainforest, situated within 5^0latitude at altitude below 200m. Natural rubber is predominantly grown in tropics between 10^0S and 8^0N latitude where equatorial monsoon prevails.

Due to unique properties of elasticity, toughness, impermeability and non-conductivity, rubber is being used in more than 50,000 products and articles of everyday use. Wide range of products, ranging from hoses to auto tyres and pharmaceutical goods are manufactured from natural rubber. Manufactured goods covers hi-tech industrial, defense, aeronautics items also.

Major NR producing countries in the world are Thailand, Indonesia, Malaysia and India. With the saturation of NR consumption in the Western countries, Asia is now the focus of growth in rubber industry. In India major portion of NR area is confined to West coast extending from Kanyakumari district of Tamil Nadu (TN) in the South to Coorg district of Karnataka in the North. Natural rubber plays a major role in Indian economy. At present there are about 4356 manufacturing units and average daily employment in rubber plantation is 4,64000 man days (Indian Rubber Statistics, 2011). Value of rubber product exported during 2010-11 was 7926.66 crore. Global NR production is 10.4 million tones and India ranks 4^{th} in production (861950 tons) and second in consumption (947715 tons) in the world after China (Indian Rubber Statistics, 2011). Productivity of NR in India is 1806 kg/ha and India ranks first in the world (IRSG 2011). Total NR imported during 2010-11 was 188337 tons valued at 2906.79 crores.

Unique characteristic of Indian rubber sector is that the natural rubber: synthetic rubber (SR) ratio is 70:30 while globally ratio is 43:57. Over the years production of SR has increased and in 2010-11 its production was 14.2 lakh tons contributing 58 per cent of world elastomers demand (Indian Rubber Statistics, 2011). While NR is obtained from non-polluting, renewable and environment friendly source, whereas SR manufacture is high energy demanding, emits polluting greenhouse gasses and SR is obtained from non-renewable petroleum source. Thus NR enjoys advantage over SR with regard to energy requirement and greenhouse gas emission. The per capita consumption of rubber in India is 1.12 kg against the world average of 3.57 kg (Indian Rubber Statistics, 2011).

After exploitation for latex, rubber trees are felled for replanting and wood from felled trees is being used for variety of purpose. Mature rubber tree gives a 0.62 m^3 stump wood and 0.4m^3 branch wood (Sekhar, 1992).With fast depletion of forest area in many parts of the world, rubber wood is becoming as a alternate timber source. Rubber wood has many attractive physical properties and can be used for multiple purposes after appropriate treatment.

Rubber plantations have green image and are inherently environment friendly (Wan and Jones, 1996). Rubber plantations aid in soil and water conservation (Krishnakumar and Potty, 1992), flood control (Sethuraj, 1996), improves soil organic matter water content and improves soil physical, chemical and biological properties through addition of litter from rubber tree and cover crop (Krishnakumar and Potty, 1992). Because of high photosynthetic rate and LAI, biomass production per unit area and time is high in *Hevea* which may give a Certified Emission Reduction (CER) of 243.7 in 21 years or 11.6 CER per year (Jacob, 2006). This should make *Hevea* a good candidate for fast afforestation and to claim carbon credit under Clean Development Mechanism (CDM) projects.

Consumption of NR in India is increasing at 1.8 per cent per year annually and there is growing gap between domestic NR production and demand. Hence production has to be increased proportionately. Increasing the rubber productivity per unit area through site specific management is the only feasible option due to the limited scope for extension of area under rubber cultivation in traditional area of the country. Like any other crops, NR also requires favorable soil and climate conditions for successful cultivation and profitable production. Ideal climatic conditions necessary for optimum growth of rubber tree are even distributed rainfall of 2000 mm or more without any marked dry season, maximum temperature of 29-34^{0}C and minimum of 20 ^{0}C or more (Webster and Baulkwill, 1989). Traditional region of rubber cultivation in India shows varied climatic conditions and only few regions in India meet all these requirements. Kanyakumari district of TN receives well distributed rainfall from both monsoons and climate is akin to equatorial monsoon. Towards North, South-West monsoon is intense but North-East monsoon becomes scantier leading to dry spell of 4-5 months during December to May (NARP, 1989). Climatic resources of rubber growing areas in the world have been grouped into six zones based on rainfall and temperature (Rao *et al.*, 1993). Broadly central and southern portion of traditional rubber growing area in India fall under the suitable zone (zone 2) where as northern portion under the moderate zone (zone 3) for rubber cultivation.

Climate, geology, geomorphology and physiography vary within traditional rubber growing regions in India. Major rock types observed are *Charnokites, Kondalites, Gneisses* and *granites.* Majority of soils in traditional rubber growing tract have been characterized and 62 soil series being identified and mapped. Out of 62 soil series, 51 are in order *Ultisols,* 9 under *Inceptisols* and 2 under *Entisols* (NBSS and LUP, 1999). Soil series association map unit are regrouped into 7 soil management units (SMU) based on three dominant soil properties observed in the rubber growing tract namely depth, gravel, and soil OC stock.

Variability in soil and climate of traditional rubber growing tract will influence the performance of rubber. There is a positive correlation between rainfall deficit and cumulative crop loss during a season (Ninane, 1970; Cretin, 1978). There are reports of steady decline in the mean yield of rubber from Kanyakumari district of TN in the South to Western part of Karnataka state in the

North (Chandy and Sreelakshmi, 2008). However, this study was mainly based on estate sector only, which accounts only 9.8 per cent of total rubber growing area.

Site specific management and precision farming are receiving more attention due to the potential benefit of increasing input use efficiency, improved economic margin of crop production and reducing the environmental risk (Yasrebi *et al.*, 2008). All the previous attempts to assess the soil and climatic variability in traditional rubber growing tracts in India lack integrated approach. There is a need to integrate the spatial soil and climate variability in rubber growing regions with the performance of rubber and only such study helps to bring out the limitations and potential of different rubber growing areas so as to increase the rubber production without horizontal expansion of area under rubber cultivation. For this purpose geographic information system (GIS) is the ideal tool to integrate all the geospatial information into one platform (Reddy, 2006) to analyze, interpret, visualize and generate maps which serve as valuable tool for planners, administrators and farmers at grass root level for decision making. In India geostatistics has been widely used for spatial variability of soil property (Grewal *et al.*, 2001; Nayak *et al.*, 2002; Chinchmalatpure *et al.*, 2005; Nayak *et al.*, 2006; Santra *et al.*, 2008; Reza *et al.*, 2012), but no such studies were seen particularly in NR to analyze the spatial variation of soil and climate and relate it with the performance of rubber.

Natural rubber is normally best suited for cultivation up to 300-350 m elevation. Owing to its attractive profit and stable price compared to other plantation crops, many enterprising farmers have taken up NR cultivation beyond 350 m elevation. A six month delay in attaining tappable girth for every 100 m rise in elevation beyond 200m has been observed due to 0.6 ^{0}C temperature decline for every 100 m increase in elevation (Dijkman, 1951; Moraes, 1977). Many environmental factors vary with elevation, so elevation gradient brings climate variation which includes varying regimes of temperature, precipitation, N availability etc. Potential net soil N mineralization (Garten and Miegroet, 1994) and turnover time of labile soil carbon (Garten *et al.*, 1999) vary along climate gradient associated with changes in elevation. Distinct difference in phenology is noticed between rubber grown in north-east India and traditional NR growing area. Alteration in phenology is likely to have effect on the adaptation and finally performance of a species. Elevation induced changes in soil nutrient dynamics and plant phenologies are receiving more attention in many other tropical trees, but such studies are lacking in NR. Studying the soil nutrient dynamics and NR phenology at different elevation gradient was felt more relevant in the context of extension of rubber cultivation to newer areas as well as changing climatic condition. Hence the present study was undertaken with the following objectives.

1. To develop database on soil, climate, rubber area and rubber yield and relate the spatial and temporal variability of rubber productivity to dominant soil and climatic factors in Kanyakumari districts of Tamil Nadu and Kasargod district of Kerala
2. To delineate the areas having productivity constraints and prepare productivity constraint map for the two districts.
3. Prepare rubber distribution map for the two districts and study the spatial distribution of rubber area over different soil and landscape.
4. To study the soil nutrient dynamics and phenology of rubber in different growing environment in Kottayam district of Kerala.

REVIEW OF LITERATURES

2. REVIEW OF LITERATURE

Para rubber is native to Amazon rain forest. Its cultivation has spread beyond its native location owing to its economic importance and increased demand. Due to increased pressure on limited land resources, there is limited scope for horizontal expansion of rubber cultivation in the traditional region of India to meet the ever increasing demand of NR in the global market. Hence there is a need to increase the productivity of existing rubber areas. At present rubber is being cultivated in varied soil and climatic condition which has significant influence on the performance of rubber. In the world rubber growing countries, initial attempts were made to characterize, group and assess the soil and climate suitability for rubber cultivation but little or no effort has been made particularly in India towards integrated analysis of soil and climate variability using modern tool of Geographical Information System (GIS), geospatial technique and Remote Sensing (RS) technology.

Phenology of rubber and soil nutrient dynamics vary with changes in climatic condition which in turn will influence the resources utilization and performance of rubber. An effort is made here to review the work done so far on the above mentioned aspects.

2.1 SOIL VARIABILITY AND PERFORMANCE OF NATURAL RUBBER

2.1.1 Variability of Rubber Growing Soils

Soil is characterized by high degree of spatial variability due to combined effect of physical, chemical and biological processes that operate at different intensities and at different scales. Rubber growing soils in the world are no exception to this. Considerable work has been done in India as well as other rubber growing countries to understand, characterize and classify the rubber growing soils. Man sas used Soil classification as a convenient tool to group the highly complex and diverse natural resources. The work on classification of rubber growing soil was started in Malaysia and later in India.

In Malaysia soil classification specially for rubber growing areas was started in 1963 and rubber growing soils were grouped into 30 soil series in West Malaysia and 250 soil series in Peninsular Malaysia (RRIM, 1971a and b), showing considerable variability in physical and chemical properties. Among 30 soil series in West Malaysia, nine soil series namely, *Munchong, Rengam, Jerangua, Serdang, Holyrood, Malacca, BaluAnam, Durian and Selangor* were most common and occupied 60 per cent of total rubber growing area. Variability in physical and chemical characteristics of soil and their interaction on performance of *Hevea* in West Malaysia have been reported (Pushparajah and Guha, 1968; Ng and Law, 1971 and Chan *et al.*, 1972.).

Traditionally rubber cultivation in India is mainly confined to laterite and lateritic types of soil and red soils (George, 1961). Laterite soils are highly weathered, loam textured with good physical properties but poor in plant nutrient and high P-fixation due to presence of Al and Fe oxides in high amount. These soils are mainly found in central portion of rubber growing tract. Red soils are less weathered, loam to silt clay loam texture, deficient in organic matter but more fertile than laterite soils. These soils are mainly found in Kanaykumari district of TN. With the aim of increasing the productivity of rubber, reconnaissance soil survey and mapping of rubber growing soils in Kerala and Tamil Nadu was done during 1996-98 which identified 62 soil series and mapped soil at soil series association level (NBSS and LUP, 1999). Rubber growing soils are mainly distributed on four land forms namely *Khondalite, Charnockite, Granite-gneiss and laterite* landforms. Out of 62 soil series identified, *Kunnathur, Kanjirapally, Thrikannamangal, Lahai, Koruthode, Kadambanad, Thiruvanchur, Vazhoor, and Vijayapuram* are the dominant soil series observed in the traditional rubber growing areas of India. These nine major soil series cover 50 per cent of rubber growing area. Soils of traditional rubber growing area showed variability mainly with respect to depth, gravel and organic carbon stock (Naidu *et al.*, 2008). Very deep soil was noticed in 41 per cent of total rubber area surveyed. Soil with more than 35 per cent gravel was seen in 55 per cent of rubber area where as 67 per cent of the rubber area was low in available water holding capacity (50-100mm).

Grouping of large number of soil series into few management groups based on distinct soil properties helps to prioritize and focus the issues related to management and fertility problems. In this direction 250 soil series in Peninsular Malaysia were placed into 25 soil management groups which have been distinguished mainly due to difference in soil depth, drainage, texture, structure, and absence of toxic nutrient, extreme nutrient deficiency, soil acidity and slope (RRIM, 1992).

Using all the properties of 62 soil series identified in the rubber growing tract of India, Rao *et al.* (2007) identified 8 groups using the cluster analysis technique. These 8 clusters could be used as the basis for evolving management practices. Based on variability in properties among the 62 soil series mapped (NBSS and LUP, 1999), Naidu *et al.* (2008) delineated the land areas that has uniform capability for rubber production and grouped the soils of rubber growing areas into seven soil management units (SMU). Soil management unit 1 represents more desirable soil properties and least limitation with respect to rubber production, whereas SMU 7 represents less desirable soil properties with more limitations.

2.1.2 Effect of soil Variability on Performance of Rubber

Rubber needs a minimum soil depth of 1 m without hard pan and yield reduction in shallow soil compared to soil with adequate depth has been reported (Dijkman, 1951; Pushpadas and Karthikakuttyamma, 1980). For optimum growth and yield, rubber needs well drained, medium textured soil with minimum depth of 100 cm without any intervening hard pan and pH range of 4.0 – 6.5 (Pushpadas and Karthikakuttyamma, 1980).

Soil characterization, grouping and mapping will be relevant only when they are assessed for the suitability for cultivation of rubber. There is considerable variability in physical and chemical properties of soil under rubber and attempts were made to relate this with the performance of rubber. Chan and Pusparajah (1972) studied the performance of class I *Hevea* clones over 9 major soil series observed in Western Malaysia and reported that *Munchong* series gives highest yield, *Selangor* series lowest yield and rest fall in between. High yield in *Munchong* series was because of very good physical properties under uniform climatic condition. Chan *et al.* (1974) studied the influence of soil morphology and physiography on performance of rubber in six soil series observed in Peninsular Malaysia and reported that girth improved by 1-5 per cent and yield by 3-18 per cent with increase in clay content. Similarly positive effect of soil depth on girth and yield has been reported. They also observed the increase in girth and yield with increase in slope up to 26 per cent due to better drainage. Similarly Yew and Pushparajah (1991) studied the influence of soil condition on growth of *Hevea* under glass house condition and reported that *Oxisols* produced more dry matter than *Ultisols*. Least dry matter production was with *Histosols* soils. Variation in dry matter production was attributed to difference in physical condition favoring the rubber growth.

Evaluating the soil-site conditions suitability for rubber in India, Kharche *et al* (1995) attempted to identify the kind and degree of major constraint for rubber production. The most striking parameter influencing the yield of rubber was the period of moisture availability followed by soil depth, available water content (AWC), slope, winter temperature and excess rains. Similarly Satisha *et al* (2002) assessed the soil-site characteristic and their limitation for rubber cultivation in northern Mizoram, a non-traditional rubber growing area of India and found that soils of high elevation (> 400 m) in Bikhawthlir and Thingdawl area are marginally suitable due to severe limitation of slope and coarse fragment. Soils of Bairhat, Tuichubam and Chimluang located at < 400 m elevation grouped as moderately suitable with moderate limitation of texture, slope and low minimum temperature.

Using factor analysis approach Rao *et al* (2002) analyzed the inter relationship between different soil properties and rubber growth (RRII 105) and found two major factors: soil reaction factor and P limiting factor affected the plant growth. First factor included positive contribution from exchangeable Ca, Mg, K and Na, while negative contribution from exchangeable Al and DTPA extracted Zn. Second factor included positive contribution from pH and Mn and negative contribution from exchangeable Al and P. Regression analysis of tree volume with factor score revealed that P factor essentially influenced the plant growth.

Guha *et al* (1971) studied the relationship between soil classification unit and soil fertility in 10 Malayan soil series and found that soil derived from marine alluvium required least manuring, whereas soil derived from igneous rock required complete N, P, K fertilizer. The positive effect of soil physical properties like depth and clay content on performance of rubber reflected in better leaf nutrient status like N, P, K, Ca and Mg (Chan *et al*., 1974). Apart from soil physical condition, soil chemical property mainly soil fertility influences nutrient requirement of *Hevea*.

2.2. CLIMATE AND NATURAL RUBBER

2.2.1. **Climate Requirement**

Climate is an important ecological factor as the soil characters to great extent are dictated by climate in which they occurs. The most important elements of climate which influences the rubber cultivation are rainfall, temperature and wind. Rubber needs warm tropical monsoon climate with mean monthly temperature of 25-28^{0}C, high atmospheric humidity with moderate wind, bright sunshine amounting to 2000 hours per annum and annual rainfall of more than 2000 mm with 125 to 150 rainy days per annum (Webster and Baulkwill, 1989; Rao and Vijayakumar, 1992).

2.2.2. Climate and NR Performance

Geoclimatic comparison of environment in which rubber is grown in the world reveals a spectrum of climatic condition, indicating its adaptability to diverse climate. However, adverse effect of temperature when ambient temperature goes below 15^0C (Zongdao and Xueqin, 1983) or above $34\text{-}40^0C$ (Chandrasekhar *et al.*, 1990; Ong *et al.*, 1998) have been reported. Mean annual temperature range of $20\text{-}28^0C$ is optimum for growth and latex production (Shamsuddin, 1988). A decline in mean annual temperature of as much as 3^0C can result in a 15 per cent reduction in growth of rubber tree and consequent drop in latex production has been reported (Thomas *et al.*, 1995). With regard to rainfall, distribution is more important than total annual rainfall and importance of this on better growth and yield of rubber has been reported (Kharche *et al.*, 1995; Dea *et al.*, 1996; Thanh *et al.*, 1997). Rubber needs evenly distributed rainfall without any marked dry season (Vijayakumar *et al.*, 2000). Rainfall of 9-11 mm/day has been reported optimum (Pushparajah, 1983). The pattern of rainfall distribution in the rubber growing tract of India is clearly reflected in the decline in average yield of rubber from south to north (Pushpadas and Karthikakuttyamma, 1980; Chandy and Sreelakshmi, 2008).

Specific areas of Thailand, India, Cote d'Ivoire, Vietnam and China fall into non-traditional rubber growing areas that experience one or more stress situation. Dea *et al.* (1996) studied the behavior of rubber tree in marginal climatic zone of Cote d'Ivoire and reported that long duration of dry season and water balance deficit appears to be major limiting factor for growth and tapping age of rubber tree. Average yield of rubber was 50 per cent of that of traditional region. Thanh *et al.* (1997) investigated the seasonal yield variation of different *Hevea* clones in Vietnam in relation to climatic condition, and reported that long dry season affected the rubber yield and period of tapping. Rubber yield during the dry period was 8.5 per cent of annual yield. Highest yield (41.5 per cent of annual yield) was obtained in last quarter of the year because of favorable climatic condition (low air temperature) for yield and the effect of rain on tapping was minimized. Concentrated rainfall and high number of rainy days affected the tapping days in highland and South-East region of Vietnam.

Decline in growth and delayed maturity due to stress from atmospheric and soil drought has been reported from non-traditional rubber growing areas of India (Devakumar *et al.*, 1998; Dey and Vijayakumar, 2005). Similarly Rantala (2006) studied the rubber plantation performance in North-East and East of Thailand in relation to environmental condition and found highest wood production potential in Nang Khai areas of East Thailand due to favorable rainfall for rubber growth. North-East Thailand experienced marginal environment. Similarly Ekpoh *et al.* (2008) studied the relationship between rubber latex exudates and climatic factors in Nigeria with an aim to identify the critical element in explaining the yield variation. They reported that rainfall, temperature, sunshine hours and evaporation are the most significant variables and had significant negative effect on rubber yield.

There are reports indicating role of climate and growth period in occurrence of tapping panel dryness (TPD), a syndrome encountered in rubber plantation characterized by spontaneous drying up of tapping cut resulting in stoppage of latex production. (Compagnon *et al.*, 1953; Harmsen, 1989; Bealing and Chua, 1972).

Development of suitable agro climatic indices is one of the approaches used to assess the climate resources for particular crop and in this direction Rao *et al.* (1993) developed a simple hydrothermal index incorporating temperature and rainfall distribution with respect to climatic requirement of rubber. Using this index, climatic resources of rainfed rubber cultivation area was grouped into six categories: highly suitable, suitable, moderate, marginal, conditional and not favorable. Mostly Trivandrum, Quilon, Alleppey, Kottayam and Ernakulam district of Kerala, Kanyakumari district of Tamil Nadu and Port Blair are grouped as climatically suitable zone, whereas Palghat, Calicut, Kasargod district of Kerala, Mangalore district of Karnataka and Agartala and Silchar in North-

Eastern India grouped as moderately suitable for rubber cultivation based on hydrothermal index. Rest of the rubber growing area in India grouped as marginally suitable. Using the same index, Senai of Malaysia was identified as the most suitable for rubber cultivation. Climate of this location was characterized by equally distributed rainfall with maximum and minimum temperature range of 30.3 – 30.6 and 21.4 -22.9 ^{0}C respectively. These conditions are close to optimum condition for highest production, however climatic conditions of none of the rubber growing area in India could match the optimum condition and hence no rubber growing area in India was grouped as most suitable category. Thomas *et al.* (2002) developed criteria for agro climatic zoning taking into account of annual rainfall, number of dry months, elevation, biotic and abiotic stress and grouped the rubber growing areas of Indonesia into seven zones which almost matched with ground yield level.

To identify the agro climatically potential rubber land in Sri Lanka, Domoroes (1984) attempted to correlate general climatic requirement of rubber cultivation with climatic condition of Sri Lanka. The identified potential rubber land coincided with present distribution of rubber cultivation in Sri Lanka. Unlike other crops, diurnal variation in rainfall is also important in rubber for uninterrupted tapping (Liyanage *et al.*, 1984; Haridas and Subramaniam, 1985; Thanh *et al.*, 1997). In a critical study of hydrological cycle of matured rubber plantation in Malaysia, Haridas and Subramaniam (1985) reported that rubber yield showed curvilinear relation with rainy days ($Y= 123.119 - 8.46X + 0.241 X^2$) and rainfall intensity ($Y= -97.5 +29.88X - 1.34X^2$) and rubber yield declined with increase in rainy days and as for rainfall intensity yield increased up to 10-11 mm per day after which declining trend seen.

2.2.3 **Physiographic Effect**

Among the physiographic features, elevation influences the growth of rubber. At high elevation, apart from low temperature, high humidity favors the incidence of *Oidium* resulting in retarded growth (Bansil, 1971). At higher elevation, temperature becomes unfavorable for growth. Increase in immaturity period by six month for every 100m rise in altitude has been reported (Foth and Turk, 1973). Elevation up to 450 m above mean sea level was found to be satisfactory for growth of rubber (Pushpadas and Karthikakuttyamma, 1980).

2.2.4 **Water Balance**

Water is the fundamental requirement for all crops and plays important role in yield of crops. Soil is the store house of water, which can hold a limited amount of easily available water in the root zone. Soil moisture level influences fundamental ecological processes such as photosynthesis, respiration and nutrient uptake (Band *et al.*, 1993). In rainfed agriculture, moisture supply to plant depends on precipitation and water holding capacity of soil. Urban *et al.* (2000) depicted different environmental factors governing soil moisture at different spatial scale: climate (macro scale), topography (meso and micro scale), and soil depth, texture and water storage capacity (micro scale) into forest simulation model to examine the montane environment gradient and assess the response to climate change.

Monthly water balance was first developed by Thornthwaite (1948) and later revised by Thornthwaite and Mather (1955, 1957). Thornthwaite (1948) proposed a book-keeping procedure for the computation of the elements of water budget of a region by treating precipitation as income, potential evapotranspiration (PET) as expenditure and the moisture stored in the soil mantle as a kind of reserve for use in times of deficient precipitation. Of the three major elements of water balance, namely, Water Surplus (WS), Water Deficiency (WD), and Actual Evapotranspiration (AET), water surplus is of interest to the hydrologist and water deficiency to the agriculturist. The AET represents in a way the absolute amount of water that is actually available in the soil for use by vegetation. PET, as water need, represents the maximum amount of water evaporated and transpired under conditions of no water deficiency at any time. The ratio of AET to PET termed as "index of moisture adequacy" (MAI)

(Subrahmanyam *et al.*, 1964) varies with the available moisture in the soil and thus provides a good indication of the moisture status of the soil in relation to the water-need. Low MAI values signify poor moisture availability. Index of moisture adequacy is being used in assessing the crop performance (Mokashi *et al.*, 2008) as well as in drought monitoring (http://dmc.kar.nic.in/maiweekly.htm. www.dsc.nrsc.gov.in/DSC/Drought/**index**.jsp).

Frere and Popov. (1986) proposed rainfed crop specific Water Resources Satisfaction Index (WRSI), which is by definition is ratio between summations of AET to PET of a crop during crop season. Studies by Food and Agricultural Organization (FAO) (Doorenbos and Pruitt, 1977) have shown that WRSI can be related to crop production using a linear-yield reduction function specific to a crop. Verdin and Klaver (2002) and Senay and Verdin, (2003) demonstrated the regional implementation of WRSI in assessing the crop performance in a grid-cell based modeling environment on southern Africa.

Similarly Senay and Verdin (2003) reported the utility of GIS based crop water balance model WRSI in characterizing yield reduction as well as distinguishing water limited and unlimited areas in Ethiopia. In a study on monitoring WRSI and production potential of rainfed crops in eastern Rajasthan using satellite data, meteorological and soil information, Patel *et al.* (2011) reported that WRSI was found promising in capturing inter-annual and spatial variability in water availability to rainfed crops. They also reported that, WRSI showed significant relationship with reported yield in drought prone areas.

In recent years simple water balance software for calculation of water balance are being developed like CropWat (http://www.fao.org/ nr/water/ infores_databases_cropwat.html) , BUDGET (http://www.biw.kuleuven.be/ lbh/ lsw/ iupware/downloads/elearning/software/), Thornthwaite monthly water balance (http://wwwbrr.cr.usgs.gov /projects /SW_MoWS / TWB. html), ArcGIS water balance tool box (Dyer, 2009) (http://www.ohio.edu /people /dyer /water_balance.html), Soil Water Balance (SWB) (Westenbroek *et al.*, 2010) (http://pubs.usgs.gov/tm/tm6-a31/) and proved useful (Reynold *et al.*, 2000; Satti and Jacob, 2004; Dashrath, 2005;Sarkar, 2008).

FAO (1978) introduced the concept of "Length of Growing Period" (LGP), which is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration. Kharche *et al* (1995) evaluated the soil-site condition suitability for rubber in India using LGP as one of the criteria and found that LGP is the most striking parameter influencing the yield of rubber followed by soil depth, AWC, slope, winter temperature and excess rains.

2.3 MAPPING RUBBER DISTRIBUTION AND SPATIAL ANALYSIS

2.3.1 **Remote Sensing**

Remote sensing is defined as the science and art of obtaining information about an object, area or phenomenon through an analysis of the data acquired by an device which is not in contact with object, area or phenomenon under investigation (Reddy, 2006). Efficiency in the agricultural sector can be augmented effectively by using Information Technology tools such as remote sensing and GIS. The database for the agriculture sector can ensure greater reliability of estimates and forecasting that will help in the process of planning and policy making.

Today, the remote sensing technology applications include diverse areas like forestry, agricultural crop acreage and yield estimation, land use/land cover mapping, waste land and water resource management, drought and flood monitoring, urban development, mineral prospecting, forest resource survey and management, weather forecasting, environmental impact assessment, and so on, thus encompassing the almost every facets of sustainable resource development and management (Rao, 1991). Large volume of literature is available on basics and application of remote sensing and GIS. Literatures pertaining to mapping tree crops, particularly rubber, using satellite image and spatial analysis of data in GIS are presented in this section.

2.3.2 **Mapping Natural Rubber**

Every object on the earth has a unique spectral reflectance/emittance in a particular region of electromagnetic spectrum and this unique spectral reflectance/emittance is called as spectral signature (Reddy, 2006). Different vegetation's are mapped using the spectral signature unique to each vegetation. Teak forest plantation was identified using Indian Remote Sensing (IRS) Satellite data in Soanabhadra district of Uttar Pradesh and Silent Valley of Kerala (Jadhav, 1992; Menon and Ranganath, 1992). Using IRS LISS II data, *sal* forest was identified in South forest division of Sikkim (Jadhav, 1992), Midnapur forest division (Sudhakar *et al.*, 1992), and Rajaji National Park in Uttar Pradesh (Tiwari *et al.*, 1992). Similarly Oak was identified by Jadhav (1992) and Tiwari *et al.*, (1992) using IRS LISS II data in Sikkim and Western Himalaya respectively.

Similarly plantation crops like coffee area was mapped using Landsat ETM+ image in Costa Rica (Cordero-Sancho and Sader, 2007), El Salvador (Ortega-Huerta *et al.*, 2012) and oil palm using SPOT image in Malaysia (Wahid, 1998; Wahid *et al.*, 2010). Delineation of tea plantation was also reported by Menon and Ranganath (1992), Dutta *et al.* (2009) and Dutta (2011).

First report on identification of rubber area under small holding of Kerala using Landsat TM data was reported by Gopinath and Samad (1985).Similarly rubber plantations were identified using SPOT satellite data in Thailand (Bruneau *et al.*, 1988) and Liberia (JeanJean *et al.*, 1991). Subsequently rubber plantations were identified using IRS data in Kerala (Menon, 1991; Menon and Ranganath, 1992; Rao, 2000). Zhe Li and Fox (2012) mapped the rubber tree growth in midland Southeast Asia using time series Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m Normalized Difference Vegetation Index (NDVI) image.

Charat and Wasana (2010) estimated rubber plantation in North-East Thailand by visual interpretation of SPOT and THEOS satellite data along with climate, land form and soil data. Similarly Suratman *et al.* (2004) estimated rubber plantation area, age and volume using Landsat TM data. Pensuk and Shrestha (2008) used multi-temporal Landsat data to identify the paddy area converted to rubber plantation in Patthalung watershed, Southern Thailand.

Mc Morrow and Heng (2000) assessed the suitability of Landsat TM satellite image for oil palm estate management to visually detect the between and within block variation and reported that age of palm significantly explained the between block variation whereas block leaf area index (LAI) and topography had significant effect on within block variation.

Mapping plantation tree crops using remote sensing technique, particularly rubber tree, faces some significant challenges like isolated small holding size, matching of spectral signature with tropical ever green vegetation and undetectable spectral signature from young rubber plantation (Zhe li and Fox, 2012). Young rubber trees are being grown in a complex and heterogeneous mixture of crops including bare or fallow soil and rubber takes more than 3-4 years to completely cover the planted area. Because of these reasons, many researchers expressed the difficulty in mapping young rubber (Meti *et al.*, 2008; NRSC, 2012 and Zhe li and Fox, 2012).

2.3.3. Geographical Information System (GIS) and Geospatial Analysis

2.3.3.1. *GIS*

GIS is a system of hardware, software and procedures designed to capture, store, update, manipulate, analyze and display all forms of geographically referenced data for solving complex planning and management problem (Rhind, 1989). Research work on spatial science and GIS began in late 1950 and much of the credit for early development of GIS goes to Roger Tomilson and he is also known as father of GIS. Today GIS technology is being used in disciplines like, Geography, Geology, Pedology, Agronomy, Soil and Water conservation, Cartography, Remote sensing, Photogrammetry, Surveying, Geodesy, Statistics operation research, Computer science and Mathematics. So GIS application involves wide scientific field and in this section effort is made to review the work related to use of GIS in plantation crops, particularly rubber with special emphasis on geospatial analysis.

GIS has been widely used in integrating the spatially and temporally varying natural resources like soil and climate to assess their suitability (Solanki *et al.*, 2005; Bhagat *et al.*, 2009; Velmurugan and Carlos, 2009; Rasheed and Venugopal, 2009; Satish and Niranjana, 2010; Laosuwan, *et al.*, 2012; Prabhuraj *et al.*, 2012), constraint (Shalima Devi and Anil Kumar, 2008; Velmurugan and Carlos, 2009; Kalra *et al.*, 2010) and potential yield of crops (Gontia and Tiwari, 2011; Reddy and Reddy, 2012).

National Agriculture and Forestry Research Institute (NAFRI) (2005) has attempted to map rubber suitability zone in the Central Development Zone, Na Mo district, Oudomsay province, Laos using the physical, biophysical, ecological and spatial information in GIS and mapped the potential areas and marked the existing rubber plantation. On ground verification it was found that forest areas were not encroached and most of the rubber planting to date taking place in high risk zone.

Fairhurt *et al.* (2000) attempted to link the digital maps with agronomic data base using GIS, Global positioning system (GPS) equipment to generate the maps like yield and soil fertility maps in oil palm plantation with an aim to pinpoint and monitor agronomic problem areas. Similarly Seng and Rahim (2000) attempted yield mapping of oil palm estate in Selangor, Malaysia using GIS and GPS and reported that it is technically feasible to map yield and analyze along with soil and topographic information of the site.

In a case study on Cimanuk watershed of West Java, Indonesia, Reich *et al.* (1995) demonstrated the application of GIS in identification of areas where there may be biophysical constraint to implement sustainable agriculture and identify the areas potential for crops like coconut, banana, cocoa, oil palm, rubber and rice. Kokmila *et al.* (2010) attempted to identify the suitable areas for rubber plantation in Laos using GIS data base such as land use type, forest type, and Digital Elevation Model (DEM) and soil characteristics and delineated the suitable areas using multi criteria evaluation technique.

Integrating GIS with crop growth models helps to simulate the growth under different scenarios. Pratumintra and Kesawapitak (2002) attempted to integrate the GIS with maximum production potential model to estimate the rubber production potential under the varying climatic and soil conditions in East Thailand. Dansagoonpon *et al.*, (2004) attempted to evaluate the land potential for rubber and oil palm production based on the crop requirements for rubber and oil palm, and climatic and physical-chemical soil properties, which will allow the prediction of yields and crop substitution between rubber and oil palm. Similarly Ayanu (2009) attempted to simulate the consequence of land use change on hydrological landscape functions and sustainable crop production in Northwest Vietnam using GIS and land use change impact assessment tool. Findings of the study is that if agricultural expansion into forest areas in the uplands of Northwest Vietnam is deemed unavoidable, then rubber plantation appear better land use option than maize monocropping from stand point of runoff and discharge generation of the area.

2.3.3.2. *Geospatial Analysis*

Since publication of first application of geostatistics to soil data in early 1980s (Burgess and Webster, 1980, Webster and Burgess, 1980; Burgess *et al.*, 1981), geostatistical methods have become popular in soil science. Soil scientists are aware that, the soil properties vary spatially (Trangmar *et al.*, 1985; Warrick *et al.*, 1986). Characterization of spatial variability of soil attribute is essential to achieve a better understanding of complex relation between soil properties and environmental factors. Geostatistics has proved effective in assessing the variability of soil nutrients (Webster and Oliver 2001; Gilbert and Wayne 2008). In India geostatistics has been widely used for spatial variability of soil properties like phosphorus (Grewal *et al.*, 2001), boron (Chinchmalatpure *et al.*, 2005), micronutrients (Nayak *et al.*, 2006) and hydraulic parameters (Santra *et al.*, 2008), soil OC, pH, available N and K (Reza *et al.*, 2010).

Prediction is made possible by the spatial dependence between observation as assessed by semivariogram or correlogram. Geostatistics provide a set of statistical tools for incorporating the spatial coordinates of soil observations in data processing, allowing for description and modeling of spatial pattern, prediction at un-sampled location and assessment of the uncertainty attached to these predictions (Geovaerts, 1998). One of the main applications of geostatistics is the prediction of attribute values at un-sampled location (Yao *et al.*, 2004).

Geostatistics uses semivariogram to quantify the spatial variation of regionalized variable and provides the input parameters for spatial interpolation method (Matheron, 1963). Among different interpolation methods, kriging (Krige, 1951) is a widely used method to predict and interpolate data between measured locations (Burgess and Webster 1980). Vieira *et al.* (2010) used geostatistical technique to determine the spatial variability of rubber tree growth characteristics and soil-water physical properties. The field saturated hydraulic conductivity of soil at 0-0.10m layer showed strong linear and spatial correlation with diameter of rubber trees as confirmed by the spatial variability of maps of both attributes. Similarly Reza *et al.* (2012) used kriging technique to determine the spatial variability of soil pH, OC, available N and K in Brahmaputra plains of Assam and found kriging successfully interpolated soil properties except available N.

2.4. PHENOLOGY

Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and inter-annual variations in climate. The word is derived from the Greek, *phainō* means, "to show, to bring to light, make to appear" *logos*, means "study, discourse, reasoning" (Anonymus, n.d.). So with respect to plants, phenology is principally concerned with date of occurrence of events in their annual life cycle like leaf colouring and fall in deciduous trees, emergence of new leaves and flowers. Observations of phenological events have provided indications of the progress of the natural calendar since ancient agricultural times. Effort is made in this section to review the work on phenology-elevation-soil nutrient interaction.

Phenological records can be a useful proxy for temperature in historical climatology because plant phenological events are very sensitive to small variations in climate, especially to temperature (Meier *et al.*, 2007). Phenology is a useful indicator because it integrates climate signals over a sustained period of time and is easily measured (Nord and Lynch, 2009). The timing of reproduction and maturity is a key component of fitness (Stearns, 1992) and exhibit plastic response to resources availability (Pigliucci *et al.*, 1995; Dorn *et al.*, 2000; Gungula *et al.*, 2003).

Hevea exhibits significant changes in phenology under different geoclimates. Natural rubber is being cultivated on varied agro-climatic, conditions, which induces ample phenological changes. Comparing the phenology of rubber grown in Tripura, northeast state of India and Sao Paulo in south Brazil, Priyadarshan (2001) reported that in Sao Paulo the high yielding and low yield regimes occur at the opposite time of the year to that of Tripura. Similarly Main season of rubber flowering is February/March in northern hemisphere whereas in southern hemisphere it is July/August and Yeang (2007) attributed mainly to difference in the month of highest average solar radiation.

2.4.1 **Nutrient Dynamics**

Alteration in phenology is likely to have important effects on plant resource acquisition. Water deficit and low nitrogen accelerates senescence and reproduction (Aronson *et al.*, 1992; Marschner, 1995). Nomura and Kikuzawa (2003) and Tessier and Rayanal (2003) reported that in some ecosystems phenology is coupled to nitrogen availability, with flushes of plant growth coinciding with pulses of N availability. Warm temperature generally accelerate plant development (Zavaleta *et al.*, 2003; Badeck *et al.*, 2004) but changes in temperature may have indirect effect on water availability via changes in transpiration (Korner, 2006). Water deficit may also affect the acquisition of nutrient acquired in bulk flow (Nord and Lynch, 2009). Main drivers for the phenological changes are the temperature, water and soil nutrient particularly nitrogen (Nord and Lynch, 2009). Rainfall induced pulses of resource availability increases C and N mineralization, mineral N pools, and nutrient supply to plant roots (Huxman *et al.*, 2004; Ford *et al.*, 2007). Nitrogen regulates plant growth and is needed in large quantities, but its availability varies throughout the season because of the seasonality in organic matter input as well as nitrogen mineralization (Waldrop and Firestone, 2006). Similarly temperature may indirectly influence the rate and duration of mineralization thus affecting the nutrient availability (Borner *et al.*, 2008).

Plant phenology and growth are potentially modified not only by environmental factors, but also by soil-related factors (Brun *et al.*, 2003; Valdez-Hernández *et al.*, 2010). Cardoso *et al.* (2012) investigating the phenological pattern and stem growth of *Senna multijuga* (semi- deciduous) and *Citharexylum myrianthum* (deciduous) growing in two types of soil that display contrasting water and nutrient availability, namely Gleysol (moist and nutrient-poor) and Cambisol (drier and nutrient-poor). Both species were seasonal in all phenophase regardless of soil types; however frequency, mean date and intensity of phenophases varied according to soil type, indicating that soil also play an important role in determining phonological patterns and growth and must be considered when analysing phenological patterns in tropical forests.

Temperature decline by 0.6^0C for every 100m rise in elevation (Barry, 1981) and this altitudinal related temperature changes drives the phytophenological phases. Marrs *et al.* (1988) studied the changes in soil nitrogen-mineralization along an altitudinal transect in tropical rain forest in Costa Rica and reported that soil N mineralization and nitrification decreased with increasing altitude. Further they reported that N mineralization at higher elevation was limited by high moisture content in the soil. Contrary to this Decker and Boerner (2003) reported that there was no statistically significant relationship of nitrogen mineralization or phosphorus with elevation in Chilean *Nothofagus* forest, however there were statistically significant negative relationships between elevation and net nitrification, proportional nitrification, soil pH and organic carbon. Three factors -temperature, precipitation and soil N availability varying in a predictable manner with altitude significantly influences the soil carbon(C) dynamics. Garten Jr.(2004) summarizing the measured trend in environmental factors and ecosystem process that affect soil C balance along the elevation gradient in southern Appalachian Mountain in USA reported that forest soil C stock and turnover time of labile soil C increase with elevation. Further he concluded that litter chemistry, soil moisture, N availability and temperature interact in a complex way to regulate the soil C storage through effect on decomposition. Altitude increase brings in a progressive decrease of atmospheric temperature, and pressure, and increase in solar radiation during clear sky (Ziello *et al.*, 2009).

Investigating the effect of nitrogen (N) dynamics of alpine in Austria in relation to temperature, Huber *et al* (2007) reported that amount of total soil N, plant available N and soil C/N ration decreased significantly with increasing altitude, whereas soil pH increased. In another study on soil organic carbon dynamics along a climatic gradient in southern Appalachian spruce-fir forest in North Carolina and Tennessee border, Tewksbury and Miegroet (2007) reported that total soil C showed no trend with elevation while forest floor C accumulation decreased significantly with elevation. Cooler upper elevation showed the lowest C turnover as indicated by the lowest needle decomposition rate. Contrary to this Sheikh *et al.* (2009) reported that the stocks of soil organic carbon were found to be decreasing with altitude in temperate (*Quercus leucotrichophora*) and subtropical (*Pinus roxburghii*) forests.

Sundqvist (2011) studied the nitrogen and phosphorus dynamics across an elevation gradient in Swedish subarctic Tundra and reported that increasing elevation led to an increase in plant limitation of P relative to N, and a general decline in soil P availability but had highly variable effects of soil N availability. Similarly Zhang *et al* (2012) reported that in alpine meadow of eastern Qinghai-Tibetan Plateau, China, soil N mineralization and nitrification rates decreased with increasing altitude, but only significantly ($P<0.05$) between the lowest and the two higher altitudes. Study also suggested that soil temperature and soil water content (WC) were the controlling factors for soil N mineralization and nitrification rates across altitude with soil WC being the most important factors over positions.

Above review shows that not much work has been done on effect of elevation on rubber phenology *vis a-vis* soil nutrient dynamics.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Objectives of the proposed work were addressed by conducting two experiments.

Experiment I:

3.1 GEOSPATIAL ANALYSIS OF SOIL AND CLIMATE VARIABILITY ON PERFORMANCE OF RUBBER

3.1.1 Location of the study

In order to bring maximum variability in soil and climate, two districts namely, Kanyakumari district in southern region of traditional rubber growing area representing the agro-climatically suitable zone and Kasargod district in north of rubber growing area representing agro-climatically moderately suitable zone were selected for the study. Kanyakumari district located between latitude of 8.08^0 to 8.58^0 and longitude of 77.1^0 to 77.59^0. Kasargod district located between latitude of 12.04^0 to 12.80^0 and longitude of 74.86^0 to 75.43^0. For each district, digital database on soil, climate and rubber distribution were developed.

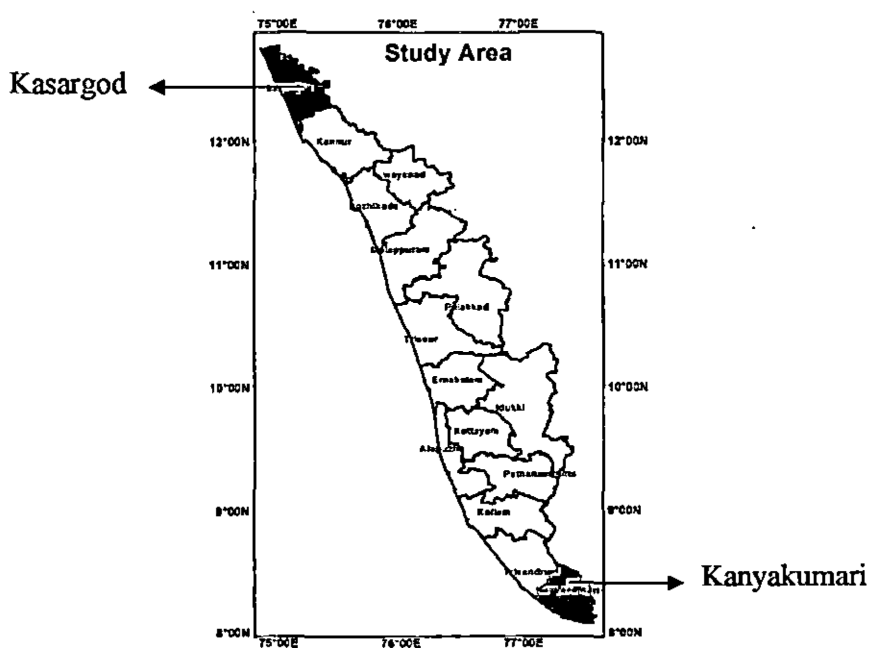


Fig1: Location of Experiment I Study area

3.1.2 Developing Soil Information Database

Soil information data base was developed from NBSS and LUP, Nagpur reconnaissance soil survey report of rubber growing area (NBSS and LUP, 1999). Soil series association map (1:50,000 scale) corresponding to area of study were colour scanned, georeferenced and vectorised. Soil maps were georeferenced using 1:50,000 scale survey of India (SOI) toposheets. WGS 1984 UTM zone 43N was used as projection coordinate system. Georeferenced maps were mosaic and clipped using the district administrative boundary derived from SOI toposheet (1:250000 scale). Database on soil properties and soil management unit (SMU) corresponding to each map unit was developed and linked with vector map to develop soil data base. Soil management unit 1 to 7 in each district were grouped into three categories like good (SMU 1 &2), moderate (SMU 3&4) and poor soil (SMU 5-7) considering their limitation of depth and gravel content.

3.1.3 Developing Rubber Distribution Map

Indian remote sensing (IRS) satellite P6 LISS III sensor image with 23.5 m resolution was used for developing rubber distribution. Row and path numbers of satellite pass covering the study area were identified and browsed from National Remote sensing Centre (NRSC) website (www.nrsc.gov.in) for all the images for the years 2005 onwards covering period from February to March coinciding with refoliation and full canopy development of rubber. Then good and cloud free scene were selected. Satellite scenes and their date of pass selected for the study is given below.

District	Row/Path number	Date of pass
Kanyakumari	101/68	08^{th} February 2007
Kasargod	98/65	18^{th} March 2006

Selected satellite scenes were indented and purchased from NRSC, Hyderabad. Satellite images were registered using the SOI toposheet (1:50,000 scale) and were orthorectified using WGS 1984 UTM zone 43N coordinate system. Projected Images were clipped using the district administrative boundary and used for image classification. District images were classified using K means clustering (minimum distance) algorithm in Geomatica software. Four bands of IRS P6 LISS III and the Normalized Difference Vegetation Index (NDVI) image created using band 2 and 3 were taken as inputs for image classification. In order to avoid mixing of spectral signature with rubber from paddy and forest vegetation, bitmap covering forests and low-lying areas was created from toposheet and used as mask. Using the ground knowledge and unique signature of NR, different classes were aggregated into different land use classes. GPS readings (Garmin Oregon 550) of dominant vegetation classes like rubber, coconut, areca nut and mixed vegetation collected from different parts of the district were used as test point and estimated classification accuracy. Total of around 100 test points readings in each district were taken from NR plantation and other vegetation of the district. After classification, classified image was filtered with 3x3 windows with median filter. Classified and filtered image was vectorised using raster to vector conversion tool and extracted rubber only and saved as rubber distribution layer.

3.1.4 **Selection of Rubber Holdings**

Criteria for selecting the rubber holdings was set as follows

a) Clone should be RRII 105
b) Age of the plantation should be 10-15 year old
c) Uniform management and tapping system
d) Holding size should have at least one tapping block (300 trees).

Details of the holdings which meet the above criteria were collected from the permit register maintained at the Rubber Board regional office of the corresponding district. Farmer's name and address were also collected from Rubber Producer Society (RPS) functioning in both the district. Apart from this, rubber plantations in large and medium estate were also identified. These identified holdings were ground visited and recorded geographical location using hand held global positioning system (GPS) and collected information regarding the clone, age, tapping system and management system. From this, holdings were selected after giving due consideration to their distribution and balance representation to three SMU groups. Total of 74 holdings from Kanyakumari district and 63 holdings from Kasargod district were selected for the study. View of some of holdings is given in Plate I. Geographical location and holdings detail is given in Appendix I. SMU wise distribution of holdings in both the district is as follows. Characteristics of SMU's are given in Appendix III

SMU group	Kanyakumari	Kasargod
SMU 1& 2	32	31
SMU 3 & 4	19	23
SMU 5, 6 and 7	23	9
Total	74	63

In Kasrgod district total geographical area as well as rubber area under SMU 5, 6 and 7 was comparatively less and hence sufficient holdings could not be selected in this category. Point vector file containing the geographical distribution of selected holding was created for each district.

3.1.5 **Soil and Leaf Sample Collection and Recording Observation**

Soil and leaf sample collection was carried out during May to June 2011. Surface soil sample (0-30 cm) was collected from inter row at 4 to 5 locations in the selected holdings and composite sample was prepared. Bulk density (BD) sample was collected using core method (Gupta and Dakshinamurthy, 1980). Girth of 100 rubber trees was recorded at breast height. Trees showing complete tapping panel dryness (TPD) were noted and expressed as percentage. Leaf samples were collected from 10-12 trees following the standard procedure. Other details like type and quantity of fertilizer applied, number of trees tapped, average weight of a sheet and presence of cover crops etc. were noted. Collected total dry rubber yield and tapping days from all the holdings on monthly basis and calculated average dry rubber yield per tree for each tapping (g/tree/tap). For each holding, annual dry rubber yield (kg/ha/year) was estimated for standard block of 350 trees per hectare by multiplying average rubber yield per tree per tap with the respective annual tapping days.

Plate I. General view of small rubber holdings

3.1.6 **Physical and Chemical Analysis of Soil Samples**

Soil samples were air dried and sieved with 2 mm sieve and labeled for further analysis. Bulk density (BD) sample were dried in hot air oven at 105 ^{0}C and dry weight was recorded. The dry weight of soil divided with volume of core sampler and expressed the BD as g/cc. From core samples gravel portion was separated, weighed and estimated their volume following water displacement method. Then gravel content was expressed on volume and weight basis as per cent. Sieved soil was subsampled for determination of moisture content at field capacity (FC) (-0.03 MPa) and wilting point (WP) (-0.15 MPa) using the pressure plate method (Klute, 1986). Soil available water content (AWC) was estimated as difference between FC and WP and expressed as mm/meter after correcting with gravel content. Sieved soil samples were analyzed for following chemical parameters.

3.1.6.1 *Soil Organic Carbon*

Soil organic carbon was estimated by Walkley and Black method (Jackson, 1958)

3.1.6.2 **Soil pH**

Soil pH was measured in water (1:2.5, soil: water ratio) (Black, 1965). A measured quantity of soil was equilibrated with specified quantity of distilled water. The pH of the suspension was determined electrometrically on a direct reading pH meter with combined calomel-glass electrode.

3.1.6.3 *Available Phosphorus*

Available P was extracted using Bray-II extract (0.03 N ammonium fluoride in 0.1 N HCl) (Bray and Kurtz, 1945) and estimated colorimetrically by molybdenum blue method at 660 nm wavelength.

3.1.6.4 *Available Potassium*

Available K was extracted by Morgan's reagent (Sodium Acetate + Acetic acid buffer of pH 4.8) (Morgan, 1941) and estimated by flame photometer.

3.1.6.5 *Calcium and Magnesium*

Calcium and Magnesium from the Morgan extract was estimated by atomic absorption spectrometer.

3.1.7 Leaf analysis

3.1.7.1 *Leaf Nutrient Content*

Leaf samples were collected following standard method and analyzed for major nutrients as per the method described by Jackson (1958). Samples were dried in a hot air oven at 80^0C and powdered before analysis.

3.1.7.1.1 *Nitrogen*

Nitrogen content of leaf was determined by microkjeldhal method using a nitrogen analyser (Kjeltec 2300-FOSS Tecator, Sweden).

3.1.7.1.2 ***Phosphorus***

Phosphorus content of leaves was determined by Vanadamolybdate method using an autoanlayzer (Auto Analyzer-3_Bran Luebbe, Germany).

3.1.7.1.3 ***Potassium***

Potassium content of leaves was determined flame photometrically using an autoanalyzer.

3.1.7.1.4 *Calcium*

Calcium content of leaf was determined using atomic absorption spectrometer (Avanta GBC scientific equipment Co. Ltd, Australia).

3.1.7.1.5 ***Magnesium***

Magnesium content of leaves was determined using atomic absorption spectrometer.

3.1.7.2. ***DRIS index Calculation***

Balance in leaf nutrient status was assessed by calculating DRIS indices for N, P, K, Ca and Mg nutrient using leaf nutrient content values and DRIS norms developed by Joseph *et al.* (1993).

3.1.8 **Recording Rainfall**

Monthly rainfall readings were collected from the available weather stations in both districts. Following are the list of stations in each district from where rainfall data was collected for the year 2011-12.

District	Location	Latitude (Degree)	Longitude (Degree)
Kanyakumari	New Ambady Estate	8.436	77.267
	ABC Estate	8.388	77.274
	Kamadhenu Estate	8.42	77.320
	Velimala Estate	8.28	77.38
	Hariharaputra Estate	8.453	77.230
	Keeriparai Estate	8.385	77.415
	Vaikundam Estate	8.424	77.238
Kasargod	Kasargod	12.5	74.98
	Badiyadka	12.59	75.1
	Paika	12.54	75.1
	Uppala	12.67	74.91
	Panniyur	12.1	75.4
	Pilicode	12.2	75.2
	Manjeshwaram	12.72	74.89
	Kotamala	12.34	75.33
	Cheemeni	12.24	75.23

In order to get better spatial distribution of rainfall observations, daily rainfall readings derived from TRMM 3B42 version 7 data at 0.25 x 0.25 degree grid data were also downloaded to fill the spatial gaps (*http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V7.3B42_daily.shtml*). TRMM grid rainfall data for 6 locations in Kasargod and 4 locations in Kanyakumari were used. Point vector file was created for these stations and monthly rainfall data in excel was joined for generating the monthly rainfall map using kriging spatial interpolation technique.

3.1.9 Topographic Parameters

Topographic parameters like slope and elevation were derived for rubber growing regions of both districts from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 30 x 30 m resolution. Elevation and slope of holdings in both district was extracted by overlaying these point over the respective district map.

3.1.10 Soil Water Balance

The monthly water balance in the soil was estimated using monthly total rainfall (mm), monthly total potential evapotranspiration (PET) (mm) and Field Capacity (FC) (mm) of soil following the Thornthwaite-Mather's book keeping method (Thornthwaite and Mather, 1955). Precipitation, PET, soil moisture storage, actual evapotranspiration (AET), surplus and deficit are the water balance components. Computation of monthly water balance was carried out using the ArcGIS water balance toolbox (Dyer, 2009). Inputs used for this calculation are layers of raster image of monthly rainfall, monthly PET, and AWC image. To assess the adequacy of moisture availability, an index called Moisture availability index (MAI) was calculated i.e., MAI = AET/PET x 100. MAI values are grouped into following 4 categories (Krishnan, 1971).

1. $\geq$ 75 % - Excellent moisture availability
2. 50 – 74 % - Good moisture availability
3. 24- 49 % - Poor moisture availability
4. $\leq$ 24% -Very poor moisture availability

Category 1 and 2 indicates adequate moisture and category 3 and 4 as moisture stress (Krishnan, 1971). Using the monthly MAI values, moisture stress period was identified in both districts and climate constraint map was prepared.

3.1.11 Geo-statistical Analysis

Created attribute data table (Excel format) and entered all the soil and leaf analysis results in separate column with each row of record representing sample number. This attribute data table was linked to the holdings point data file using sample number as primary key field for joining. After joining attribute data, data exploration was done by generating histogram and descriptive statistics. Based on initial data exploration, necessary transformation was done for the variable which did not show normal distribution. Then ordinary kriging (Krige, 1951) was performed to generate the continuous interpolated surface map of an attribute from a set of scattered point sample field data. First empirical semivariogram model estimates were derived from data which indicates the spatial autocorrelation of dataset. Range, sill, and nugget are commonly used parameters to describe the empirical semivariogram model. The distance where the model first flattens is known as the range. Sample locations separated by distances closer than the range are spatially autocorrelated, whereas locations farther apart than the range are not. The value at which the semivariogram model attains the range is called the sill. Theoretically semivariogram model should pass through origin, but often intercept y axis and this is called as nugget effect and value at which intercept the y axis is the nugget value. Range, sill and nugget parameters were noted for each soil parameter and spatial dependence was assessed from ratio of nugget to sill (Cambardella *et al.*, 1994). The parameter was considered to have strong spatial dependence if ratio is less than 25 per cent and moderate spatial dependence, if ratio was 25-75 per cent. Different mathematical models like circular, spherical, exponential, Gaussian and linear were fitted to empirical semivariogram model to get continuous surface function or curve. Best fit model with smallest nugget value with minimum root mean square error (RMSE) was selected. Using the best fitted model, created continuous surface map for each soil property using the extent of rubber distribution as mask. Districtwise soil nutrient map was developed by grouping continuous spatial soil values into different classes, i.e. low medium and high based on soil ratings.

3.1.12 GIS and Overlay Analysis

For each district all the geospatial information like, rubber distribution, soil information, climate, soil maps, slope and elevation were brought into GIS platform for overlay analysis. Raster overlay analysis was done in Geomatica v 10.3.2 and vector overlay analysis in ArcGIS v 10. Vector overlay of rubber distribution and SMU layer was done to get the extent of rubber area distribution over SMU classes. Raster overlay of rubber distribution over slope and elevation layer was done to get the extent of rubber distribution over elevation and slope classes. Similarly raster overlay of soil maps with climate and rubber was done to get the extent of rubber area distribution over soil and climate constraint areas.

Experiment II:

3.2 SOIL NUTRIENT DYNAMICS OF MATURE RUBBER PLANTATION IN RELATION TO PHENOLOGY AND GROWING ENVIRONMENT

3.2.1 **Location of the Study**

Kottayam district representing the major rubber growing district in Kerala having different growing environment and elevation was selected for the study (Fig. 2). Kottayam district, located in central part of Kerala between latitude 9.41^0 to 9.71^0 and longitude of 76.36^0 to 76.59^0. Using ASTER digital elevation model (DEM), Kottayam district was divided into three growing environments based on three elevation classes; low (0-100 m), medium (100-300m) and high elevation (> 300m).

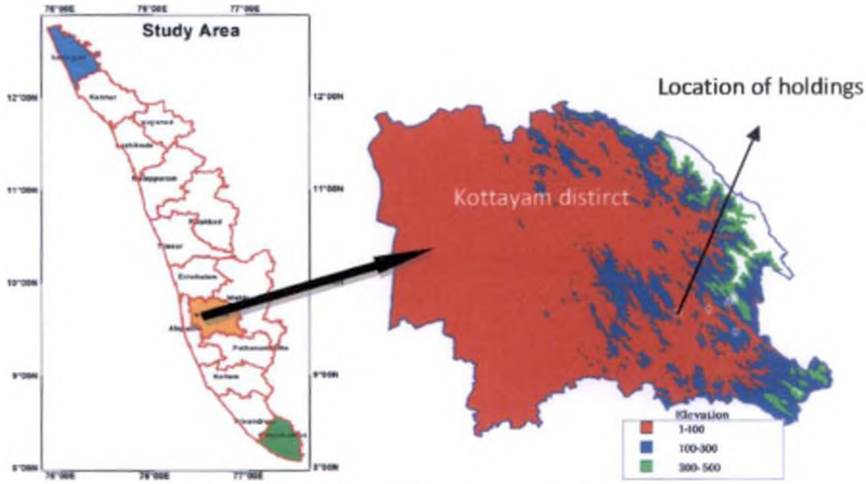


Fig. 2 Location of Experiment II study area

3.2.2 **Selection of Holdings**

Identified the rubber holdings/estates of RRII 105 of age 10-15 year old located in three elevation classes with the help of Rubber Board Regional office, Kanjirapally. Visited these identified holdings and recorded GPS readings. Using GPS readings, confirmed their locations coming within the three elevation classes. Total of six holdings were identified with two holdings in each growing environment. Details of holdings location is given below. From each holding four uniform girth rubber trees were selected as observational plants and paint marked.

Table 1: Geographical location of the holdings selected for the experiment II

Elevation	Village	Holding	Lat.	Long.	Elevation (m)
High (>300 m)	Parthanam	I	9^0 35' 30.24"	76^0 51' 14.7"	399
	Parthanam	II	9^0 35' 17.10"	76^0 51' 22.8"	432
Medium (200-300m)	Chittadi	I	9^0 32' 31.50"	76^0 51' 08.2"	204
	Choti	II	9^0 35' 02.60"	76^0 50' 49.1"	186
Low (0-100m)	Kanjirapally	I	9^0 34' 14.84"	76^0 46' 46.78"	70
	Kanjirapally	II	9^0 34' 26.50"	76^0 49' 17.2"	82

3.2.3 **Sample Collection**

3.2.3.1 ***Soil Sample Collection***

Four sampling spots were marked with peg around each observational tree. Surface soil sample (0-30 cm) was collected from these selected spots at monthly interval.

3.2.3.2 ***Leaf Litter Sample Collection***

Leaf litter fall was collected during January 2011 from 1 m square area at 5 locations in each holding and recorded dry weight and expressed as tons/ha. Similarly leaf fall due to powdery mildew disease (*Oidium heveae* Steinm) during February and *phytophthora* leaf fall (*Phytophthora palmivora* Butl.) during August/September was collected from 1m square area at 5 locations in each holdings and recorded dry weight and expressed as kg/ha.

3.2.4 **Leaf Litter Decomposition**

Rate of leaf litter decomposition was assessed by following litter bag method (Bocock and Gilbert, 1957). In each holding 10 nylon litter bag of size

30x30 cm with mesh of 2mm were used. Litter bag containing 100g of rubber litter were placed randomly in contact with surface soil in February 2011. Form each holding half of litter bags were randomly recovered during June 2011 and rest during September 2011. Recovered litter was oven dried and recorded dry weight. Loss in dry weight was expressed as per cent of initial litter weight.

3.2.5 Leaf Litter Nutrient Content

Oven dried fresh leaf litter as well as litter retrieved from litter bag study was finely ground and C, N, P, K, Ca and Mg content were estimated following standard procedure mentioned previously.

3.2.6 Recording Observations

Girth of observational tree was recorded at breast height at quarterly interval. Light intensity below the canopy was recorded using light meter and expressed as per cent to open. Rubber yield was recorded from selected holdings at monthly interval and expressed as gram per tree per tap (g/t/t).

3.2.7 *Phenology*

In each holding, observational trees as well as whole block were visually assessed and noted at monthly interval for the phenological events like leaf shedding, leaf flushing, leaf maturity, flowering and fruit growth. In addition, occurrence of leaf disease like *Oidium* and abnormal leaf fall were also noted.

3.2.8 *Weather Parameters*

Weather parameters; rainfall, maximum and minimum temperature, were recorded daily at one locations in each elevation classes. Above weather parameters were recorded at Palampara estate representing low elevation, Vengahtanam and Chittadi Estate representing medium elevation and Kuttical Estate representing high elevation.

3.2.9 *Soil Moisture*

Soil moisture was recorded (gravimetric) at monthly interval from the surface (0-30 cm). Soil sample was collected from the observational trees at each location and expressed as per cent dry weight.

3. 2.10 **Analysis of Soil Samples**

From each selected holdings, soil sample was collected from four locations around each observational trees at monthly interval and analyzed for following chemical properties.

3.2.10.1 *Mineral Nitrogen*

Mineral nitrogen was extracted from field moist soil with 2 M KCl (soil: solution ratio, 1:5) shaking for one hour and filtered. Nitrate (NO_3^-) and Ammonium (NH_4^+) nitrogen content of extract was determined by microkjeldhal method using a nitrogen analyser (Kjeltec 2300-FOSS Tecator, Sweden) (Bremner and Keeney, 1965). The sum of nitrate (NO_3^-) and ammonium (NH_4^+) nitrogen is referred to as Mineral-N (Keeney and Nelson, 1982; Buresh, *et al.*, 1982).

3.2.10.2 ***Soil Organic Carbon***

Soil organic carbon of air dried and sieved soil was estimated by Walkley and Black method (Jackson, 1958)

3.2.10.3 **Soil pH**:

Soil pH was measured in water (1:2.5, soil: water ratio) (Black, 1965). A measured quantity of soil was equilibrated with specified quantity of distilled water. The pH of the suspension was determined electrometrically on a direct reading pH meter with combined calomel-glass electrode.

3.2.10.3 *Exchangeable Aluminium*

Soil was leached with un-buffered 1M KCl in the ratio of 1:10 and the exchangeable aluminum (Al^+) in the leachate was estimated colorimetrically with aluminon method (Mc Lean, 1965) and the intensity of the colored complex was measured at 535 nm (Hsu, 1963; Jayman and Sivasubramhaniam, 1974).

3.2.10.4 ***Nitrogen Mineralization***

Nitrogen mineralization was recorded using the modified *in situ* soil core method (Raison *et al.*, 1987). In each holding three pairs of galvanized iron soil cores of 30 cm length and 3 cm diameter were installed at different location. One soil core was kept open and another was covered with tin sheet cap to avoid entry of rain water (Plate II). After one month, open and covered soil cores were recovered and soil was analyzed for mineral nitrogen content following the method described above.

3.2.11 **Nutrient Resorption**

Green and ripened leaves were collected from selected four observational plants in each plot. Green leaves were collected following standard procedure and ripened leaves were collected before falling by shaking the braches/trees. Leaf samples were processed for leaf area and mass estimation and then oven dried to constant mass at 60^0C. Oven dried leaf samples were powdered and analyzed for major nutrient content following standard procedures described earlier. Leaf nutrient content was expressed on leaf area basis to account for confounding reduction of leaf mass during senescence. Nutrient Resorption Efficiency (NRE) was calculated according to Finzi *et al.* (2001).

$$\text{NRE (\%)} = \frac{\text{Nutrient conc. of green leaf - Nutrient conc. of ripened leaf}}{\text{Nutrient conc. of green leaf}} \times 100$$

3.2.12 **Statistical Analysis**

Data were screened for normal distribution and wherever necessary appropriate transformation was applied to the data to make it normal distribution. The data collected from the experiment were analyzed by applying the analysis of variance (ANOVA) technique (Gomez and Gomez, 1984). Significance of

Plate II. In-situ soil core nitrogen mineralization technique variation of a variable among the SMU's was tested following one way ANOVA with three SMU groups as treatments and number of holdings coming under each SMU group as replication. Whenever significant difference was observed between treatments, critical difference (CD at 5 % level) was provided for means comparison. Two samples 't' test was used to compare two sample means. In experiment II repetitive observation were analysed by two way ANOVA with elevation and months as factors. Correlation studies were also conducted to ascertain relation between various parameters. Factor analysis was done to represent correlated variable with small homogeneous set of factor/component that represent underlying process/factor and are independent of one another. Factors were extracted following principle component analysis method. Extracted component rotated with varimax method. Factors whose eigenvalue was more than one were only selected. Based on loading of dominant variables into selected component, each component was named and Pearson correlation coefficient was estimated to assess relation between extracted component and rubber growth and yield.

3.2.13 **Software Used**

SPSS v 9.0 was used for statistical analysis. Geo-statistical analysis and mapping was performed using geo-statistical analyst extension of ArcGIS v 10. Water balance calculation was done using ArcGIS water balance toolbox (Dyer, 2009). Geomatica v 10.2 was used for image analysis. ArcGIS v 10 was used for database creation, geospatial analysis and overlay analysis.

RESULTS

4. RESULTS

Observations recorded under the experiments as mentioned in the previous chapter are processed, analyzed and presented experimentwise in this chapter.

Experiment I:

4.1 GEOSPATIAL ANALYSIS OF SOIL AND CLIMATE VARIABILITY ON PERFORMANCE OF RUBBER

4.1.1 **Soil Variability.**

Descriptive statistics of different soil parameters recorded from soil samples collected from different holdings in Kanyakumari and Kasaragod district are presented in Table 2. Different soil properties of all the holdings in a district are presented as bar graph (Fig 3 to 10).

4.1.1.1 *Soil Organic Carbon*

Mean organic carbon (OC) of the holdings was 1.3 and 3.0 per cent with range of 3.6 and 4.7 in Kanyakumari and Kasargod district respectively (Table 1). Broadly OC level was medium in Kanyakumari district where as it was high in Kasargod district. Two sample 't' test showed the significant difference between mean OC of two districts (Table 2). In Kanyakumari, 66 per cent of holdings showed soil OC in medium range (0.75 – 1.5 %) and 19 per cent above medium range. In Kasargod, 95 per cent of the holdings soils OC were above the medium range (Fig. 3).

4.1.1.2 *Soil Available Phosphorus*

Mean available P of holdings was 19.9 and 4.7 mg/kg with range of 123.4 and 75.5 mg/kg in Kanyakumari and Kasargod district respectively (Table 2). Two sample 't' test showed that the mean available P between the districts is significantly different (Table 1). Soil available P of 50 per cent holdings in Kanyakumari were in low range (< 10mg/kg), 28 per cent in medium range (10-25 mg/kg) and 21 per cent in high range (>25 mg/kg). In Kasargod 90 per cent holdings showed soil available P in low range (Fig 4).

4.1.1.3 ***Soil Available Potassium***

Mean available K of holdings was 100.4 and 56.2 mg/kg with range of 271.3 and 99.0 mg/kg in Kanyakumari and Kasargod district respectively (Table 2). Available potassium of 69 per cent of holdings in Kanyakumari was within medium range (50-125 mg/kg), 20 per cent in high range and 10 per cent low range of available K (Table 2 and Fig. 5). In Kasargod district available K of 52 % of holdings was in the lower range (<50 mg/kg) and 48 per cent in medium range (50-125 mg/kg). Two sample 't' test showed that the mean available K of Kanyakumari district (100.4 mg/kg) was significantly different from mean available K of Kasargod district (56.2 mg/kg) (Table 2).

Table 2. Descriptive statistics of soil parameters

Parameter	District	Mean	Range	S.Em	Sample Variance	Two sample 't' test
OC (%)	Kanyakumari	1.3	3.6	0.1	0.4	12.82*
	Kasargod	3.0	4.7	0.1	0.8	
Av P (mg/kg)	Kanyakumari	19.9	123.4	3.3	787.1	4.37*
	Kasargod	4.7	75.5	1.3	103.6	
Av K (mg/kg)	Kanyakumari	100.4	271.3	6.1	2778.3	6.71*
	Kasargod	56.2	99.0	2.9	518.5	
Av Ca (mg/kg)	Kanyakumari	237.3	847.7	20	29534.3	3.29*
	Kasargod	343.6	945.4	23.5	34676	
Av Mg (mg/kg)	Kanyakumari	63.9	217.1	6.1	2732.6	4.91*
	Kasargod	142.1	517.9	14.2	12774.2	
pH	Kanyakumari	4.8	2.2	0.0	0.1	11.05*
	Kasargod	5.3	0.7	0.0	0.0	
Gravel (%)	Kanyakumari	8.2	22.1	0.73	38.1	1.96*
	Kasargod	6.6	7.8	0.25	4.0	
B D (g/cc)	Kanyakumari	0.8	0.4	0.0	0.0	1.31
	Kasargod	0.7	0.7	0.0	0.0	
AWC (mm/m)	Kanyakumari	47.6	88.3	2.2	364.7	0.27
	Kasargod	46.8	117.2	2.3	327.5	

* Two sample 't' test significant at 0.05 level

4.1.1.4 ***Soil Available Calcium***

Mean available calcium of Kanyakumari and Kasargod was 237.3 and 343.6 with range 847.7 and 945.4 mg/kg respectively (Table 2). In Kanyakumari

76 per cent of holdings were above high range (>125mg/kg) and 20 per cent in medium range (50-125 mg/kg) (Table 2 and Fig. 6). Four per cent holdings showed available calcium in low range. In Kasargod available calcium of 94 per cent of the holdings were in high range (>125mg/kg) and rest in medium range (50-125 mg/kg). Two sample 't' test showed that the mean available Calcium of Kanyakumari district (237.3 mg/kg) was significantly lower from mean available Calcium of Kasargod district (343.6 mg/kg) (Table 2).

4.1.1.5 *Soil Available Magnesium*:

Mean available soil magnesium of Kanyakumari and Kasargod was 63.9 and 142.1 mg/kg with range of 217.1 and 517.9 mg/kg respectively (Table 2). In Kanyakumari 81 per cent of holdings have soil available magnesium in high range (>25 mg/kg) and 16 per cent in medium range (10-25 mg/kg) (Fig. 7). In Kasargod 98 per cent of the holdings showed soil available magnesium in high range. Two sample 't' test showed that the mean available Mg between the districts is significantly different (Table 2).

4.1.1.6 *Soil pH*

In Kanyakumari 70 per cent of the holdings showed soil pH of 4.5-5.0 whereas in Kasargod 94 per cent of holdings showed soil pH of > 5.0 indicating slightly more acidic soil reaction in Kanyakumari (Fig 8). Mean soil pH was 4.8 and 5.3 with range of 2.2 and 0.7 in Kanyakumari and Kasargod district respectively (Table 2). However in both districts, soils pH range was within the optimum range (4.5 - 5.5) for rubber. Two sample 't' test showed that the soil pH of Kanyakumari district was significantly different from Kasargod (Table 2).

4.1.1.7 *Gravel Content*

Mean gravel content of soil in Kanyakumari was 8.2 and 6.6 per cent with range of 22.1 and 7.8 per cent respectively (Table 2 and Fig. 9). In Kanyakumari 88 per cent of holdings showed < 15 per cent and rest above 15 per cent gravel content. In Kasargod all holdings showed less than 15 per cent gravel content. In general gravel content varied more among the holdings in Kanyakumari than Kasargod district. Two sample 't' test showed soil gravel content of Kanyakumari and Kasargod differed significantly (Table 2).

4.1.1.8 *Soil Bulk Density*

Mean soil bulk density (BD) was 0.8 and 0.7 g/cc with range of 0.4 and 0.7 g/cc in Kanyakumari and Kasargod respectively (Table 1). Two sample 't' test showed that the soil BD of Kanyakumari and Kasargod did not differ significantly (Table 2).

4.1.1.9 *Soil Available Water Content*

Mean available water content (AWC) of soil was 47.6 and 46.8 mm/m with range of 88.3 and 117.2 mm/m in Kanyakumari and Kasargod respectively (Table 2). In Kanyakumari 62 per cent of holdings showed < 50 mm/m and 34 per cent holdings showed 50-100 mm/m AWC (Fig. 10). In Kasargod 59 per cent holdings showed < 50 mm/m and 40 per cent 50-100 mm/m AWC. Two sample 't' test showed that the soil AWC of Kanyakumari and Kasargod did not differ significantly (Table 2).

4.1.1.10 *Developing Soil and Holdings Database*

Districtwise soil and soil management unit (SMU) map brought into GIS is presented in Fig 11a. Using the GPS readings, holdings were marked as point and linked the holdings database containing farmers detail, holdings elevation, slope and all the soil and leaf analysis results of corresponding holding. Districtwise distribution of holdings over SMU is given in Figure 11b. Holding database linked to point file is given in Appendix II.

4.1.1.11 *Soil Management Units*

Soil management unit area under each districts rubber growing zone is presented in Figure 12. Area under soil management unit 1 and 2 was 20731.4 ha in Kanyakumari compared to 40680.5 ha in Kasargod district (Fig. 12). Similarly area under SMU 3-4 was 12602.6 and 19501.3 ha and area under SMU 5-7 was 7868.8 and 6534.2 ha in Kanyakumari and Kasargod district respectively. In general the extent of SMU 1 & 2 having less limitation for rubber cultivation was more in Kasargod compared to Kanyakumari district. Spatial distribution of SMU shows that SMU 1&2 in Kanyakumari is concentrated in southern part of district whereas in Kasargod it is randomly distributed.

4.1.2 Spatial Variability of Soil Parameters

Experimental variogram model parameters and predicted continuous surface map of each property is presented in Table 3 and Figures 13a to 13e respectively. Exponential model was the best fitted model for most of the soil parameters. Ratio of nugget to sill indicating the spatial dependence was strong with respect to available K and Ca whereas soil OC and average rubber yield showed moderate spatial dependence in both district (Table 3). Available P showed moderate spatial dependence in Kanyakumari whereas strong spatial dependence was seen in Kasargod. Similarly available Mg showed strong spatial dependence in Kanyakumari whereas it was moderate in Kasargod. Range, which is a measure of length of spatial autocorrelation, was sufficiently long in most parameters, thus the current sampling distance is appropriate. Except available P and average yield of rubber in Kasargod, RMS error of prediction was low in all the parameters indicating the better prediction. Predicted continuous surface map of soil nutrients grouped into low, medium and high ranges showed variability in both district (Fig.13a and e).

Table 3. Variogram model parameters of soil and yield parameters

Parameter	District	Model	Nugget	Sill	Range	Nugget / Sill	RMSE
OC (%)	Kanyakumari	Spherical	0.03	0.11	1823	0. 28*	0.32
	Kasargod	Exponential	0.33	0.75	4528.8	0.44*	0.83
Av. P (mg/kg)	Kanyakumari	Exponential	0.95	2.91	4566.3	0.33*	1.69
	Kasargod	Spherical	0.0	3.16	455.43	0.01**	9.18
Av. K (mg/kg)	Kanyakumari	Exponential	1.19	6.30	5158.5	0.19**	2.5
	Kasargod	Exponential	0.04	0.14	2625	0.25**	0.37
Av. Ca (mg/kg)	Kanyakumari	Exponential	0.10	0.46	3586.8	0.22**	0.61
	Kasargod	Exponential	0.06	0.28	455.4	0.19**	0.63
Av. Mg (mg/kg)	Kanyakumari	Exponential	0.08	0.72	5414.6	0.11**	0.68
	Kasargod	Exponential	0.11	0.40	5956.58	0.26*	0.59
Average. Rubber yield (g/tree/tap)	Kanyakumari	Exponential	0.06	0.15	4931.8	0.37*	0.31
	Kasargod	Exponential	0.04	0.08	4827.6	0.48*	10.7

** Strong spatial dependence * Moderate spatial dependence

4.1.2.1 **Soil Nutrient Constraint Areas**

All interpolated soil nutrient maps were brought into GIS and made union. Then grouped into different areas having combination of different levels of nutrients and presented in Fig. 14. Numbers of soil nutrient combinations were more in Kanyakumari compared to Kasargod. In Kanyakumari major area was medium in OC, available K, low in available P and high in available Ca and Mg. In Kasargod major area was low in available P, medium in available K, high in OC, available Ca and Mg.

4.1.3 **Variation of Land Topography.**

Topographic features like elevation and slope map derived from ASTER Digital Elevation Model (DEM) for rubber growing region of Kanyakumari and Kasargod district is presented in Fig 15a and 16a. Elevation and slope distribution in rubber growing tract of each district is presented in Fig. 15b and 16b.

4.1.3.1 ***Elevation***

In Kanyakumari district major area (70 %) was under the low elevation (0-100m), where as in Kasargod 43 per cent area was under 0-100 m and 39 per cent under 100-200m elevation (Fig 15b) indicating the higher elevation area in Kasargod compared to Kanyakumari.

4.1.3.2 ***Slope***

In Kanyakumari district major area (80 %) was under the slope below 5-10 per cent where as in Kasargod district area spread over all slope class with large area between the slope classes of 5-10 to 15-25 per cent indicating higher slope area in Kasargod compared to Kanyakumari (Fig 16b).

4.1.4 **Climate Variability**

Monthly total rainfall and potential evapotranspiration for 2011-12 for Kanyakumari and Kasargod is presented in Fig 17-18.Total annual rainfall for 2011-12 in Kanyakumari was 1228 mm compared to 3462 mm received in Kasargod district (Table 4a). Monthly rainfall distribution in Kanayakumari was bimodal with one peak during monsoon season and another in post monsoon season (Fig 17). On the other hand, rainfall in Kasasrgod was unimodal distribution with peak during monsoon (Fig 18). Post monsoon rainfall was not prominent in Kasargod. Another characteristic is that in Kanaykumari rainfall was well distributed and almost all months received rain, where as in Kasargod bulk of the rainfall was received over 5 months starting from June to October and during December to March no rains were received. Spatial distribution of annual rainfall in both districts is given in Figure 19a. In Kanyakumari spatial distribution of annual rainfall showed variation with central portion of Kanyakumari receiving more rainfall and it declined progressively towards south. In Kasargod also spatial distribution of annual rainfall showed variation with coastal region around Iriyani received more rainfall and it reduced progressively towards South-West region. During 2011-12 total annual potential evapotranspiration (PET) of Kanyakumari was 1981 mm compared to 1770 mm observed in Kasargod district. Peak PET (>150 mm) was observed during January to April months in both districts (Fig 17 and 18). Spatial distribution of annual PET for Kanyakumari and Kasargod is presented in Fig 19b. Annual PET showed spatial variation in both districts with high elevation showing low PET compared to lower elevation.

4.1.4.1 *Water Balance*

Different components of monthly water balance for each district was estimated and presented in Table 4a and b and Fig 20-21. In Kanyakumari, annual total rainfall was 1228.1mm against the potential evapotranspiration (PET) demand of 1749.5mm leading to the annual deficit of 546.4 mm and surplus of 8.7mm (Table 4b). Similarly in Kasargod district annual rainfall was 3461.7mm against the PET of 1770.1mm leading to annual deficit of 589.8mm and 2281.4mm rainfall as surplus which was 65.9 per cent of annual rainfall. This clearly indicates the tight water balance situation existing in Kanyakumari district. Monthly distribution of water balance components shows little surplus during June and October to Nov in Kanyakumari (Fg.20), whereas in Kasargod large surplus was seen during June to October period (Fig. 21). With respect to deficit, December to March is the period of deficit in both district, but the extent and severity was more in Kasargod. During August-September, coinciding with the period of end of South-West monsoon and before the onset of North-East monsoon, slight deficit was seen only in Kanyakumari. Annual AET in Kanyakumari was slightly more than Kasargod district.

Moisture adequacy index (MAI) estimated for both districts to assess the adequacy of moisture and to identify the stress period is presented in Figure 22-23. In Kanyakumari district moisture adequacy was poor during January and March and during rest of the month it was good to excellent. But in Kasargod, moisture adequacy was very poor during January to March and good to excellent during rest of the month. In Kanyakumari, during the month of September, moisture adequacy was reduced from excellent to good due to end of south-west monsoon and it again regained to excellent in October after start of north-east monsoon.

4.1.4.2. ***Climate Constraint Areas***

Using spatial MAI values in both districts, areas were grouped into different moisture stress category and presented in Figure 24. From the figure it is clear that in Kanyakumri even during the December to March period, central portion of the district showed good moisture adequacy indicating no moisture stress. Rest of the region showed poor moisture adequacy. On the other hand in Kasargod district during the same period, areas with good moisture status was not seen. Major area was under the poor moisture adequacy concentrated in Eastern part followed by very poor moisture adequacy areas in western part. Apart from moisture stress during December –March, one more moisture stress was seen in Kanyakumari district for short period during August to September coinciding with end of south-west monsoon and just before start of north-east monsoon (Figure 24). During August-September MAI was poor mainly in south-west part of Kanyakumari and rest of the area MAI was good (Fig 24).

Table 4a. Monthly water balance of Kanyakumari and Kasargod district (mm)

Month	Rainfall		PET		AET		Storage		Deficit		Surplus	
	Kanyakumari	Kasargod	Kanyakumari	Kasargod	Kanyakumari	Kasargod	Kanyakumari	Kasargod	Kanyakumari	Kasargod	Kanyakumari	Kasarg
Jan	13.2	1.3	164.0	175.5	60.1	44.1	19.8	34.1	103.9	131.4	0.0	0.0
Feb	79.8	2.5	178.8	128.9	88.2	18.1	11.8	18.5	90.6	110.9	0.0	0.0
Mar	40.9	3.2	211.8	222.5	49.5	15.0	3.2	6.7	162.4	207.5	0.0	0.0
Apr	170.2	135.0	142.8	136.0	138.7	127.3	34.7	14.4	4.0	8.7	0.0	0.0
May	80.8	95.8	147.7	148.3	93.8	98.4	21.8	11.8	53.9	49.8	0.0	0.0
Jun	194.5	831.6	120.8	127.2	122.3	127.2	122.6	211.7	0.0	0.0	0.0	504.
Jul	71.7	927.9	128.3	118.2	114.7	118.2	80.4	211.7	13.7	0.0	0.2	809.
Aug	67.2	748.5	130.8	108.4	95.7	108.4	51.6	211.7	35.1	0.0	0.6	640.
Sep	56.0	374.9	134.9	139.4	79.1	139.4	28.0	211.7	55.8	0.0	0.0	235.
Oct	174.6	227.5	136.3	135.9	135.3	135.9	67.7	211.7	1.0	0.0	0.0	91.6
Nov	193.1	108.9	148.5	162.7	145.9	155.8	107.1	164.8	2.6	6.9	7.9	0.0
Dec	85.8	4.5	149.7	167.1	126.2	92.5	66.6	76.9	23.5	74.6	0.0	0.0
Total	1228.1	3461.7	1794.5	1770.1	1249.5	1180.3	615.2	1385.8	546.5	589.8	8.7	2281.

AET-Actual Evapotranspiration PET- Potential Evapotranspiration

Table 4b. Annual water balance, mm

District	Rainfall	PET	AET	Deficit	Surplus
Kanyakumari	1228.06	1794.48	1249.52 (69 % PET)	546.45 (30 % PET)	8.72 (0.7% RF)
Kasargod	3461.65	1770.10	1180.28 (66.7 % PET)	589.82 (33 % PET)	2281.38 (65.9% RF)

4.1.5 Performance of Rubber

4.1.5.1 *Girth of Rubber*

Descriptive statistics of girth of rubber in different holding of each district is given Table 5. Mean girth of rubber was 63.4 and 58.6 cm with standard error of mean (S.Em) of 0.7 and 0.5 cm and range 28.8 and 18.2 cm in Kanyakumari and Kasargod district respectively (Table 5). Two sample't' test has shown that mean rubber girth of Kanyakumari and Kasargod district differed significantly (Table 6). Rubber girth in Kanyakumari was significantly higher than Kasargod district. Distribution of rubber girth in Kanyakumari and Kasargod is presented in Figure 25. In Kanyakumari, girth was above 60cm in 70 per cent of the holdings whereas in Kasargod girth was less than 60 cm in 65 per cent of holdings. Variation in rubber girth among SMU was analyzed by one way ANOVA and presented in Table 7. Rubber girth varied significantly among SMU groups in Kanyakumari district with SMU 1-2 and 3-4 recording significantly higher girth compared to SMU 5-7. However girth did not differ significantly between SMU 1-2 and 3-4. In Kasargod district girth did not differ significantly among SMU groups.

Table 5. Descriptive statistics of rubber girth, TPD in Kanyakumari and Kasargod

Parameter	Kanyakumari		Kasargod	
	Girth (cm)	TPD (%)	Girth (cm)	TPD (%)
Mean	63.4	5.6	58.6	8.5
S.Em	0.7	0.5	0.5	0.9
Range	28.8	26	18.2	38
Minimum	49.4	0	49.6	0
Maximum	78.2	26	67.8	38
No. of observations	74	74	63	63

Table 6. Comparison of rubber performance between two districts

Parameter	Kanyakumari	Kasargod	't" value
Girth (cm)	63.38	58.61	5.87*
TPD# (%)	4.71 (2.17)	7.08 (2.66)	-2.46*

Square root transformed * Significant at 0.05 level.
Figures in the parenthesis are transformed data

Table 7. Variation in rubber girth and TPD as influenced by SMU

SMU groups	Kanyakumari		Kasargod	
	Girth (cm)	TPD (%)*	Girth(cm)	TPD (%)
1 & 2	64.77[a]	5.11 (2.26)	58.5	7.38
3 & 4	64.57[a]	4.4 (2.10)	58.37	9.95
5,6 and 7	60.53[b]	4.54 (2.13)	58.7	6.98
Mean	63.48	4.71 (2.17)	4.07	8.42
S.Em	0.68	0.11	0.5	0.9
C.D. at 0.05	Sign at 0.05	NS	NS	NS

* Square root transformed. Figures in the parenthesis are transformed data

4.1.5.2 ***Tapping Panel Dryness*** (TPD)

Descriptive statistics of TPD observations in each district is presented in Table 5. Mean TPD incidence was 5.6 and 8.5 per cent with SEm of 0.5 and 0.9 per cent and range of 26 and 38 per cent in Kanyakumari and Kasargod district respectively. TPD incidence in two districts was compared using Two sample't' test and results showed that mean TPD incidence in Kasragod (7.1 %) was significantly higher than Kanyakumari (4.7 %)(Table 6). Variation in TPD incidence among the different SMU group in both districts was analyzed by one way ANOVA and presented in Table 7. Results have shown that TPD incidence among SMU groups in both districts did not show significant variation.

4.1.5.3 ***Leaf Nutrient Content***

Descriptive statistics of leaf nutrient content in different holdings of two districts is presented in Table 8. Variation in leaf nutrient content as influenced by SMU was analyzed by one way ANOVA and presented in Table 9. Mean leaf N content was 4.01 and 3.58 per cent with S.Em 0.05 and 0.04 and range of 3.03 and 1.20 in Kanyakumari and Kasargod district respectively (Table 8). In Kanyakumari leaf N was in high range where as in Kasargod it was in medium range. Leaf N content of rubber was not significantly influenced by the SMU in Kanyakumari as well as Kasargod districts (Table 9). Mean leaf P content was 0.29 and 0.25 with SEm of 0.01 and 0.003 and range of 0.2 and 0.1 in Kanyakumari and Kasargod respectively. In both districts leaf P contents was in medium range. In Kasargod leaf P content was significantly influenced by SMU with significantly low leaf P recorded in SMU 5- 7 compared to SMU 1-2 and SMU 3-4 (Table 9). Leaf P content did not differ significantly between SMU 1-2 and SMU 3-4.

Table 8. Descriptive statistics of leaf nutrient content, per cent

	Kanyakumari					Kasargod				
	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg
Mean	4.01	0.29	1.58	1.09	0.39	3.58	0.25	1.38	1.03	0.41
SEm	0.05	0.01	0.03	0.05	0.01	0.04	0.003	0.03	0.02	0.01
Range	3.03	0.20	1.06	2.02	0.27	1.20	0.10	1.60	0.55	0.31
Minimum	1.37	0.18	0.97	0.46	0.24	2.90	0.20	0.40	0.83	0.26
Maximum	4.40	0.38	2.03	2.48	0.51	4.20	0.30	2.00	1.38	0.57

In Kanyakumari district leaf P content was not significantly influenced by SMU. In Kanyakumari and Kasargod districts mean leaf K content was 1.58 and 1.38 per cent with SEm 0.03 and 0.03 and range of 1.06 and 1.60 respectively (Table 8). In both districts leaf K contents was in medium range. Leaf K content was not significantly influenced by SMU in both districts (Table 9). Mean leaf Calcium content was 1.09 and 1.03 per cent with SEm of 0.05 and 0.02 and range 2.02 and 0.55 in Kanyakumari and Kasargod district respectively. In both districts leaf Ca contents was in medium range. SMU did not significantly influence the leaf calcium content in both districts (Table 9). Mean leaf Mg content was 0.39 and 0.41 with SEm of 0.01 and 0.01 and range 0.27 and 0.31 in Kanyakumari and Kasargod district respectively. Leaf Mg content was significantly influenced by SMU in Kanyakumari district with SMU 5-7 recording significantly higher leaf Mg compared to SMU 3-4 but on par with SMU 1-2 (Table 9). Leaf Mg content in both districts was in high range. Leaf Mg content in SMU 3-4 did not differ significantly from leaf Mg content of SMU 1-2. In Kasargod district leaf Mg content did not vary significantly among the SMU.

4.1.5.4 ***Leaf Nutrient Index***

Using standard DRIS norms, nutrient indices were estimated for N, P, K, Ca and Mg nutrients for each district and descriptive statistics of indices are presented in Table 10. In Kanyakumari district mean nutrient index values were 0.84, -0.68, 1.83, -7.61, and 5.62 with SD of 5.73, 10.91, 8.92, 18.97, and 7.09 for N, P, K, Ca and Mg respectively. In Kanyakumari district, the mean nutrient index values indicate the balanced level of N, P and K nutrients whereas deficiency of Ca and excess level of Mg in relation to other nutrients. In Kasargod district, mean nutrient index values were -2.2, -5.89, -0.93, -3.88 and 12.9 with SD of 5.28, 6.09, 7.66, 4.55, 8.99 and range of 24.2, 27.1, 35.7, 22.8 and 41.1 for N, P, K, Ca and Mg respectively. Mean nutrient index values indicated the balance level of K and excess level of Mg nutrient whereas deficiency of nutrient in the order of P > Ca > N in relation to other nutrients in Kasargod.

Table 9: Leaf nutrient content as influenced by SMU

SMU	Kanyakumari					Kasargod				
	Leaf N	Leaf P#	Leaf K	Leaf Ca$	Leaf Mg	Leaf N#	Leaf P#	Leaf K#	Leaf Ca$	Leaf Mg#
1 & 2	4.00	0.30 (0.74)	1.62	1.04 (0.31)	0.38[ab]	3.53 (1.88)	0.25 (0.50)[a]	1.38 (1.37)	1.07 (0.26)	0.41 (0.64)
3 & 4	4.10	0.28 (0.73)	1.53	1.19 (0.34)	0.37[a]	3.61 (1.90)	0.25 (0.50)[a]	1.40 (1.38)	0.99 (0.24)	0.41 (0.64)
5- 7	4.08	0.30 (0.74)	1.58	0.99 (0.30)	0.41[b]	3.46 (1.86)	0.22 (0.47)[b]	1.24 (1.32)	1.07 (0.26)	0.38 (0.62)
Mean	4.04	0.28 (0.73)	1.59	0.99 (0.30)	0.39	3.57 (1.89)	0.25 (0.50)	1.38 (1.37)	1.03 (0.25)	0.41 (0.64)
S.Em C.D. 5%	0.03 NS	0.01 NS	0.03 NS	0.04 NS	0.01	0.01 NS	0.003	0.01 NS	0.003 NS	0.01 NS

#Square root transformed $ Log_{10} transformed   Figures in the parenthesis are transformed data

Table 10. Descriptive statistics of DRIS indices

District	Kanyakumari					Kasargod				
Parameters	N index	P index	K index	Ca index	Mg index	N index	P index	K index	Ca index	Mg index
Mean	0.84	-0.68	1.83	-7.6	5.62	-2.20	-5.89	-0.93	-3.88	12.90
SEm	0.67	1.27	1.04	2.21	0.82	0.67	0.77	0.97	0.58	1.14
SD	5.73	10.91	8.92	18.97	7.09	5.28	6.09	7.66	4.55	8.99
Range	25.39	57.7	46.58	107.7	40.22	24.16	27.06	35.70	22.76	41.12
Minimum	-14.0	-33.2	-21.8	-58.2	-18.4	-16.1	-19.2	-19.5	-13.4	-6.40
Maximum	11.39	24.47	24.75	49.49	21.87	8.04	7.84	16.23	9.38	34.72
No. of Observations	74	74	74	74	74	63	63	63	63	63

Variation in nutrient index values among the SMU was analyzed following one way ANOVA and presented in Table 11. Nutrient index values of N, P K and Ca did not vary significantly among SMU groups in Kanyakumari (Table 11). Mg index varied significantly among SMU with significantly higher Mg in SMU 5-7 compared to SMU 1-2 and SMU 3-4. On the other hand in Kasargod N, P, K and Mg index values did not vary significantly among SMU, but Ca index showed significant variation (Table 11). SMU 3-4 showed significantly lower Ca index value compared to SMU 1-2 and SMU 5-7 but Mg index of SMU 1-2 and SMU 5-7 were on par.

Table 11. Nutrient index values as influenced by SMU

SMU	Kanyakumari					Kasargod				
	N index	P index	K index	Ca index	Mg index	N index	P index	K index	Ca index	Mg index
1-2	0.39	-0.37	3.54	-8.53	4.96 [a]	-3.4	-5.0	-0.7	-3.2 [a]	12.2
3-4	1.56	-1.70	-0.03	-2.25	2.42 [a]	-1.5	-6.1	-0.5	-5.5 [b]	13.6
5-7	1.23	-1.05	1.23	-10.49	9.09 [b]	0.7	-9.5	-4.0	-0.7 [a]	13.5
Mean	0.93	-0.90	1.98	-7.53	5.53	-2.2	-5.9	-0.9	-3.9	12.9
S.Em	0.64	1.25	1.00	2.10	0.84	0.67	0.77	0.97	0.58	1.14
C.D. (0.05)	NS	NS	NS	NS	*	NS	NS	NS	*	NS

* Significant at 0.05

4.1.5.5 *Rubber yield*

Descriptive statistics of average per tree per tap rubber yield (g/tree/tap) and annual total rubber yield (kg/ha/yr) is presented in Table 12.

Table 12.Descriptive statistics of rubber yield

District	Kanyakumari		Kasargod	
Parameters	Average yield (g/tree/tap)	Annual total yield (kg/ha/year)	Average yield (g/tree/tap)	Annual total yield (kg/ha/year)
Mean	39.21	1779.06	39.10	1472.71
S.Em	1.84	66.35	1.32	51.35
S.D.	14.47	522.44	10.43	404.35
Range	69.69	2779.53	42.55	1755.11
Minimum	17.26	942.24	18.22	720.66
Maximum	86.95	3721.77	60.77	2475.77
No. of Observations	72	72	62	62

In Kanyakumari district, mean per tree rubber yield was 39.21 g/tree/tap with SD of 14.47 and range of 69.7 g/tree/tap. Similarly annual total rubber yield was 1779.1 kg/ha/year with SD of 522.4 and range of 2779.5 kg/ ha/year. In Kasargod district mean per tree rubber yield was 39.1 g/tree/tap with SD of 10.43 and range of 42.6 g/tree/tap. Annual total rubber yield in Kasargod district was 1472.7 kg/ ha/year with SD of 404.4 and range of 1755.1 kg /ha/year. Wide range in average per tree rubber yield and annual rubber yield was observed in Kanyakumari district compared to Kasargod district.

Annual total rubber yield and mean per tree per tap rubber yield during different periods was compared between two district using two sample 't" test and presented in Table 13. Average per tree rubber yield (g/tree/tap) as well as average per tree rubber yield (g/tree/tap) during different period did not differ significantly between two districts, except during December to March period (Table 13 and Fig. 26). Average per tree per tap rubber yield during December to March was significantly high in Kanyakumari compared to Kasargod. The annual total yield differed significantly between two districts with Kanyakumari (1779.1 kg/ha/year) recording significantly higher annual yield than Kasargod (1472.71 kg/ha/year). Mean number of tapping days during different season in two districts is presented in Figure 27. Number of tapping days in both districts during dry period (February-May) and post monsoon period (October – January) did not differ much, whereas during monsoon period mean tapping days in Kanyakumari was 45 days compared to 29 days in Kasargod district. Spatial interpolated map of average rubber yield (g/tree/tap) as well as annual total yield presented in Fig 28a and b. In Kanyakumari average as well as annual total yield of South-Western portion of rubber growing area was low compared to other areas. In Kasargod district no such trend was observed.

Table 13 Rubber yield variation between two districts at different period

District	Dec-Mar yield (g/tree/tap)	Feb -May yield (g/tree/tap)	June-Sept yield (g/tree/tap)	Oct to Jan yield# (g/tree/tap)	Average yield# (g/tree/tap)	Annual yield (kg/ha/year)#
Kanyakumari	43.2	30.16	39.91	40.85 (1.61)	36.59 (1.57)	1779.1 (3.22)
Kasargod	37.3	31.37	42.88	40.0 (1.60)	37.70 (1.58)	1472.7 (3.15)
't' Test	2.36*	0.65	1.16	0.44	0.50	3.30*

log_{10} transformed * Significant at 0.05 Figures in the parenthesis are transformed data

Rubber yield variation among SMU in each district was compared using one way ANOVA and results presented in Table 14 and 15. In Kanyakumari per tree rubber yield during February to May period only showed significant variation among the SMU, whereas per tree rubber yield during other period did not differ significantly among the SMU (Table 14). During February – May period SMU 5-7 recorded significantly low per tree yield compared to SMU 3-4 but on par with SMU 1-2 (Table 14). Annual total rubber yield did not show significant variation among SMU in Kanyakumari (Table 14). In Kasargod, per tree rubber yield during different period as well as annual yield did not show significant variation among the SMU (Table 15).

Table14. Rubber yield during different period as influenced by SMU

SMU	Kanyakumari					
	Dec-Mar yield (g/tree/tap)	Feb -May yield # (g/tree/tap)	Jun-Sep yield (g/tree/tap)	Oct to Jan yield# (g/tree/tap)	Average yield# (g/tree/tap)	Annual total yield (kg/ha/year)
1 & 2	42.3	27.7 (1.44)[ab]	38.96	41.26 (1.61)	35.9 (1.55)	1817.5
3 & 4	48.5	33.4 (1.53)[b]	45.97	47.0 (1.66)	42.9 (1.63)	1737.3
5 - 7	39.9	24.5 (1.39)[a]	36.21	38.9 (1.58)	33.4 (1.52)	1617.0
Mean	43.2	28.18 (1.45)	39.91	40.74 (1.61)	36.3 (1.56)	1739.0
C.D 0.05	NS	*	NS	NS	NS	NS

Log_{10} transformed. Figures in the parenthesis are transformed data

Table15. Rubber yield during different period as influenced by SMU in Kasargod

SMU	Kasargod					
	Dec-Mar yield (g/tree/tap)	Feb -May yield (g/tree/tap)	June-Sep yield (g/tree/tap)	Oct to Jan yield $ (g/tree/tap)	Average yield $ (g/tree/tap)	Annual Total Yield # (kg/ha/year)
1 & 2	37.4	31.63	41.00	42.3(6.50)	38.19(6.18)	1318.3(3.12)
3 & 4	36.2	31.43	44.32	39.6(6.29)	37.82(6.15)	1288.3(3.11)
5- 7	42.1	29.82	46.28	42.9(6.55)	42.12(6.49)	1445.4(3.16)
Mean	37.3	31.37	42.88	41.2(6.42)	38.4(6.2)	1318.3(3.12)
C.D 0.05	NS	NS	NS	NS	NS	NS

Log_{10} transformed $ square root transformed Figures in parenthesis are transformed data

Pearson correlation coefficient was estimated to know the relationship of rubber performance with different soil properties in each district and results are presented in Table 16 and 17. In Kanyakumari district soil OC showed significant positive relation with rubber girth (r =0.33) and average rubber yield (r = 0.4) but did not show significant relation with annual rubber yield (Table 16). Available Mg showed significant negative relation (r = -0.31) with rubber girth. Gravel content of soil showed significant negative relation with average rubber yield. Bulk density of soil showed significant negative relation with average rubber yield but correlation with annual rubber yield and girth was not significant. At the same time girth showed significant positive relation with TPD (r = 0.34), average rubber yield (r = 0.46) as well as annual rubber yield (r = 0.37) (Table 16).

Table16. Correlation of soil properties with rubber girth, TPD and rubber yield at Kanyakumari

	OC	Av. P	Av. K	Av. Ca	Av. Mg	pH	Gravel	BD	AWC	Girth	TPD
Girth	**0.33****	0.15	-0.16	-0.19	**-0.31****	-0.06	-0.16	-0.11	-0.09	1.00	
TPD	0.17	-0.02	-0.02	-0.14	-0.11	-0.04	0.10	0.02	-0.10	**0.34****	1.00
Avg. yield	**0.40****	-0.01	-0.02	-0.09	-0.21	-0.09	**-0.24***	**-0.3****	-0.15	**0.46****	0.18
Annual yield	0.06	0.10	-0.13	-0.16	-0.22	0.06	0.02	-0.03	-0.07	**0.37****	0.11

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation of rubber performance with soil properties in Kasargod district is presented in Table 17. In Kasargod district, soil properties did not show significant relation with rubber growth as well as rubber yield and TPD (Table 17).

Table 17. Correlation of soil properties with rubber girth, TPD and rubber yield at Kasargod

	OC	Av. P	Av. K	Av. Ca	Av. Mg	pH	Gravel	BD	AWC	Girth	TPD
Girth	0.02	0.11	-0.13	-0.04	0.01	-0.16	0.06	-0.07	0.17	1.00	-0.05
TPD	-0.05	-0.17	0.03	-0.06	0.04	-0.19	0.08	0.14	0.04	-0.05	1.00
Avg. yield	0.13	-0.07	0.09	0.00	-0.07	0.14	0.08	0.05	0.03	-0.11	-0.08
Ann. yield	0.12	-0.06	0.05	-0.04	-0.10	0.13	0.11	0.06	-0.01	-0.10	-0.11

Pearson correlation coefficient was estimated to find the relation of rubber performance with leaf nutrient content and DRIS index and result is presented in Table 18-19. In Kanyakumari district only leaf Mg content showed significant negative relation with girth of rubber (r = -0.34) and average per tree rubber yield (g/tree/tap) (r = -0.25) (Table 18).

Table 18. Correlation of rubber yield with leaf nutrient and DRIS indices in Kanyakumari

	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg	N index	P index	K index	Ca index	Mg index
Girth	0.00	-0.05	0.22	-0.09	**-0.34****	0.11	0.01	**0.29***	-0.05	**-0.33****
TPD	-0.17	-0.04	0.07	-0.10	-0.14	0.02	0.03	0.15	-0.07	-0.07
Average yield	0.00	-0.21	- 0.10	0.14	**-0.25***	0.14	-0.18	-0.03	0.17	-0.23
Annual yield	0.04	0.08	0.10	-0.08	-0.14	0.03	0.12	0.13	-0.09	-0.13

Other leaf nutrient contents did not show significant relation with rubber growth and yield. Among the nutrient indices, K index and Mg index showed significant relation with rubber growth and yield (Table 18). K index showed significant positive relation with girth of rubber (r = 0.29) whereas Mg index showed significant negative relation with girth of rubber (r= -0.33). In Kasargod district leaf N and Calcium content showed significant positive relation with average rubber yield (r = 0.27) (Table 19).

Table 19. Correlation of rubber yield with leaf nutrient content, DRIS indices in Kasargod

	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg	N index	P index	K index	Ca index	Mg index
Girth	0.02	-0.04	-0.16	-0.15	-0.10	0.21	0.09	-0.20	-0.05	0.01
TPD	0.06	0.10	0.20	0.06	-0.05	-0.02	0.00	0.17	-0.01	-0.13
Average yield	**0.27***	0.00	-0.08	**0.27***	0.25	0.11	-0.16	-0.23	0.14	0.17
Annual yield	0.23	-0.04	-0.13	**0.27***	**0.30***	0.08	-0.21	-0.23	0.13	0.22

* Correlation is significant at the 0.05 level** Correlation is significant at the 0.01 level

Annual rubber yield showed significant positive relation with leaf Ca and Mg content. All nutrient indices did not show any significant relation with growth as well as yield of rubber (Table 19). Pearson correlation coefficient was estimated to know the correlation of rubber girth and yield with climate and topographic factors and result is given in Table 20a and 20b. In Kanyakumari district girth showed significant positive correlation with annual rainfall (r =0.47), annual surplus rainfall (r =0.4) and AET (r =0.38) (Table 20a).

Table 20a. Correlation of topography and water balance with rubber performance at Kanyakumari

Kanyakumari	Elevation (m)	Slope (%)	Annual RF	Ann. PET	Ann. AET	Ann. surplus	Ann. Deficit
Girth	0.13	-0.09	**0.47****	-0.06	**0.38****	**0.40****	-0.05
TPD	0.21	0.10	**0.24***	-0.04	0.16	0.15	-0.22
Avg. yield	**0.36****	**0.24***	**0.32****	0.21	0.23	**0.33****	0.05
Annual yield	0.05	0.03	**0.30***	0.03	0.20	**0.31****	-0.16

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 20b: Correlation of topography and water balance with rubber performance at Kasargod

Kasargod	Elevation	Slope	Annual RF	Ann. PET	Ann. AET	Ann. surplus	Ann. Deficit
Girth	-0.17	0.05	-0.10	0.11	0.05	-0.12	0.12
TPD	0.11	0.07	-0.01	-0.07	0.03	-0.01	-0.10
Avg. yield	**0.33****	0.21	-0.03	0.09	0.14	-0.08	0.04
Annual yield	**0.31***	0.25	0.06	0.19	0.22	-0.02	0.13

With regard to rubber yield, rainfall showed significant positive relation with average rubber yield (r = 0.32) and annual yield (r = 0.3). Among the water balance components, annual surplus, annual AET and PET showed significant correlation with rubber yield. Annual surplus, showed significant positive correlation with average per tree rubber yield (r =0.33) and annual rubber yield (r =0.31). Topographic factors such as elevation and slope showed correlation with average per tree rubber yield but not with annual rubber yield (Table 20a). Elevation showed a significant positive correlation with average rubber yield (r =0.36. Slope showed a significant positive correlation with average rubber yield (r =0.24). In Kasargod district no climatic factors as well as water balance components except annual surplus rainfall showed a significant correlation with growth as well as rubber yield (Table 20b). Annual surplus showed significant negative correlation with per tree rubber yield during Oct-Jan (r =-0.25). Among the topographic components, only elevation showed significant relation with rubber yield and not with rubber girth (Table 20b). Elevation showed significant positive correlation with average rubber yield (r =0.33) and annual rubber yield (r =0.31).

4.1.5.6 **Factor Analysis**

Results of factor analysis of different soil and climatic variables in Kanyakumari and Kasargod district is given in Table 21-26. In Kanyakumari district factor analysis extracted three components explaining the 83 per cent variance together (Table 21). Loading of different variables into these extracted components is given in Table 22. Component 1 had positive higher loading from BD, annual rainfall and negative loading from annual deficit. Component 2 has higher positive loading from available Ca and Mg whereas for component 3, organic carbon showed high positive loading. Based on loading of variables, component 1 can be referred as water balance factor, component 2 as soil cation factor, component 3 as soil health factor. Correlation of these three components with rubber growth and yield is presented in Table 23. Component 3 (soil health factor) showed significant positive correlation with girth of rubber (r =0.46) and average per tree rubber yield (r =0.51) and average per tree rubber yield during different period. Component 1(water balance factor) did not show significant correlation with girth, TPD and yield of rubber. Component 2(soil cation factor) showed significant negative correlation with per tree rubber yield during June-Sep (r = -0.31) and girth of rubber (r = -0.29). In Kasargod district three components were extracted accounting 89 per cent variance together (Table 24). Loading of different variables into components in Kasargod is presented in Table 25. Component 1 showed high positive loading from Annual PET, annual deficit and annual AET, whereas with respect to component 2 annual rainfall and annual surplus showed higher positive loading.

Table 21. Total variance explained by the factor components in Kanyakumari

Component	Initial Eigen values	% of Variance	Cumulative %
1	2.59	**43.16**	**43.16**
2	1.29	**21.44**	**64.60**
3	1.11	**18.55**	**83.16**
4	0.46	7.70	90.86
5	0.33	5.44	96.30
6	0.22	3.70	100.00

Extraction Method: Principal Component Analysis

Table 22. Loading of different variables into factor components in Kanyakumari

Variables	Component		
	1 (Water balance factor)	2 (Soil cation factor)	3 (Soil health factor)
Av Ca	-0.29	**0.88**	0.16
Av Mg	-0.07	**0.94**	-0.08
BD	**0.75**	-0.03	-0.42
OC	-0.08	0.08	**0.94**
Ann RF	**0.77**	-0.25	0.44
Ann Deficit	**-0.84**	0.21	0.08

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Table 23. Correlation of rubber yield, girth and TPD with factor components in Kanyakumari

Component	Average yield (g/t/t)	Annual total yield (kg/ha/yr)	Average per tree yield (g/tree/tap) during			Girth	TPD
			Feb-May	Jun-Sep	Oct-Jan		
Water balance factor	-0.05	0.14	-0.08	-0.07	0.01	0.12	0.19
Soil Cation factor	-0.21	-0.20	-0.22	**-0.31****	-0.15	**-0.29***	-0.11
Soil health factor	**0.51****	0.17	**0.46****	**0.46****	**0.49****	**0.46****	0.20

** Significance at 0.01 levels * Significance at 0.05 levels

Table 24. Total variance explained by the factor components in Kasargod

Component	Eigen values	% of Variance	Cumulative %
1	2.72	**38.84**	**38.84**
2	1.94	**27.66**	**66.50**
3	1.58	**22.54**	**89.03**
4	0.45	6.48	95.52
5	0.31	4.49	100.00
6	9.689E-10	1.384E-8	100.00
7	4.654E-11	6.649E-10	100.00

Extraction Method: Principal Component Analysis.

Table 25. Loading of different parameters into the extracted factor components in Kasargod

Variables	Component		
	(Water balance factor)	(Rainfall factor)	(Topographic factor)
Annual AET	**0.81**	-0.11	0.37
Annual surplus	-0.09	**0.99**	-0.11
Annual RF	0.23	**0.96**	0.04
Annual deficit	**0.87**	0.18	-0.31
Annual PET	**0.99**	0.09	-0.09
Elevation	-0.29	-0.01	**0.86**
Slope	0.17	-0.05	**0.86**

Table 26. Correlation of rubber yield, girth and TPD with factor components in Kasargod

Component	Average yield	Annual yield	Feb-May yield	Jun-Sep Yield	Oct-Jan Yield	Girth	TPD
Water balance factor	0.09	0.19	-0.08	0.01	0.11	0.12	-0.06
Rainfall factor	-0.04	0.03	-0.04	0.08	-0.21	-0.13	-0.01
Topography factor	**0.30***	**0.32***	**0.28***	0.12	**0.33****	-0.08	0.12

** Significance at 0.01 levels * Significance at 0.05 levels

Annual AET, PET and rainfall deficit showed high positive loading to component 1. Annual rainfall and surplus showed high positive loading into component 2 whereas elevation and slope showed high positive loading into component 3. Based on loading of variables, component 1 can be referred as water balance factor, component 2 as rainfall factor, component 3 as topographic factor. Correlation of different components with rubber growth and yield is presented in Table 26. Component 3 (Topographic factor) showed significant positive correlation with average per tree rubber yield (r = 0.3), annual yield (r =0.32) and per tree rubber yield during Feb-May (r =0.28) and Oct-Jan (r =0.33) but did not show significant correlation with rubber girth and TPD. All other components did not show significant correlation with rubber growth as well as rubber yield.

4.1.6 **Mapping Rubber Area Using Satellite Image**:

Mapping rubber area in study area was attempted using Indian Remote Sensing (IRS) satellite P6 LISS II image and satellite image of both the districts is given in Fig. 29. During February/March period rubber showed a distinct signature compared to other vegetation especially in Band 3 of IRS P 6 satellite image (Fig 30). Rubber showed more reflectance in Band 3(0.77 – 0.86 μm) compared to forest, teak, coconut/ arecanut and mixed vegetation, indicating the unique signature of rubber during refoliation period. In Band 1(0.52 – 0.59 μm) and Band2 (0.62 – 0.68

μm), reflectance from rubber did not differ from other vegetation. Using three bands of IRS P6 satellite image and Normalized Difference in Vegetation Index (NDVI) image calculated from Band 3 and 2, rubber area was delineated and presented in Fig 31. Using GPS readings collected during ground verification, classification accuracy was estimated and is given in Table 27 and 28.

In Kanyakumari district rubber area is mainly concentrated in central part of the district whereas in Kasargod district rubber area is concentrated in south-western portion of district (Fig 31). In Kanyakumari district overall classification accuracy of satellite image was 91.3 per cent with Kappa statistics of 0.87 compared to 85 per cent overall accuracy with Kappa statistics of 0.78 obtained in Kasargod district (Table 27).

Table 27: Classification accuracy of satellite image

District	Overall Accuracy (%)	Overall Kappa statistics
Kasargod	85.00	0.78
Kanniyakumari	91.25	0.87

Total rubber area estimated using satellite image was 20781.7 and 20052.7 ha accounting 12.4 and 10.1 per cent of geographical area in Kanyakumari and Kasargod district respectively (Table 28). Satellite based rubber area in Kanyakumari was 14 per cent higher than ground statistics whereas in Kasargod it was 21 per cent lower than ground statistics (Table 28).

Table: 28. Comparison of satellite based rubber area with ground statistics

District	Ground Survey statistics (ha)	Satellite based rubber area (ha)	Variation in rubber area (% of ground statistics)	Rubber area (% geographical area)
Kasargod	25374	20052.69	-20.97	10.08
Kanniyakumari	18225	20781.71	14.02	12.36

4.1.7 **GIS and Overlay Analysis:**

All the layers of information were brought into Geographical Information System (GIS) platform to do spatial overlay analysis and querying. The result of the overlay analysis is presented as follows.

4.1.7.1 ***Rubber Distribution Over SMU***

Results of overlay analysis of rubber distribution and soil management unit map are presented in Figure 32-33. In Kanyakumari district major rubber area is distributed over SMU 1- 2 (40 %) followed by SMU 3-4 (20 %) and SMU 5- 7 (18 %) (Fig. 32). About 22 per cent of rubber area was distributed outside the NBSS and LUP surveyed area. In Kasargod district major rubber area was distributed over SMU 1-2 (54 %) followed by SMU 3 - 4 (26 %) (Fig. 33). Very little rubber area was distributed over SMU 5-7. In Kasargod district about 16 per cent of rubber area was distributed outside the NBSS and LUP surveyed area.

4.1.7.2 ***Rubber Distribution over Elevation***:

Output from overlay analysis of rubber distribution over elevation is presented in Figures 34-35. In Kanyakumari district 69 per cent of rubber area was distributed over 0-100 m elevation followed by 27 per cent over 100-300 m elevation (Fig.34). Very little rubber area (4 %) was distributed over elevation more than 300 m. In Kasargod district major rubber area (60 %) was distributed over elevation 100-300 m followed by 0-100 m (30 %) (Fig.35). Only 10 per cent of rubber area was distributed over more than 300 m elevation.

4.1.7.3 ***Rubber Distribution over Slope Classes***:

Results of overlay analysis of rubber distribution with slope are presented in Figures 36-37. In Kanyakumari district, 37 per cent rubber area is distributed over slope class 5-10 per cent followed by 24 per cent rubber area over 3-5 per cent slope, 16 per cent rubber area over < 3 per slope and 12 per cent area over 10-15 per cent slope (Fig. 36). About 11 per cent area is distributed over slope above 15 per cent. In Kasargod district 31 per cent rubber area is distributed over 5-10 per cent slope followed by 26 per cent area over 10-15per cent slope (Fig 37). Compared to Kanyakumari, more rubber area (33 %) in Kasargod was distributed over slope more than 15 per cent. In Kasargod very little area (3 %) was distributed over slope < 3 per cent.

4.1.7.4 ***Distribution of Rubber over Climate Constraint Areas***

Output from overlay analysis of rubber area over climatic constraint areas in Kanyakumari and Kasargod district is presented in Figure 38. Extent of rubber area with poor moisture adequacy during December – March was 11347.4 and 16260.5 ha in Kanyakumari and Kasargod respectively (Fig 38). In Kasargod 3579.3 ha rubber area was distributed over area with very poor moisture adequacy during December – March but same thing in Kanyakumari was not seen. On the other hand in Kanyakumari 3173.4ha rubber area was distributed over area with poor moisture adequacy during August – September period and not in Kasargod. Considerable extent of rubber area (9345.7 ha) in Kanyakumari district was distributed over area without any moisture stress but same thing was not seen in Kasargod. In general, all rubber area in Kasargod district experience poor to very poor moisture adequacy during December-March period compared to only 48 per cent of rubber area experiencing only poor moisture adequacy in Kanyakumari district. Part of Kanyakumari district experience poor moisture adequacy for second time during August-September and extent of rubber area coming under this area was 3173.4 ha. Broadly the extent of rubber area under climatic stress as well as severity of climatic stress was more in Kasargod compared to Kanyakumari.

4.1.7.5 ***Distribution of Rubber over Soil Constraint Areas***

Distribution of rubber area over soil nutrient constraints is presented in Figure 39. In Kanyakumari district 28 per cent of rubber area is distributed over area low in available P, medium in OC, K and high in Ca, Mg followed by 18 per cent over area with medium OC, available P and K and high in Ca and Mg and 13 per cent over area low in available P, OC, medium in K high in Ca, Mg, (Figure 39). In

Kasargod district 61 per cent rubber area is low in available P, medium in available K and high in OC, available Ca and Mg followed by 24 per cent area low in available P and K high in OC, available Ca, Mg. (Fig. 39) and 14 per cent rubber is medium in available P, K and high in soil OC, available Ca and Mg. Number of soil nutrient constraints were more in Kanyakumari than Kasargod.

Experiment II:

4.2 SOIL NUTRIENT DYNAMICS OF MATURE RUBBER PLANTATION IN RELATION TO PHENOLOGY AND GROWING ENVIRONMENT

Observations recorded under the experiment II titled soil nutrient dynamics of mature rubber plantations in relation to phenology and growing environment are processed, analyzed and presented as follows.

4.2.1 Climate at Different Elevation

Monthly maximum and minimum temperature and rainfall of the study area is presented in Figures 40-42. Except during summer period, the maximum temperature was low at high elevation by 2-3 ^{0}C compared to medium and low elevation (Fig. 40). During summer maximum temperature at high elevation was higher than low and medium elevation. In general maximum temperature decreased with increase in elevation. Minimum temperature during summer period at high elevation was lower than medium and low elevation, but during other months it did not vary along the elevation (Fig. 41). Total annual rainfall at medium elevation was higher compared to low and high elevation (Fig. 42). Monthly rainfall between low and high elevation did not differ much.

4.2.2 Leaf litter

4.2.2.1 *Leaf Litter Addition and Decomposition*

Leaf litter addition during wintering and due to disease is presented in Table 29. Leaf litter addition during wintering was ranged from 1.67-1.92 tons/ha and it did not vary significantly along elevation level (Table 29). Leaf fall due to abnormal leaf fall (*Phytophthora palmivora* Butl.) and powdery mildew (*Oidium heveae* Steinm) disease was recorded and presented in Table 29.

Table 29. Annual litter fall, leaf fall due to disease and annual girth increment (GI) at different elevation

Elevation	Annual litter fall (t/ha)	Leaf fall due to disease		Annual GI (cm)
		Phytophthora *(g/m2)	*Oidium* (kg/ha)	
Low Elevation	1.67	31.5 (5.79) [a]	429.7	2.13
Medium Elevation	1.95	81.5 (9.33) [b]	384.3	1.73
High Elevation	1.92	204.4 (14.67) [c]	222.5	1.73
S.Em	0.13	0.94	58.96	0.03
CD 5%	NS	2.86	NS	NS

* Square root transformed. Figures in the parenthesis are transformed data

Leaf fall due to *Phytophthora* disease, which occurs during monsoon period was observed at all elevation but intensity varied (Table 29). Leaf fall due to *Phytophthora* disease ranged from 31.5 to 204.4 g/m^2 and it varied significantly among the elevation. Leaf fall due to *Phytophthora* increased significantly with increase in elevation. Severity of disease was more at high elevation recording highest leaf fall compared to medium and low elevation. Leaf fall due to powdery mildew disease did not vary significantly among the elevation.

4.2.2.2 ***Leaf litter decomposition***

Leaf litter bag technique was used to record rate of leaf litter decomposition at different elevation and result is presented in Table 30. Rate of leaf litter decomposition varied significantly along elevation at 210 days after incubation with high elevation recording significantly lower rate (53.5 %) compared to medium (68.8 %) and low elevation (66.1 %). However decomposition rate between medium and low elevation did not differ significantly. Leaf litter decomposition rate did not vary significantly among elevation at 120 days after incubation. Pooled analysis has showed the significant effect of elevation and period of incubation but interaction between them was not significant. Decomposition after 210 days of incubation (62.8 %) was significantly higher than decomposition at 120 days (40.4 %).

Table30. Litter decomposition at different elevation

Elevation	Litter decomposition (%) (Litter bag study)		Mean of elevation
	After 120 days	After 210 days	
Low Elevation	42.5	66.1[a]	54.3
Medium Elevation	37.2	68.8[a]	59.9
High Elevation	25.2	53.5[b]	40.6
Mean of period	40.4	62.8	51.6
S.Em CD (0.05)	9.3 NS	5.8 12.4	
Pooled analysis	Elevation(A)	Period(B)	AxB
S.Em CD (0.05)	4.9 10.5	3.8 7.8	4.6 NS

4.2.2.3 ***Litter Nutrient Content***

Nutrient content of fresh litter and litter recovered at different period from litter bag study is presented in Table 31. No significant difference in N, P and K content of initial/fresh leaf nutrient content among elevation was observed. However Ca and Mg content varied significantly among elevation. Calcium content of leaf litter at high elevation (1.88 %) was significantly higher than low elevation (1.6 %) but on par with medium elevation (1.71 %). Magnesium content of leaf litter at high elevation (0.32 %) was significantly higher than low and medium elevation (0.24 %). After 120 days of incubation leaf litter nutrient content with respect to N and P showed significant variation among elevation, whereas K, Ca and Mg did not show significant variation (Table 31). After 120 days of incubation, nitrogen content of leaf litter at high elevation was significantly lower (2.10 %) compared to low (2.52 %) and medium (2.25 %) elevation. With respect to P content after 120 days of incubation, high elevation showed significantly low P content (0.08 %) compared to low (0.12 %) and medium elevation (0.15 %). After 210 days of incubation leaf litter nutrient content with respect to K and Mg content showed significant variation among elevation but no significant variation in N, P and Ca content (Table 31). At higher elevation K and Mg content of litter was significantly higher than low elevation but on par with medium elevation. Pooled analysis has showed significant interaction effect of elevation and period of incubation on P, K and Mg content of leaf litter. At lower elevation liter P content significantly increased at 120 days after incubation compared to initial content as well as 210 days after incubation. At medium and high elevation litter P content increased significantly at 120 days after incubation compared to initial P content but on par with P content at 210 days after incubation. At all elevation K content of litter differed significantly at different period of incubation. Litter K content declined significantly at all elevation with increase in incubation period. Litter Mg content varied significantly at 120 days after incubation. Medium and high elevation recorded significantly higher Mg content compared to lower elevation.

4.2.3 **Soil Nutrient Dynamics:**

Observation on dynamics of soil pH, OC, Exchangeable Al, nitrogen and soil moisture are processed, analyzed and presented as follows.

4.2.3.1 ***Soil pH***:

Soil pH recorded at monthly interval is presented in Table 32 and Fig.43. Pooled analysis of soil pH at different month showed no significant variation among elevation, but variation between month and interaction between month and elevation was significant. Significantly higher soil pH was observed during June (4.81), October (4.78), November (4.82) and January (4.79) months compared to other months. Significantly lower soil pH was observed during April (4.36) and September

Table 31: Leaf litter nutrient content at different elevation and period

Elevation	Initial Leaf litter nutrient content (%)					Leaf litter nutrient content after 120 days (%)					Leaf litter nutrient content after 210 days (%)				
	*N	P	K	Ca	Mg	N	P#	K	Ca	Mg	N	P	K	Ca	Mg
Low	1.53 (1.59)	0.07	0.69	1.6^{a}	0.24^{a}	2.52^{b}	0.12 (8.79)^{a}	0.18	1.47	0.21	2.1	0.08	0.01^{a}	0.75	0.26^{a}
Medium	1.58 (1.6)	0.05	0.73	1.71^{ab}	0.24^{a}	2.25^{ab}	0.15 (8.20^{a})	0.21	1.75	0.27	1.1	0.11	0.06^{b}	0.86	0.41^{b}
High	1.57 (1.6)	0.04	0.46	1.88^{b}	0.32^{b}	2.10^{a}	0.08 (12.3^{b})	0.16	1.8	0.25	1.96	0.14	0.08^{b}	0.91	0.52^{b}
S.Em	0.03	0.02	0.09	0.06	0.02	0.08	0.98	0.02	0.16	0.02	0.19	0.03	0.02	0.10	0.04
CD (0.05)	NS	NS	NS	0.20	0.06	0.27	3.7	NS	NS	NS	NS	NS	0.05	NS	0.12

* Square root transformed # Inverse transformed Figures in the parenthesis are transformed data

(4.27) compared to all other months. During February to April pH of low elevation soil was significantly higher than medium and high elevation soil. During rest of the months soil pH did not vary significantly among the elevation.

Table 32: Monthly soil pH at different elevation (0-30 cm)

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	4.7	4.8	4.6	4.7	4.9	4.8	4.4	4.8	4.8	4.6	4.8	4.7
Medium	4.6	4.4	4.3	4.5	4.7	4.6	4.1	4.8	5.0	4.6	4.7	4.6
High	4.4	4.1	4.2	4.6	4.8	4.6	4.3	4.8	4.6	4.5	4.9	4.5
Mean	4.56	4.45	4.36	4.62	4.81	4.67	4.27	4.8	4.8	4.6	4.8	4.6

	Pooled analysis		
	Elevation	Month	Interaction
S.Em	0.10	0.10	0.12
C.D 5%	NS	0.08	0.24

4.2.3.2 ***Soil Organic Carbon***

Monthly soil organic carbon content at different elevation was recorded and presented in Table 33 and Fig. 44. Pooled analysis has showed a significant variation in soil OC due to elevation and month of observation and their interaction effect was also significant. Soil OC at high elevation (3.02 %) was significantly higher than medium (2.4 %) and low elevation (2.19 %). Organic carbon of low and medium elevation did not differ significantly.

Monthly pattern of soil OC has indicated that during April to August soil OC decreased significantly when compared to February/March period but during September soil OC increased back to original level and maintained in subsequent period. In general at lower elevation soil OC was significantly lower during April-August and October compared to other months, but at medium and high elevations inter-monthly variation in soil OC was not significant (Table 33). During all months'

Table33. Monthly soil organic carbon at different elevation, per cent

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	2.29 (0.36)	2.9 (0.46)	1.8 (0.25)	2.1 (0.31)	1.9 (0.28)	2.1 (0.32)	2.6 (0.41)	1.7 (0.23)	2.5 (0.39)	2.4 (0.38)	2.5 (0.38)	2.19 (0.34)
Medium	2.75 (0.44)	3.1 (0.49)	2.0 (0.29)	2.4 (0.37)	2.2 (0.35)	2.3 (0.35)	2.7 (0.43)	2.0 (0.29)	2.6 (0.41)	2.5 (0.39)	2.4 (0.38)	2.40 (0.38)
High	3.47 (0.54)	2.4 (0.36)	2.5 (0.40)	2.8 (0.45)	2.7 (0.43)	3.0 (0.47)	3.5 (0.54)	3.4 (0.52)	3.5 (0.54)	3.4 (0.53)	3.4 (0.53)	3.02 (0.48)
Mean	2.80 (0.44)	2.8 (0.44	2.0 (0.31)	2.4 (0.38)	2.2 (0.35)	2.4 (0.38)	2.9 (0.46)	2.2 (0.35)	2.8 (0.44)	2.8 (0.44)	2.7 (0.43)	2.51 (0.40)

	Pooled analysis: Elevation	Month	Interaction
S.Em	0.03	0.02	0.09
C.D 5%	0.06	0.03	0.17

Figures in the parenthesis are Log_{10} transformed data soil OC of low and medium elevation were on par but significantly lower than high elevation.

4.2.3.3 *Soil Exchangeable Aluminium*

Dynamics of soil exchangeable Al was recorded at monthly interval and presented in Table 34 and Fig. 45. Pooled analysis has showed that elevation, period of observation and their interaction had significant influence on soil exchangeable Al (Table 35). Mean soil exchangeable Al at low elevation (1.22 meq/100g) was significantly lower than medium (2.08 meq/100g) and high elevation (2.44 meq/100g), but difference between medium and high elevation was not significant. Among different months mean soil exchangeable Al during May (0.86 meq/100g) and September-October (1.0 meq/100g) month was significantly lower than rest of the months (Table 34). At lower elevation, exchangeable Al of soil was significantly lower in all the months compared to highest observed in February and March, whereas at medium and high elevation, soil exchangeable Al was significantly low only during May and August – November period compared to highest observed during February/March month.

4.2.3.4 *Soil Nitrogen*

Monthly dynamics of soil nitrate, ammonical and total nitrogen is presented in Table 35-37. Pooled analysis of monthly soil nitrate nitrogen showed significant influence of elevation, month of sampling and their interaction (Table 35). Significantly higher mean soil nitrate nitrogen was observed at medium elevation (5.51 mg/kg) compared to low (4.78 mg/kg) and high elevation (4.72 mg/kg). Mean soil nitrate nitrogen content of low and high elevation soil did not differ significantly. Among the months significantly higher soil nitrate nitrogen was observed during May-August months compared other months. During April, September and October months soil nitrate nitrogen was significantly lower than

Table 34.Monthly soil exchangeable Aluminium at different elevation, meq/100g

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	3.08 (1.75)	1.53 (1.22)	1.33 (1.03)	0.45 (0.68)	1.22 (1.01)	1.27 (1.11)	0.49 (0.67)	0.61 (0.69)	1.02 (0.97)	1.29 (1.09)	1.10 (1.00)	1.22 (0.99)
Medium	2.98 (1.73)	2.44 (1.52)	2.08 (1.44)	0.94 (0.95)	2.32 (1.51)	2.10 (1.43)	1.60 (1.28)	1.26 (1.10)	1.99 (1.41)	2.47 (1.56)	2.18 (1.48)	2.08 (1.40)
High	3.05 (1.74)	2.68 (1.63)	2.20 (1.48)	0.92 (0.96)	2.72 (1.64)	2.01 (1.41)	1.15 (1.06)	1.52 (1.22)	2.11 (1.45)	2.36 (1.53)	2.55 (1.59)	2.44 (1.43)
Mean	1.63 (2.66)	1.46 (2.13)	1.32 (1.74)	0.86 (0.74)	1.39 (1.93)	1.31 (1.72)	1.00 (1.00)	1.00 (1.00)	1.27 (1.61)	1.40 (1.96)	1.36 (1.83)	1.27 (1.61)

	Pooled analysis: Elevation	Month	Interaction
S.Em	0.11	0.04	0.13
C.D 5%	0.24	0.07	0.25

Figures in the parenthesis are square root transformed data

other months. Pattern of monthly soil nitrate nitrogen at low elevation showed a significant declining phase during April and September-October period and significant increase phase during February-March, May-August and November-January. At medium elevation significantly higher soil nitrate nitrogen phase was observed during February to August period and then showed declining phase and remained low during September to January. On the other hand at high elevation the trend was similar to low elevation. Nitrate nitrogen content of soil varied significantly among elevation only during February-March and May months with medium elevation recording significantly higher nitrate nitrogen compared to low and high elevation.

Results of monthly soil ammonical nitrogen content at different elevation are presented in Table 36. Pooled analysis has indicated significant influence of elevation, month of observation and their interaction on ammonical nitrogen content.

Ammonical nitrogen content of low and medium elevation was on par but significantly higher than high elevation. Among the months ammonical nitrogen was significantly higher during February-August compared to rest of the months. Elevationwise soil ammonical nitrogen varied significantly during all the months except June and October. During most of the months soil ammonical nitrogen of medium elevation was significantly higher than high elevation but on par with low elevation. Results of the observation on dynamics of monthly soil total nitrogen are presented in Table 37 and Fig. 46. Pooled analysis of soil total nitrogen has shown a significant influence of elevation, month of observation and their interaction on soil total nitrogen (Table 37). Mean soil total nitrogen at medium and low elevation was significantly higher (4.2 mg/kg) than high elevation (4.0 mg/kg). Among the months mean soil total nitrogen was significantly lower during September to December period compared to rest of the months. Monthly total nitrogen varied significantly along elevation during February-May and August with medium elevation recording significantly higher total nitrogen compared to high elevation but on par with low

Table 35. Seasonal soil NO_3 nitrogen at different elevation, mg/kg

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	22.2 (4.7)	25.5 (5.1)	9.7 (2.3)	37.3 (6.1)	30.3 (5.5)	46.4 (6.9)	12.2 (3.5)	13.5 (3.7)	25.2 (4.6)	35.5 (5.7)	22.0 (4.5)	22.8 (4.8)
Medium	33.9 (5.8)	39.8 (6.2)	35.1 (5.0)	49.9 (7.0)	55.8 (7.50)	51.3 (7.2)	13.3 (3.7)	15.1 (4.0)	18.6 (4.4)	23.7 (4.9)	24.3 (5.0)	30.4 (5.5)
High	20.3 (4.5)	21.2 (4.7)	9.8 (2.6)	32.3 (5.6)	54.3 (7.42)	35.4 (6.0)	13.4 (3.6)	12.5 (3.7)	24.0 (4.9)	17.7 (3.8)	26.3 (5.1)	22.3 (4.7)
Mean	25.1 (5.0)	28.4 (5.3)	10.7 (3.3)	38.8 (6.2)	46.4 (6.81)	44.4 (6.7)	13.1 (3.6)	14.4 (3.8)	21.5 (4.6)	23.0 (4.8)	23.8 (4.9)	25.0 (5.0)

Pooled analysis

	Elevation	Month	Interaction
S.Em	0.27	0.43	0.77
C.D at 5%	0.58	0.85	1.50

Figures in the parenthesis are square root transformed data

Table36. Seasonal soil NH_4 nitrogen at different elevation, mg/kg

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	42.4 (6.4)	49.9 (7.0)	49.8 (7.0)	52.7 (7.2)	59.8 (7.6)	51.4 (7.4)	23.1 (4.7)	16.6 (4.0)	21.9 (4.6)	9.9 (3.1)	26.9 (5.2)	33.64 (5.8)
Medium	52.0 (7.2)	58.1 (7.6)	73.9 (8.3)	62.8 (7.8)	68.0 (8.2)	51.1 (7.1)	9.9 (3.0)	19.6 (4.4)	9.4 (3.1)	1.95 (1.3)	26.6 (5.2)	33.64 (5.8)
High	28.5 (5.4)	32.8 (5.7)	32.8 (5.7)	45.2 (6.7)	73.3 (8.6)	39.3 (6.3)	17.2 (4.2)	12.4 (3.3)	12.5 (3.5)	3.5 (1.8)	26.3 (5.1)	26.3 (5.1)
Mean	39.7 (6.3)	45.6 (6.8)	49.3 (7.0)	52.0 (7.2)	65.9 (8.1)	48.0 (6.9)	15.5 (3.9)	15.1 (3.9)	13.9 (3.7)	4.4 (2.1)	26.6 (5.2)	30.9 (5.6)

Pooled analysis	Elevation	Month	Interaction
S.Em	0.13	0.33	0.38
C.D 5%	0.28	0.65	0.74

Figures in the parenthesis are square root transformed data

Table 37: Monthly soil total nitrogen at different elevation, mg/kg

Elevation	Feb 2011	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan 2012	Mean
Low	1.78 (70.1)	1.84 (75.4)	1.72 (59.5)	1.92 (90.0)	1.93 (97.1)	2.0 (85.6)	2.0 (35.3)	1.51 (30.1)	1.43 (47.1)	1.59 (45.4)	1.58 (48.9)	1.72 (64.7)
Medium	1.94 (90.9)	1.91 (97.9)	1.96 (109)	1.94 (112.6)	2.0 (124.9)	2.08 (102.4)	2.0 (22.0)	1.33 (34.6)	1.51 (28.0)	1.44 (25.7)	1.40 (50.9)	1.75 (66.7)
High	1.67 (57.4)	1.73 (53.9)	1.60 (42.7)	1.86 (77.6)	2.10 (127.6)	1.86 (74.6)	1.45 (30.6)	1.31 (21.7)	1.54 (31.9)	1.22 (21.2)	1.70 (52.6)	1.63 (55.7)
Mean	1.78 (71.5)	1.84 (75.7)	1.75 (68.0)	1.93 (96.5)	2.04 (107.8)	1.95 (99.5)	1.43 (37.3)	1.42 (37.3)	1.52 (44.3)	1.36 (36.6)	1.69 (59.1)	1.70 (62.2)

	Pooled analysis: Elevation	Month	Interaction
S.Em	0.03	0.06	0.10
C.D at 5%	0.07	0.12	0.20

Figures in the parenthesis are Log_{10} transformed data elevation. During rest of the months total nitrogen did not vary significantly among elevations. Mineralization potential recorded at different elevation using in-situ soil core method is presented in Figure 47-48. At medium elevation mineralization potential of ammonical nitrogen was more (25 mg/kg) compared to low (21 mg/kg) and high (12.5 mg/kg) elevation (Fig 47). At the same time the difference between actual and potential ammonical nitrogen was more at medium and low elevation compared to high elevation. Nitrate nitrogen potential was more at medium (35 mg/kg) and low (31 mg/kg) elevation compared to high elevation (22 mg/kg) (Fig 48). But actual nitrate nitrogen mineralization did not differ much along elevation. However the difference between actual and potential nitrate nitrogen mineralization was more at low and medium elevation compared to high elevation.

4.2.3.5 ***Soil moisture***

Dynamics of soil moisture at three elevations is presented in Table 38 and Fig. 49. Elevation, month of sampling and their interaction showed significant effect on the soil moisture content. Mean soil moisture content varied significantly among elevation with high elevation recording significantly higher soil moisture (31.8 %) followed by medium elevation (27.7 %) and low elevation (25.8 %). Lowest mean soil moisture was recorded during the month of January (22.7 %) and February (24.4 %) months and highest during May to October. Elevationwise monthly soil moisture pattern followed the similar trend. During January to May and October months high elevation recorded significantly higher soil moisture compared to low elevation but on par with medium elevation. During rest of the months soil moisture did not vary significantly among the elevation.

Table 38: Seasonal soil moisture at different elevation, per cent

Elevation	Feb	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec	Jan	Mean
Low	21.0	24.6	26.0	28.1	28.0	28.9	27.3	26.4	27.5	25.3	20.8	25.8
Medium	25.1	27.5	28.3	32.3	30.9	34.6	27.6	28.8	23.3	26.8	19.8	27.7
High	27.1	29.5	33.4	35.5	32.2	35.8	31.5	35.9	31.7	29.6	27.4	31.8
Mean	24.4	27.2	29.2	32.0	30.4	33.1	28.8	30.4	27.5	27.2	22.7	28.4

	Pooled analysis		
	Elevation	Month	Interaction
S.Em	0.95	0.97	2.95
C.D 5%	2.03	3.74	5.78

4.2.4 Performance of Rubber

4.2.4.1 *Phenology*

Phenological stages of rubber such as wintering, refoliation, leaf growth, flowering and fruiting recorded elevationwise are presented in Figure 50. Wintering at high elevation began in middle of November whereas same at low and medium elevation was delayed to December. As a result refoliation and flowering was earlier (December/January) at high elevation and late (January/February) at low and medium elevation. Number of new flush are four to five in low and medium elevation compared to three new flushes observed at high elevation. Powdery mildew disease (*Oidium*) which occurs immediately after refoliation was observed at all elevation. Time of occurrence of abnormal leaf fall (*Phytophora* disease) varied among elevation. Incidence of abnormal leaf fall was early at high elevation (August) compared to low and medium elevation (September).

4.2.4.2 *Annual Girth Increment and Light Interception by Rubber*

Annual girth increment (GI) and light interception by rubber at different elevation is presented in Table 39. Annual GI of rubber did not differ significantly among the elevation. Light interception by rubber varied significantly among the elevation. During refoliation light intensity below canopy at high elevation was significantly lower (18.68 % of open) compared to medium elevation (39.4 % open) but on par with low elevation (26.4 % open). After refoliation light intensity below canopy at high elevation was significantly lower than at lower elevation but on par with medium elevation indicating the more light interception by rubber canopy at higher and medium elevation compared to low elevation. During October light intensity below canopy at high elevation was significantly higher (51.3 % open) compared to low (28.9 % open) and medium (37 % open) elevation. After wintering (December), the light intensity below canopy did not vary significantly among the elevation.

Table 39. Annual GI and light interception at different elevation

Elevation	Light intensity below canopy(% of open)				Annual GI (cm)
	After wintering (December)	After refoliation (March)	After abnormal leaf fall (October)	During refoliation (January)	
Low	3.67	2.58[b]	28.9[a]	26.35[a]	5.21
Medium	3.46	2.0[ab]	36.95[a]	39.41[b]	5.17
High	3.85	1.32[a]	51.25[b]	18.68[a]	5.17
S.Em	0.20	0.4	6.0	5.13	0.03
CD 5%	NS	0.85	12.9	11.0	NS

4.2.4.3 ***Nutrient Resorption Efficiency***

Nutrient resorption efficiency of rubber at different elevation was estimated and presented in Table 40. Resorption efficiency of P and K showed a significant variation among the elevation but N resorption efficiency did not vary. Resorption efficiency of P at high elevation (80.4 %) was significantly higher than low (63.0 %) and medium (58.2 %) elevation, but resorption efficiency of low and medium elevation did not differ significantly. Similar trend was observed with respect to resorption efficiency of K.

Table 40. Nutrient resorption efficiency of rubber at different elevation

Elevation	Nutrient re-sorption efficiency (%)		
	N	P	K
Low Elevation	53.2	63.0[a]	38[a]
Medium Elevation	44.9	58.19[a]	44.1[a]
High Elevation	40.8	80.35[b]	67.8[b]
S.Em	4.9	7.3	10.9
CD (0.05)	NS	15.6	23.4

4.2.4.4. ***Rubber Yield***

Monthly mean dry rubber yield at three elevations is presented in Figure 51. High elevation showed better yield during June-August, whereas during October-Jan it showed low yield compared to low and medium elevation. Mean monthly dry rubber yield at low (38.9 g/tree/tap), medium (38.0 g/tree/tap) and high elevation (37.0 g/tree/tap) did not differ significantly.

4.2.4.5 ***Correlation of rubber yield with nutrient dynamics and climate***

Correlation of rubber yield with soil nutrient dynamics at different elevation is presented in Table 41-43. At lower elevation current month rubber yield showed significant negative correlation (r= -0.68) with ammonical nitrogen content (Table 41). Current month exchangeable aluminium content in soil at lower elevation showed significant negative correlation with next month rubber yield. Weather parameters did not show any significant relation with current as well as next month rubber yield. However minimum temperature at lower elevation showed significant negative relation with OC content of soil (r = -0.75).

At medium elevation current month rubber yield showed significant negative relation with ammonical (r = -0.75) and total nitrogen (r = -0.66) (Table 42). Similarly next month rubber yield showed significant negative relation with ammonical (r = -0.73) and total nitrogen (r = -0.71) content of soil at medium elevation. At medium elevation also weather parameters did not show significant relation with rubber yield. However soil nitrate nitrogen content showed significant positive correlation with soil moisture (r= 0.6) and rainfall (r=0.6). Exchangeable Al content of soil at medium elevation showed significant negative correlation (r = -0.65) with minimum temperature.

At high elevation current month rubber yield showed significant negative correlation (r= -0.85) with maximum temperature (Table 43). At the same time

Table 41.Correlation of rubber yield with soil properties at Low elevation

		1	2	3	4	5	6	7	8	9	10	11
1	Current month Yield	1.00										
2	Next month yield	0.46	1.00									
3	pH	-0.03	-0.05	1.00								
4	Exch. Al	-0.18	**-0.75***	0.36	1.00							
5	OC	-0.27	-0.02	-0.18	0.27	1.00						
6	NH4 nitrogen	**-0.68***	-0.49	0.37	0.26	-0.23	1.00					
7	NO3 nitrogen	-0.07	-0.14	0.49	0.16	0.02	0.39	1.00				
8	Total N	-0.52	-0.42	0.50	0.26	-0.15	0.90**	0.75**	1.00			
9	Soil moisture	0.17	0.63	-0.04	-0.56	-0.35	0.22	0.36	0.33	1.00		
10	T max	-0.39	-0.44	0.08	0.40	0.19	0.01	-0.40	-0.18	-0.71*	1.00	
11	T min	0.06	0.22	-0.16	-0.60	**-0.75****	0.36	0.08	0.29	0.76**	-0.43	1.00
12	RF	0.18	0.24	0.35	-0.13	-0.38	0.43	0.47	0.53	0.75**	-0.79**	0.52

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Table 42: Correlation of yield with soil properties at medium elevation

		1	2	3	4	5	6	7	8	9	10	11
1	Current month Yield	1.00										
2	Next month yield	0.64	1.00									
3	pH	0.31	0.60	1.00								
4	Exch. Al	0.28	-0.05	0.05	1.00							
5	OC	0.22	-0.19	-0.18	0.38	1.00						
6	NH4 nitrogen	**-0.75***	**-0.73***	-0.22	0.09	-0.20	1.00					
7	NO3 nitrogen	-0.43	-0.56	-0.02	0.13	-0.11	0.83**	1.00				
8	Total N	**-0.66***	**-0.71***	-0.18	0.10	-0.16	0.98**	0.91**	1.00	0.54		
9	Soil moisture	-0.50	-0.46	-0.22	-0.35	-0.33	0.47	**0.63***	0.54	1.00		
10	T max	0.12	-0.10	-0.01	0.04	0.14	0.06	-0.26	-0.01	-0.50	1.00	
11	T min	-0.38	-0.29	-0.09	**-0.65***	-0.52	0.39	0.18	0.33	0.07	0.27	1.00
12	RF	-0.50	-0.10	-0.02	-0.26	-0.55	0.43	**0.62***	0.47	0.81**	-0.74**	0.17

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Table 43: Correlation of yield with soil properties at high elevation

		1	2	3	4	5	6	7	8	9	10	11
1	Current month Yield	1.00										
2	Next month yield	0.64	1.00									
3	pH	0.50	**0.65***	1.00								
4	Exch. Al	-0.21	**-0.68***	-0.10	1.00							
5	OC	0.41	-0.10	0.39	-0.11	1.00						
6	NH4 nitrogen	0.22	0.45	0.14	0.18	**-0.64***	1.00					
7	NO3 nitrogen	0.54	0.53	0.53	0.18	-0.28	0.81**	1.00				
8	Total N	0.36	0.50	0.31	0.19	-0.52	0.97**	0.93**	1.00			
9	Soil moisture	0.41	**0.83****	0.18	**-0.69***	-0.27	0.20	0.16	0.19	1.00		
10	T max	**-0.85****	**-0.70***	-0.58	0.47	-0.43	0.03	-0.30	-0.11	-0.46	1.00	
11	T min	-0.32	**0.65***	0.30	-0.44	-0.35	0.36	0.12	0.28	0.37	-0.03	1.00
12	RF	**0.64***	**0.77****	0.20	-0.25	-0.42	**0.64***	**0.62***	**0.66***	0.73*	-0.56	0.17

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

current month soil moisture content and rainfall showed significant positive correlation with next month rubber yield whereas maximum temperature showed significant negative relation (r= -0.7) with next month rubber yield. Unlike low and medium elevation rubber yield at high elevation did not show significant relation with soil nutrient dynamics. Exchangeable Al content of soil showed significant negative correlation (r= -0.69) with soil moisture content whereas OC content showed significant negative correlation with ammonical nitrogen content of soil. Rainfall showed significant positive correlation with nitrate (r= 0.64), ammonical (r= 0.62) and total nitrogen (r= 0.66) content of soil.

4.2.4.6 *Factor Analysis*

Results of factor analysis of soil nutrient dynamics and climatic factors at three elevation is presented in Table 44-49. At low elevation factor analysis extracted 2 components, explaining cumulative variance of 70.6 % together (Table 44). At the same time at medium and high elevation factor analysis extracted 2 components explaining cumulative variance of 71.7 and 82.8 % respectively (Table 46 and 48). At low elevation soil moisture and minimum temperature showed high positive loading and maximum temperature negative loading into the component 1 (Table 46). On other hand at medium and high elevation nitrate, ammonical and total nitrogen content showed high positive loading into the component 1 (Table 47 and 49). For component 2 soil pH and total N showed high positive loading at low elevation (Table 45). At medium elevation maximum and minimum temperature showed high positive loading into component 2 (Table 47). At high elevation exchangeable Al showed high negative loading whereas minimum temperature and soil moisture showed high positive loading into component 2 (Table 49). Based on loading of factors, component 1 and 2 at low elevation are named as climatic and soil reaction factor respectively. Similarly at medium elevation two components are named as mineralization and temperature factor and at high elevation as mineralization and climate factor.

Bivariate correlation between rubber yield and different component extracted at three elevations is presented Table 50. At low elevation extracted three components did not show significant correlation with rubber yield. At medium elevation component 1 showed significant negative correlation with next month rubber yield whereas at high elevation component 2 showed significant positive correlation with next month rubber yield.

Table 44.Total variance explained by different components at low elevation

Component	Eigen values	% of Variance	Cumulative %
1	**2.77**	**46.15**	**46.15**
2	**1.47**	**24.41**	**70.56**
3	0.98	16.32	86.88
4	0.51	8.54	95.42
5	0.25	4.11	99.53
6	0.03	0.47	100.00

Extraction Method: Principal Component Analysis.

Table 45. Loading of variables into components at low elevation

	Component	
	1 (Climatic factor)	2 (Soil reaction factor)
pH	-0.15	**0.91**
OC	-0.64	-0.26
Total N	0.29	**0.80**
Soil moisture	**0.90**	0.06
T_{max}	**-0.73**	0.07
T_{min}	**0.92**	0.04

Extraction Method: Principal Component Analysis.

Table 46. Total variance explained at medium elevation

Component	Eigen values	% of Variance	Cumulative %
1	**3.0**	**49.93**	**49.93**
2	**1.3**	**21.75**	**71.68**
3	0.97	16.20	87.88
4	0.64	10.60	98.49
5	0.08	1.42	99.91
6	0.01	0.09	100.00

Extraction Method: Principal Component Analysis.

Table 47. Loading of variables into components at medium elevation

	Component	
	1 (Mineralization factor)	2 (Temperature factor)
pH	-0.17	-0.26
NH_4 nitrogen	**0.93**	0.29
NO_3	**0.96**	-0.11
Total N	**0.97**	0.20
T_{max}	-0.25	**0.83**
T_{min}	0.28	**0.72**

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

Table 48. Total Variance explained at high elevation

Component	Eigen values	% of Variance	Cumulative %
1	**3.0**	**49.92**	**49.92**
2	**1.97**	**32.84**	**82.76**
3	0.68	11.30	94.06
4	0.23	3.89	97.95
5	0.12	2.05	100.00
6	4.400E-7	7.333E-6	100.00

Extraction Method: Principal Component Analysis

Table 49. Loading of variables into components at high elevation

	Component	
	1 (Mineralization factor)	2 (Climate factor)
Exch. Al	0.27	**-0.90**
NH_4 nitrogen	**0.96**	0.11
NO_3 nitrogen	**0.93**	0.01
Total N	**0.99**	0.07
Soil moisture	0.13	**0.85**
T_{min}	0.261	**0.69**

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

Table 50. Correlation of different component with rubber yield at three elevations

	Low elevation		Medium elevation		High elevation	
	Comp 1	Comp. 2	Comp. 1	Comp. 2	Comp. 1	Comp. 2
Current month yield	0.22	-0.29	**-0.64***	-0.21	0.33	0.14
Next month yield	0.40	-0.30	**-0.67***	-0.17	0.45	**0.81****

*. Correlation is significant at the 0.05 level . **. Correlation is significant at the 0.01 level .

4.2.4.7 *Phenology and Soil Nutrient Dynamics*

Monthly dynamics of soil pH at three elevations (Figure 43) indicated that at medium and high elevation rubber refoliation, flowering and fruit growth coincided with more acidic soil pH compared to low elevation. At all elevation soil pH increased during May to August and then declined during September coinciding with occurrence of abnormal leaf fall.

Monthly soil OC dynamics (Figure 44) indicated that during refoliation and flowering soil OC was high at all elevation. During subsequent flushes and fruit growth soil OC showed declining trend and remained low at low and medium elevation, but at high elevation it showed increasing trend after initial decline during April. So in general during active growth period of rubber (May-September) soil OC level was low at low and medium elevation but not at high elevation.

Monthly dynamics of soil total nitrogen at three elevations (Figure 46) indicated that level of soil total nitrogen after refoliation at low and medium elevation was more than that of high elevation. After refoliation, production of further new flushes and fruit growth coincided with soil total nitrogen level in the soil. At Low and medium elevation soil total N level remained at higher level from April to August during which 2-3 new flushes were produced. At high elevation soil total nitrogen remained high only during June and only 1 new flush coincided with this peak period. At low and medium elevation soil total N level was high during majority part of active growth period where as at high elevation it was not.

Dynamics of soil exchangeable Al (Figure 45) indicated that yhe pattern of exchangeable Al dynamics at three elevations was same but the level of exchangeable Al was low at low elevation compared to medium and high elevation. At low and medium elevation, wintering period coincided with peak exchangeable Al and during subsequent refoliation period it showed declining trend, but at high elevation it continued to show increasing trend after refoliation and started declining only during February. At all the elevations soil exchangeable Al declined during February to May and attained lowest level by May. This February – May period coincided with flowering and fruit growth. During monsoon period (May-September) soil exchangeable Al increased and attained peak during June then declined and attained lowest by September. During this period of high exchangeable Al activity two new flushes were produced at low elevation compared to only one flushes at medium and high elevation.

DISCUSSION

5. DISCUSSION

Variability in soil and climate influences performance of rubber and for this, site specific management helps to increase input use efficiency and enhance crop production. The present investigation was undertaken as two experiments in traditional rubber growing areas of the country to understand the soil and climate variability on performance of rubber as well as the nutrient dynamics of mature rubber plantation in relation to phenology and growing environment. Results of the individual experiment are discussed as below.

Experiment I

5.1 GEOSPATIAL ANALYSIS OF SOIL AND CLIMATE VARIABILITY ON PERFORMANCE OF RUBBER

In order to bring maximum variability in soil and climate, two districts, Kanyakumari representing south and Kasargod representing north of traditional rubber growing region were selected for the study.

5.1.1 **Soil Variability**:

Soil is characterized by high degree of spatial variability due to combined effect of physical, chemical and biological processes that operate at different intensity and scales as well as the parent rock from which they are derived. Kanyakumari and Kasargod showed significant difference in their soil physical and chemical properties. Kanyakumari showed significantly higher available P, K and gravel content whereas Kasargod showed significantly higher soil OC, available Ca, Mg, and soil pH (Table 2). Soil BD and AWC did not differ significantly between districts. Kanyakumari soil recorded medium level of soil OC, available P and K content , whereas Kasargod soil recorded high soil OC content with low available P and K content. Soil available Ca and Mg content in both districts was in a high range. This difference in soil nutrient content could be attributed to the difference in their land forms as well their parent materials. Soils of Kanyakumari are grouped under the *Khondalite* land forms whereas soils of Kasargod are grouped under the *charnockite and laterite* landforms. (NBSS and

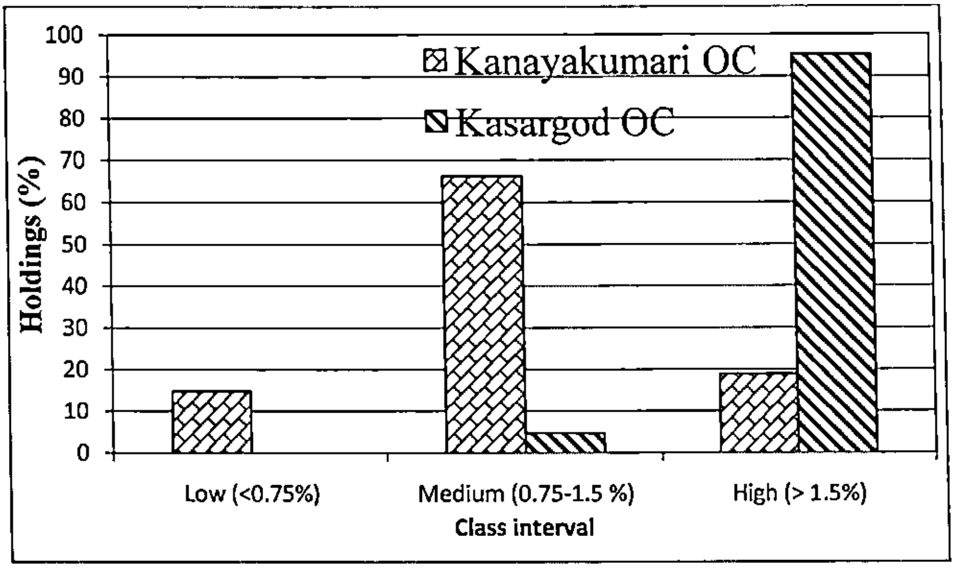


Fig. 3: Distribution of holdings with respect to soil OC

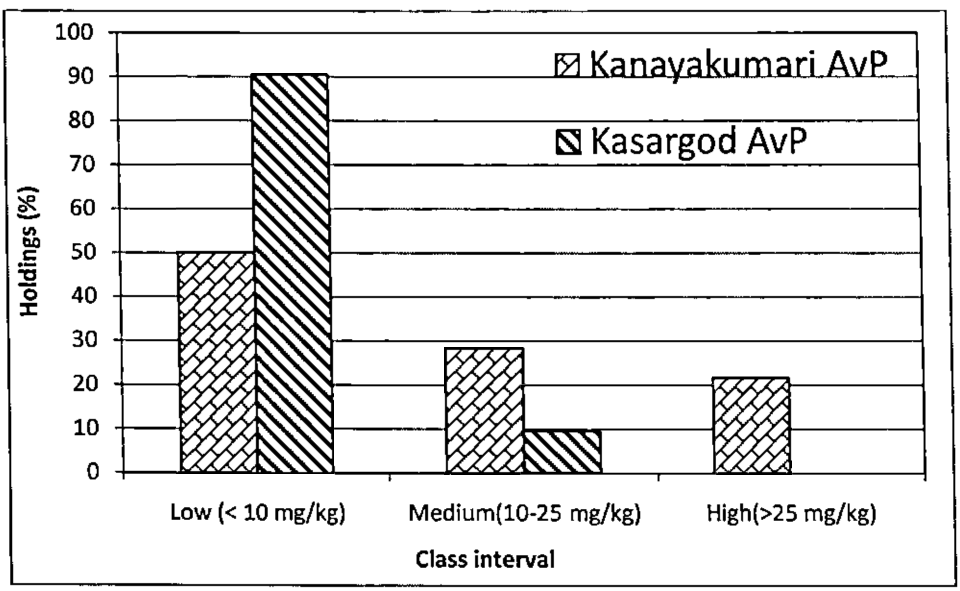


Fig. 4: Distribution of holdings with respect to soil available P

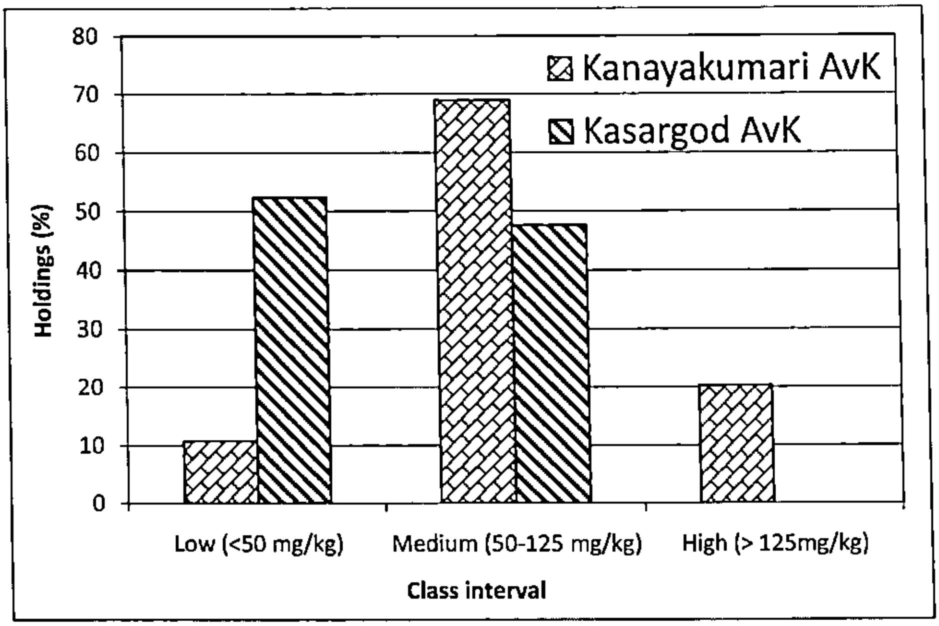


Fig. 5: Distribution of holdings with respect to soil available K

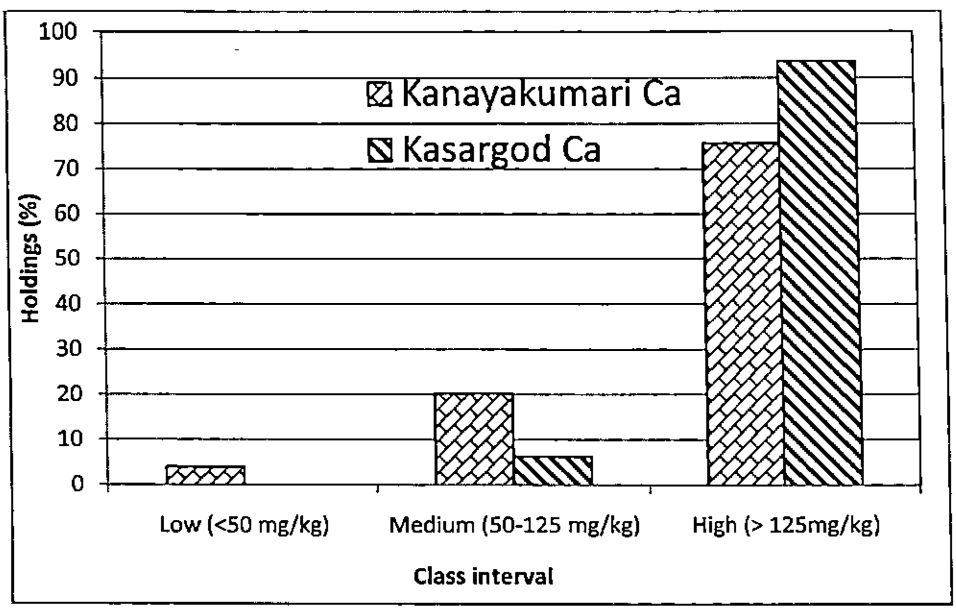


Fig. 6: Distribution of holdings with respect to soil available Ca

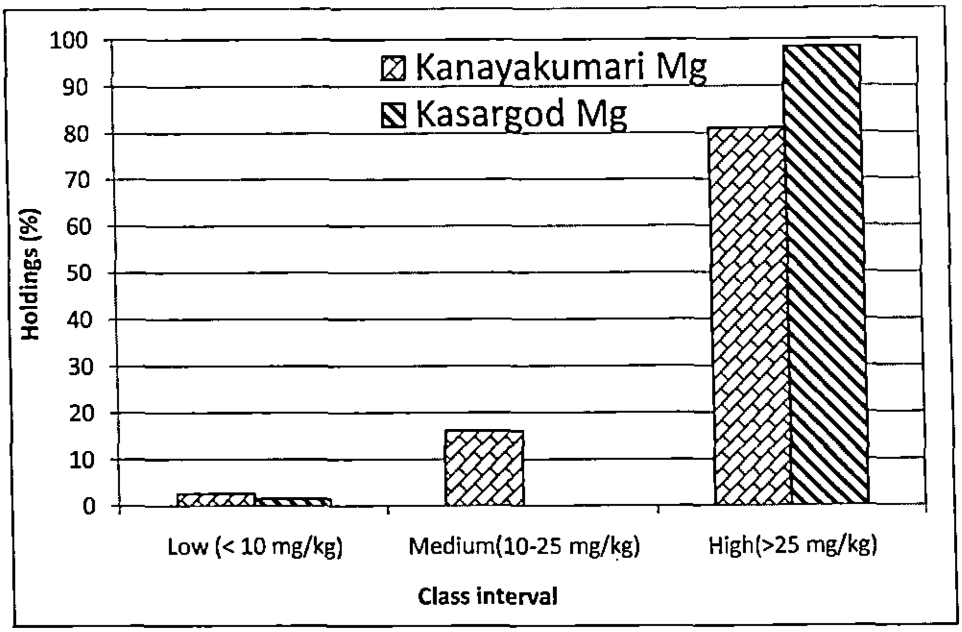


Fig. 7: Distribution of holdings with respect to soil available Mg

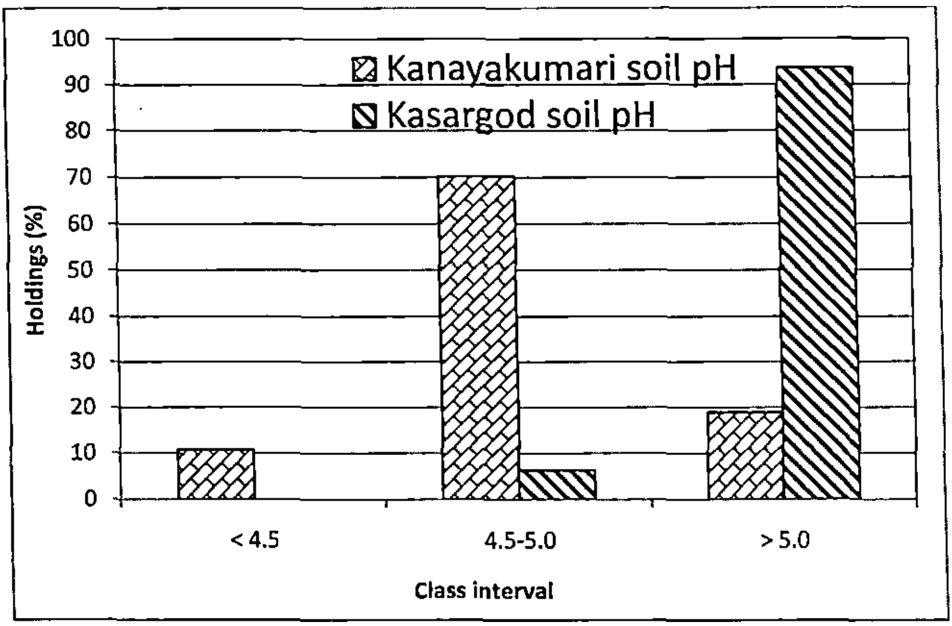


Fig. 8: Distribution of holdings with respect to soil pH

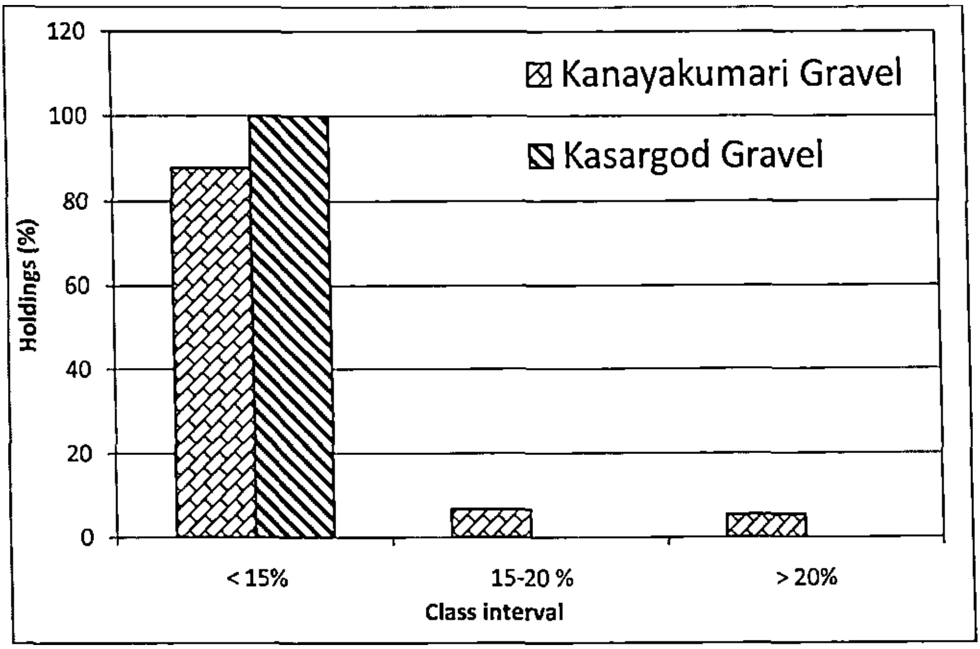


Fig. 9: Distribution of holdings with respect to gravel content (%)

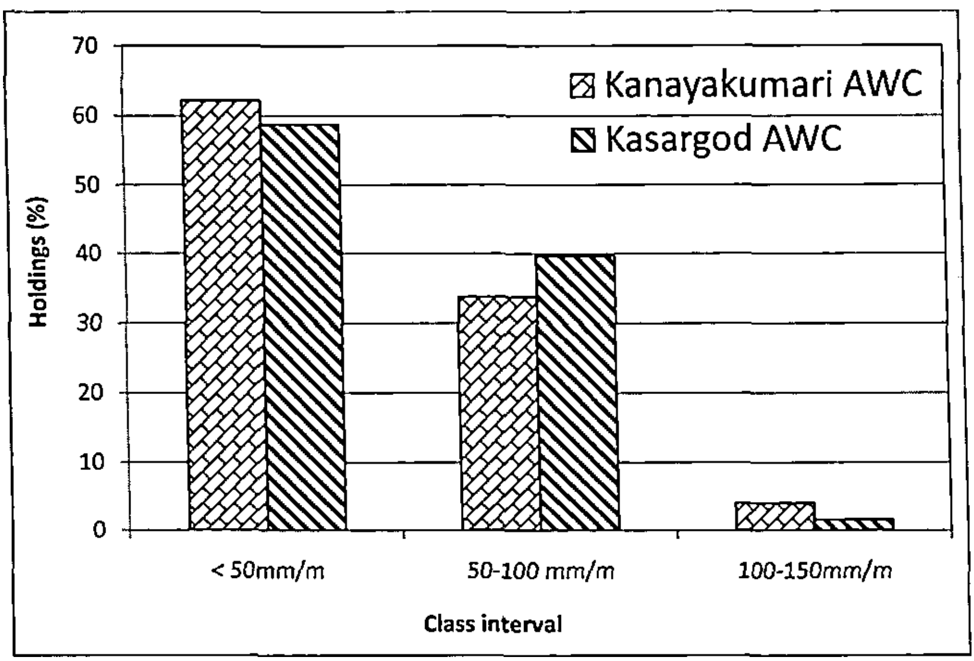


Fig. 10: Distribution of holdings with respect to soil Available Water Content

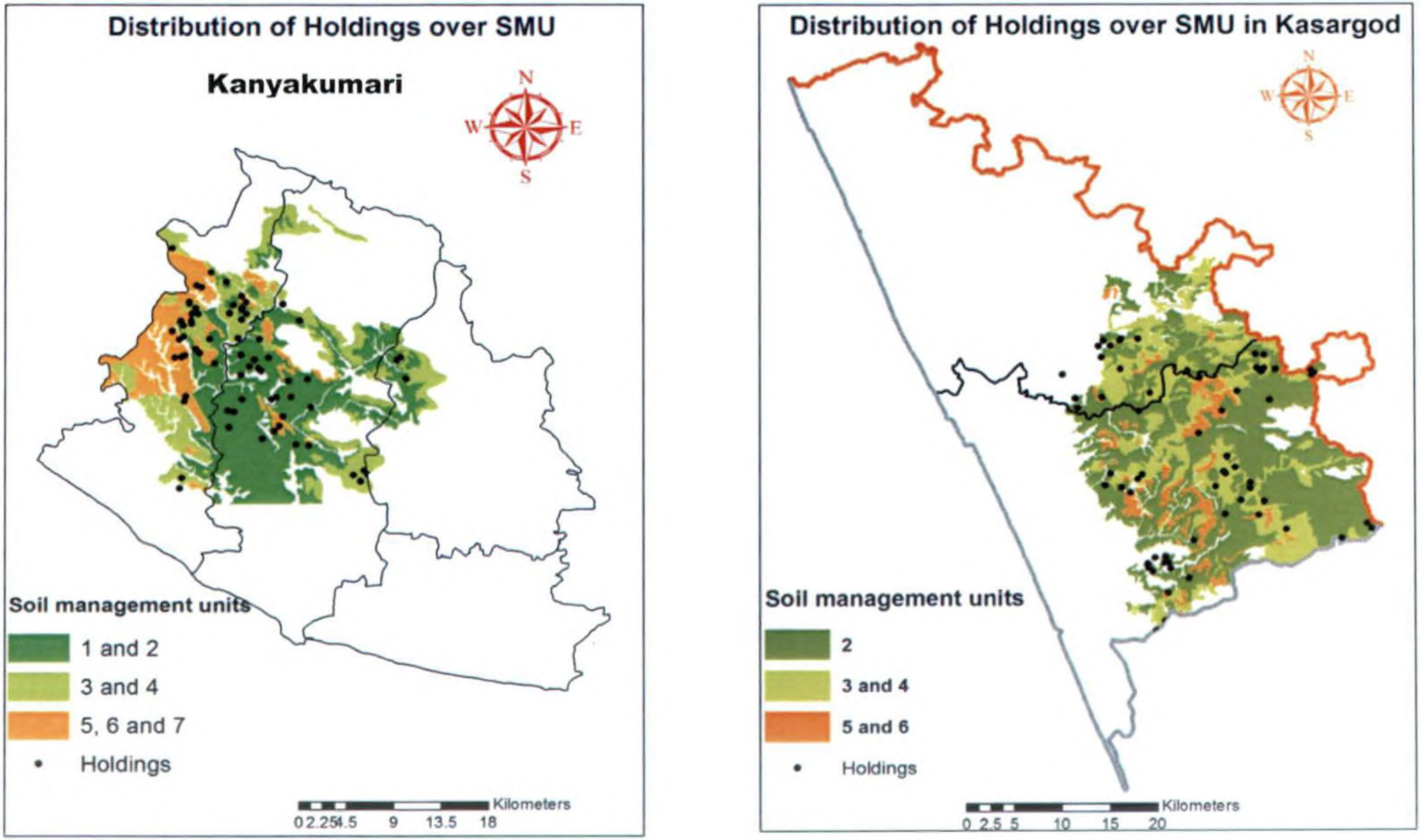


Fig. 11b: Holdings distribution over SMU in study area

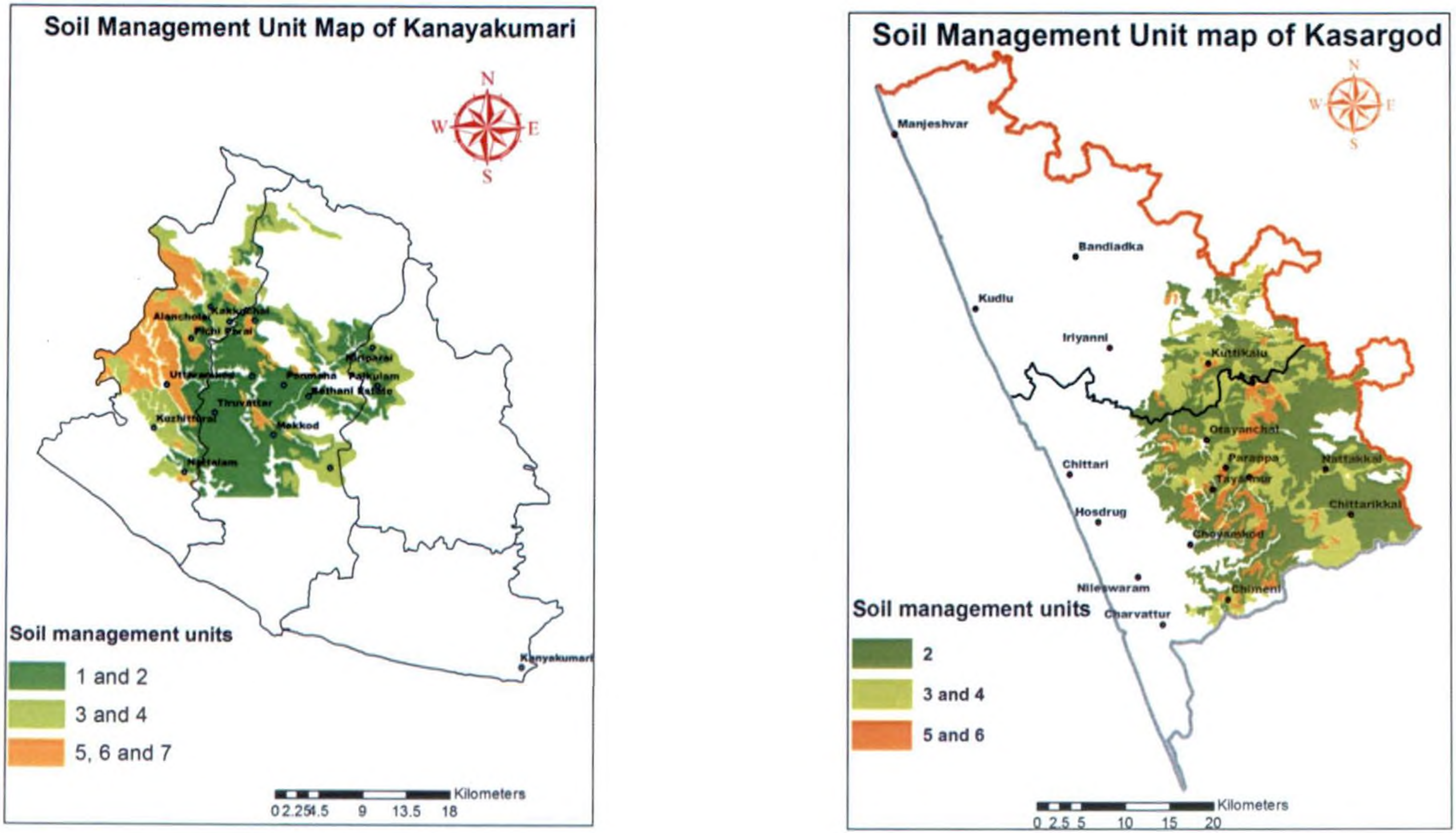


Figure.11a. Soil Management Unit map

LUP.,1999). *Khondalite* and *Laterite* are the major rock type observed in Kanyakumari compared to extensive *charnockite* rock observed in Kasargod district. A major soil forming factor in rubber growing area is climate (NBSS and LUP, 1999). Because of distinctly different climate observed in the two districts, the genesis of soil might have occurred differently, leading to difference in their basic physical and chemical properties. Rubber cultivation in India is confined to laterite and lateritic type of soil and red soils (George, 1961). Soils of Kasargod belong to lateritic which are highly weathered and leached and are having good physical property but poor in plant nutrients (Karthikakuttyamma *et al.*, 2000). On the other hand, soils of Kanyakumari belong to red soils which are less weathered, loam to silt clay loam texture, deficit in OM but more fertile compared to laterite soils. This might be the reason for the lower OC but high soil nutrient status in Kanyakumari soil compared to Kasargod.

Majority of rubber area in Kanyakumari was brought under rubber long back and are now under second or third cycle of cultivation compared to first or second cycle in Kasargod. Because of continuous rubber cultivation over long period, decline in soil OC under rubber and buildup of soil available P due to fixing of continuous applied P through rock phosphate has been reported (Karthikakuttyamma, 1997). Since rubber plant utilize limited quantity of P (10 kg P_2O_5) to produce 1500 kg rubber (Landon, 1984), part of applied P was fixed by soil due to inherent P fixing nature of soil clay type (Kaolinite) present in rubber growing soil, leading to P build up over period. This might be the reason for the very low soil P and high soil OC in Kasargod compared to Kanyakumari.

Within the districts soil OC, pH, BD, AWC, available P, K, Ca and Mg showed significant variation as indicated by the distribution of holdings over soil nutrient ratings (Fig 3-10). Extent and spatial distribution of SMU in both districts (Fig. 11 and 12) as well as interpolated soil nutrient maps (Fig. 13a to e) showed variation between and within the districts .Soil OC and available P in Kanyakumari and available K in Kasargod district showed more spatial variability. Soil properties varied within the district and it can be attributed to

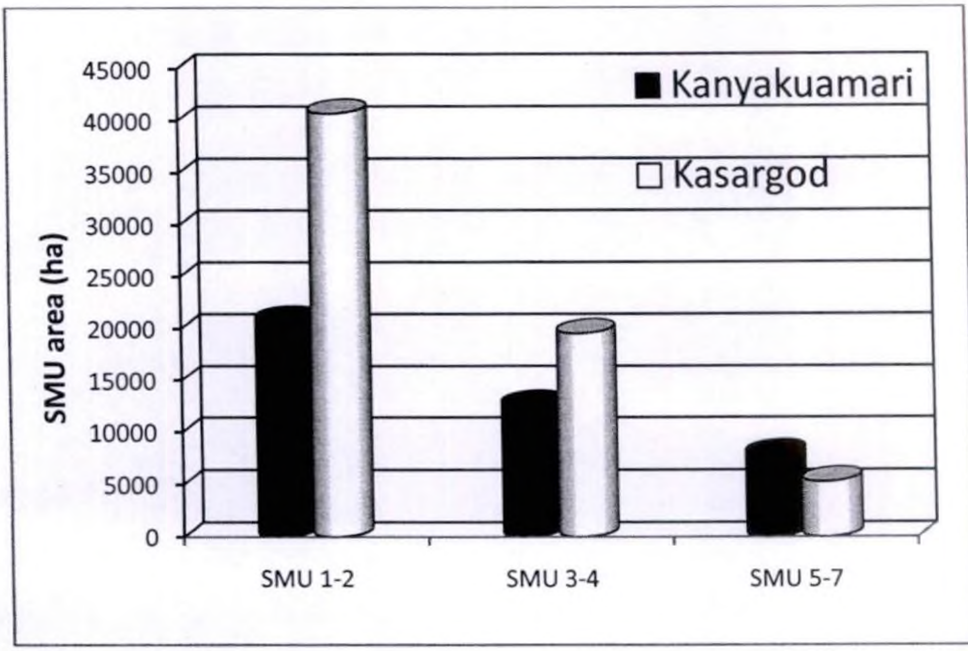


Fig 12: Area under soil management units in Kanyakumari and Kasargod

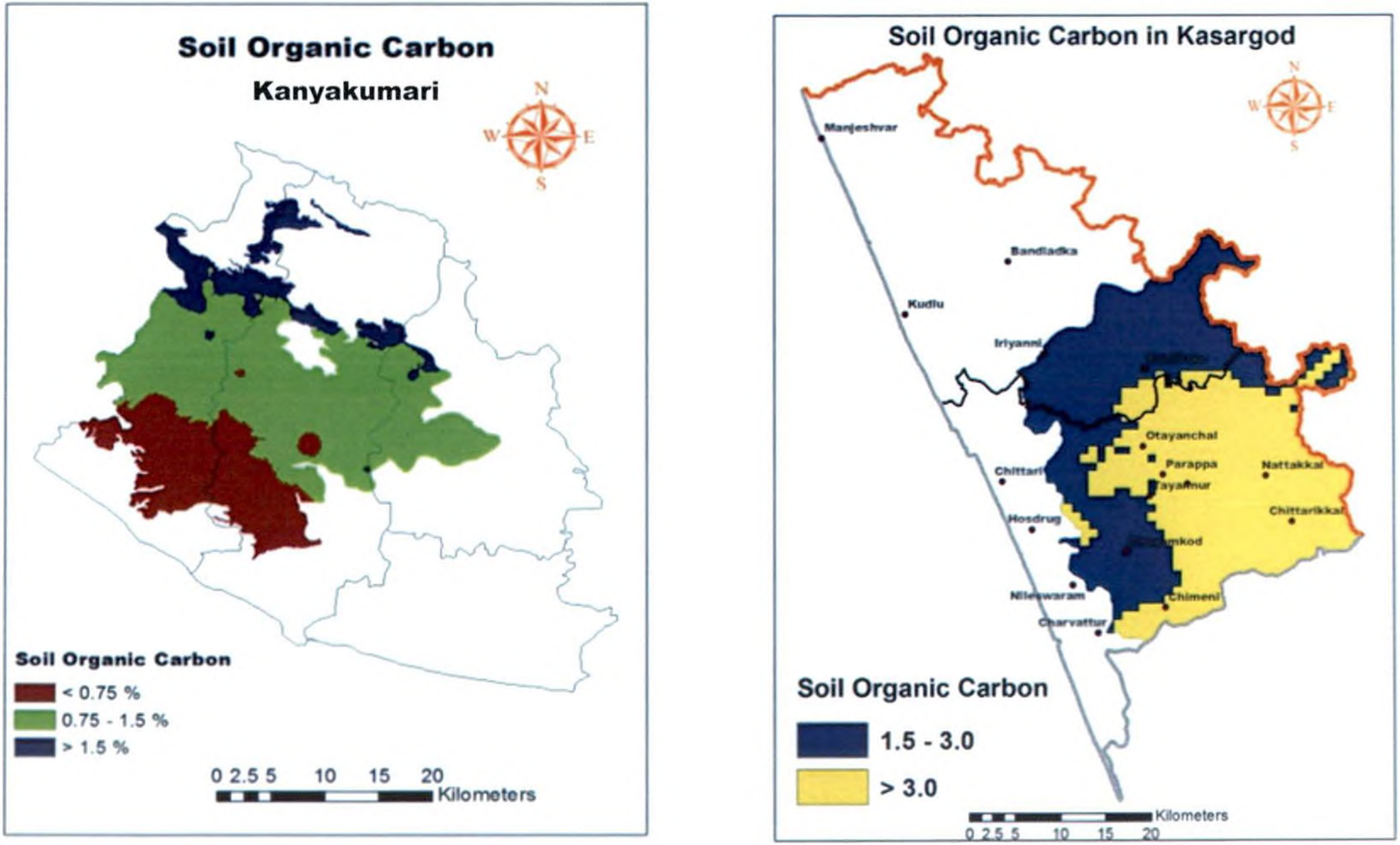


Figure 13a: Spatial interpolated map showing ranges of soil nutrients status

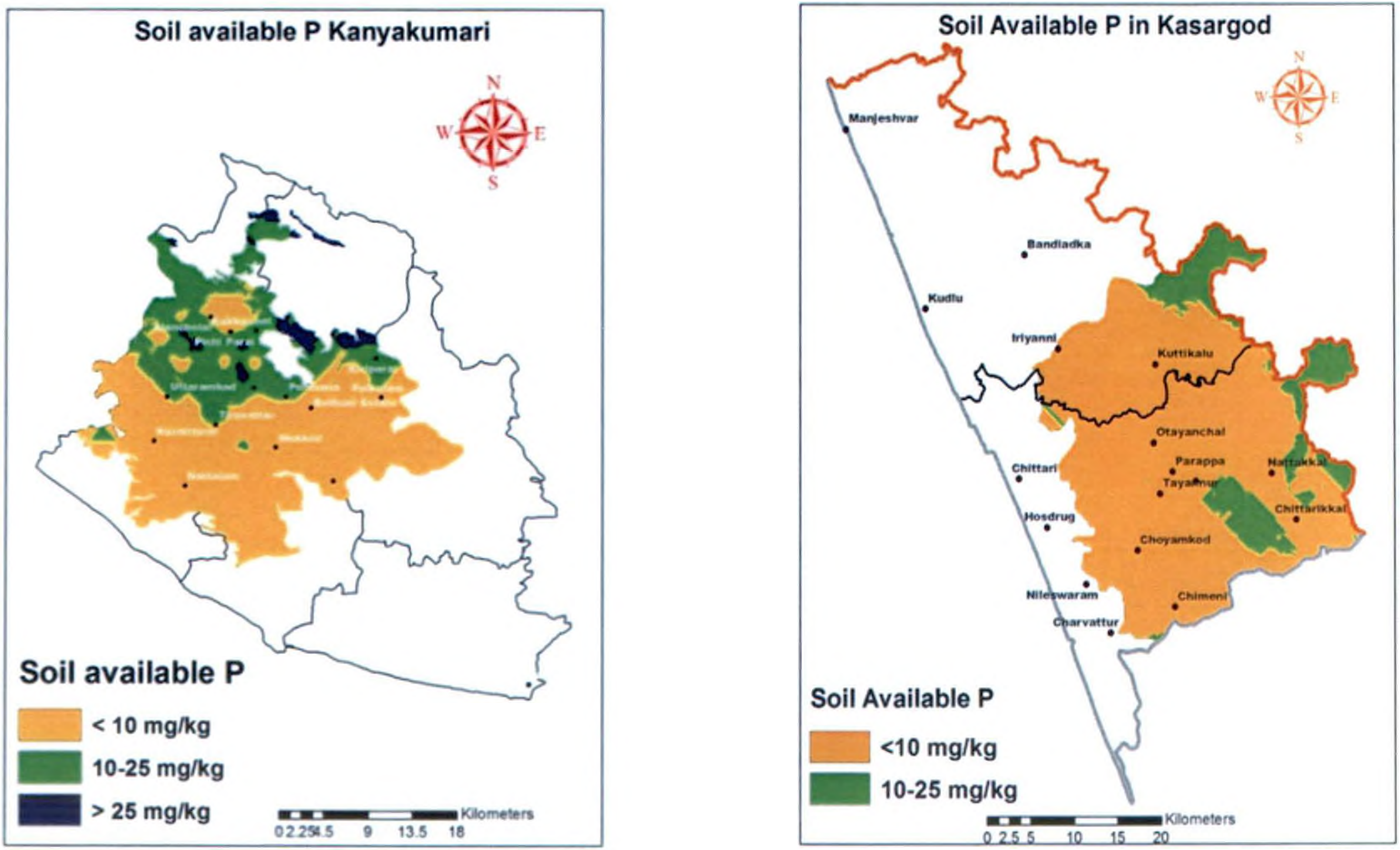


Figure 13b: Spatial interpolated map showing ranges of soil nutrients status

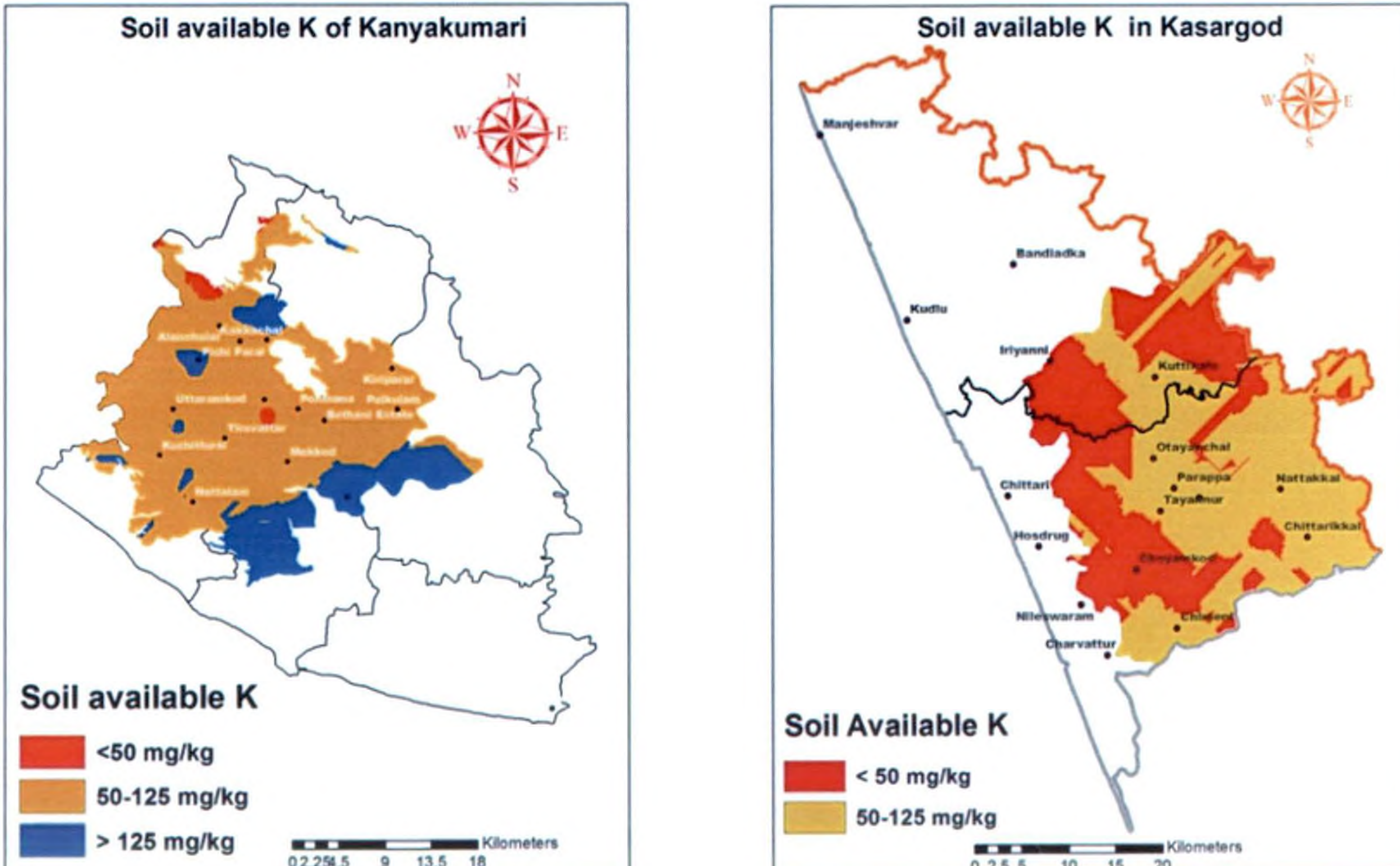


Figure 13c: Spatial interpolated map showing ranges of soil nutrients status

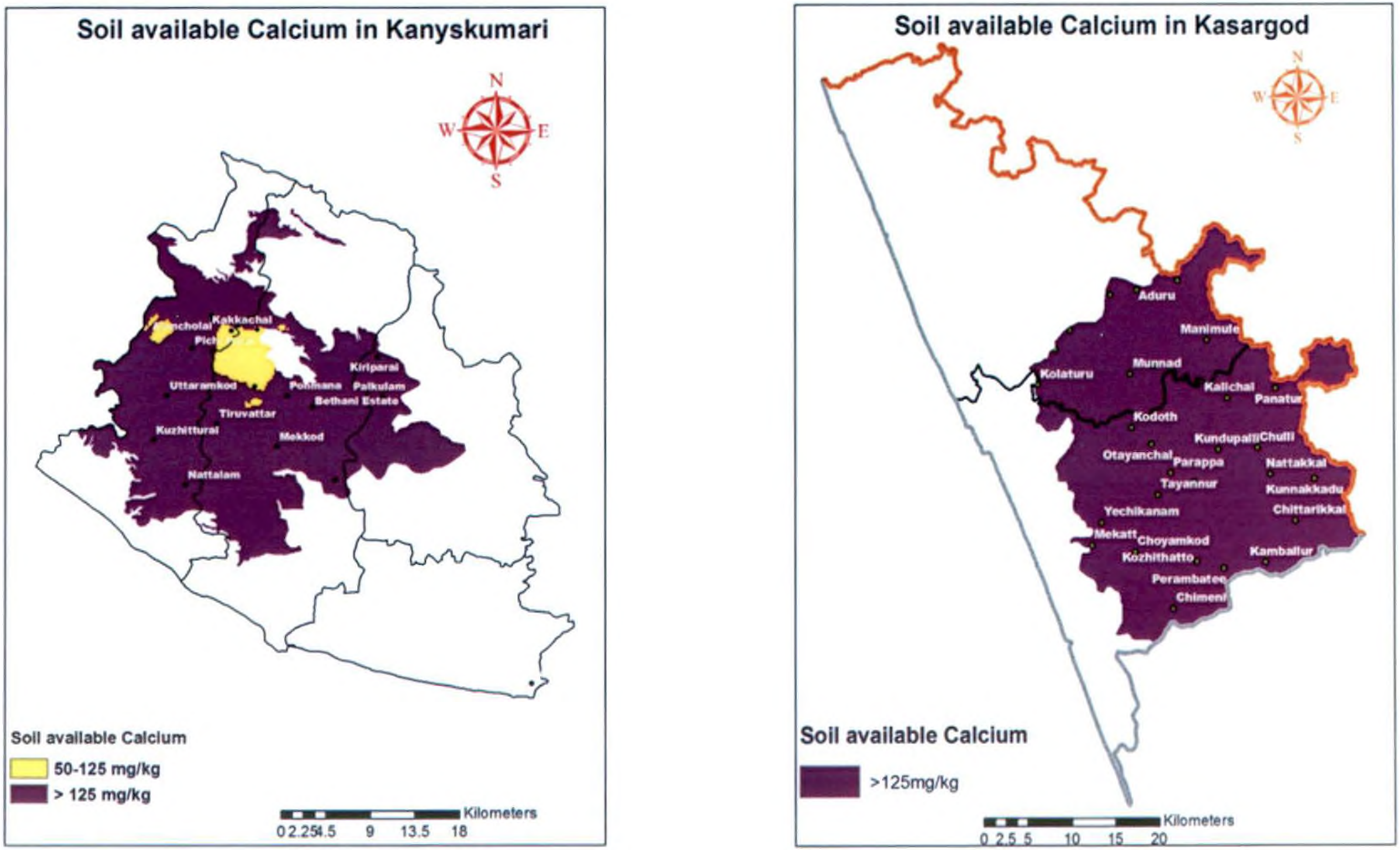
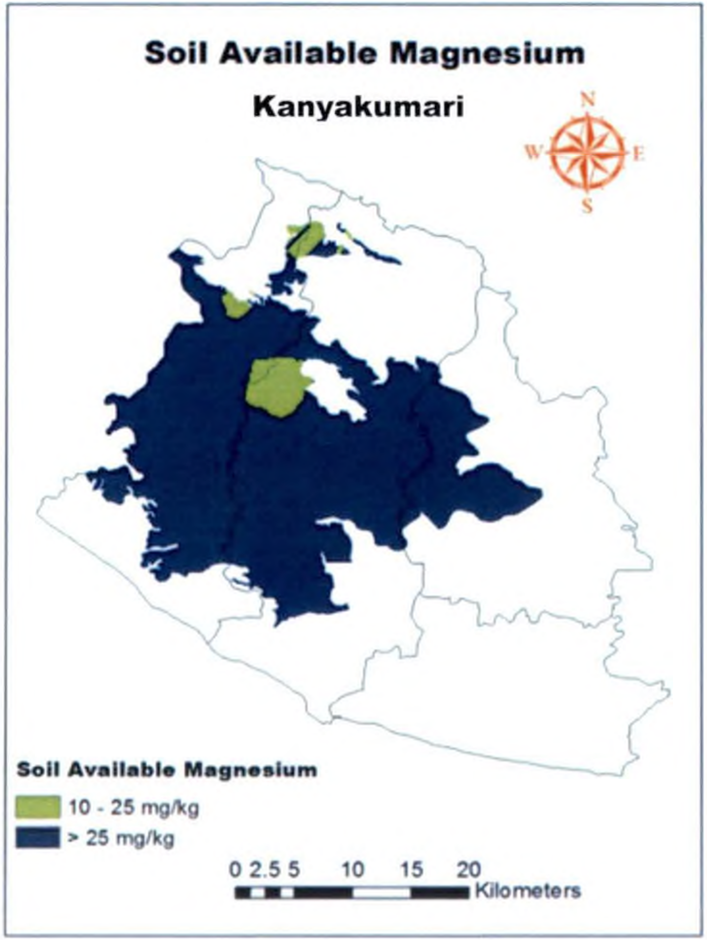


Figure 13d: Spatial interpolated map showing ranges of soil nutrients status



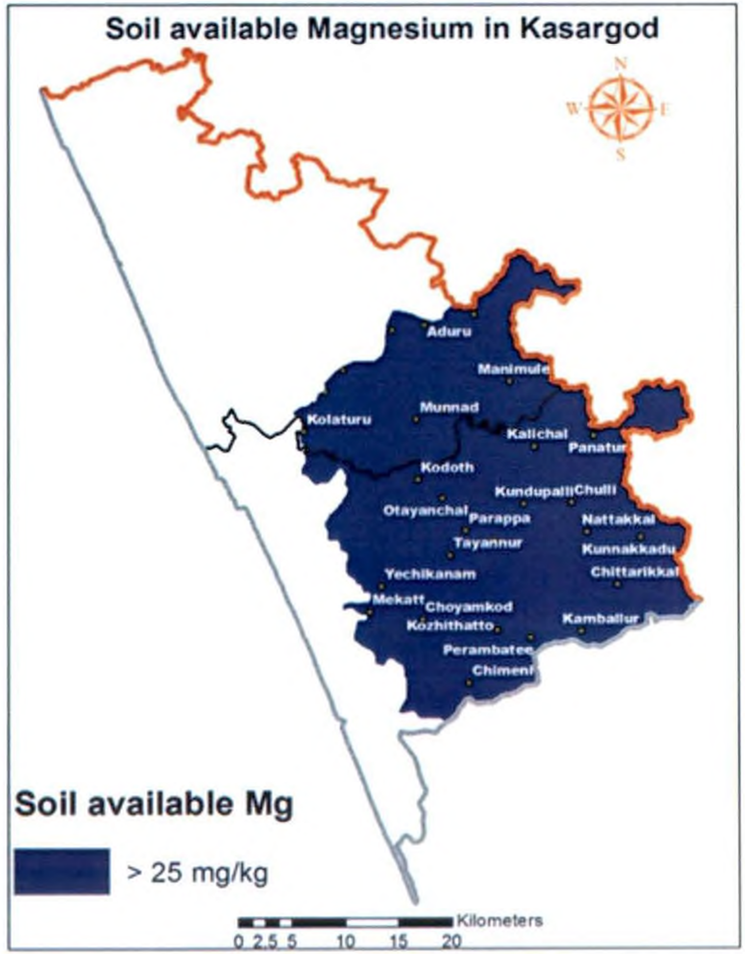


Figure 13e: Spatial interpolated map showing ranges of soil nutrients status

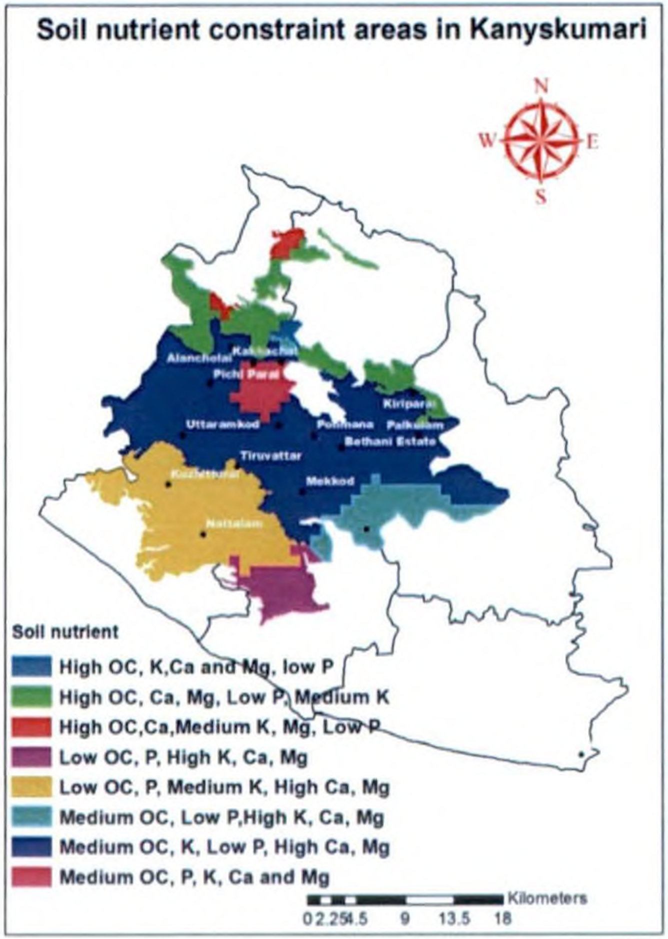
different soil series observed in the district as reported by NBSS and LUP (1999). In Kanyakuamari, nine soil series were observed, out of which *Kunnathur, Manalodi, Kadambanad* and *Kodayar* series were widely occuring covering 89 per cent of rubber growing area of the district. High gravel content, P fixation and low exchangeable K were the major limitation of these soil series. In Kasargod, eleven soil series were occuring and out of which *Arur, Kanjirapally, Lahai, Vijayapuram* and *Tulapalli* are the widely observed soil series covering 81 per cent of rubber growing area of Kasargod district. High gravel content and low exchangeable K were the major limitations of these soils series. Hence soils of Kanyakumari and Kasargod district differed significantly with respect to available K and P. Similar trend of variation in soil nutrients in Kanyakumari and Kasargod has been reported by NBSS & LUP (1999) from the grid samples collected during the soil survey conducted during 1996 .

It was interesting to note that the ratio of nugget to sill which is a measure of spatial dependence was significant for all the nutrients indicating the strong spatial dependence of soil nutrient values within the district. Among the nutrients, available calcium and potash showed strong spatial dependence compared to phosphorus and OC. Range which is a measure of spatial autocorrelation was sufficiently wide in most of the nutrients indicating the appropriateness of current sampling distance.

In general, available Ca and Mg as well as physical properties like BD, gravel content and AWC did not differ between two districts.

5.1.1.1 **Soil nutrient constraint areas**

Soil nutrient constraint map indicated more number of soil nutrient constraints in Kanyakumari than Kasargod (Fig. 14). By critically analysing the data on soil nutrients, it could be elucidated that in Kanyakumari district, major soil nutrient constraints are high Ca and Mg followed by low-medium OC whereas in Kasargod, high OC, Ca and Mg followed by low-medium P are the major soil nutrient constraints. It must be mentioned that high Ca and Mg is a



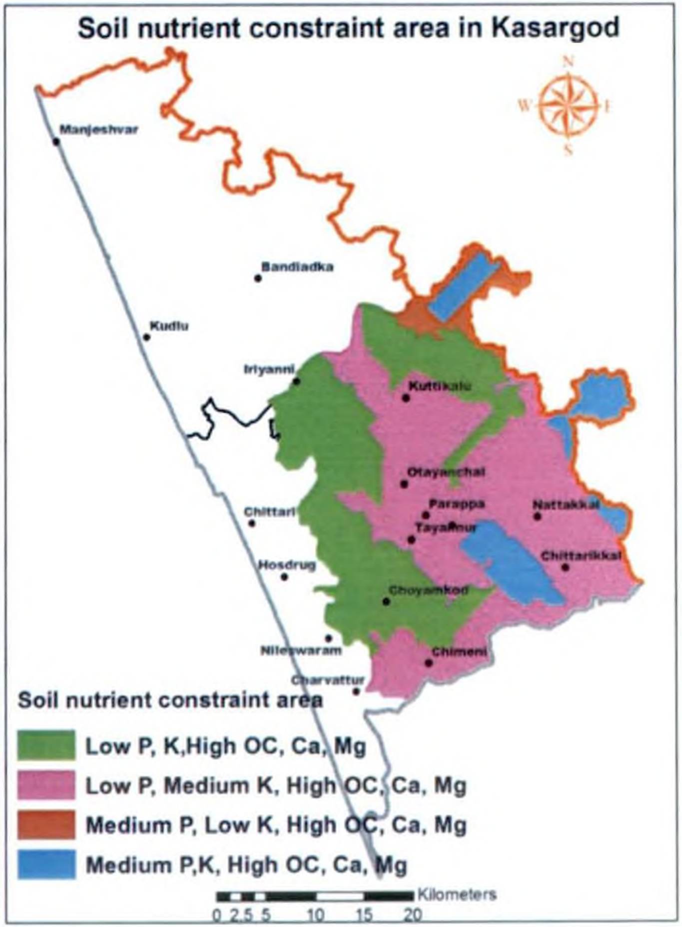


Fig 14: Spatial distribution of soil constraint areas

major soil nutrient constraint in both districts. This is in conformity with the report of NBSS & LUP (1999) that rubber growing soils recorded high available calcium and magnesium. Similar report of high available Ca and Mg in rubber growing soils has been reported from Malaysia and Cambodia (Pushparajah, 1969 and de Geus, 1973). In general, available P was low in rubber growing soils and this is in conformity with the findings of Osodeke and Kamalu (1992) and NBSS& LUP (1999). The reason might be due to the dominance of Kaolinite and goethite in soil clay.

5.1.2 **Topographic Variability**

Topographic parameters like elevation and slope derived from ASTER DEM (Fig. 15a and b) for Kanyakumari and Kasargod showed variation. It can be elucidated that (Fig.16a and b) majority of rubber growing areas in Kanyakumari was less elevated (<100m) and less slopy (< 5-10%) whereas in Kasargod, majority of area was more elevated ((0-200m) and more slopy (>5-10 %)

5.1.3 **Climate variability**:

Annual total rainfall and its distribution showed a distinct pattern in Kanyakumari and Kasargod districts (Fig 17-18). In Kanyakumari, annual rainfall was only 1228 mm compared to 3462mm in Kasargod, but the rainfall was well distributed and bimodal in Kanyakumari whereas the rainfall was unimodal and concentrated in Kasargod. In Kanyakumari district all the months received rainfall not less than 50mm, whereas in Kasargod major portion of annual rainfall was received during June- September with November to March being dry period. This is in line with the report of Rao *et al* (1990) that the intensity of rainfall increased during June-September from south to north of rubber growing region of south India. Expressing similar view Simon and Mohankumar (2004) reported that North of 10^0N Kerala receives more rainfall than South of 10^0N with 65 per cent annual rainfall during South-West monsoon period. Significant variation in spatial distribution of rainfall was seen between

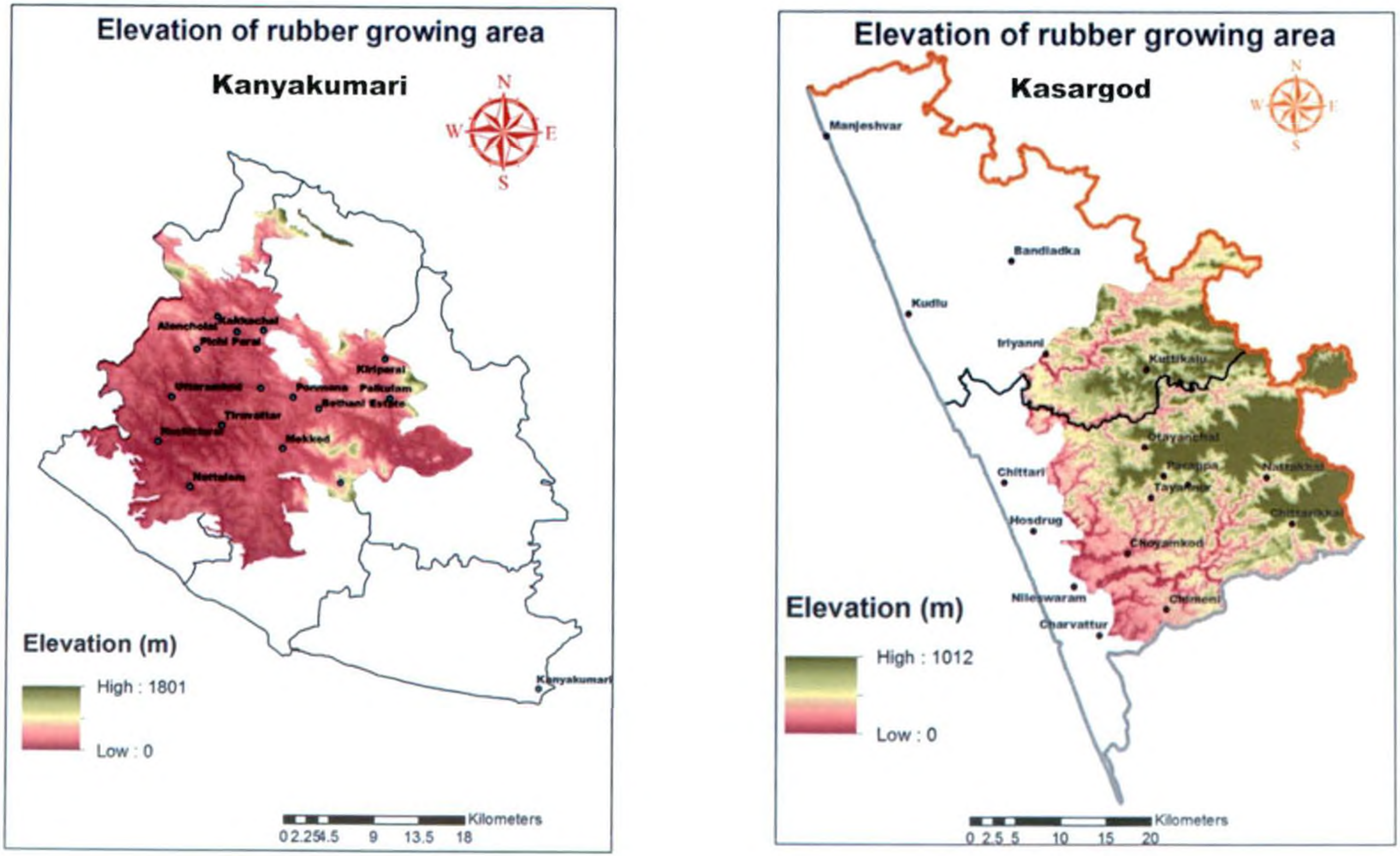
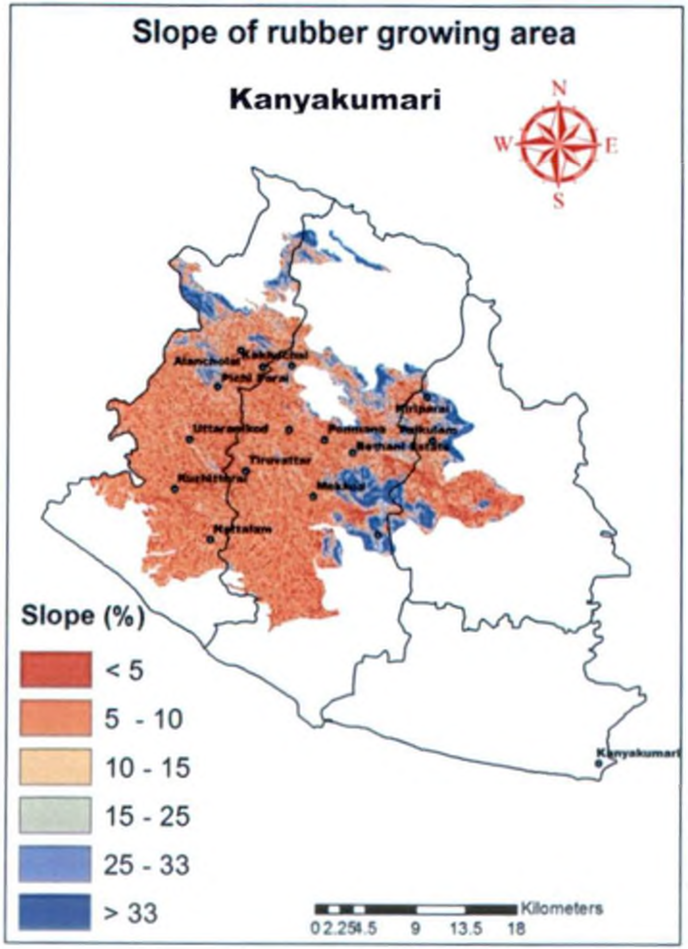


Fig 15a: Elevation map of study area



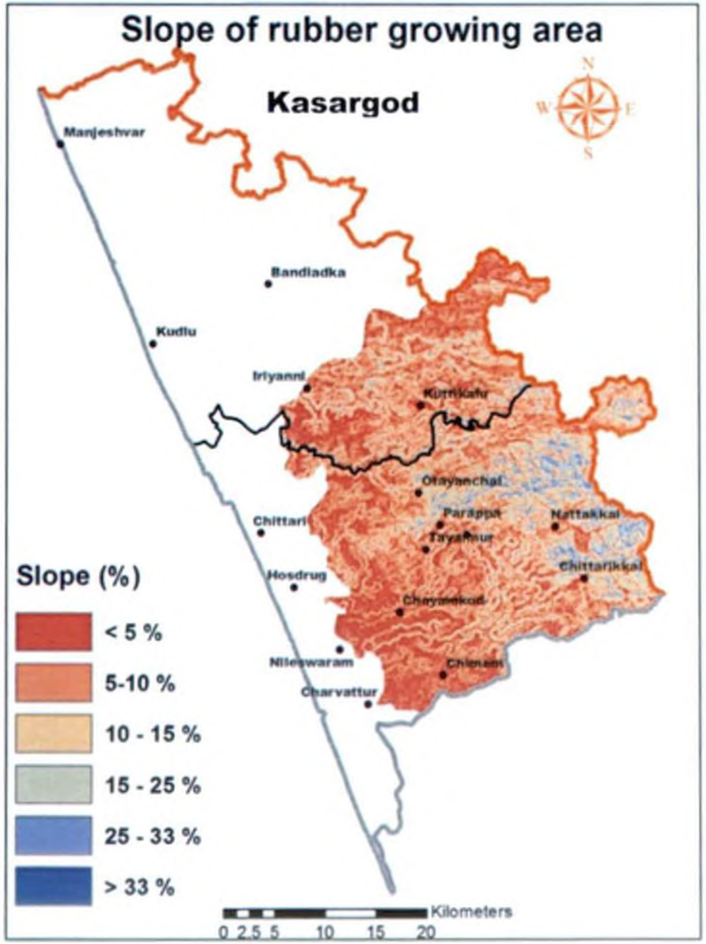


Fig 16a: Slope Map of study area

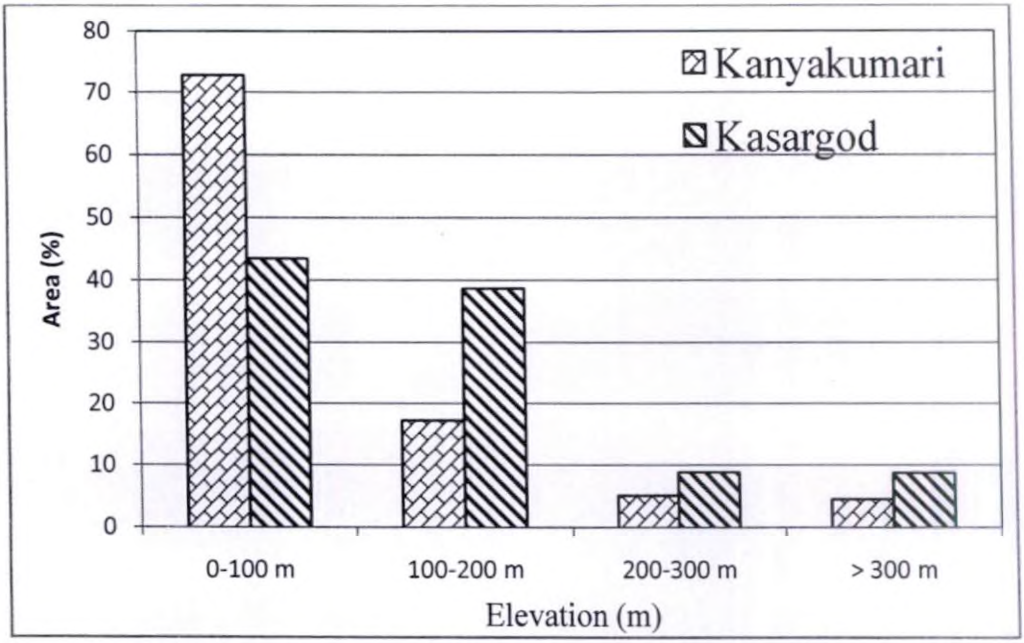


Fig 15b: Distribution of elevation (% of geographical area)

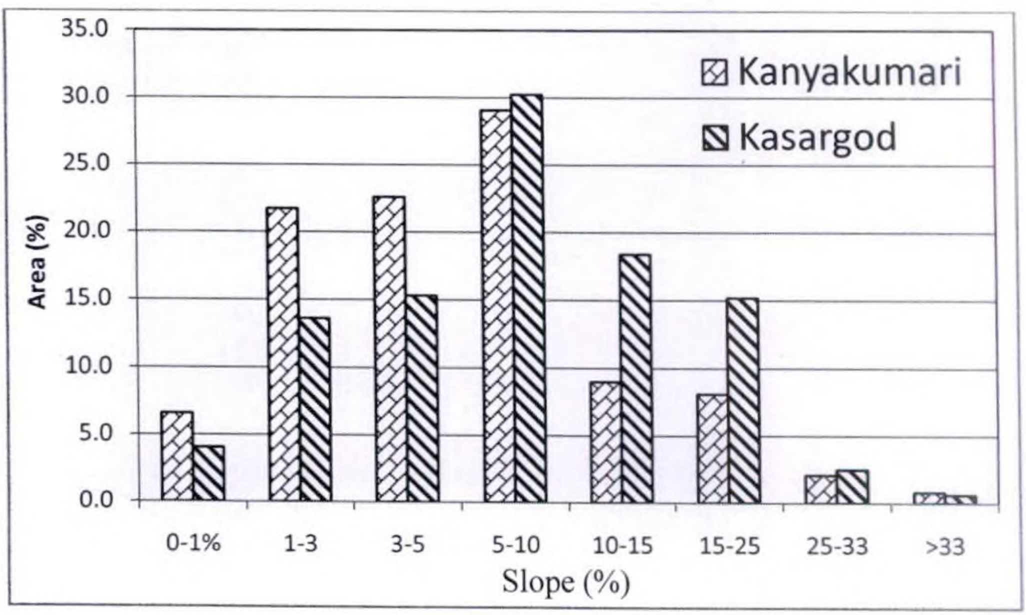


Fig 16b: Distribution of slope (% of geographical area)

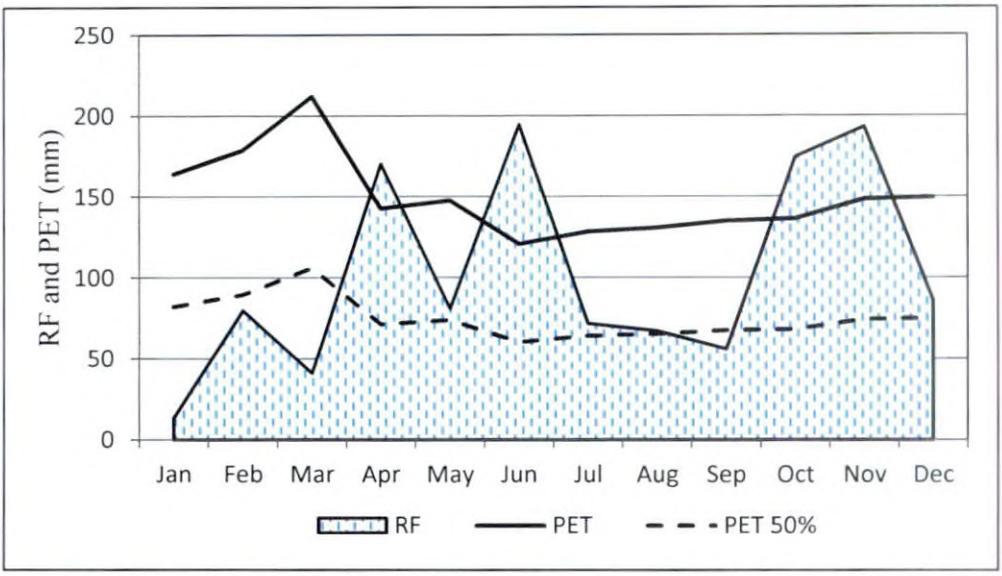


Fig 17: Rainfall and PET of Kanyakumari for 2011

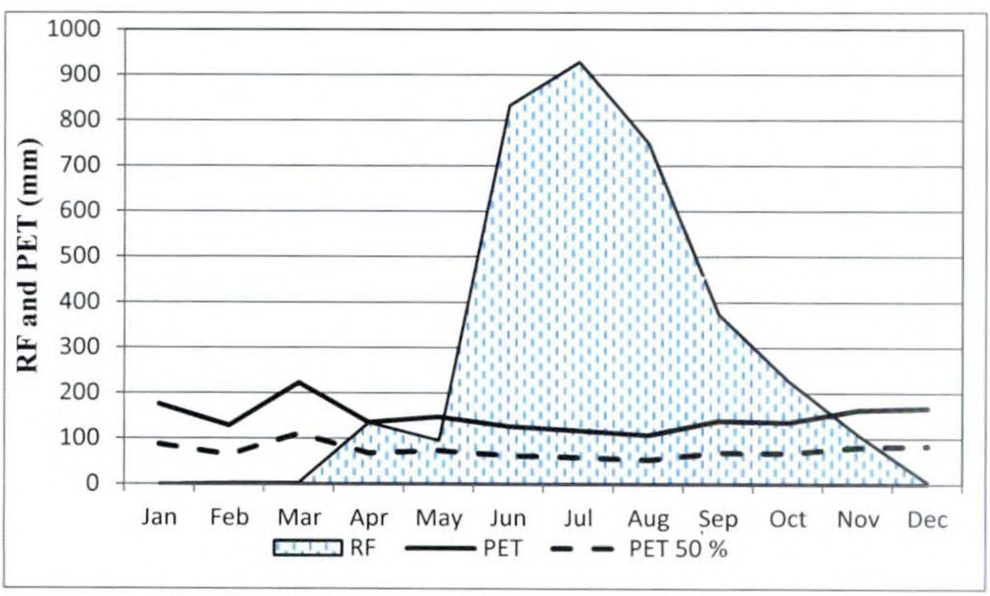


Fig 18: Rainfall and PET of Kasargod for 2011

districts as indicated in Fig 19a. Central part of Northern Kanyakumari received more rainfall whereas Western part of Kasargod received more rainfall.

Annual PET did not differ much between two districts but showed significant spatial variation (Fig 19b). Northern part of Kanyakumari and Eastern part of Kasargod showed less annual PET and this could be due to difference in the elevation.

Monthly water balance showed deficit rainfall in both districts during December to March period and this is evident from Fig 20-21. However the severity of deficit was more in Kasargod (524 mm) compared to Kanyakumari (380 mm) district. This result was in conformity to the report of Rao *et al* (1990) who analyzed the water balance of rubber growing regions of south India and reported less intensity of moisture stress or water deficit in southern region and severe in northern part of traditional regions of rubber cultivation. Similarly Moisture Adequacy Index (MAI) which indicates moisture availability was poor for two months in Kanyakumari whereas it was very poor in Kasargod for consecutive three months (Fig 22-23). The result agrees with that of Rao and Vijayakumar (1992) who reported severe moisture stress for 4-6 months in non-traditional rubber growing regions (above 10^0N), even where annual rainfall is sufficient. Grouping the traditional rubber growing area in India based on soil-site condition, Kharche *et al.* (1995) grouped the Kanhangad area of Kasargod into group having severe limitation of dry spell whereas Kulasekharam area of Kanyakumari under group having no severe limitation of dry spell. This is in agreement with Rao *et al.* (1990) who analysed the water balance of rubber growing regions in south India, and reported that intensity of moisture stress was less and it was for 4 months in Trivandrum region whereas it was severe and for 6 months in Thrissur to Cannanore region.

It is also interesting to note that during December to March, total actual evapotranspiration (AET) in Kanyakumari was higher (324 mm) compared to Kasargod (170 mm) because of the receipt of intermittent and adequate pre-

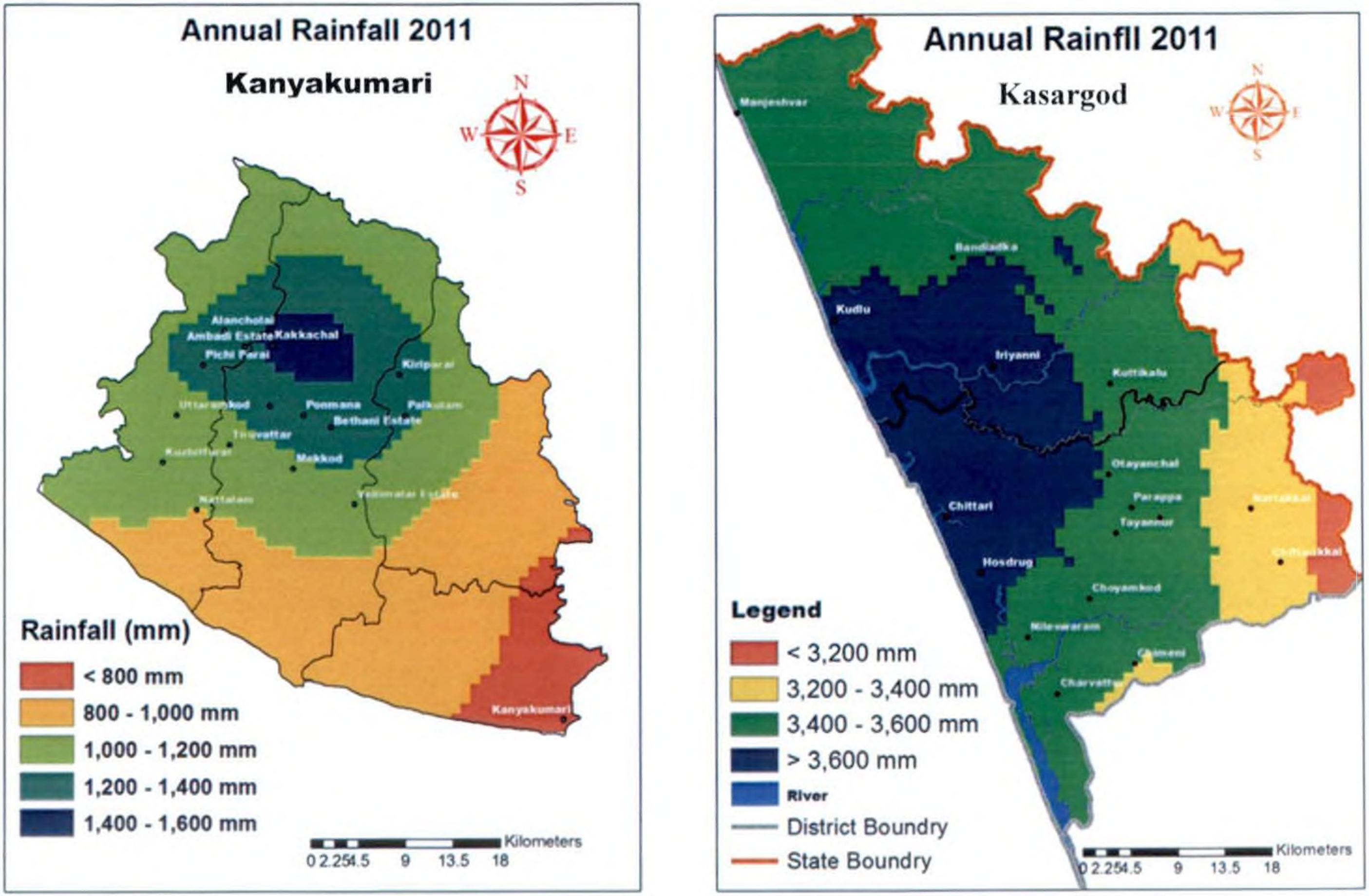
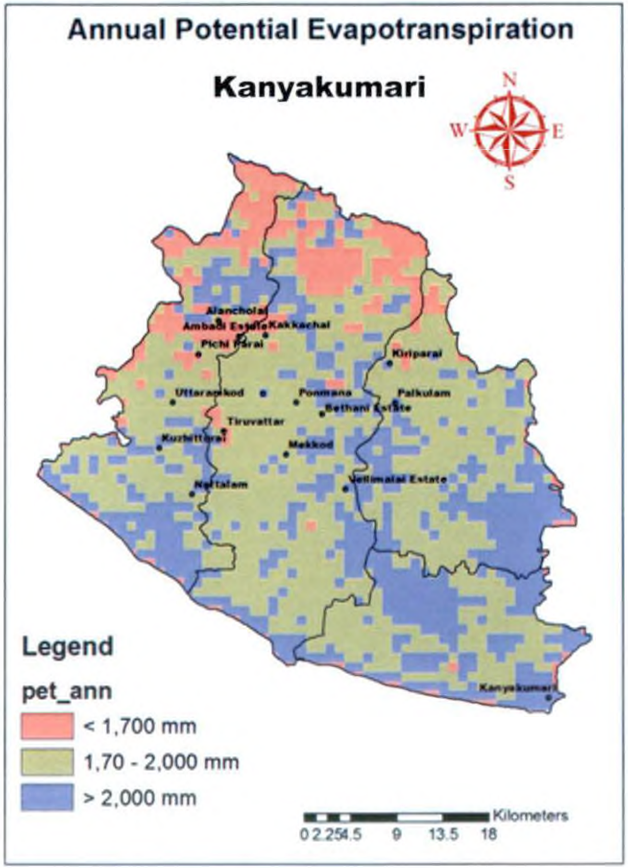


Fig.19a. Spatial distribution of annual rainfall in Kanyakumari and Kasargod



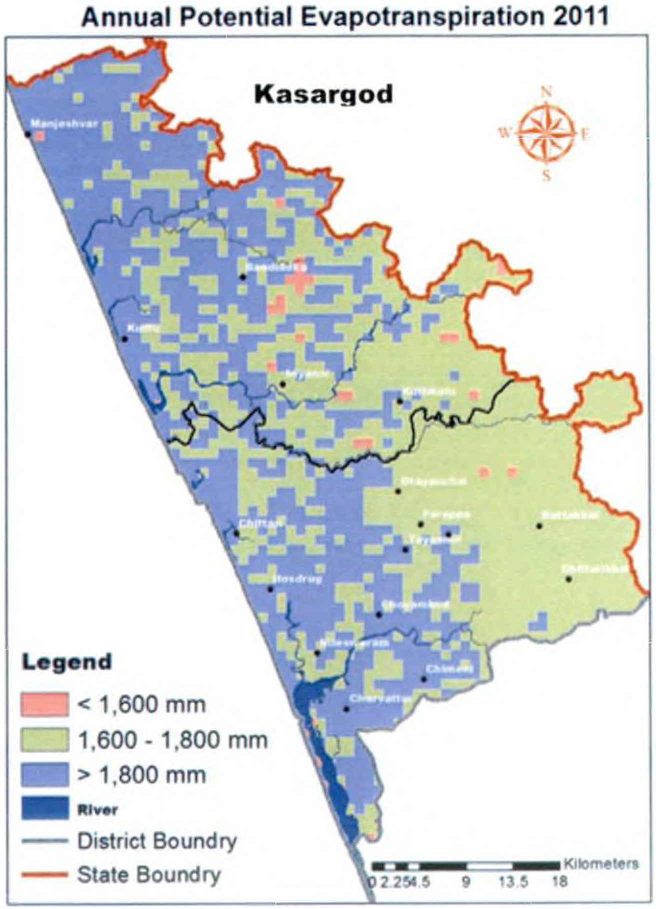


Fig. 19b: Spatial distribution of annual PET in Kanyakumari and Kasargod

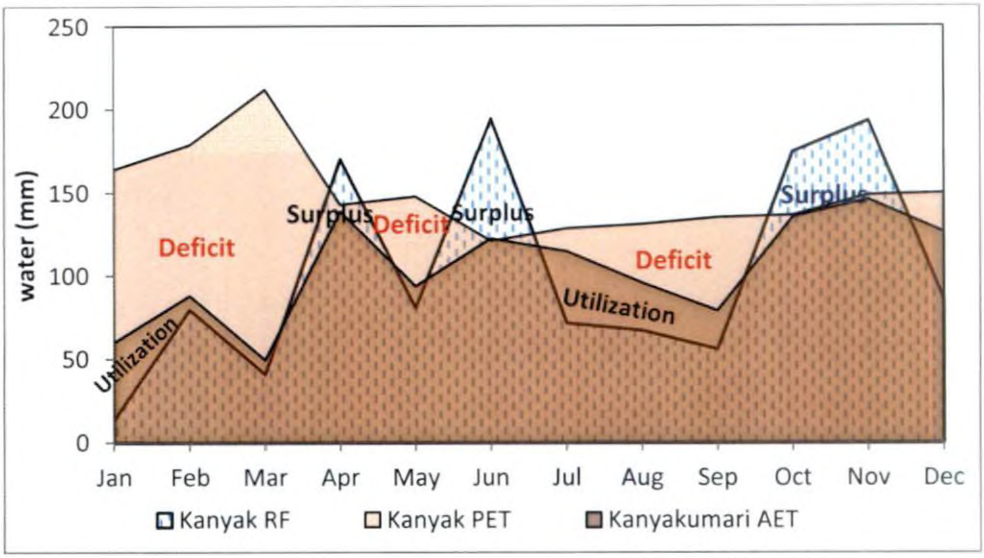


Fig 20: Water balance of Kanyakumari

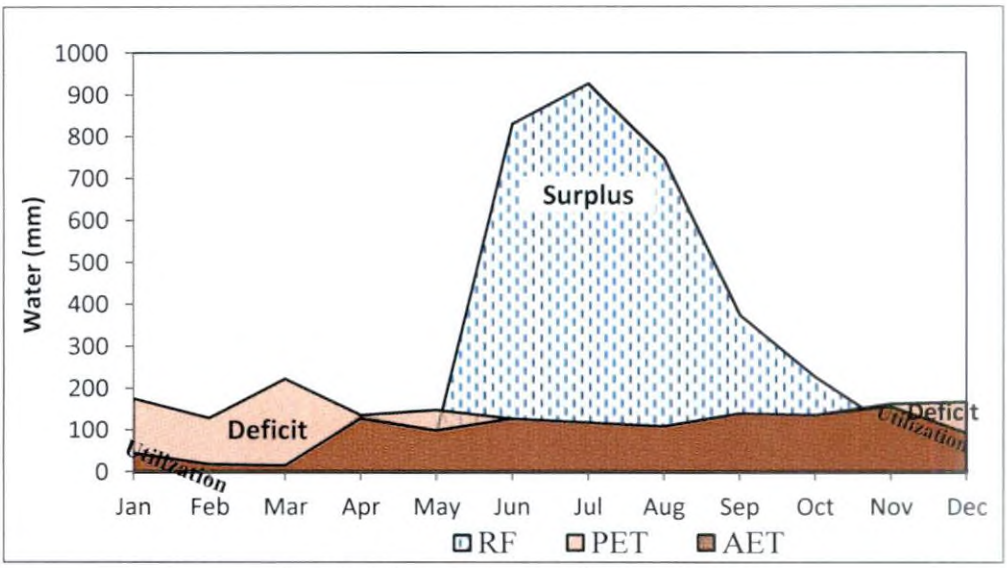


Fig 21: Water balance of Kasargod

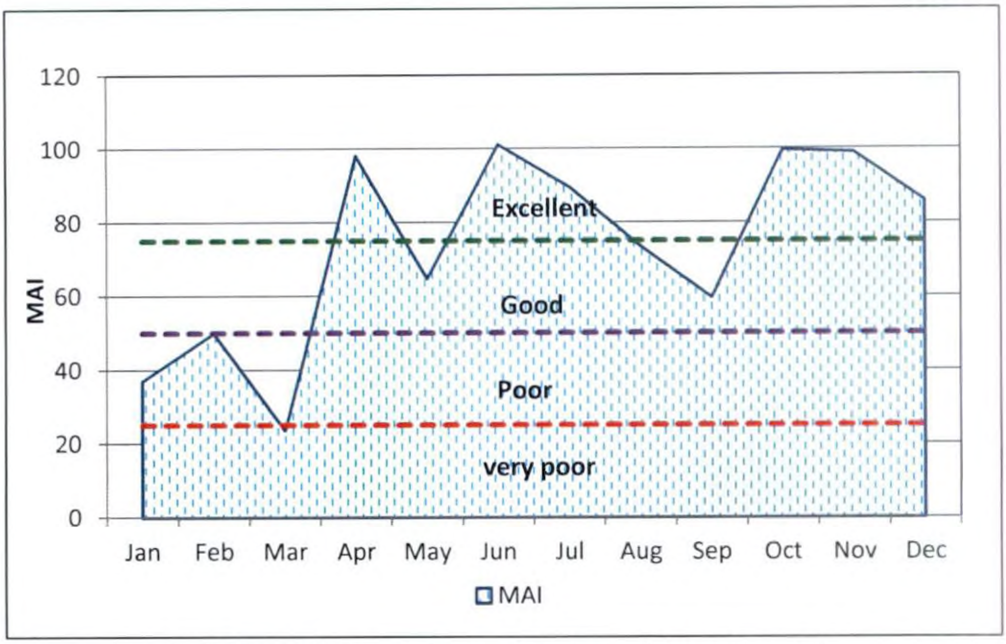


Fig 22: Moisture Adequacy Index ofKanyakumari

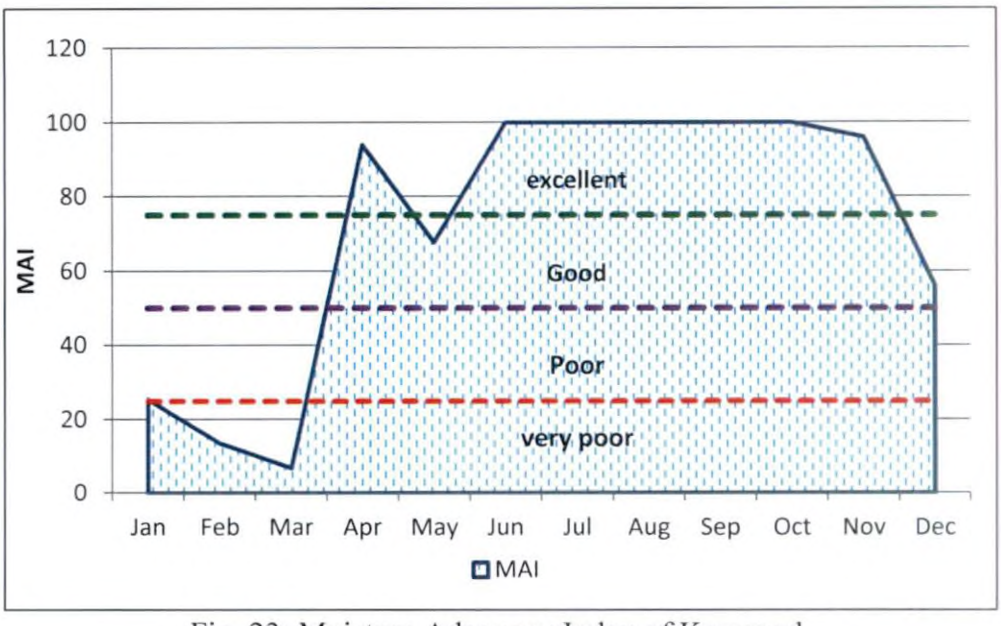


Fig. 23: Moisture Adequacy Index of Kasargod

monsoon showers in Kanyakumari, which might have helped to meet the evaporative demand of atmosphere. Hence moisture adequacy during this period was poor to good in Kanyakumari compared to very poor to poor status in Kasargod district. Expressing a similar view, Rao et *al.* (1990) mentioned the benefit of pre-monsoon showers in relieving the trees from stress in the south. Present study noticed one more deficit period in Kanyakumari district only during August-September (Fig 20). This stress period coincided with the end of south-west monsoon and before the beginning of north-east monsoon. However it was interesting to note that the AET was higher and MAI was good during this period (Fig.22) indicating the mild nature of stress. This might be due to the utilization of stored soil moisture in the profile indicating the importance of soil in tiding over short spell of moisture stress.

Moisture stress during December to March varied spatially in both districts (Fig24). In Kanyakumari, moisture stress was seen only in southern part of district whereas central part of district showed no moisture stress. But in Kasargod district, moisture stress free area was not at all seen during December to March and intensity of stress was more in South-Western part of the district. (Fig.24). Moisture stress during August-September in Kanyakumari was seen only in south-west portion and rest of the area was stress free (Fig 24). All previous attempts to assess the water balance of rubber growing region were based on point weather data and no report of spatial analysis. Previous studies grouped the entire southern region and in particular Kanyakumari belt of rubber growing area in India as mild or no moisture stress and northern region as moisture stress area (Rao *et al.*, 1990; Rao *et al.*, 1993). Spatial analysis in the present study helped to delineate the specific area with and without moisture stress within a district, which was not reported so far.

Length of growing period (LGP) is the duration in days during which rainfall exceeds 0.5 PET and extends till soil moisture storage reduces to 0.25 PET coinciding with maturity of crop (Higgins and Kassam, 1981). LGP estimated from monthly water balance (Fig 20-21) showed that LGP in

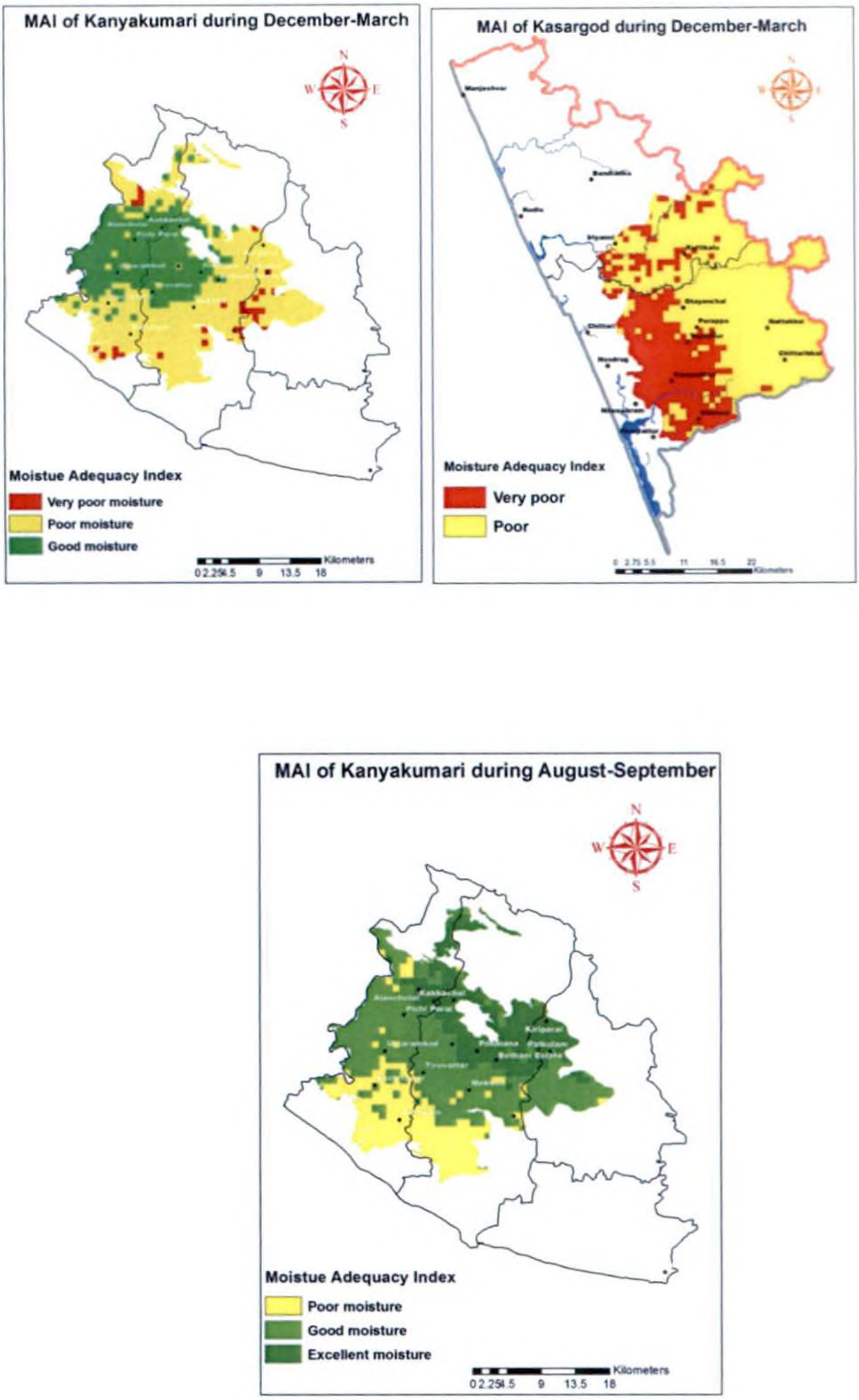


Fig 24: MAImap ofKanaykumari and Kasargod at different period

Kanyakumari was 303 days compared to 244 days in Kasargod district. This was in conformity with Kharche *et al.* (1995) who reported 330 days LGP for Kulasekharam area of Kanyakumari and 240 days of LGP for Kanhangad area of Kasargod. Expressing a similar view, Naidu *et al.* (2008) estimated 5-6 months dry period for Kasargod district based on LGP.

Better climate, long growing period and less dry period in Kanyakumari compared to Kasargod might be due to its geographical location with respect to world natural habitat of rubber (8^0N and 10^0S latitude) characterized by well distributed rainfall and no long dry periods (Vijayakumar *et al.*, 2000). Geographically, Kanyakumari (8^0N) is very close to world natural habitat of rubber whereas Kasargod (12^0N) is located in non-traditional rubber growing region of the world (above 10^0N latitude). Classifying the world rubber growing areas based on rainfall and temperature distribution, Rao *et al* (1993) classified the Kasargod district as moderately suitable zone for rubber and Kanyakumari district as suitable zone.

5.1.4 **Performance of rubber**

5.1.4.1 ***Girth***

Rubber trees in Kanyakumari recorded significantly higher girth compared to Kasargod (Fig 25 and Table 5-6) and this could be attributed mainly to climate. Like any other crops, rubber requires favorable soil and climate for optimum growth and yield. Climate is the important ecological factor, as soil characters are determined to a great extent by climate in which they occur (Pushpadas and Karthikuttyamma, 1980). The most important climatic element which influenced rubber performance is the rainfall. Rubber needs a well distributed rainfall without any marked dry season (Vijayakumar *et al.*, 2000). Rainfall and water balance analysis indicated that Kanyakumari district being close to world traditional rubber growing area received well distributed rainfall with long growing period compared to Kasargod district, which is close to non-traditional area. Non-uniform rainfall distribution with long dry period resulted in

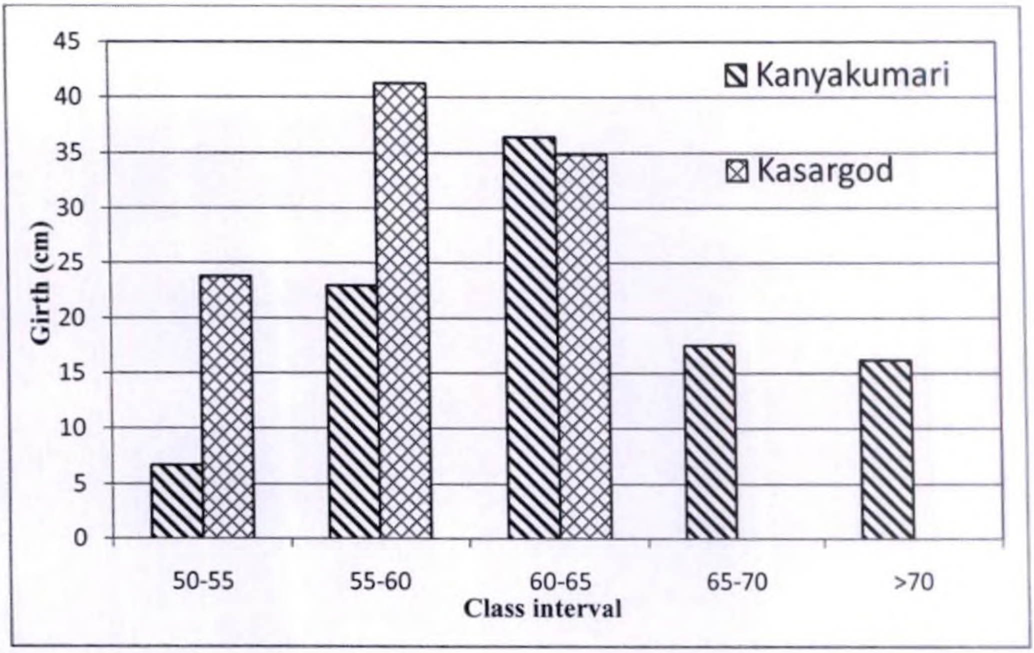


Fig 25. Distribution of rubber girth

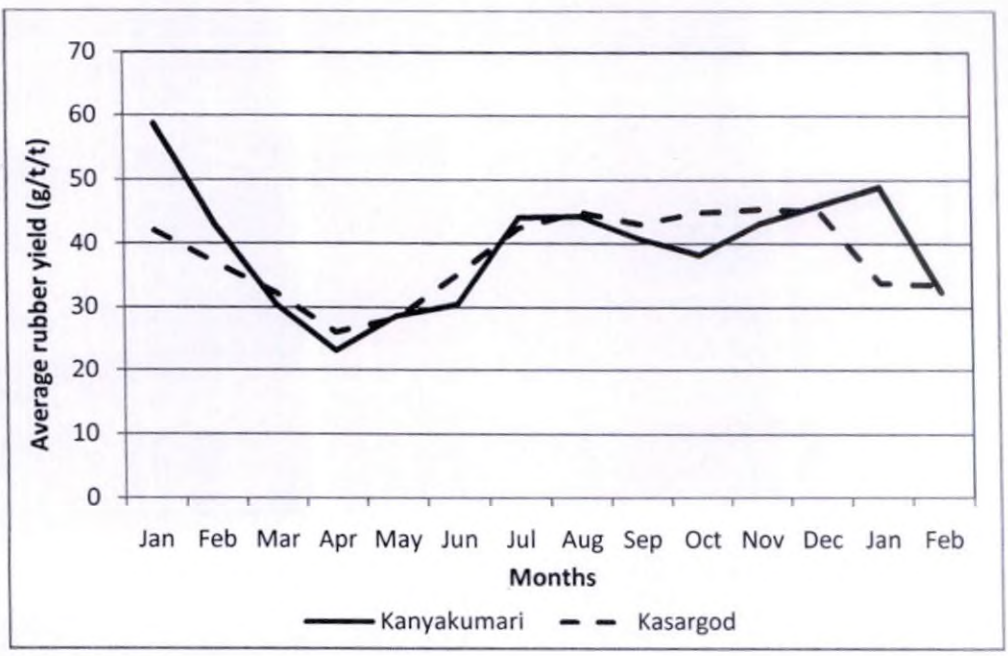


Fig 26: Monthly rubber yield (g/tree/tap)

comparatively less girth in Kasargod compared to Kanyakumari. This result was in conformity with the previous works (Karche *et al.,* 1995; Dea *et al.*, 1996; Thanh *et al.*, 1997; Wijeyasuriya *et al.*, 2010) which highlighted the importance of well distributed rainfall with short dry period from major rubber growing countries in the world. Water stress is the major factor limiting the growth of crops (Fisher and Turner, 1978). Decreased growth under dry areas might have resulted in a cumulative effect of decreased leaf area development (Da Matta *et al.*, 1993; Karyudi and Fletcher, 1999) and photosynthetic rate (Li *et al.*, 1993). Under harsh environment, decreased plant growth resulting in delayed maturity has been reported from India (Sethuraj *et al.*, 1989; Chandrasekhar *et al.*, 1996; Devakumar*et al.*, 1998), Thailand (Rantala, 2006), Cote d Ivories (Dea *et al.*, 1996) and Sri Lanka (Wijeysuriya *et al.*, 2010). Cumulative effect of minimum growth during summer and shrinkage of trunk due to negative turgor pressure in xylem (Chandrasekhar *et al.*, 1996) could have resulted in decreased girth in Kasargod compared to Kanyakumari. With marked dry season, 15-20 per cent reduction in growth has been reported from Thailand (Saengruksowong *et al.*, 1983) and India (RRII, 1986). Dey *et al.* (1998) reported the low growth of rubber in Dapchari, Maharashtra representing dry sub humid compared to Chethackal, Kerala representing humid climate.

Girth showed significant relation with annual rainfall, AET and annual surplus rainfall in Kanyakumari only. This could be due to the favorable rainfall distribution, and LGP observed in Kanyakumari compared to Kasargod. In Kasargod, even though annual rainfall was more but effective rainfall was low due to uneven distribution of rainfall leading to more surplus (i.e. loss) and hence rainfall did not show any relation with growth of rubber. Difference in the influence of rainfall on growth of rubber between two districts could also be due to within district variation in climate. In Kanyakumari district, difference in rainfall, PET and moisture stress was observed between north and south of district, whereas such contrasting difference were not seen in Kasargod. It is interesting to note that in Kanyakumari, girth showed significant positive relation with annual surplus rainfall. Under tight water balance situation observed in Kanyakumari, whatever surplus rainfall was beneficial for plant and this highlighted the importance of water conservation measures in Kanyakumari.

Soil moisture is highly spatial variable and different environmental factors govern soil moisture at different spatial scale. At micro scale, soil depth, texture and water holding capacity of soil determine the soil moisture level. Under uniform climatic condition, soil water retention capacity determined the soil moisture available to plant. Soil moisture level influenced fundamental ecological process such as photosynthesis, respiration and nutrient uptake (Band *et al.*, 1993). Soil is the store house of water for plant growth. Rubber being perennial rainfed crop, moisture holding capacity assumes great importance (Krishnakumar, 1989). Quantum of soil moisture held in a soil varies depending on nature of clay and gravel content (Ali *et al.*, 1966). In Kanyakumari, soil management unit(SMU) 5-7 characterized by shallow soil depth with more gravel content showed significantly low girth and yield of rubber compared to girth and yield of rubber on SMU 1-4 with deep and low gravel content soil. Under the tight water balance situation observed in Kanyakumari district, soils of SMU 5-7 could not have stored the enough soil moisture, compared to SMU 1-4, to support the evaporative demand of plants during summer. Similarly Chan and Pushparajah (1972) and Chan *et al.* (1974) reported significant effect of soil depth on growth of rubber. Prolonged soil moisture deficit is known to inhibit the growth and productivity of rubber (Omont, 1982; Saengruksowong *et al.*, 1983; Sethuraj *et al.*, 1989 ;Chandrasekhar *et al.*, 1996; Withanage *et al.*, 2007). Soil moisture is the balance between water supply and demand. Rainfall in Kasargod district showed imbalance in rain water supply with 66 per cent rainfall as surplus (i.e. loss). Because of non-uniform rainfall distribution and undulating terrain observed in Kasargod, even SMU 1-4 having good soil depth and low gravel content could not hold much soil moisture during summer. This is clearly evident from more soil moisture deficit observed in Kasargod during December to March despite more area under SMU 1-4 compared to Kanaykuamri. This might be the reason why in Kasargod SMU's did not significantly influence the growth and yield of rubber.

5.1.4.2 **Rubber yield**

Crop yield is the function of many factors like weather, soil type and its nutrients status, management practices and other input variables. Of these, weather plays important role and more so in Indian aberrant weather condition. Average per tree rubber yield (g/tree/tap) during December to March was significantly higher in Kanayakumari compared to Kasargod (Table 13 and Fig. 26). However during rest of the period per tree rubber yield did not differ between two districts, indicating the effect of dry period on rubber yield. Lower per tree rubber yield in Kasargod during December to March could be attributed to the severe moisture deficit rubber trees experienced in Kasargod due to poor water balance. Moisture deficit during December to March as indicated by Moisture Adequacy Index (MAI) was more in Kasargod compared to Kanyakumari. During December to March, moisture deficit in Kasargod was two times that of Kanyakumari. Similar results was reported by Rao *et al.* (1990) indicating water deficit increased by 2-3 times from south to north along Western Ghat and 93 per cent yield variation in different agroclimatic condition could be explained by annual MAI. At low soil moisture level the rate and duration of latex flow as well as yield were reduced (Buttery and Boatman, 1976; Sethuraj *et al.*, 1984; Rao *et al.*, 1988; Withanage *et al.*, 2007).

For rubber, rainfall distribution is more important than total rainfall. Rubber needs evenly distributed rainfall without any marked dry season (Vijayakumar *et al.*, 2000). In Kasargod major portion of rainfall is received during May-September with little or no rainfall during rest of the months. On the other hand, in Kanyakumari even though annual rainfall was only 1228mm compared to 3462 mm in Kasargod, rainfall was well distributed in Kanyakumari. In Kanyakumari almost all months received significant quantity of rainfall and hence the severity of moisture stress during summer was low in Kanyakumari.

The importance of well distributed rainfall on better growth and yield of rubber has been reported (Kharche *et al.*, 1995; Thanh *et al.*, 1997; Dea *et al.*, 1996). Rao (1982) also reported that continuous dry spell for six months and high surplus rainfall during July had significant negative effect on subsequent year coconut yield in Kasargod. Pattern of rainfall distribution in the rubber growing tract of India clearly reflected declining trend of average yield of rubber from South to North (Pushpadas and Karthikakuttyamma, 1980; Chandy and Sreelakshmi, 2008).

Natural habitat of rubber is the rain forest of Amazon basin situated within the 5^0 latitude. Rubber is predominantly grown in tropics between 10^0S and 8^0N latitude characterized by receipt of annual rainfall of over 2000 mm with absence of dry periods (Vijayakumar *et al.,* 2000). Non-traditional rubber growing regions (above 10^0N latitude) is characterized by unevenly distributed annual rainfall and 4-6 months dry periods (Rao and Vijayakumar, 1992). Kanyakumari district located between 8.2^0 – 8.4^0N latitude lies geographically very close to predominant rubber growing tract of the world having well distributed rainfall with less than 4 months dry periods and LGP of 303 days. On the other hand, Kasargod district located between 12.2^0 – 12.5^0N latitude lies geographically in non-traditional region of rubber cultivation with unevenly distributed annual rainfall and showed 4 months dry period and LGP of 244 days only. Rainfall and water balance components showed significant positive relation with per tree rubber yield as well as annual yield and rubber girth in Kanyakumari but not in Kasargod. This indicated the importance of well distributed rainfall over quantity of rainfall. Among the water balance components, only annual surplus rainfall showed significant positive relation with rubber yield and girth. It is interesting to note that only during February-May and October-January, per tree rubber yield showed significant positive correlation with annual rainfall surplus and not in June-September yield (Table 20). This could be because in Kanyakumari , majority of rubber area is under levelled to gentle slopy and hence whatever excess rainfall occurred during June-

September might have percolated and stored in bottom layer of soil. This deep stored soil moisture could help the trees to meet the wide gap between rainfall and PET observed during February-May and October-January period.

During monsoon (June-September), sunlight is the most limiting resource for plants due to cloud overcast. Normally high ET indicated the better photosynthetic activity of plant canopy, and helped the plant to draw nutrients particularly mobile nutrients from the soil along with transpiring water. So under adequate soil moisture condition, higher AET indicated better plant photosynthetic activity leading to better growth and yield. This could be the reason why AET and PET showed significant positive correlation with per tree rubber yield during June-September in Kanyakumari. In Kasargod, major portion of rainfall is received during June-September and chance of cloud overcast will be more and hence AET and PET did not show correlation with rubber yield.

Rainfall influences the quantity and quality of latex harvested, as it interferes with tapping operation. Lee and Tan (1979) and Wijeysuriya *et al.* (1997) reported rubber as a crop which exhibited seasonal variation in yield. So any change in seasonal pattern of rainfall might have adverse impact on harvesting of latex in rubber plantation. This is clearly evident from less number of tapping days farmers are getting in Kasargod during June-September period compared to Kanyakumari (Fig. 27). Low tapping days during this period could be due to interference from rain received during this period. In Kasargod, more than 50 per cent of annual rainfall is received during June-September which may cause physical hindrance to tapping operation. It is understood from discussion with farmers that rain gaurding is not practical in Kasargod climatic condition, as rain occurs mostly during tapping hours and because of physical inconveniences tappers are not willing to tap trees. Hence rainguarding is not economical and most famers tap the trees on the day when tapping panel not wetted by rain. Similarly Thanh *et al* (1997) reported about the effect of concentrated rainfall and high number of rainy days on tapping days during July-September in rubber growing region of Vietnam. Hence farmer in Kasargod are losing 15-20 days

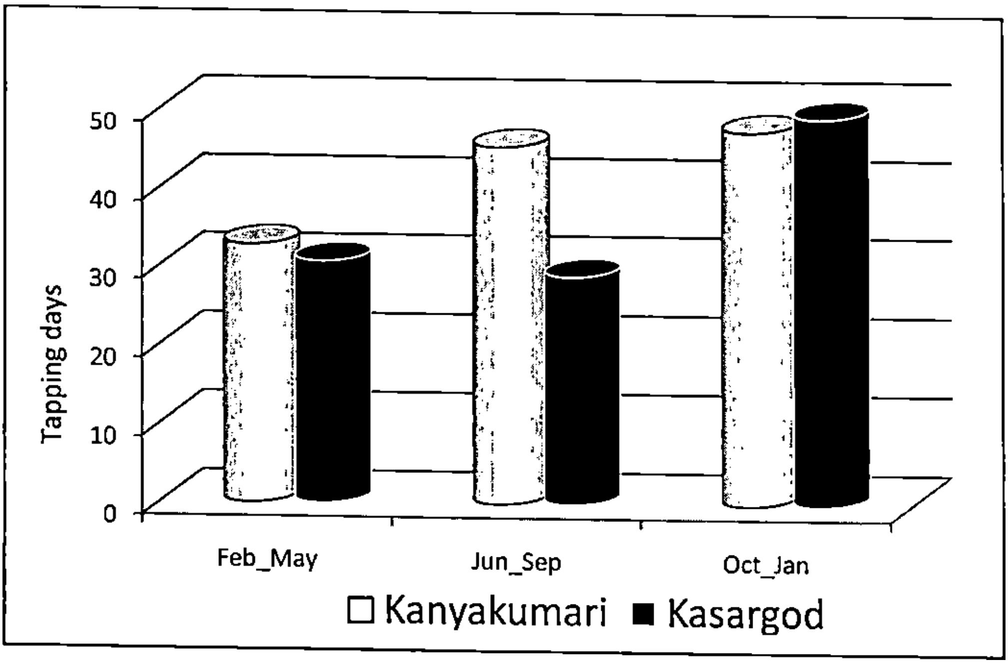
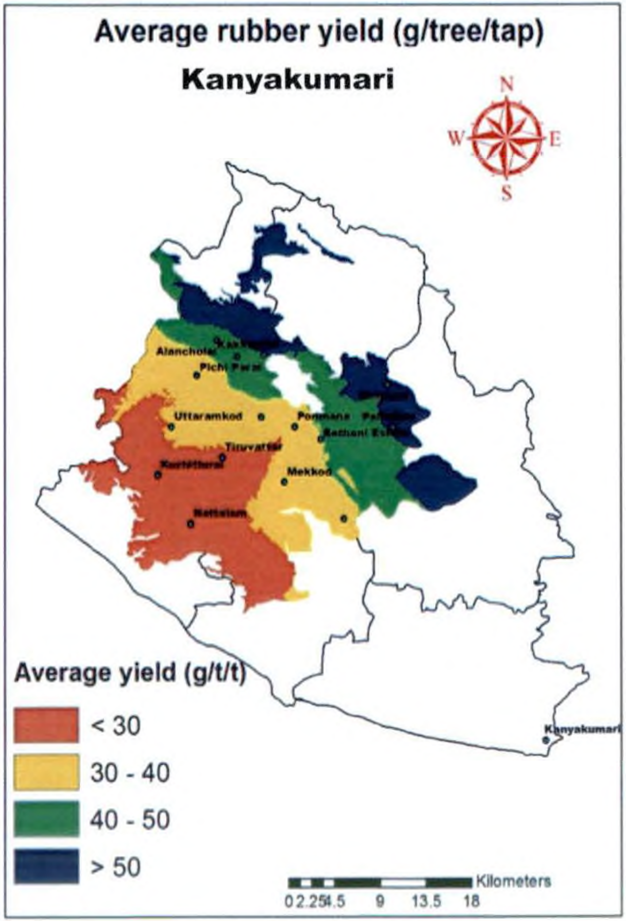


Fig 27: Tapping days during different season

tapping during June-September and because of this reason, farmers are compelled to tap trees during summers despite low yield due to moisture stress. This might be the reason why annual yield varied significantly between Kanyakumari and Kasargod with Kanyakumari recording significantly higher yield compared to Kasargod. Several studies were reported in India, Malaysia and Sri Lanka where rainfall is considered as major factor influencing the productivity of rubber plantation (Samarappuli, 1988; RRIM, 1998; Devakumar *et al.*, 1998).

Length of tapping cut is one of the four major components that determine the per tree rubber yield at each time, tree is tapped (Sethuraj, 1992) and tapping cut length is determined by girth of tree. Girth showed significant positive relation with soil OC in Kanaykumari and at the same time rubber yield also showed significant relation with soil OC. Hence soil OC influenced the yield through the increase in tapping cut length by better girth of plant. Similarly Dey *et al.* (2004) reported the significant influence of tapping cut length on yield of RRIM 600 clone in Tripura.

Soil OC of Kanyakumari varied more compared to Kasargod and showed significant relation with rubber growth and yield. Spatial yield variation in Kanyakumari (Fig.28a and b) showed more resemblance to soil OC variation, indicating the strong influence of soil OC on yield. This may be the reason why soil OC alone showed strong positive loading in to the factor component 3 (Table 22) which showed significant relation with rubber growth and yield (Table 23). Soil OC played important role in supplying plant nutrients, enhancing CEC, improving soil aggregation and water retention and supporting biological activity (Dudal and Decker, 1993). Soil OC is simultaneously a source and sink for nutrients and it plays a vital role in soil fertility maintenance. Kaolinite as the main clay type in major rubber growing soils, CEC of soil heavily depends on soil OC. Thus the high soil OC observed in Kasargod might be the reason for the non-significant relation of soil nutrients with rubber growth and yield. Soils in the traditional rubber growing tract are inherently deficit in available P due to high P fixation by Fe and Al (Osodeke and Kamalu, 1992). Major soil series of



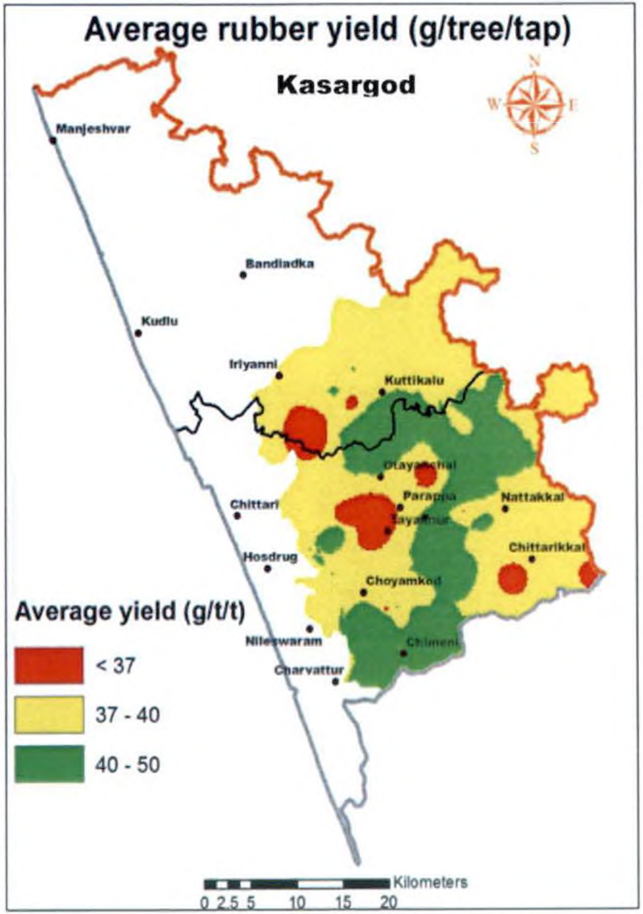


Fig: 28a Average dry rubber yield (g/tree/tap) in Kanyakumari and Kasargod

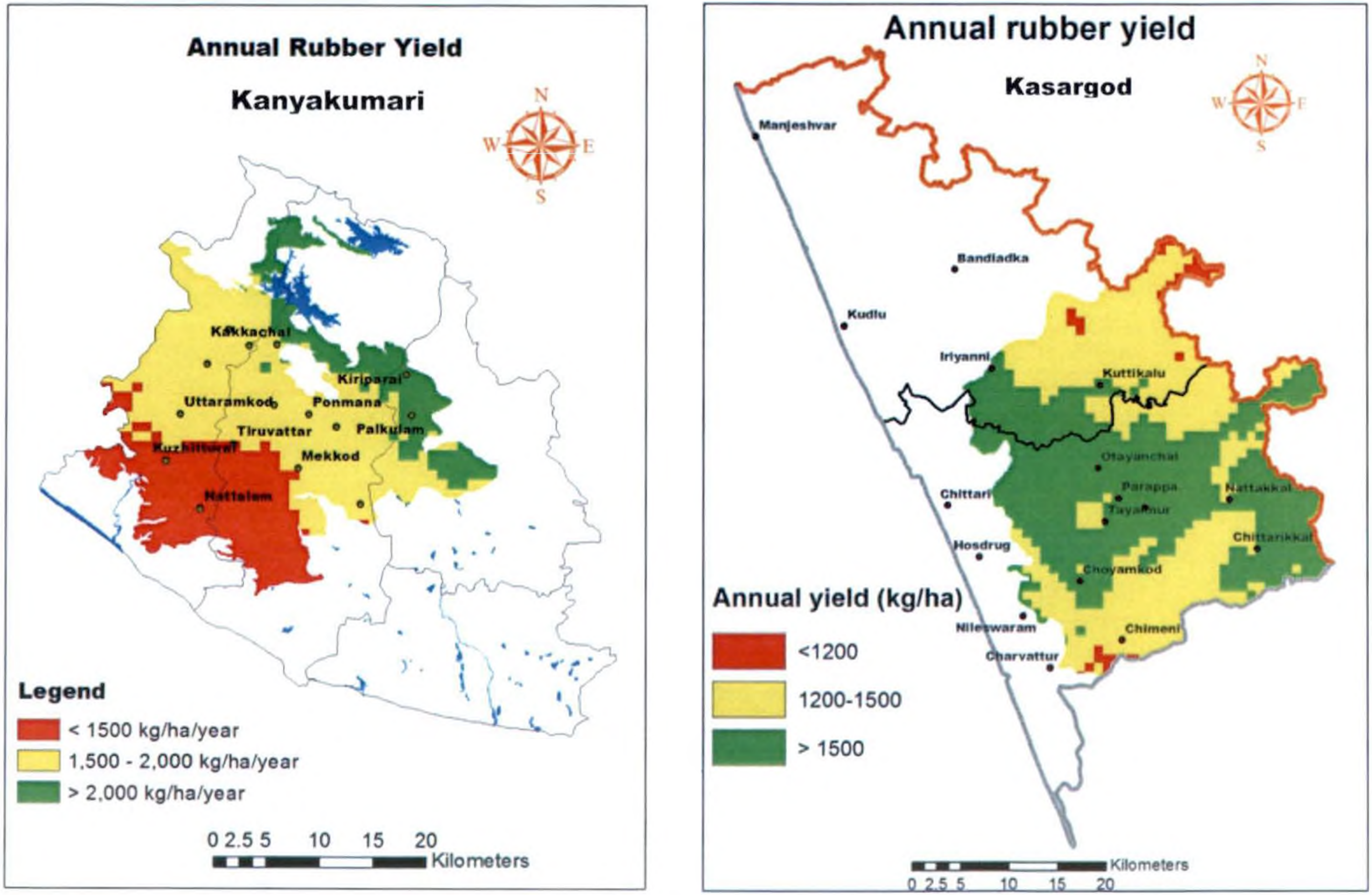


Fig: 28b Annual dry rubber yield (kg/ha/yr) in Kanyakumari and Kasargod traditional rubber growing tract contain 61-86 per cent of total P as organic P (Prasannakumari *et al.*, 2005) indicating the organic P as major share and part of OM. Plants are known to utilize this organic P by secreting acid phosphatase enzyme from root to hydrolyze the organic bound P (Tarafdar, 1998; Jessy, 2004). Despite low available soil P in Kanyakumari and Kasargod, leaf P content was in medium range, indicating the importance of organic P in plant P nutrition. Similarly in a study on correlation between nutrient level in soil and leaf and yield of *Hevea*, Pushpadas *et al.* (1974) reported that leaf P was not correlated with soil P and rubber yield.

In Kanyakumari, rubber yield showed significant negative relation with soil BD but positive relation with slope of land. This could be because, physical properties are generally considered more important in assessing the merit of soil with respect to rubber (Chan and Pushparajah, 1972) and rubber needs a well-drained soil (Webster, 1989). In Kanyakumari district, 40 per cent of rubber area is in flat or gentle slope land (< 5 % slope) (Fig. 16). High BD indicated the less soil aeration resulting in poor root growth and less exploitation of soil resources and moisture from deep layer. But increase in slope of land helps to improve the drainage condition. Hence BD showed negative relation with rubber yield. Similarly Chan *et al.* (1974) and Yew and Pushparajah (1991) also demonstrated the importance of good soil physical conditions in performance of rubber.

Growth and yield of rubber is found to be very much reduced in shallow soil compared to soil having adequate depth (Dijkman, 1951 and Chan *et al.*, 1974). Deeper soil provided greater soil volume so that better exploitation of soil moisture and nutrient resulting in more effective nutrient uptake (Chan *et al.*, 1974). Hence in Kanyakumari rubber growth and yield in SMU 1-2 and 3-4 having deep and less gravel soil was better compared to shallow and gravely soil of SMU 5-7.

Gravel content of soil helped to improve drainage condition of soil during rainy season but at the same time more gravel content drastically reduced the available water holding capacity of soil resulting in less volume of soil moisture available for plant to explore during summer. This might be the reason for the significantly negative relation of gravel content with rubber yield in Kanyakumari during summer (Feb-May) but not during monsoon period . Expressing similar view Dea *et al.* (1996) reported that at Njapidou, Cote d Ivoire in spite of favorable rainfall and short dry season, growth of rubber was weak due to the presence of more gravel content.

Soil available Mg as well as leaf Mg content showed significant negative relation with rubber growth as well as yield in Kanyakumari district. Magnesium is known to reduce the rate and volume of latex flow due to pre-coagulation in tapping cut (RRIM, 1964). The negative effect of magnesium on rubber yield in Kanyakumari could be attributed to high level of available Mg observed in soil (Fig. 5 and 11b) and it showed strong spatial variability (Table 3). Similar negative relation of soil and leaf Mg with rubber yield has been reported by Punnoose (1993) from Kulasekharam area of Kanyakumari. Suppressive effect on growth due to high level of Mg in soil was observed by earlier workers (Fairfield, 1950 and Boltejone, 1954). In Kasargod district negative effect of magnesium and Calcium was not observed despite excess level compared to Kanyakumari. This could be due to the undistributed and concentrated rainfall distribution observed in Kasargod. During heavy rainfall bases like magnesium will be leached out to lower horizon (Joseph *et al.*, 2008) resulting in temporary decline of magnesium level in surface layer. Hence rubber under the climatic condition of Kasargod did not show negative effect.

Factor analysis is the statistical method to understand the dimensionality of set of variables. In Kanyakumari district factor analysis extracted three components namely, soil cation component, water balance component and soil health component. This indicated the water balance and soil factor are the predominant factor operating in the rubber ecosystem of the district. Out of three factors, only soil cation and soil health factors showed significant relation with rubber growth and yield. Rainfall was evenly distributed with good water balance, long growing period and less dry period. Within district, slight difference in climate and water balance was observed but it was for short period and mild. Chan *et al.* (1972) observed that under uniform climate condition, soil could exert considerable influence on rubber yield. Hence in Kanyakumari district only soil component, i.e. soil cation and soil OC influenced the rubber growth and yield. Soil cation factor with high positive loading from available Ca and Mg showed significant negative correlation with girth of rubber and rubber yield during June-Sep indicating the adverse effect of high level of Ca and Mg observed in the soil. In the present study, available Mg as well as leaf Mg content showed significant negative relation with rubber growth and yield. Reports of negative effect of high level of available Mg on rubber growth (Fairfield, 1950; Boltejone, 1954; Punnoose,1993) and rubber yield (RRIM, 1964; Punnoose, 1993) are reported earlier also. Soil pH of Kanyakumari was slightly more acidic, as a result more chance of P fixation by the abundant aluminium present in acidic condition. Soil OM forms a complex with active Al ions present in soil solution leading to less P fixation. This way soil OC not only acts as source and sink of nutrients, it helps in balancing the cation there by making essential elements available to plants. This might be the reason for the growth and yield of rubber showing significant correlation with soil health factor having positive loading from soil OC.

In Kasargod district, factor analysis extracted three components, namely water balance, rainfall and topographic factor, indicating the predominance of climate factor in Kasargod rubber ecosystem. However climate and rainfall factors did not show significant correlation with rubber growth and yield in Kasargod, instead topography showed correlation. For any crop to perform better, climate is the prerequisite. Decline in atmospheric temperature by 0.41^0C and increase in rainfall by 5.7 cm for every 100m rise in altitude has been reported (Shanks, 1954; Webster, 1989). Topographic factors like, slope, aspect and elevation are reported to have profound influence on performance of rubber (Chan *et al.*, 1972). Because of changes in climatic condition associated with altitudinal gradient, altitude acted as a modifier and hence elevation mediated climate effect showed influence on rubber performance under the uneven distributed rainfall, long dry period and moisture stress observed in the Kasargod rubber ecosystem. With concentrated and uneven distributed rainfall condition observed in Kasargod, increase in slope helps to maintain good drainage condition and hence slope also showed significant positive influence on rubber performance in Kasargod. Chan *et al.* (1974) reported increase in girth and yield with increase in slope up to 26 per cent due to better drainage. Rao and Jose (2003) reported the influence of physiography slope on fertility capability classification of soil under rubber. Unlike Kanyakumari, soil OC and cation factor failed to dominate in the Kasargod rubber ecosystem. This might be due to the fact that soil OC in Kasargod was at high level compared to Kanyakumari. Under heavy and concentrated rainfall condition, all exchangeable cations are leached down from profile (Joseph *et al.*, 2008), so despite of high level of Ca and Mg observed in Kasargod, cation factor did not show dominant negative effect on rubber performance.

At macro level in Kasargod, topography mediated climate and slope are operating as predominant process influencing the rubber ecosystem of the district. Because of this reason in Kasargod 70 and 59 per cent of rubber area distributed at elevation 100-300m and above and slope 10-15 per cent and above compared to 31 and 23 per cent respectively in Kanyakumari (Fig. 33-34). For any soil to exert influence on crop performance, ideal climate for crop to perform is a prerequisite. So at macro level, soil in Kasargod did not show dominant influence on rubber. But at micro level, soil may show influence in Kasargod and to capture this, intensive soil sampling is required. Spatial distribution of average (g/tree/tap) and annual rubber yield (kg/ha/year) in Kanyakumari and Kasargod (Fig.28a & b) clearly followed the pattern of soil OC and topography variation respectively, broadly indicating the influence of these factors on performance of rubber in these districts.

5.1.4.3 **Tapping Panel Dryness (TPD)**

Tapping panel dryness (TPD) is a syndrome encountered in rubber plantation characterized by spontaneous dying up of tapping cut resulting in abnormally low yield and stoppage of latex production. TPD was reported for the first time in Brazil in 1887 in the Amazon forest and at the beginning of 20th century in plantation in Asia (Rutgers and Dammerman, 1914). There are several reasons for which TPD is known to occur like reduced water availability due to soil compaction (Nandris *et al.*, 2006), high intensity of exploitation (Bealing and Chua, 1972), unbalanced nutrition (Phusphadas *et al.*, 1975) etc. TPD is described as abnormal physiological phenomenon (IRRDB, 1992). TPD varied significantly between two districts with Kasargod district showing significantly higher TPD incidence compared to Kanyakumari. High incidence of TPD in Kasargod could be attributed to the stress, rubber plants experienced long dry period and reduced growth period. Influence of climate and growth period was also reported as one of the reason for TPD occurrence (Compagnon *et al.*, 1953; Bealing and Chua, 1972; Harmsen, 1989). TPD showed significant positive relation with girth of rubber in Kanyakumari and at the same time girth showed significant positive relation with rubber yield. This indicated the close relation of TPD with vigorous growth and high yield. Expressing a similar view, Mydin *et al.* (1999) reported significant positive correlation of TPD with girth and girth increment of rubber. Hartman *et al.* (2006) also reported that TPD trees are somewhat higher girth than mean girth of healthy trees and most of the biggest trees are TPD affected.

5.1.5 **Mapping rubber area**

Remote sensing and GIS are the modern tools available for mapping, monitoring and analyzing natural resources on earth surface spatially and temporally at reasonable cost and time. Feasibility of identifying rubber area in Kerala using satellite image was first reported by Gopinath and Samad (1985) and subsequently rubber plantations were identified using IRS data (Menon, 1991; Menon and Ranganath, 1992; Rao, 2000). Rubber mapping was attempted using IRS P6 LISS III satellite image (Fig. 29) and rubber showed a distinct signature compared to other vegetation like, forest, teak, coconut and mixed vegetation (Fig. 30). Rubber showed above 60 per cent reflectance in near infra red (NIR) band (band 3) of February/March month IRS P6 LISS III satellite image. In other bands (Band 1 and 2) no difference in reflectance among different vegetation. This unique signature of rubber over other vegetations during Feb/March period can be attributed to the deciduous nature of rubber. During February/March period, rubber plantations will be having young lush green foliage compared to leafless or less green old foliage as in other vegetations. Healthy vegetation reflects back most of the incident NIR radiation while absorb most of incident visible radiation (Jenson, 1986). Hence rubber showed distinct signature compared to other vegetations. Similarly Rao (2000) also reported high reflectance by rubber vegetation in NIR band of IRS IB image compared to teak, mixed vegetation and river. Within rubber, two distinct signatures were observed and this might be because of the difference in density of canopy between young and old plantation. Because of more foliage and dense canopy observed in young plantation (above 10 years), it showed more reflectance in NIR band compared to old plantation. Using the unique signature of rubber, rubber area was delineated for Kanyakumari and Kasargod district after classifying the satellite image (Fig.31).Overall classification accuracy was 91 and 85 per cent in Kanyakumari and Kasargod district respectively. Menon (1991) identified the rubber plantations in Thrissur region of Kerala using IRS 1A LISS I data and reported 90 per cent accuracy. Similarly Menon and Ranganathan (1992) and Meti *et al.* (2008) reported identification of rubber area from different parts of Kerala. Mapping rubber area using satellite image has been reported from other rubber growing countries in the world (Pensuk and Shrestha 2008; Mc Morrow and Heng, 2000; Charat and Wasana, 2010). Total rubber area estimated using satellite image was 14 per cent higher over ground survey statistics in Kanyakumari whereas in Kasargod it was 21 per cent lower. These discrepancies attributed to the fact that in Kasargod district small holdings are more and are

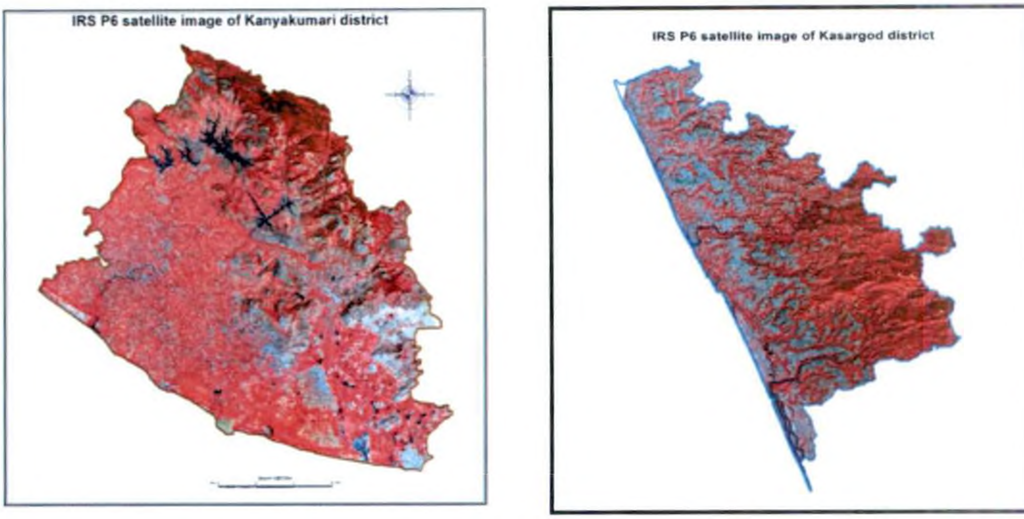


Fig 29: IRS P 6 LISS III satellite image of KanyakumariandKasargod

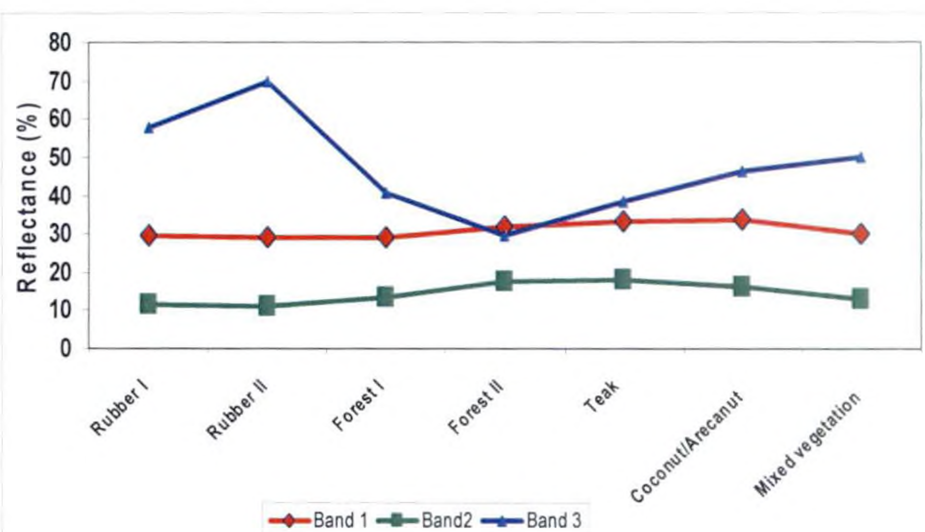


Fig. 30: Spectral signature of different vegetation

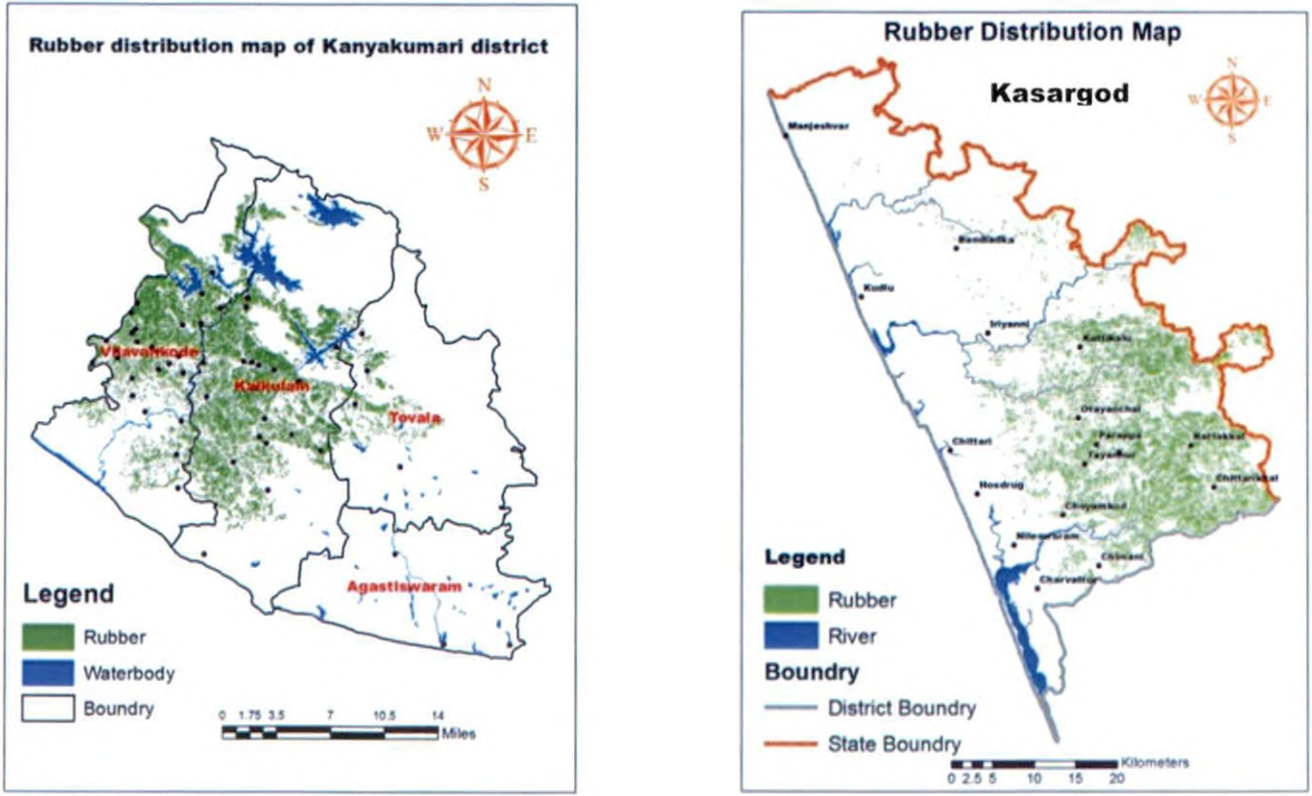


Fig 31: Spatial distribution of rubber in Kanyakumari and Kasargod

scattered, sparse and newly planted. With partially closed canopy, scattered and sparse plantation, it is difficult to identify the rubber area accurately because of poor signature. Expressing a similar view Parthasarathy *et al* (2004) reported the difficulty of identifying the coconut and other vegetation in scattered small homesteads in Assam. Zhe li and Fox (2012) also reported the challenge of isolated small holdings, mixed and undetectable spectral signature in mapping vegetation particularly rubber. High resolution image may help to overcome this limitation but it has its own limitation of low temporal and spatial coverage.

5.1.6 ***GIS and Overlay analysis***

Recently emerged technology like GIS and GPS made the integrated analysis and extraction of information from different geographical/spatial related data in one platform. Overlay analysis of rubber distribution with SMU revealed that 60 per cent of rubber in Kanyakumari and 80 per cent in Kasargod distributed over SMU 1-4 characterized as good to moderate soils for rubber cultivation (Fig 32-33). Extent of distribution of rubber over SMU 5-7 characterized as poor soil with low depth was little more in Kanyakumari (22%) compared to Kasargod (4 %). Majority of SMU 5-7 area in Kanyakumari geographically falls within the identified moisture stress free zone. However little area of SMU 5-7 in Kanyakumari and entire area of SMU 5-7 in Kasargod fall in area identified to have poor moisture adequacy during December-March. In these areas, there is a need to take up proper rainwater harvesting measures like silt pits, terracing and moisture conservation measures like mulching to reduce the severity of moisture stress. Good extent of rubber area in Kanyakumari (22 %) and Kasargod (16%) distributed outside the SMU map and hence there is no information about the nature of soil for these areas. NBSS and LUP Bangalore conducted survey during 1996-98 and prepared the SMU map. Distribution of present rubber area outside SMU map indicated extension of rubber cultivation to new area outside the previously NBSS and LUP surveyed area and this calls for up gradation of SMU map.

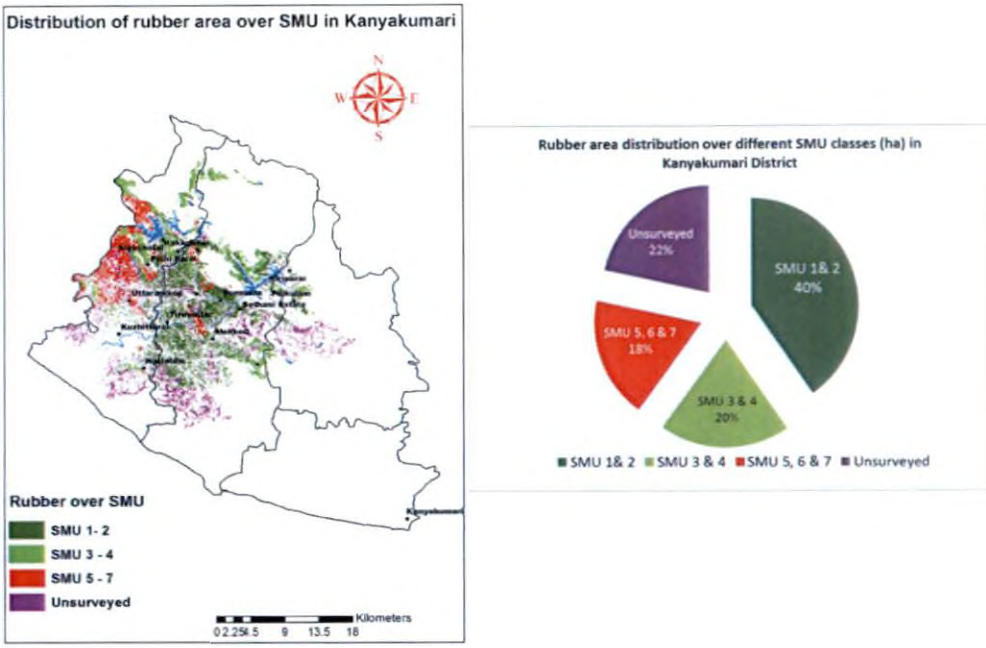


Fig 32: Distribution of rubber over SMU in Kanyakumari

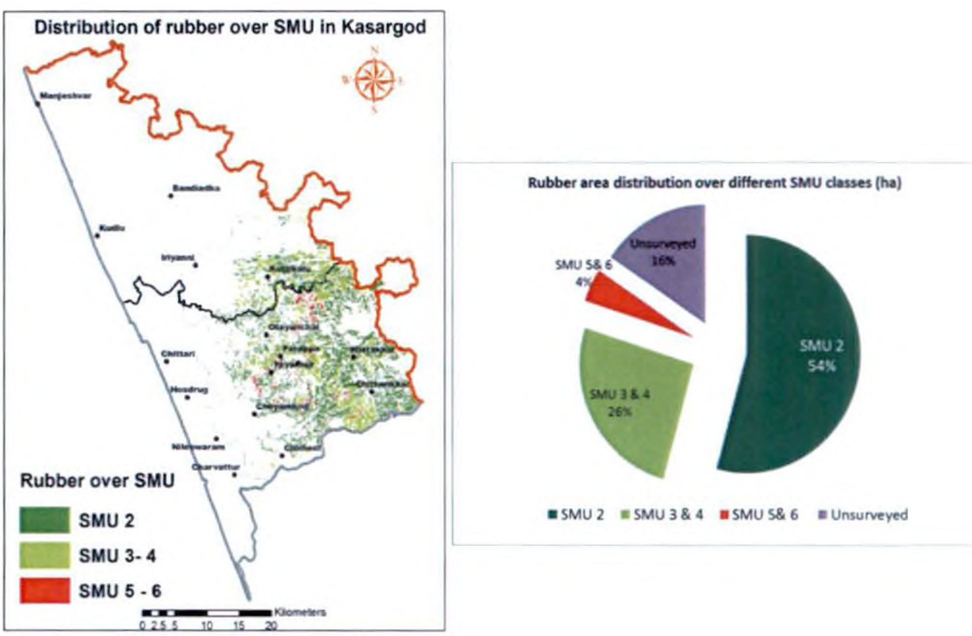
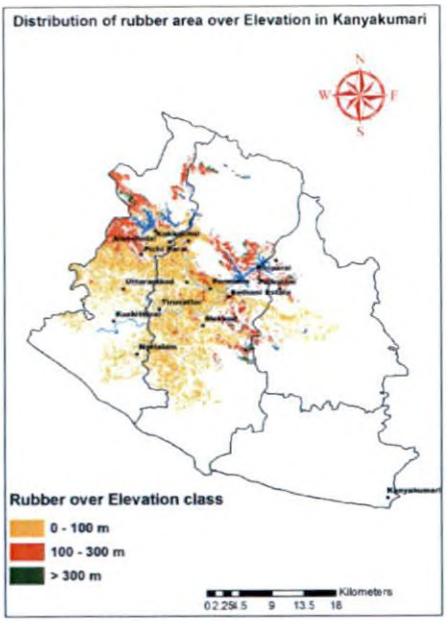


Fig33: Distribution of rubber over SMU in Kasargod

Overlay analysis of rubber distribution with elevation revealed that 96 per cent of rubber area in Kanyakumari and 90 per cent in Kasargod, distributed below 300 m elevation (Fig. 34-35). Little extent of rubber area is distributed over above 300m elevation in both districts. Satisfactory growth of rubber up to 450 m above MSL was reported by Pushpadas and Karthikakuttyamma, (1980).

Overlay analysis of rubber distribution with slope of land indicated that majority of rubber area in Kanyakumari (89 %) was distributed over slope less than 10-15 per cent (Fig 36), which is considered as ideal for rubber (Pushpadas and Karthikakuttyamma, 1980). Rubber needs a well-drained soil (Karthikakuttyamma *et al*., 2000) and in Kanyakumari 40 per cent rubber area is distributed over level land (< 3 % slope). Soil drainage in these areas was affected during heavy rainfall and providing open drains facilitate the drainage of excess moisture (Webster, 1989). Contrary to Kanyakumari, 33 per cent of rubber area in Kasargod was distributed over slope more than 15 per cent (Fig. 37). Soil conservation measures like contour bunding, terracing, establishing cover crops, making silt pits help to reduce the soil erosion in these areas. This finding is corroborated by George *et al.* (2005) who recommended soil conservation measures in rubber plantation.

Overlay analysis of rubber area with climate constraint map indicated that extent of rubber area with poor moisture adequacy during December to March was more in Kasargod (82 %) compared to Kanyakumari (40 %) (Fig 38). About 18 per cent of rubber area in Kasargod is distributed over area with very poor moisture adequacy during Dec-Mar period. Considering the unevenly distributed rainfall and topography of the Kasargod district, integrated watershed approach, earthen check dams made from locally available resources such as stones and wooden logs, low cost earthen rainwater harvesting tank lined with polyethylene sheet etc., helps to capture and store runoff water (www.chimalaya.org). Silt pits at the rate of 250 per ha helped to conserve rainwater and extend the soil moisture availability during summer resulting better growth and yield of rubber (George *et al*., 2006 and 2007).



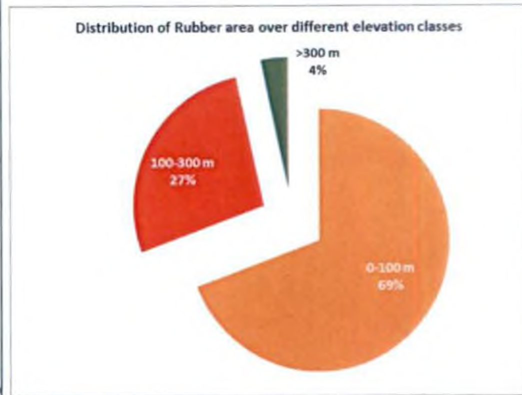
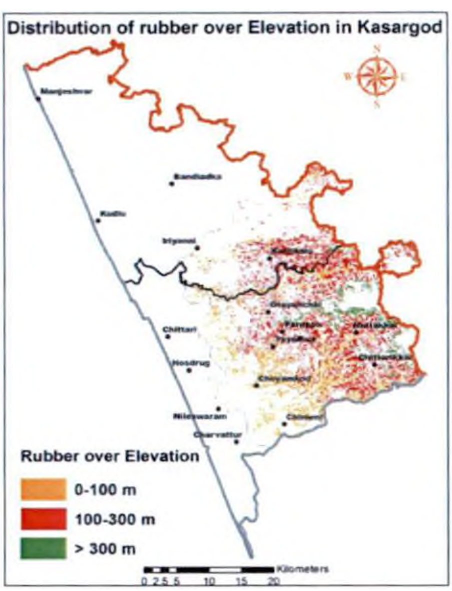


Fig.34 Distribution of rubber over elevation classes in Kanyakumari



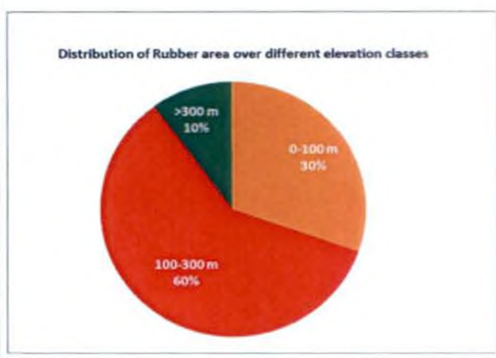


Fig.35 Distribution of rubber over elevation classes in Kasargod

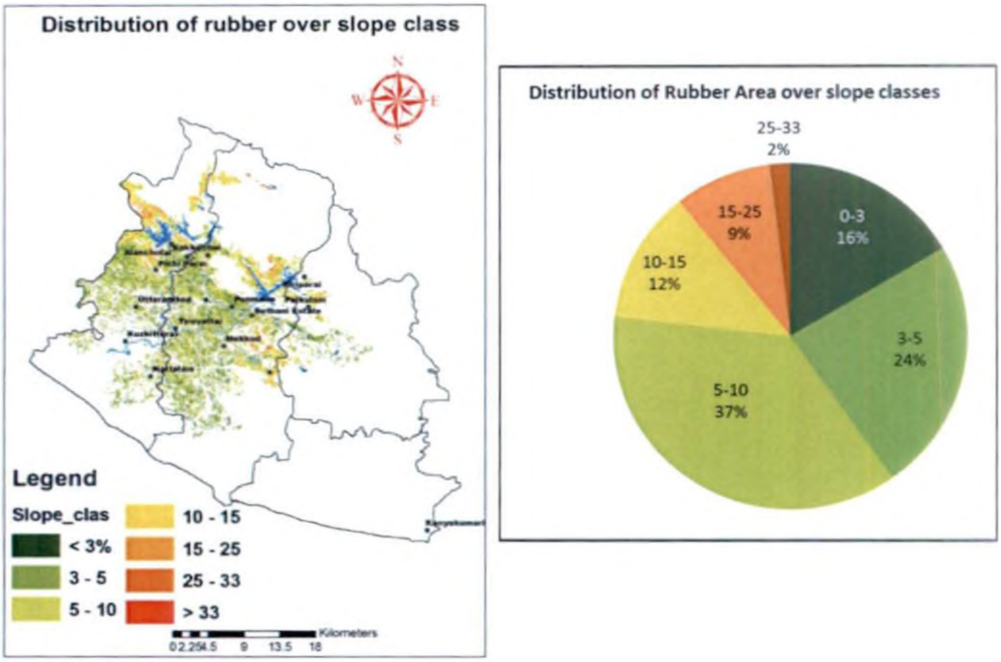


Fig: 36. Distribution of rubber over slope classes in Kanyakumari district

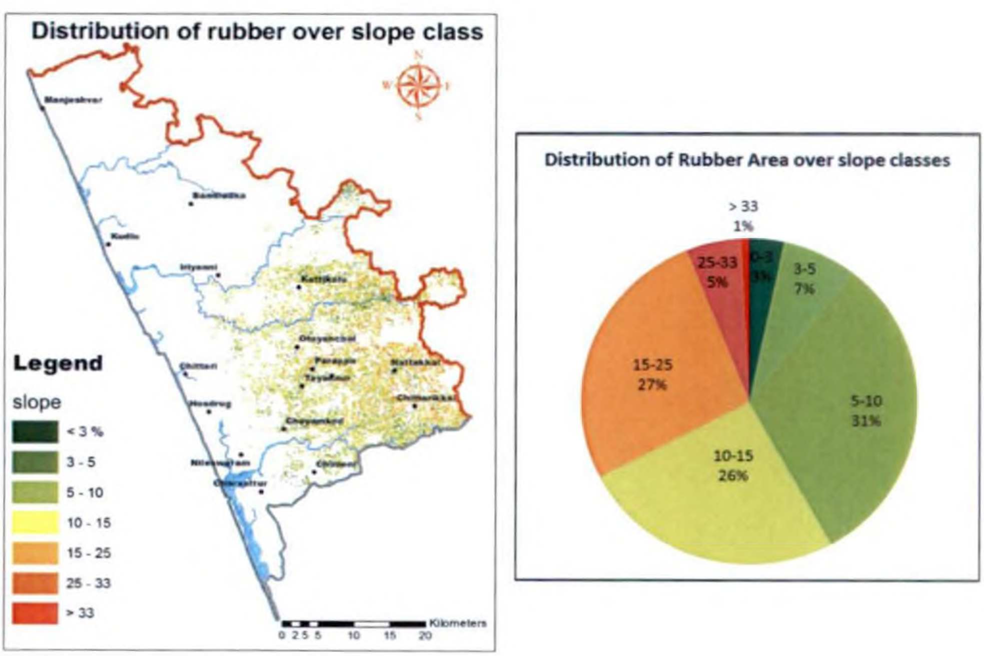


Fig 37. Distribution of rubber over slope classes in Kasargod district

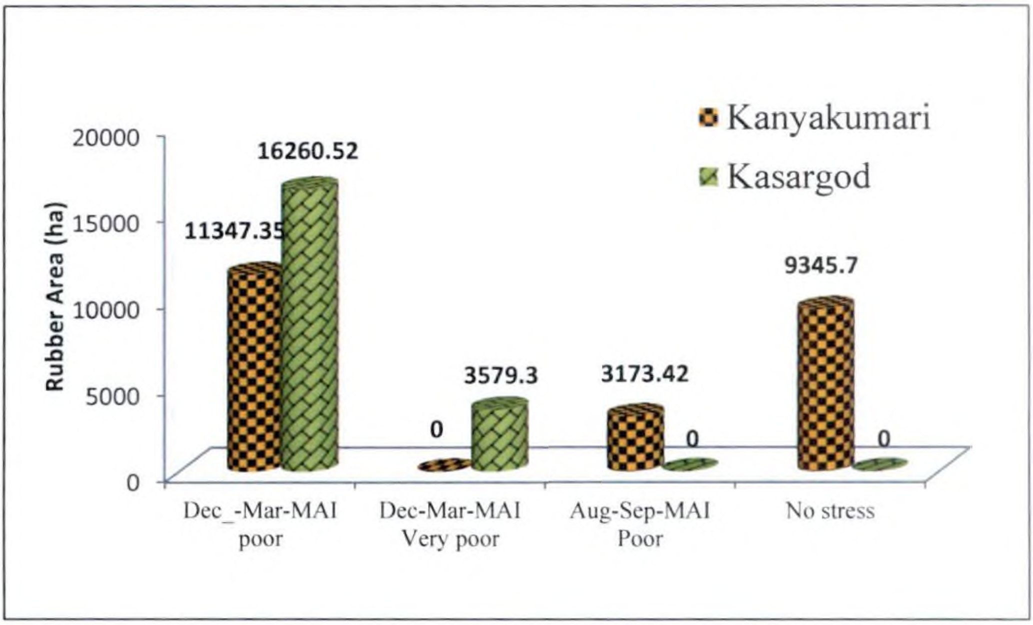
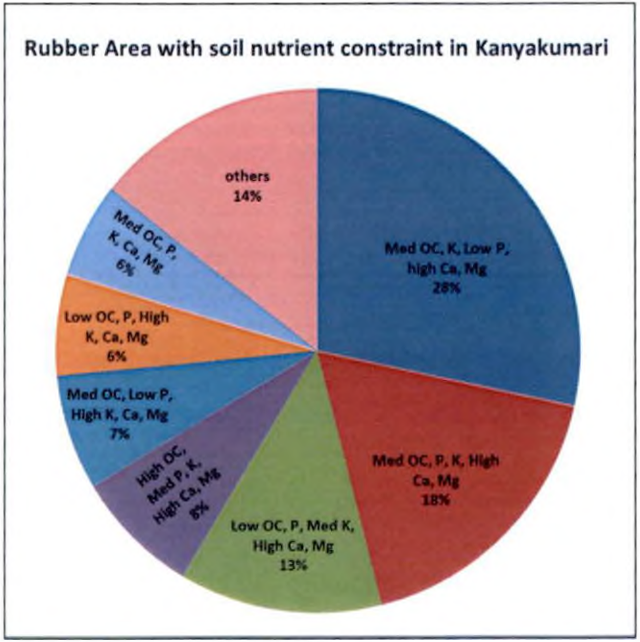


Fig: 38. Rubber Area under climatic stress

Overlay analysis of rubber area distribution with soil nutrient constraint map indicated that major rubber area in both district is distributed over area with high available Ca, Mg followed by low-medium P (Fig 39). Since rubber could thrive on low level of bases (NBSS & LUP 1999) depressive effect of high level of Ca and Mg on growth and latex yield has been observed in the present study and same has been reported earlier also (Fairfield 1950; Boltejone 1954; Punnoose (1993). In this context, Pushparajah (1969) cautioned about rise in available calcium following continuous application of rock phosphate in rubber plantations. Available Mg in soil as well as leaf Mg content was in high range in both districts. Magnesium supply to plants depends on Mg/K ratio and not on level of Mg alone (Yamasaki *et al.*, 1956). So in both districts ,there is a need to balance the K and Mg level in soil by applying more K in areas identified as low in K and high in Mg (Fig.14). Similarly, use of high K fertilizer has been recommended in Malaysia and Cambodia to narrow the Mg/K ratio (Pushparajah, 1969; de Geus, 1973). Considering the critical value of 62.9mg/kg soil of available K for getting yield response (Joseph *et al.*, 1998), all the soil nutrient constraint areas which are medium in available K in both districts may need more K application to enhance the rubber yield. Increase in latex volume and dry rubber yield with K application up to 60 kg/ha in soil low in available K has been reported by Joseph *et al.* (1996). However, removal of K from soil pool through replanting cycle amount to 451-1400 kg/ha (Karthikakuttyamma, 1997) which exceeds the amount drained with latex (Pushparajah 1977; Lim 1978) needs a serious attention particularly in these districts where Mg level is high. This way soil nutrient constraint map can be put to practical use in both districts.



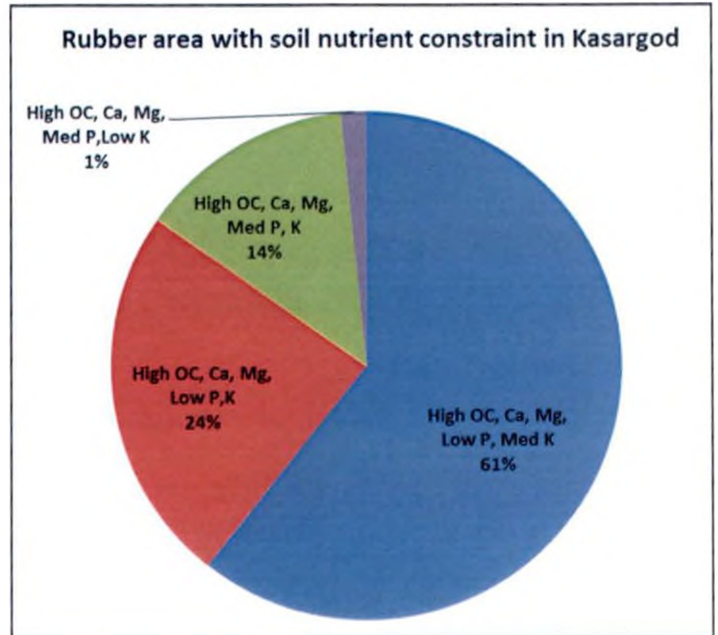


Fig 39: Rubber area under the soil nutrient constraint in Kanyakumari and Kasargod districts

Experiment II.

SOIL NUTRIENT DYNAMICS OF MATURE RUBBER PLANTATION IN RELATION TO PHENOLOGY AND GROWING ENVIRONMENT

5.2 Nutrient Dynamics at Different Elevation

5.2.1 *Litter addition and decomposition*

Litterfall constituted a major portion of nutrient cycling between plant and soil and it acted as an input-output system of nutrients (Das and Ramakrishnan, 1985). The rate of litterfall and its decomposition regulated energy flow, primary productivity and nutrient cycling in ecosystem (Waring and Schlesinger, 1985). Rate of annual litter fall in rubber ecosystem was around 1.9 tons/ha/year, which was comparatively lower than 5-6 tons as reported earlier (Krishnakumar and Potty, 1992; Philip *et al.*, 2003). Low litter addition observed was attributed to heavy incidence of *Phytopthora* leaf fall observed before annual leaf fall during December. Rate of annual litter addition in rubber ecosystem at different elevation did not vary significantly but the rate of decomposition varied significantly. Rate of litter decomposition after 210 days of incubation was significantly higher at low elevation (69 %) compared to high elevation (54 %) (Table 30). There were no reports on variation in rubber litter decomposition rate among elevation, however rubber litter decomposition studied using litter bag technique by Philip and Abraham (2009) reported as 75 per cent by 210 days. Influence of geographical variables such as latitude and longitude on litter decomposition has been reported earlier (Aerts, 1997; Silver and Miya, 2001) and this variation was attributed to the geographical difference in temperature among latitude (Zhang *et al.*, 2008). In the present study, maximum temperature at high elevation was low compared to low elevation (Fig.40) and minimum temperature during summer at high elevation was low compared to low elevation (Fig.41). Decomposition rate reported to decline exponentially as temperature fall along elevation gradient (Vitousek *et al.*, 1994) and hence high elevation showed significantly low rate of decomposition. High rate of litter decomposition at low elevation could be attributed to favorable temperature condition stimulating the

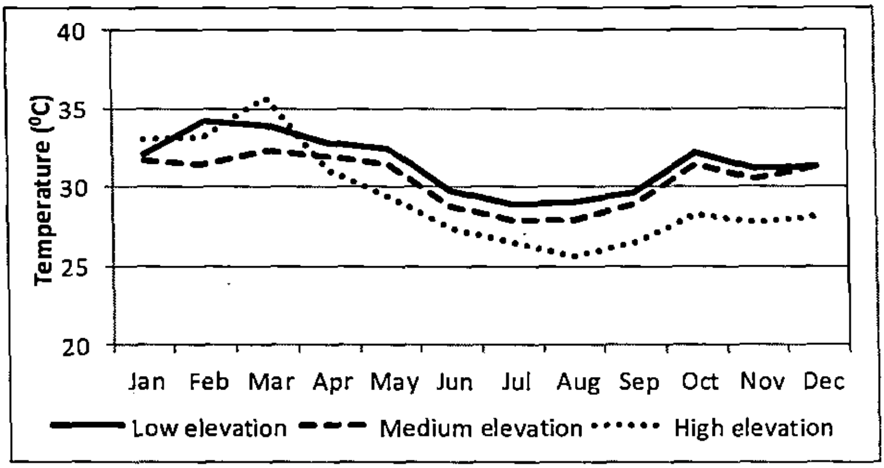


Fig. 40: Maximum air temperature at different elevation

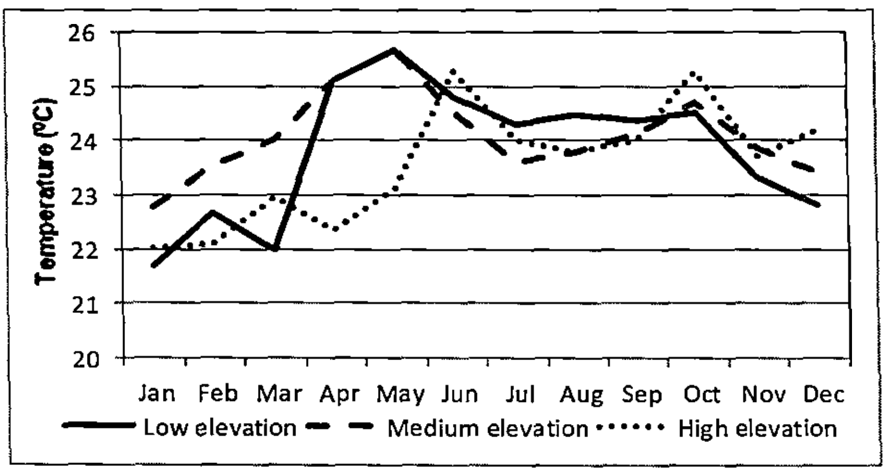


Fig.41:Minimum air temperature at different elevation

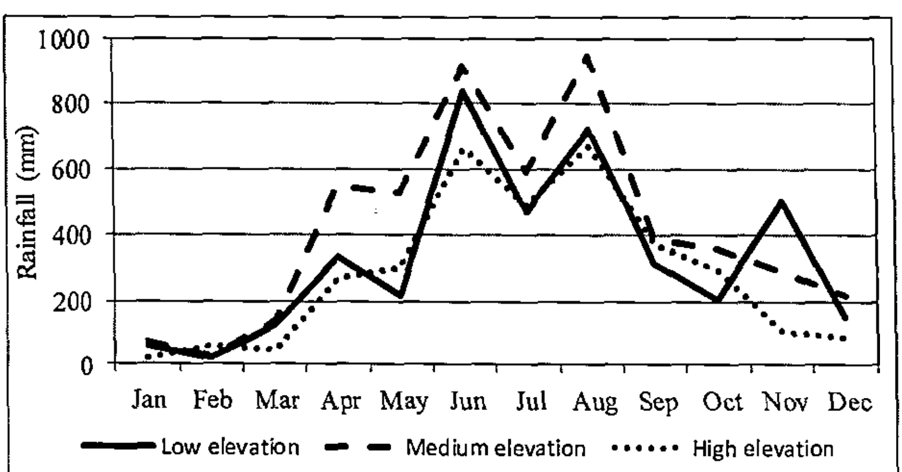


Fig.42:Monthly rainfall at different elevation

activity of decomposer community there by accelerating the litter decomposition (Zhang *et al.*, 2008).

Nutrient content of residual litter during decomposition varied significantly among the elevation due to the variation in decomposition rate among elevation gradient. Nitrogen content in litter increased at beginning and the declined slightly compared to the initial level. Similar trend was reported by Philip and Abraham (2009) during a study on litter chemistry and decomposition in rubber plantation. Initial increase of N was more at low elevation compared to high elevation. During decomposition, initially microbes immobilize the N to breakdown the carbon compound (Wang and Ruan 2011) and reduce the C/N ratio. The high immobilization of N at initial stage at low elevation compared to high elevation showed the high rate of decomposition by microbes due to favorable temperature. At 210 days, calcium and potash in residual litter declined compared to initial level and the decline was more at low elevation. Similar trend of decline in K and Ca at later stage of decomposition was reported by Berg *et al* (1992) and Philip and Abraham (2009) and attributed to leaching loss.

5.2.2 ***Nutrient dynamics***

Soil nutrient dynamics particularly soil OC, nitrogen and exchangeable Al showed significant influence by elevation gradient (Fig 43-46). Soil OC showed significant increase with elevation (Fig. 44) and numerous studies have indicated increased soil OC stock with increase in altitude (Townsend *et al.*, 1995; Trumbore *et al.,* 1996; Bolstad et al., 2001). At high elevation, during active growing period (April-August) decline in soil OC was less and for short period compared to low elevation (Fig 44). This indicated less decomposition of soil organic carbon by microbes due to unfavorable temperature and soil moisture at high elevation. Decreased decomposition rate with increasing elevation is a direct cause of humus accumulation at high elevation (Jenny, 1980). So turn over time of soil carbon increases with elevation (Townsend *et al.*, 1995; Trumbore *et al.*, 1996). Lower decomposition rate is linked to reduced nutrient mineralization particularly nitrogen. At high elevation, nitrate and ammoniacal nitrogen

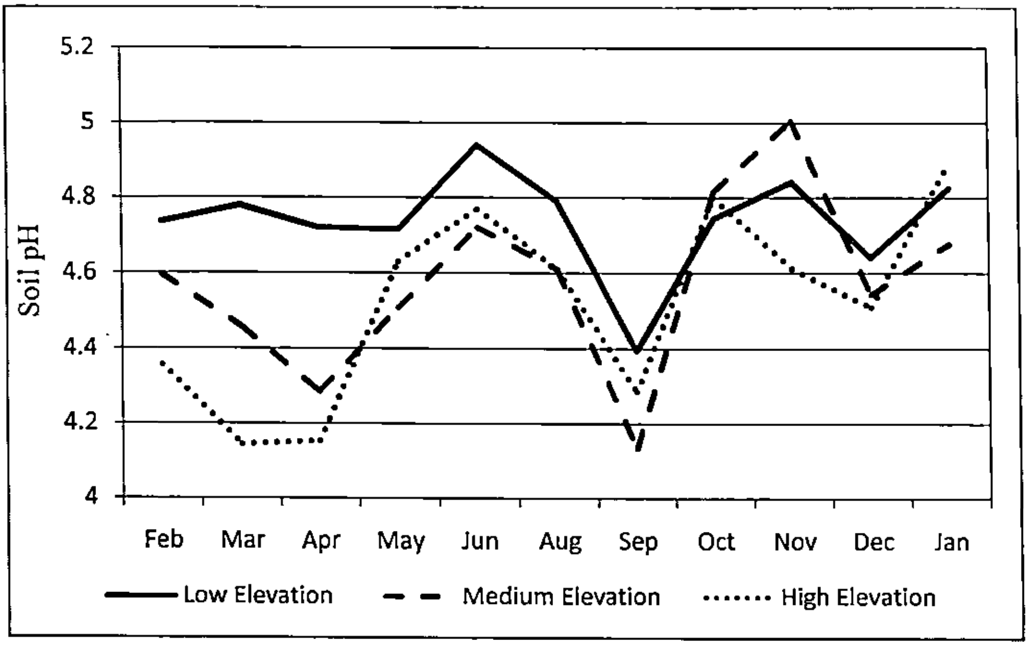


Fig 43: Soil pH at different elevation

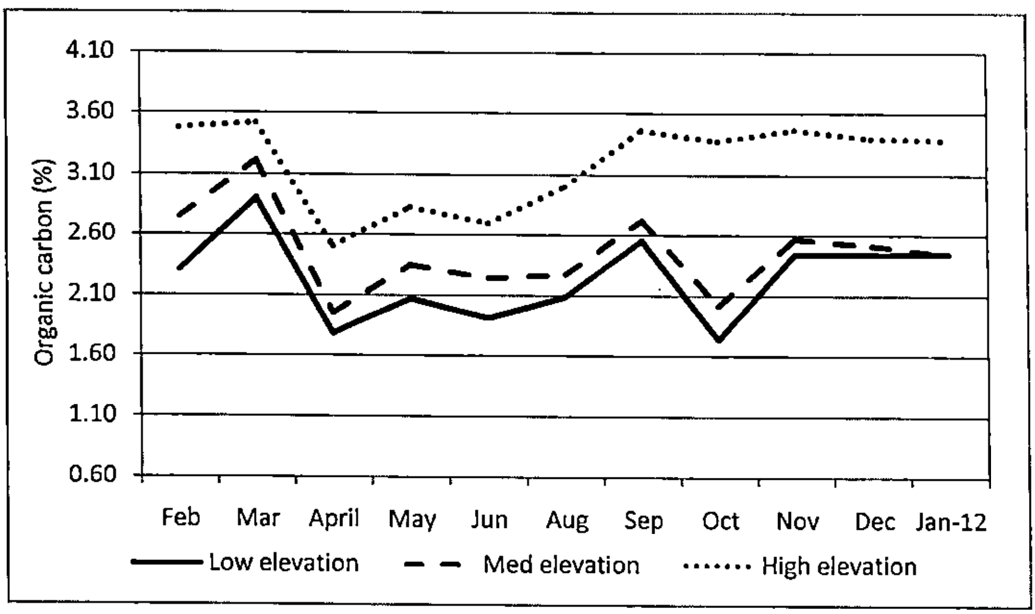


Fig 44: Monthly Soil OC at different elevation

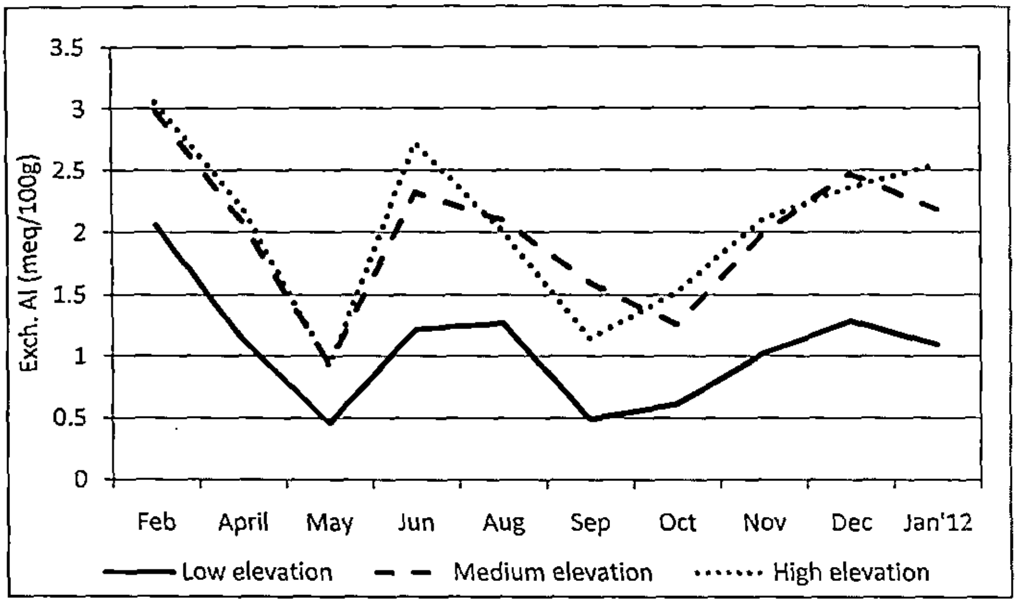


Fig.45: Soil exchangeable aluminium at different elevation

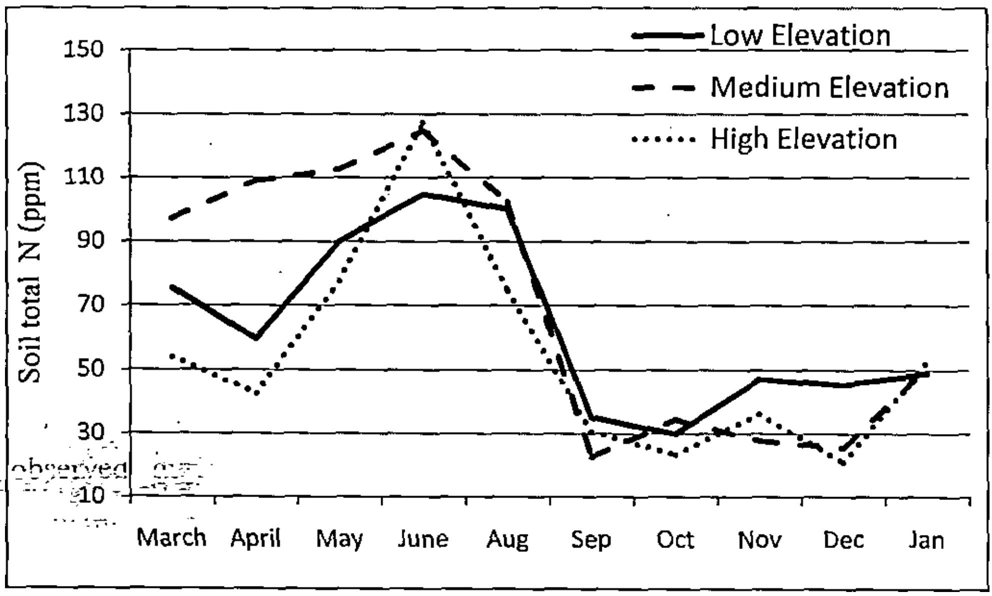


Fig 46: Soil Total N at different elevation

mineralization potential was low compared to low elevation (Fig. 47-48). Temporal soil total N at high elevation showed peak value for a short period compared to low elevation (Fig. 46). So far, there were no reports on effect of elevation on nitrogen mineralization in rubber plantation, however reports of lower total N content in rubber growing soil at higher altitude compared to lower altitude has been reported from India (Satisha *et al.*,2000) Nigeria (Eshett and Omueti, 1989) and South-East Brazil (Centurion *et al.*, 1995).

Scrutiny of the data on temporal dynamics of exchangeable Al showed two peaks, one during monsoon and another during winter period (Fig 45). Exchangeable Al reached lowest during April/May and September/October. Dynamics of exchangeable Al almost followed temporal dynamics of soil pH (Fig 43) and OC (Fig 44). Exchangeable Al showed significant negative relation with minimum temperature and soil moisture, indicating their negative influence. During summer and September/October because of the favorable moisture and temperature, mineralization of soil OC by microbes was more as indicated by the decline in soil OC. During mineralization of soil OC, lot of organic compounds and cations were released which forms complex with Al ions (Stevenson and Vance, 1989) thus reducing the concentration of active Al ions in soil solution. During south-west and north-east monsoon period, increase in exchangeable Al might be because of loss of bases and cations through leaching, causing increase in Al in exchange complex. In general, exchangeable Al showed an increasing trend with elevation. This is mainly because of the significantly higher soil OC observed at high elevation. Soil cation exchange capacity of soil heavily depends on soil OC than soil clay (Manu *et al.*, 1991). de Ridder and Vankeulen (1990) found a difference of 1g/kg in soil to result in difference of 0.25 cmol/kg of soil CEC. So, high soil OC at high elevation indirectly contributed to high exchangeable Al.

Soil moisture and temperature are the major environmental factors affecting the nitrogen mineralization (Agehara and Warncke, 2005). At high elevation, temperature was low and soil moisture was significantly high (Fig. 49

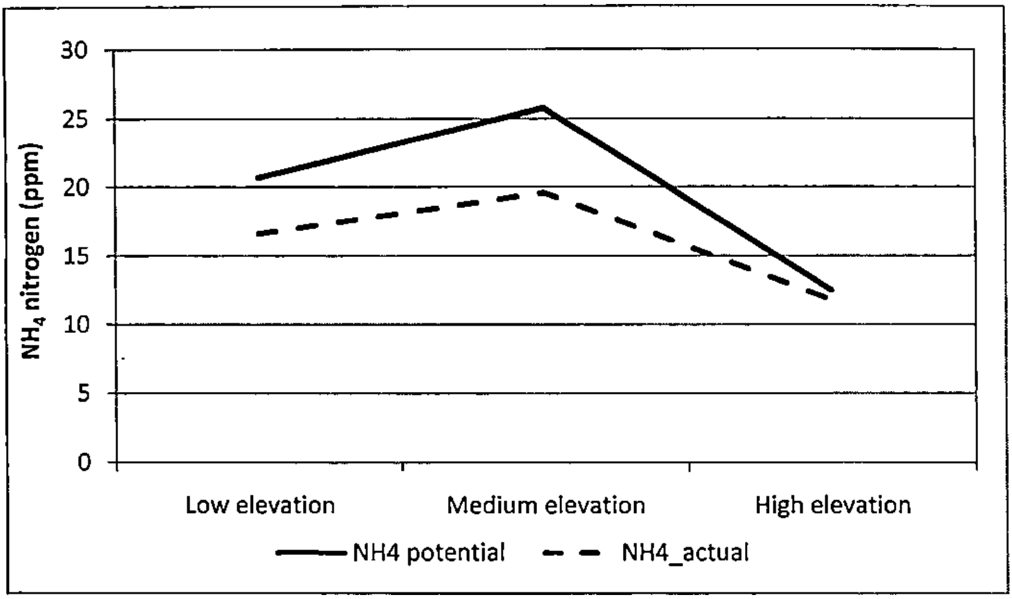


Fig 47: Ammonical nitrogen mineralization potential at different elevation

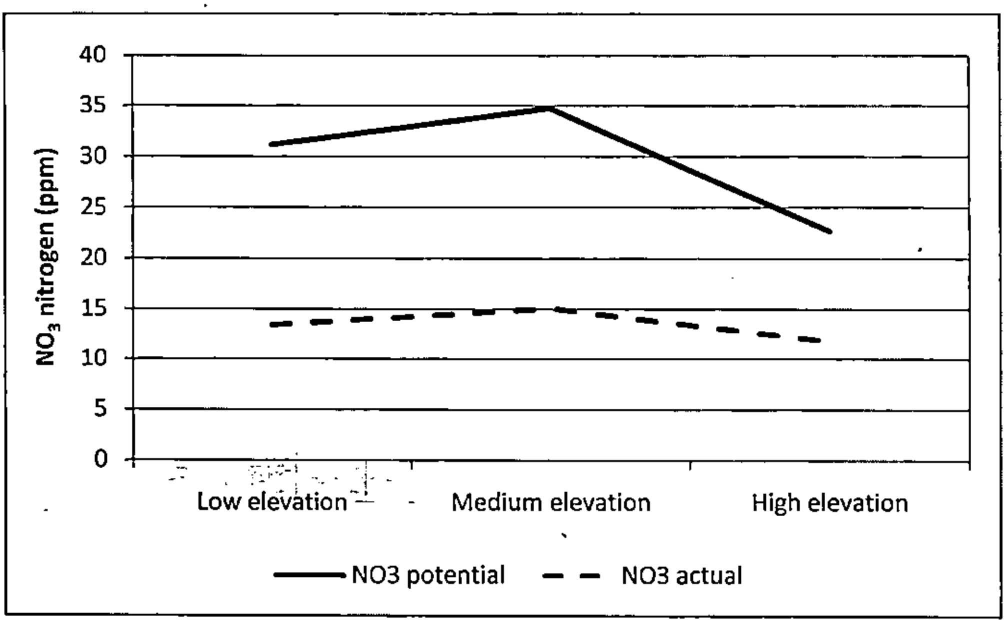


Fig 48: Nitrate nitrogen mineralization potential at different elevation

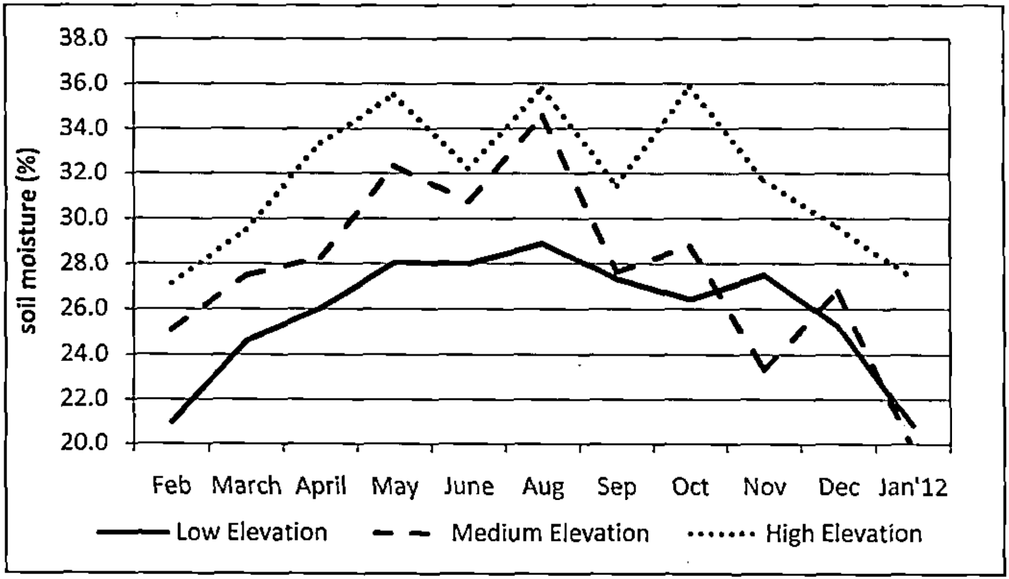


Fig.49: Soil moisture at different elevation

and Table 38) compared to low elevation. This high moisture and low temperature reported to lower the microbial and soil enzymatic activity particularly urease activity (Vlek and Carter, 1983; Sahrawat, 1984; Moyo *et al.*, 1989; Schinner, 1982).

Foliar resorption, the process of nutrient re-translocation from old leaves into storage tissue during senescence was significantly higher for P and K at high elevation compared to low elevation. High re-translocation of P and K at high elevation indicated tight circulation of these nutrients at high elevation rubber ecosystem. Soils in traditional rubber tract are inherently deficit in available P (Osodeke and Kamalu, 1992) and organic P constitute major share. Because of slow mineralization of organic carbon at high elevation, the turn over time of soil OC was high resulting in locking in of more organic P. Because of this reason, trees might have resorted to resorption of more P from senescing leaves so as to meet the requirement of emerging leaves. And also high exchangeable Al at high elevation might have led to more P fixation. Being mobile nutrient, potassium is vulnerable to leaching losses. High exchangeable Al at high elevation replaced the much of K held at exchangeable site and replaced K lost through leaching due to high moisture noticed at high elevation. Hence trees resorbed more K from senescing leaves to overcome shortage.

5.2.3 ***Phenology and Rubber Performance***:

Seasonal arrangement of life cycle events (phenophase) is important for survival and reproductive success of plant. At high elevation rubber trees showed early annual leaf fall compared to low elevation (Fig. 50). At high elevation after August/September, soil OC was maintained at steady level compared to low elevation indicating the slowdown of mineralization activity and hence total N was relatively low at high elevation during this period. Consequently, accelerated senescence of leaves as a typical symptom of N deficiency was reported by Marschner (1995). Exchangeable Al during October/November at medium and high elevation was significantly high. High exchangeable Al is known to cause

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Flowering		New flush	Flowering	New flush		New flush		New flush		Wintering	New flush
Oidium	Fruit growth	Oidium	Fruit growth				Phytophthora disease				Oidium

(a) Low Elevation

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Flowering		New flush	Flowering	New flush				New flush		Wintering	New flush
Oidium	Fruit growth	Oidium	Fruit growth				Phytophthora disease				Oidium

(b) Medium Elevation

Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Flowering		New flush			New flush					New flush	Flowering
Oidium	Fruit growth	Oidium	Flowering		Oidium	Phytophthora disease			Wintering		Oidium

(c) High Elevation

Figure 50: Phenological stages of rubber at different elevation

reduced root growth (Foy, 1988), and as a result, trees face nutrient and/or water stress. Added to this, trees at high elevation experienced severe leaf fall due to abnormal leaf fall disease during August-October (Fig.50) which was little earlier compared to low elevation. Because of these reasons, rubber at high elevation showed early wintering compared to low elevation.

At high elevation, disease incidences and severity was more compared to low elevation. At high elevation, apart from low temperature, high humidity favours the incidence of *Oidium* resulting in retarded growth (Bansil, 1971).

Perusal of the data on latex yield revealed peak yield during winter period (November-December) at low and medium elevations (Fig. 51). Such a peak rubber yield during winter period was reported by Priyadarshan (2011).This higher yield may be due to the favorable temperature which stimulated and favored latex flow and production. It is contradictory to note that at high elevation rubber yield was low during this winter period. Severe leaf fall during September/October due to abnormal leaf fall disease and low temperature during subsequent winter has put rubber at high elevation under more stress. Defoliation is a phenomenon to circumvent moisture and low temperature stress through minimizing transpiration so as to ensure reproduction (Priyadarshan, 2011). So rubber at high elevation showed early wintering/leaf shed and refoliation. Refoliation and subsequent flowering utilized large amount of carbohydrate reserve and hence yield during November/December was low at high elevation compared to low and medium elevation.

Active growth period of rubber coincided with monsoon period during which peak nitrogen mineralization was observed. Rubber yield was low during monsoon period at low and medium elevation due to competition from developing leaves and fruit for the carbohydrates. Low latex production was also attributed to short sunshine duration during rainy season (Ailiang, 1984). However at high elevation, rubber yield was comparatively more. Because of the early refoliaton and less number of new flushes during monsoon, there may be

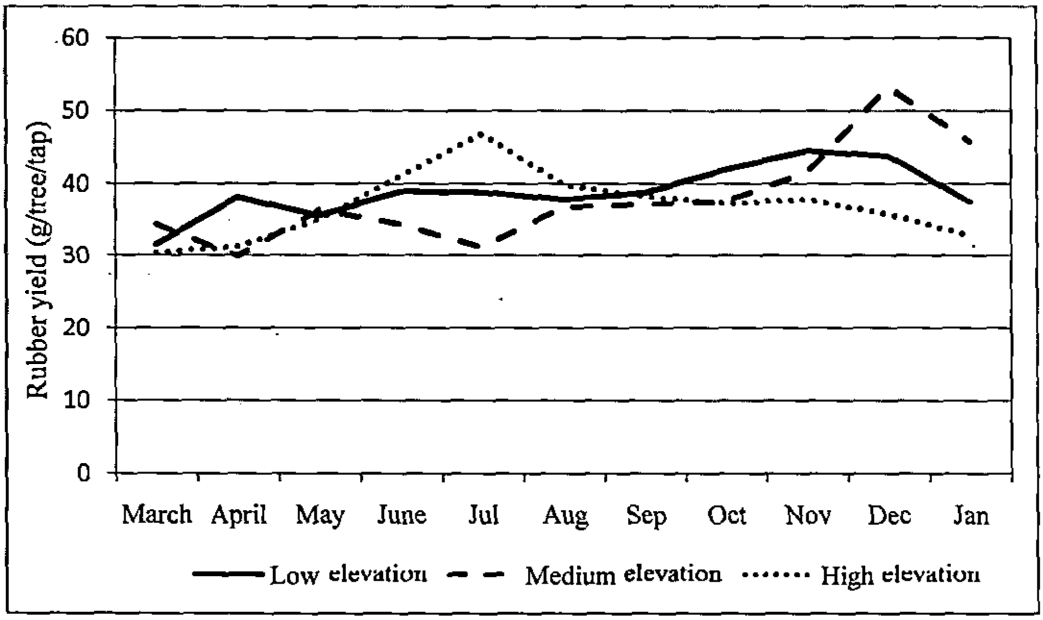


Fig 51: Monthly dry rubber yield (g/tree/tap) at different elevation

less competition from the developing leaves and fruit for the carbohydrates. At the same time, minimum temperature at high elevation was low during monsoon period which might have favoured latex flow resulting in more rubber yield. While studying the rubber cultivation at high altitude in China, Ailiang (1984) also reported that low temperature at high elevation benefited the latex flow ,but not benefited the growth of rubber .

Considering the active growth and peak yielding phase vis-a-vis soil nutrient dynamics particularly nitrogen, showed perfect match for active growth and mismatch for peak yield phase of rubber at low and medium elevation. Peak yield coincided with low N mineralization period and low yield with peak nitrogen mineralization period at low and medium elevation and hence rubber yield showed significant negative relation with nitrogen. At high elevation, low and peak yield phase matched with mineralization pattern and hence it showed non-significant positive relation.

Factor analysis showed significant positive correlation of climatic factor at high elevation with next month rubber yield indicating the importance of minimum temperature and rainfall in rubber ecosystem at high elevation. It is evident that altitudinal related changes in climatic conditions, litter decomposition rate and soil nutrient dynamics has altered the rubber phenology and yielding phase particularly at high elevation. Altitudinal induced changes in climate, soil nutrient dynamics particularly nitrogen and phenological changes has effectively reduced the growing period and resource acquisition by rubber trees at high elevation. This might be the reason for the reported poor performance and increased immaturity period of rubber with increase in altitude (Foth and Turk, 1973). At low elevation extracted climate component did not show significant correlation with rubber yield indicating that climate condition at low elevation is not limiting rubber performance.

Annual increase of 0.04^0C and 0.02^0C maximum and minimum temperature respectively has been reported from rubber growing regions in India

(Shammi *et al.*, 2011) unlike the faster rate of increase of minimum temperature as reported by the Inter-government Panel on Climate Change (IPCC , 2007). Use of elevation gradient as a potential natural resource for studying climate change effects is receiving much attention nowadays owing to high cost associated with controlled large scale field experiments on climate change studies. Present study indicated that elevation gradient associated variation in climate resulted in lower nitrogen mineralisation potential, slow litter decomposition rate and long turnover time of soil carbon with increase in altitude. Thus results from such experiments based on natural altitudinal gradient, one can easily infer the consequence of climate change on ecosystem processes. In the context of projected change in climate particularly temperature, above mentioned ecosystem processes may be enhanced, resulting in increased nutrient supply thus may enhance the productivity of the rubber at high elevation. Since soil OC and nitrogen mineralization showed negative trend with elevation, increasing temperature under climate change situation may further enhance nitrogen mineralization at lower elevation. This may result in a faster decline of soil OC, affecting the nutrient supplying capacity of soil, thus affecting the productivity of rubber. Analyzing the impact of climate warming on natural rubber productivity in different agro-climatic regions in India, Satheesh and Jacob (2011) also reported that NR productivity in Kerala may be reduced by 4-7 per cent and that in cold prone North-East India could be up by 11 per cent in the next decade if present trend of warming continues.

SUMMARY

6. SUMMARY

Objectives of the present investigation were addressed by conducting two experiments. Experiment I located in Kanyakumari and Kasargod districts, representing south and northern part of traditional rubber growing region of the country, was aimed at studying the geo-spatial analysis of soil and climate variability on performance of rubber. Experiment II located at Kottayam district, representing central belt and predominant rubber growing area, was aimed at studying the soil nutrient dynamics and rubber phenology along the altitude induced growing environments.

- Soil and climatic condition of rubber growing areas in Kanyakumari and Kasargod district varied significantly. Kanyakumari soils were medium in available P, K and soil OC whereas Kasargod soils were high in soil OC low in available P and K. Available Ca and Mg in both district was in high range.
- Kanyakumari soils were slightly acidic and gravelly compared to Kasargod soils. Soil BD and AWC did not differ significantly between two districts.
- Available Ca and Mg showed strong spatial dependence in Kanyakumari whereas available P, K and Ca showed strong spatial dependence in Kasargod.
- Majority of rubber growing area in Kanyakumari was low elevated and less slope compared to high elevated and slope area in Kasargod.
- Annaul rainfall, its distribution and water balance was distinctly different in two district. In Kanyakumari annual rainfall showed bimodal distribution compared to concentrated unimodal rainfall of Kasargod resulting in better water balance in Kanyakumari.
- Monthly water balance indicated long dry period and short length of growing period in Kasargod compared to Kanyakumari.

- Moisture adequacy during December-March dry period was very poor in Kasargod compared to poor status observed in Kanyakumari.
- Moisture adequacy during December – March varied spatially in both district. Southern part of Kanyakumari district showed poor moisture adequacy whereas central part showed adequate moisture indicting no moisture stress. In Kasargod eastern part of rubber growing area showed poor moisture adequacy and rest area very poor adequacy. In Ksargod areas with adequate moisture during December-March was not seen.
- Growth and yield of ruber was significanty better in Kanyakumari compared to Kasargod.
- In Kanyakumari SMU showed significant influence on growth and average per tree yield during Feb-May with SMU 1-4 recording better growth and yield over SMU 5-7. In Kasargod SMU did not show significant influence on rubber performance.
- TPD incidence was significantly low in Kanyakumari compared to Kasargod. However TPD incidence did not vary significantly among SMU in both district.
- Per tree rubber yield during dry period (Dec-March) and annual yield (kg/ha/year) was significantly higher in Kanyakumari district compared to Kasargod.
- In Kanyakunari soil OC showed significant positive effect on girth whereas available Mg showed negative effect. Soil BD and gravel content showed depressive effect on per tree average rubber yield. In Kasargod soil did not show any influence on rubber performance.
- Underlying factors influencing the rubber performance were different in both districts. In Kanyakumari district soil health and soil cation factor (Ca and Mg) were identified as dominant factor influencing rubber performance significantly. In Kasargod topographic factor (elevation and slope) was found as dominant factor influencing rubber.
- Rubber showed distinct spectral signature compared to other vegetation.

- Satellite based rubber area estimation was comparable with ground statistics with 15-20 per cent variation.
- Overlay analysis indicated that majority of rubber area in both district distributed over SMU1-4. Considerable rubber area in both districts was distributed outside the SMU areas indicating extension of rubber cultivation and this call for updating SMU map.
- In Kanyakumari, majority of rubber area distributed over elevation 0-100m and slope less than 5-10 per cent compared to 100-300m elevation and more than 5-10 per cent slope in Kasargod.
- In both district considerable rubber area distributed over soil and climate constraint areas. However compared to Kasargod, extent of rubber area in good climate was more in Kanyakumari district.
- Climate factors mainly temperature varied along elevation gradient with high elevation recording low minimum and maximum temperature compared to low elevation.
- Leaf litter addition did not vary significantly along elevation gradient but rate of litter decomposition and dynamics of soil OC, exchangeable Al, nitrogen and pH varied along elevation. Rate of litter decomposition and nitrogen mineralization potential were low at high elevation compared to low elevation.
- Soil OC and moisture showed increasing trend with elevation gradient whereas soil total nitrogen content showed declining trend with elevation.
- Phenology of rubber varied along elevation gradient. Rubber at high elevation showed early wintering and refoliation compared to low elevation. Number of new flushes were more at low elevation compared to high elevation.
- At high elevation rubber showed high resorption of P and K from ripened leaves compared to low and medium elevation.
- Rubber yield did not show variation along elevation gradient but peak yielding period differed at high elevation compared to low elevation. At

low and medium elevation peak yield was during November/December coinciding with low soil nitrogen content. At high elevation it was during July coinciding with peak soil N content. However at all elevation active growing period coincided with peak soil nitrogen content.

- Climate (minimum temperature and soil moisture) was the major factors influencing the rubber yield at high elevation ecosystem. At medium elevation ecosystem nitrogen mineralization was the major factor influencing the rubber yield. At low elevation, climate as well as nitrogen mineralization did not show influence on rubber yield indicating that they are not the limiting factors at low elevation ecosystem of rubber.

Future line of Work

Further studies on the following lines helps to throw more light on variation in rubber performance so as to enhance productivity.

1. Response of rubber to measures in balancing excess calcium and magnesium in Kanyakumari district.
2. Intensive sampling considering the topographic and climate factors may help to throw some light on influence of soil on rubber performance in Kasargod.
3. Integrated soil and water conservation measures on watershed basis and its impact on ecological water balance and rubber performance in Kasargod district.
4. Site specific integrated measures to address the soil nutrient and climate constraints and its impact on rubber performance.

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ArcGIS water balance tool box (Dyer, 2009) (http://www.ohio.edu /people /dyer /water_balance.html)

Soil Water Balance (SWB) 2010) (http://pubs.usgs.gov/tm/tm6-a31/)

APPENDICES

Appendix- I

List of Rubber holdings with their geographical location in Kanyakumari

Sl. No	Lat. (Deg)	Long. (Deg)	Elevation (m)	Aspect (Deg)	Farmers/Estate Name	Village	Year of planting	Tapping system
1	8.3336	77.3085	50	210	Meenakumari S.K	Aruvikarai	1994	D2
2	8.3662	77.3134	80	194	Neelakantan Pillai	Ponmana	1994	D2
3	8.3678	77.3297	85	216	Saraswati	Ponmana	1997	D2
4	8.3515	77.3155	83	218	Rajasekharan S	Ponmana	1995	D2
5	8.3513	77.3030	71	216	Ajith Kumar	Ponmana	1994	D2
6	8.3495	77.2984	59	116	Padmakumar	Ponmana	1995	D2
7	8.3178	77.3012	71	225	Prdeep P	Chenkodi	2001	D2
8	8.3249	77.3053	91	90	M..Kanakambaran	Macod	2001	D2
9	8.3133	77.2908	69	104	C.Swami Das	Macod	1997	D2
10	8.3389	77.2610	20	220	T. Rajendran	Thiruvattar	1995	D2
11	8.3498	77.2732	73	7	Vikraman Nair	Thiruvattar	1999	D2
12	8.3380	77.2662	24	191	R. Purushotaman	Thiruvattar	1995	D2
13	8.4048	77.2195	52	135	Krishnan Kutty	Mancode	1999	D2
15	8.4219	77.2209	125	333	Gokul Kumar	Mancode	1994	D2
16	8.4219	77.2300	137	233	Reghu K	Mancode	2000	D2
17	8.4194	77.2302	127	348	Dr. Jayaraj	Mancode	1997	D2
18	8.4282	77.2302	169	246	D.M. Convent	Mancode	1995	D2
19	8.3921	77.2368	98	244	M. S. Nair	Arumana	1996	D2
20	8.3861	77.2219	75	113	Natarajan S.	Manjalmood	1998	5Taps
21	8.3901	77.2242	54	104	Thengapattan Party	Manjalmood	1994	D2
22	8.3895	77.2224	68	139	Annie Bai	Manjalmood	1995	D2
23	8.3883	77.2153	56	215	Denison	Manjalmood	1995	D2
24	8.3830	77.2497	50	135	Thomas K.M	Kalial	1995	D2
25	8.4025	77.2464	88	355	K Sabarikantan	Kalial	1995	D2
26	8.3958	77.2338	62	196	Joseph Rupan	Karod	1997	4Taps
27	8.4071	77.2228	67	233	Johnson	Arumana	1998	4Taps
28	8.4148	77.2239	125	246	Sreekantan	Arumana	1996	D2
29	8.4059	77.2704	57	0	T.K Rajendrakumar	Kalial	1995	D
30	8.4048	77.2888	66	270	Dr. Prakash George	Kulasekharam	1999	D2
31	8.3861	77.2843	90	218	Rana Deepak	Kulasekharam	1995	D2
32	8.3797	77.2800	68	233	Highland Estate	Kollara	1995	D2
33	8.3777	77.2877	82	225	Jayalaksmi Estate	Kulasekharam	1995	D3
34	8.3757	77.2897	66	251	Rajesh R.	Kulasekharam	1996	D2
35	8.4217	77.3231	86	56	Kamadhenu Estate	Kulasekharam	1997	D3
36	8.4342	77.3096	68	119	Haritha Estate	Thirparappu	1995	D3
37	8.3878	77.2964	78	306	Balendran Nair	Kulasekharam	1995	D2
38	8.3881	77.2735	83	329	ABC Estate	Kulasekharam	1998	D4
39	8.4228	77.2735	89	198	Maruti Estate	Kulasekharam	1994	D3
40	8.4283	77.2628	75	296	Maruti Estate	Kulasekharam	2001	D3
41	8.3719	77.2724	16	63	Appookuttan	Thiruvattar	1996	D2
42	8.4885	77.2138	140	240	George Kutty PB	Arukani	1995	D2

43	8.4550	77.2608	89	104	Abraham	Maruthampara	1991	D2
44	8.4638	77.2480	155	191	Sebastin KD	Arukani	1991	D2
45	8.4535	77.2343	90	78	Hariharaputra Estate	Arukani	2000	D6
46	8.4517	77.2354	148	180	Hariharaputra Estate	Arukani	1997	D6
47	8.3423	77.3326	62	296	Usha Devi	Ponmana	1995	D2
48	8.3671	77.4148	172	255	Pioneer Kumaraswamy	Keeriparai	1995	D3
49	8.3678	77.4137	150	270	Pioneer Kumaraswamy	Keeriparai	1999	D3
50	8.3868	77.4093	105	90	Arasu Keeriparai	Keeriparai	1994	D2
51	8.3851	77.4151	110	246	Arasu Keeriparai	Keeriparai	1994	D2
52	8.4349	77.2311	165	129	Vaikundam Estate	Kulasekharam	1995	D3
53	8.4354	77.2291	167	50	Vaikundam Estate	Kulasekharam	1995	D3
54	8.4298	77.2353	131	29	Vaikundam Estate	Kulasekharam	1995	D3
55	8.4243	77.2381	120	47	Vaikundam Estate	Kulasekharam	1999	D3
56	8.3525	77.2247	71	320	Saveriyar Adimai	Anducode	1996	D2
57	8.3477	77.2233	20	220	Soloman	Anducode	1996	5Taps
58	8.2837	77.3775	376	195	Velimala Estate	Velimala	1997	D3
59	8.2802	77.3807	423	326	Velimala Estate	Velimala	1996	D3
60	8.2741	77.3745	312	277	Velimala Estate	Velimala	1995	D3
61	8.2793	77.3687	195	33	Velimala Estate	Velimala	1999	D3
62	8.3038	77.3213	71	30	G. Laurence	Makod	1996	D2
63	8.3048	77.3312	87	251	Albert Rajayan	Velimala	1995	4Taps
65	8.2756	77.2215	63	161	Mohankumar Jacob	Tholiavattam	1995	5Taps
66	8.2316	77.2244	65	180	Saving Cross	Midalam	1996	D2
67	8.2318	77.2306	30	75	Yesudhas	Midalam	1997	D2
68	8.3241	77.2621	52	90	Praveen Ramesh T	Attoor	1995	5Taps
69	8.4371	77.2703	80	0	New Ambady Estate	Kulasekharam	1995	D3
70	8.4298	77.2745	118	42	New Ambady Estate	Kulasekharam	1998	D3
71	8.4308	77.2740	103	341	New Ambady Estate	Kulasekharam	1999	D4
72	8.4279	77.2776	108	215	New Ambady Estate	Kulasekharam	1997	D5
73	8.4359	77.2665	93	194	New Ambady Estate	Kulasekharam	2000.	D6
74	8.4363	77.2773	184	28	New Ambady Estate	Kulasekharam	1995	D7

List of Rubber holdings with their geographical location in Kasargod district

Sl. No	Lat (Deg)	Long (Deg)	Elevation (m)	Aspect (Deg)	Farmers/Estate Name	Village	Year of planting	Tapping System
75	12.36	75.20	185	206	XAVIER P.T	THAYANOOR	1997	D3
76	12.36	75.20	146	326	PRINCE SEBASTIN	THAYANOOR	1995	D2
77	12.35	75.19	92	270	SREEDHARAN NAIR	THAYANOOR	1998	D2
78	12.35	75.18	94	206	PHILOMINA CHACKO	THAYANOOR	1999	D2
79	12.37	75.17	76	4	AMBASALI	PARKALAI	1995	D2
80	12.35	75.17	111	12	SHAJI AUGUSTIN	PARKALAI	1997	D2
81	12.31	75.42	172	247	JOSE TOM	PALAVAYAL	1996	D2
82	12.31	75.42	86	180	CHANDY K.A	PALAVAYAL	1995	D2
83	12.30	75.39	72	153	THOMAS K.J.	PALAVAYAL	1995	D2
84	12.32	75.28	121	102	JOSEPH P.M	BEEMANADY	1995	D2
85	12.34	75.30	51	168	GEORGE P.M	BEEMANADY	1995	D2
86	12.35	75.31	133	180	JOSEPH V.J.	WEST ELERI	1996	D2
87	12.36	75.31	179	221	MATHAI M.K	BEEMANADY	1995	D2
88	12.34	75.32	85	23	KURIAKOSE C.T	WEST ELERI	1995	D2
89	12.32	75.31	139	258	JOYICHAN JOSEPH	WEST ELERI	1996	D2
90	12.31	75.34	172	237	GEORGE D.K	CHITTARIKAL	1995	D2
91	12.49	75.31	141	168	SURESH BABU	PANATHADY	1996	D3
92	12.48	75.32	238	216	SUSHEELAMMA	PANATHADY	1996	D2
93	12.47	75.31	97	135	R. Nair	PANATHADY	1997	D2
94	12.44	75.32	363	210	RAJAN T.R	PANATHADY	1996	D2
95	12.43	75.28	143	21	NARENDRA BHAT	KALLAR	1996	D2
96	12.47	75.32	78	291	NSS ESTATE	PANATHADY	1995	D2
97	12.47	75.32	98	90	NSS ESTATE 1995A	PANATHADY	1995	D2
98	12.47	75.33	115	204	NSS ESTATE	PANATHADY	1997	D2
99	12.47	75.33	112	204	NSS ESTATE	PANATHADY	1999	D2
100	12.47	75.32	132	510	NSS ESTATE	PANATHADY	1996	D2
101	12.45	75.29	99	49	NSS ESTATE	PANATHADY	2000	D2
102	12.47	75.36	185	194	TOMY THOMAS	PANATHADY	1995	D2
103	12.46	75.37	117	99	MONCY	PANATHADY	1995	D2
104	12.47	75.37	125	98	GEORGE KUTTY	PANATHADY	1995	D2
105	12.41	75.26	278	253	THOMAS P.J	KALLAR	1995	D2
106	12.28	75.21	19	231	KUNJAMBU NAIR P.	KARINDALAM	1996	D2
107	12.28	75.22	11	243	NARAYANAN T.	KARINDALAM	1995	D2
108	12.28	75.23	50	251	KUNJURAMAN	KARINDALAM	1995	D2
109	12.27	75.23	12	0	RAGHAVAN K.P.	KARINDALAM	1995	D2
110	12.30	75.25	61	185	RAMANATHAN K.	KARINDALAM	1998	D2
111	12.27	75.21	49	129	PRABHAKARAN	KAYYUR	1995	D2
112	12.27	75.22	68	278	KARIKUTTY K.M.	KAYYUR	1998	D2
113	12.27	75.21	82	161	GANGADHARAN	KAYYUR	1998	D2
114	12.27	75.21	27	236	BABU JOSE	KAYYUR	1995	D2
115	12.24	75.23	65	352	PRABHAKARAN M.P	CHEEMENI	1995	D2

116	12.26	75.25	17	·0	THANICKAL ESTATE	CHEEMENI	1995	D2
117	12.22	75.22	0	510	KUNJIKANNAN P.	KODAKKAD	1996	D2
118	12.21	75.22	0	510	SOUDAMINI	KODAKKAD	1997	D2
119	12.49	75.16	122	352	NARAYANAN C.	BEDADKA	1997	D2
120	12.50	75.16	192	246	KUMARAN NAIR	BEDADKA	1996	D2
121	12.48	75.16	34	225	HARIHARAN K.	BEDADKA	1998	D2
122	12.49	75.17	114	230	A. K.NAIR	MUNNAD	1997	D2
123	12.50	75.18	144	231	A. KUNJAMBU NAIR	MUNNAD	1996	D2
124	12.50	75.18	177	201	BALAKRISHAN NAIR	MUNNAD	1996	D2
125	12.50	75.20	206	143	K.K. MANIYONI	KUTTIKOLE	1995	D2
126	12.47	75.13	110	343	DAMODARAN NAIR	KUNDAMKUZY	1997	D2
127	12.44	75.14	52	257	KARTHIANIAMMA A.	KUNDAMKUZY	1999	D2
128	12.43	75.14	70	0	CHARADAN NAIR	KUNDAMKUZY	1997	D2
129	12.44	75.16	148	315	KUNHIRAMAN Nair C.	BEDADKA	1997	D2
130	12.43	75.20	54	324	GEORGE K.K.	BEDADKA	1996	D2
131	12.45	75.21	129	291	RAMAKRISHNAN T.	MUNNAD	1996	D2
132	12.47	75.18	167	280	SEKHARAN NAIR K.	MUNNAD	1996	D2
133	12.36	75.28	94	63	VARKEY K.J.	BALAL	1998	D2
134	0.00	75.28	126	116	VARKEY K.J.	BALAL	1996	D2
135	12.35	75.27	169	12	R . PANICKER	PARAPPA	1996	D2
136	12.38	75.28	130	344	GEORGE K.J.	BALAL	1998	D2
137	12.37	75.29	114	195	ANIAMMA THOMAS	BALAL	1995	D2

Appendix II

Holdings database of Kanyakumari district

SampleNo	AREA	OC	AvP	AvK	AvCa	AvMg	pH	Gravel vol	BD
1	1.50	1.04	1.10	63.80	177.00	32.50	4.59	4.10	0.62
2	4.00	1.01	34.00	82.80	134.50	37.30	4.65	4.99	0.72
3	1.60	0.95	31.50	120.00	202.00	107.50	4.83	9.80	0.82
4	2.00	0.83	9.70	88.70	191.70	43.40	5.13	9.27	0.86
5	0.86	0.74	2.30	24.10	104.00	41.60	4.97	5.35	0.80
6	2.97	0.90	9.50	39.10	103.60	28.00	4.89	12.83	0.85
7	2.00	0.80	0.50	88.70	335.80	159.00	4.99	8.91	0.79
8	1.10	1.04	9.30	75.00	431.00	225.00	5.08	17.65	0.86
9	1.00	0.74	31.50	107.00	206.10	37.50	4.55	3.21	0.79
10	0.65	0.71	36.50	111.50	471.10	131.00	4.93	1.07	0.82
11	1.00	0.83	8.70	89.70	150.10	40.60	4.98	13.73	0.77
12	8.50	0.86	14.10	88.70	153.60	47.00	4.89	13.19	0.67
13	3.00	0.74	14.50	105.00	194.30	40.50	4.95	13.19	0.86
14	7.00	1.25	4.40	61.90	64.60	22.60	4.58	13.55	0.78
15	1.75	0.86	18.90	114.00	121.60	53.80	4.60	7.49	0.75
16	3.50	1.04	23.00	68.40	149.50	25.50	4.91	15.69	0.83
17	6.50	1.07	110.50	70.30	145.20	34.40	4.57	19.96	0.88
18	2.00	1.54	3.00	75.00	155.70	36.80	4.96	2.67	0.81
19	3.50	1.19	1.70	177.50	263.70	172.50	4.87	11.41	0.78
20	1.50	1.34	123.50	191.00	275.70	69.80	4.36	9.45	0.80
21	3.30	0.77	10.00	56.30	138.50	33.30	4.95	9.27	0.91
22	2.00	0.95	0.10	65.60	207.10	48.40	5.01	2.85	0.82
23	1.25	1.19	31.00	67.50	163.60	37.10	4.87	22.46	0.90
24	3.45	0.95	43.00	80.40	135.30	26.20	4.89	9.98	0.87
25	16.50	2.29	73.50	145.50	878.40	226.00	5.28	10.70	0.82
26	2.00	0.92	49.00	209.00	123.80	195.00	5.30	13.19	0.73
27	2.00	0.74	7.80	195.50	327.00	167.00	5.10	11.59	0.84
28	1.00	0.80	8.80	70.20	86.50	21.20	5.12	13.90	0.86
29	8.00	1.01	18.70	67.50	78.40	12.90	4.65	9.60	0.88
30	11.00	1.37	103.00	69.40	59.00	10.30	4.58	21.39	0.82
31	7.00	1.22	102.00	159.00	165.40	20.30	3.91	22.46	0.91
32	1.00	1.04	12.00	42.70	30.70	11.70	4.73	22.46	0.90
33	12.00	1.31	106.50	73.10	75.60	12.80	4.78	1.07	0.82
34	3.00	1.16	42.50	52.50	145.40	27.90	4.86	15.69	0.74
35	1.00	2.08	57.00	62.80	110.40	25.50	4.68	0.36	0.71
36	2.00	1.51	11.70	281.50	169.60	48.50	5.05	0.89	0.79
37	2.00	1.31	0.90	40.00	48.40	21.60	4.73	14.62	0.85
38	2.00	0.68	2.10	42.90	45.60	8.90	4.62	3.03	0.70
39	1.00	1.13	6.00	71.40	95.90	28.10	4.65	18.54	0.81
40	1.00	0.77	10.40	69.50	105.50	24.20	3.43	1.60	0.68
41	0.70	0.55	11.10	87.30	262.10	69.40	4.98	14.97	0.89
42	2.50	1.48	19.50	65.80	210.10	52.90	4.80	9.27	0.60
43	2.00	2.35	13.20	42.80	687.10	20.45	4.90	1.25	0.62
44	1.25	1.32	18.90	10.20	709.20	16.52	5.25	3.57	0.54

SampleNo	AREA	OC	AvP	AvK	AvCa	AvMg	pH	Gravel vol	BD
45	1.00	1.23	11.80	53.60	148.30	19.50	4.67	7.13	0.72
46	1.00	3.87	11.70	86.30	478.40	103.86	4.83	4.28	0.62
47	5.00	1.10	2.50	56.60	355.60	118.69	4.88	5.35	0.84
48	6.00	1.77	5.70	92.80	713.40	114.92	5.60	2.50	0.66
49	5.00	1.45	30.40	46.40	378.80	59.40	5.19	1.07	0.84
50	1.00	1.48	9.10	81.90	147.90	33.30	5.04	2.50	0.81
51	1.00	1.28	17.60	116.00	366.40	88.60	4.83	1.25	0.65
52	1.00	2.85	17.50	67.80	116.00	28.20	4.58	9.70	0.62
53	1.00	3.67	9.10	116.00	213.00	45.90	4.95	1.43	0.47
54	1.00	1.97	8.30	108.00	172.70	34.10	4.80	6.77	0.55
55	1.00	1.93	14.30	67.50	101.50	21.70	4.15	9.09	0.75
56	1.50	0.86	10.00	57.60	220.30	51.60	4.60	8.56	0.81
57	0.50	0.80	8.70	179.00	421.50	165.52	4.91	1.07	0.64
58	1.00	2.28	1.20	205.00	635.30	157.76	4.07	0.80	0.64
59	1.00	1.45	0.18	188.00	282.30	62.10	4.52	2.14	0.59
60	1.00	1.27	6.30	143.00	228.80	66.90	5.03	3.92	0.66
61	1.00	0.83	0.24	214.00	194.60	35.10	4.73	7.84	0.78
62	2.00	0.77	11.00	70.40	95.80	36.90	4.70	2.50	0.56
63	5.00	0.30	0.21	116.00	151.60	58.50	4.52	0.89	0.70
64	1.40	0.53	0.10	100.00	292.60	117.56	4.92	0.89	0.72
65	0.75	0.68	0.10	125.00	308.90	133.31	4.83	3.39	0.68
66	1.00	0.83	12.00	55.90	333.10	89.70	4.87	0.53	0.63
67	2.00	1.03	12.80	214.00	525.70	117.04	4.85	12.83	0.63
68	2.10	0.59	2.80	120.50	223.30	41.90	4.88	7.49	0.69
69	1.00	1.68	9.70	152.00	237.90	79.50	4.90	12.48	0.87
70	1.00	1.57	0.10	120.50	138.00	41.60	4.75	12.48	0.83
71	1.00	1.24	0.80	111.50	148.00	53.20	3.85	1.43	0.71
72	1.00	2.33	0.70	116.00	285.10	61.60	5.10	11.41	0.84
73	1.00	1.12	2.70	125.00	273.20	67.50	4.88	5.35	0.73
74	1.00	1.48	10.10	152.00	286.20	70.50	4.91	3.57	0.61

SampleNo	AWC_mm/m	Girth	TPD	LeafN	LeafP	LeafK	LeafCa	LeafMg	N index
1	71.94	65.68	3.00	4.20	0.38	1.97	1.00	0.40	-6.04
2	76.62	73.15	6.00	4.07	0.32	1.77	0.83	0.50	-4.09
3	58.43	60.06	6.00	3.75	0.33	1.80	0.95	0.48	-10.88
4	63.20	61.83	7.00	3.80	0.31	1.77	0.56	0.37	2.43
5	100.71	59.21	5.00	3.82	0.34	1.58	0.79	0.41	-4.00
6	60.75	71.90	5.00	1.37	0.26	1.44	1.13	0.34	-5.44
7	28.78	60.18	2.00	3.74	0.28	1.90	1.02	0.49	-9.68
8	31.16	54.24	2.00	3.72	0.29	1.38	1.00	0.43	-3.90
9	37.47	57.70	5.00	3.63	0.29	1.59	0.85	0.39	-3.98
10	38.94	62.67	4.00	4.30	0.33	1.80	0.95	0.43	-0.96
11	34.54	58.92	3.00	4.30	0.37	1.95	0.70	0.45	-0.87
12	30.83	65.41	6.00	3.89	0.30	1.54	1.06	0.36	-1.48
13	18.66	60.49	3.00	4.07	0.31	1.66	0.73	0.43	1.39
14	32.37	69.78	4.00	4.11	0.36	1.74	0.46	0.35	9.38
15	80.49	59.95	8.00	4.02	0.32	1.79	1.17	0.43	-6.18
16	29.39	55.90	3.00	4.37	0.26	1.44	1.40	0.42	3.88
17	69.02	59.21	6.00	4.39	0.35	1.91	0.63	0.40	5.15
18	55.97	61.62	6.00	4.17	0.32	1.73	0.85	0.37	1.65
19	73.25	61.26	3.00	4.30	0.35	2.03	0.61	0.45	1.95
20	44.91	58.21	2.00	4.25	0.24	1.43	0.83	0.38	10.71
21	46.24	66.89	3.00	4.06	0.29	1.85	0.81	0.39	0.93
22	66.92	53.78	5.00	4.01	0.26	1.42	1.49	0.48	-3.49
23	49.55	58.80	10.00	4.03	0.28	1.41	0.94	0.42	1.90
24	53.25	66.23	1.00	3.98	0.29	1.46	1.15	0.41	-1.47
25	30.76	55.34	5.00	3.87	0.33	1.57	1.23	0.45	-8.34
26	25.35	58.78	3.00	4.15	0.31	1.91	0.85	0.47	-2.67
27	106.95	58.84	2.00	4.10	0.29	1.78	0.80	0.51	-1.80
28	59.97	63.06	6.00	4.11	0.31	1.87	0.56	0.29	9.88
29	58.07	62.50	5.00	4.30	0.31	1.74	0.64	0.34	9.10
30	38.50	60.57	1.00	4.35	0.29	1.49	0.77	0.36	9.33
31	21.87	69.11	15.00	4.30	0.32	1.82	0.87	0.38	2.09
32	60.71	65.31	4.00	4.05	0.23	1.54	0.98	0.35	6.80
33	106.75	67.26	4.00	4.00	0.26	2.02	0.64	0.26	9.57
34	22.66	70.20	13.00	4.40	0.26	1.45	0.84	0.36	11.39
35	43.58	65.49	3.00	3.96	0.25	1.60	0.63	0.36	8.77
36	58.72	68.33	4.00	3.51	0.21	1.69	1.52	0.45	-8.80
37	69.67	64.66	6.00	4.14	0.34	1.68	0.55	0.32	8.97
38	48.87	60.55	3.00	4.31	0.28	1.60	1.04	0.38	4.23
39	40.91	77.30	13.00	3.87	0.30	1.70	0.78	0.27	4.06
40	56.87	64.56	0.00	4.40	0.27	1.41	1.03	0.35	8.93
41	44.65	56.60	0.00	4.22	0.34	1.70	1.33	0.36	-2.81
42	47.91	61.60	2.00	4.27	0.35	1.53	1.20	0.39	-1.54
43	44.08	75.90	2.00	4.19	0.32	1.80	1.16	0.38	-2.24
44	54.16	58.40	4.00	4.17	0.33	1.55	0.68	0.38	5.18

SampleNo	AWC_mm/m	Girth	TPD	LeafN	LeafP	LeafK	LeafCa	LeafMg	N index
45	72.88	63.02	5.00	4.21	0.34	1.67	1.11	0.39	-2.09
46	21.96	61.00	5.00	4.20	0.22	1.10	1.15	0.46	9.89
47	39.75	64.72	6.00	4.19	0.32	1.76	1.21	0.42	-3.62
48	28.32	71.03	8.00	4.01	0.33	1.86	1.04	0.33	-2.94
49	32.41	65.17	4.00	3.66	0.21	1.08	2.30	0.39	-3.82
50	56.86	73.77	13.00	4.09	0.33	1.64	1.23	0.42	-4.75
51	23.75	78.20	5.00	4.20	0.29	1.59	1.26	0.39	0.17
52	24.07	69.10	8.00	4.11	0.33	1.62	0.82	0.35	2.20
53	32.43	70.50	11.00	4.07	0.26	1.42	1.29	0.38	2.12
54	65.12	70.22	5.00	4.25	0.30	1.65	1.14	0.37	1.25
55	52.50	64.70	13.00	4.11	0.33	1.65	0.87	0.34	1.61
56	41.48	62.20	7.00	4.16	0.36	1.20	0.97	0.42	0.97
57	55.72	60.20	0.00	4.18	0.31	1.39	1.34	0.35	1.26
58	52.06	58.50	1.00	4.11	0.26	1.41	1.38	0.46	-0.52
59	49.08	59.50	0.00	4.20	0.27	1.39	1.48	0.34	3.48
60	41.85	62.00	11.00	3.96	0.32	1.60	1.28	0.37	-4.25
61	48.16	58.70	3.00	3.99	0.30	1.52	1.39	0.35	-2.18
62	26.76	66.20	5.00	3.76	0.30	1.70	0.81	0.36	-1.87
63	40.93	63.40	10.00	3.41	0.25	1.30	1.42	0.36	-6.07
64	37.82	49.40	1.00	3.34	0.25	1.05	2.32	0.41	-14.00
65	51.24	54.50	9.00	4.15	0.32	1.39	1.44	0.41	-2.38
66	24.44	60.10	0.00	3.68	0.19	1.01	2.48	0.36	-0.31
67	45.03	52.40	6.00	3.56	0.19	0.97	2.13	0.41	-1.21
68	34.47	60.20	7.00	4.30	0.30	1.35	1.18	0.24	10.80
69	28.93	74.10	9.00	4.27	0.22	1.38	1.43	0.34	9.38
70	33.42	63.50	4.00	4.18	0.24	1.66	1.01	0.31	8.20
71	33.59	64.10	26.00	3.81	0.23	1.69	1.06	0.32	2.64
72	36.46	69.30	5.00	3.73	0.24	1.63	0.90	0.30	3.50
73	49.75	62.00	10.00	3.80	0.18	1.05	1.99	0.42	4.28
74	47.65	70.80	16.00	3.81	0.20	1.50	1.35	0.37	3.34

SampleNo	P index	K index	Ca index	Mg index	Avg.Yield	Ann. Yield
1	10.41	7.23	-13.32	1.71	22.63	1235.52
2	2.51	4.96	-22.20	18.81	28.86	1575.84
3	4.63	5.55	-14.44	15.14	30.46	1663.35
4	11.37	13.96	-39.25	11.49	17.26	942.24
5	11.54	2.34	-20.29	10.41	24.47	1336.21
6	-0.76	2.01	1.19	3.00	40.05	2186.52
7	-6.25	9.41	-10.47	16.99	20.61	1009.81
8	1.71	-3.55	-7.17	12.91	29.70	1455.30
9	3.32	4.90	-13.53	9.29	26.39	1293.11
10	3.17	4.56	-14.30	7.53	22.68	1238.51
11	12.40	9.98	-34.42	12.91	26.57	1450.87
12	2.75	1.12	-4.45	2.05	45.33	2474.87
13	5.03	5.23	-25.45	13.81	36.20	1976.52
14	24.47	14.11	-58.18	10.22		
15	0.97	3.83	-4.78	6.15	47.94	2617.68
16	-10.26	-4.57	4.18	6.78	46.70	2549.30
17	11.97	11.80	-38.35	9.42	23.06	1258.99
18	5.46	5.91	-16.37	3.35	26.74	1459.81
19	11.01	14.72	-43.73	16.06	32.15	1869.36
20	-8.11	1.12	-13.22	9.50	36.33	2098.10
21	-0.11	10.63	-18.69	7.23	39.45	2278.46
22	-10.96	-5.90	6.19	14.15	18.70	1078.18
23	-0.95	-2.55	-9.96	11.56	21.13	1232.79
24	-0.85	-2.53	-2.52	7.37	33.65	1943.51
25	3.78	-2.13	-2.54	9.23	28.16	1626.08
26	-0.07	8.90	-20.55	14.40	24.77	1430.63
27	-3.10	6.57	-23.54	21.87	32.86	1897.88
28	11.98	18.09	-37.21	-2.74	23.75	1371.30
29	7.94	10.21	-30.73	3.48	30.26	1747.73
30	2.77	1.46	-18.72	5.16	45.41	2479.23
31	3.74	7.26	-16.51	3.43	37.39	2041.65
32	-10.80	4.93	-5.18	4.24	22.99	1242.80
33	-0.04	24.75	-25.43	-8.84	42.30	1480.58
34	-3.97	0.62	-13.30	5.26	38.54	2104.09
35	-2.02	9.82	-27.14	10.57	48.45	1695.61
36	-23.51	7.21	10.49	14.61	57.70	2021.00
37	17.99	10.67	-40.28	2.65	68.16	3721.77
38	-3.41	1.89	-6.40	3.69	71.31	1921.90
39	8.33	10.76	-14.80	-8.35	51.85	1778.60
40	-3.21	-2.32	-4.87	1.47	34.30	1201.70
41	4.35	0.94	0.77	-3.24	25.72	1404.48
42	6.99	-3.71	-3.12	1.38	32.57	1778.32
43	1.38	4.53	-4.20	0.53	48.50	2649.50
44	11.26	3.03	-27.92	8.45	40.13	2190.95

SampleNo	P index	K index	Ca index	Mg index	Avg .Yield	Ann. yield
45	5.37	0.89	-6.12	1.95	66.90	1460.70
46	-15.66	-14.12	0.02	19.87	61.88	1039.70
47	0.25	2.49	-3.56	4.44	31.51	1720.29
48	6.04	8.37	-7.02	-4.44	63.29	2215.20
49	-22.90	-17.91	39.07	5.56	56.26	1969.30
50	2.91	-0.44	-2.56	4.85	47.80	2188.11
51	-2.95	0.00	-0.01	2.79	46.40	2005.89
52	9.22	3.77	-16.92	1.74	47.12	1649.10
53	-6.54	-2.69	2.97	4.13	54.78	1917.40
54	-0.56	1.97	-3.47	0.81	48.51	1697.80
55	8.59	4.21	-13.97	-0.44	40.95	1433.40
56	14.39	-14.40	-10.59	9.63	30.97	1517.64
57	2.65	-5.60	3.45	-1.75	42.40	2075.20
58	-9.90	-5.48	3.51	12.39	39.42	1379.80
59	-5.03	-4.46	8.74	-2.73	35.60	1246.00
60	3.27	0.14	0.67	0.17	67.23	2353.10
61	0.44	-1.15	4.85	-1.95	33.33	1166.60
62	5.06	8.03	-16.11	4.89	38.71	1896.75
63	-4.63	-3.73	10.01	4.43	55.21	2705.21
64	-10.13	-21.11	37.67	7.57		
65	2.13	-7.90	4.20	3.95	22.94	1043.72
66	-30.06	-20.94	49.49	1.82	29.13	1325.29
67	-27.49	-21.83	37.29	13.24	20.11	915.01
68	6.67	-2.75	3.63	-18.35	20.36	1111.85
69	-16.66	-2.23	9.58	-0.07	48.08	1682.60
70	-9.00	7.81	-4.12	-2.88	65.93	2307.60
71	-10.46	9.81	-1.59	-0.41	49.65	1737.90
72	-5.08	9.76	-6.71	-1.47	41.62	1456.80
73	-33.23	-17.05	31.42	14.58	48.85	1709.90
74	-21.88	3.94	8.09	6.52	46.10	1613.50

Appendix II contd..

Holdings database of Kasargod district

Sample No	Area	OC	AvP	AvK	AvCa	AvMg	pH	Gravel vol	BD
75	1.00	2.50	14.10	110.00	676.80	101.60	5.50	5.00	0.80
76	3.00	3.60	1.30	68.60	495.90	98.30	5.30	6.80	0.70
77	1.10	2.10	2.70	27.70	150.90	55.60	5.00	5.40	0.60
78	1.20	2.50	4.50	62.00	536.90	108.80	5.50	6.40	0.80
79	3.00	4.00	0.00	44.00	271.40	100.50	5.30	9.60	0.70
80	1.00	3.60	6.60	46.00	635.80	341.60	5.50	8.20	0.70
81	2.00	2.70	1.00	117.00	474.90	96.40	5.10	5.40	0.60
82	2.20	3.90	10.00	68.00	600.90	292.90	5.20	8.90	0.70
83	5.50	4.20	2.50	57.00	459.50	103.50	5.20	4.30	0.60
84	8.00	4.00	7.60	86.00	416.60	86.70	5.00	9.60	0.80
85	1.50	2.90	6.60	79.00	414.90	86.20	5.20	2.90	0.80
86	2.50	3.90	3.60	60.30	476.80	238.60	5.10	5.00	0.70
87	2.50	3.40	3.00	57.00	619.70	225.40	5.50	3.90	0.80
88	2.00	3.00	18.60	40.00	423.60	98.00	5.50	3.00	0.70
89	1.96	3.20	17.70	28.00	365.10	79.90	5.40	3.70	0.90
90	2.80	5.00	1.10	67.00	559.10	95.80	5.40	7.80	0.70
91	1.55	3.20	0.80	37.00	213.60	61.00	5.30	9.30	0.90
92	3.00	1.80	3.00	62.00	523.80	104.90	5.40	6.40	0.80
93	1.88	3.30	0.00	47.00	378.00	89.90	5.50	8.60	0.90
94	2.00	3.00	0.00	123.00	491.00	226.00	5.30	4.60	0.80
95	3.50	3.50	0.00	48.00	130.40	41.20	4.90	5.40	0.90
96	0.00	3.60	1.10	37.00	276.10	70.20	5.20	7.60	0.80
97	1.00	2.40	3.20	41.00	158.40	41.80	5.10	9.30	0.90
98	0.00	2.50	2.10	66.00	309.40	96.90	5.30	4.30	0.80
99	0.00	2.90	5.60	67.00	309.80	89.60	5.20	3.60	0.70
100	0.00	2.80	3.30	38.00	145.00	51.30	5.30	10.20	1.10
101	0.00	3.40	0.00	45.00	164.90	61.40	5.20	8.90	0.80
102	4.00	3.00	2.30	59.00	291.40	103.80	5.20	5.70	0.80
103	3.50	3.30	20.20	70.00	1011.00	49.60	5.30	7.50	0.70
104	5.00	2.10	13.50	36.00	188.80	44.90	5.20	8.20	0.90
105	2.50	2.50	0.00	45.00	236.90	66.20	5.40	4.90	0.80
106	1.50	2.50	0.00	30.00	144.50	103.40	5.40	7.50	0.50
107	2.00	2.30	0.00	32.00	368.00	315.40	5.40	4.80	0.40
108	1.00	1.00	0.00	29.00	251.70	259.60	5.30	7.10	0.70
109	2.00	1.10	0.00	43.00	540.60	472.00	5.40	8.20	0.60
110	5.00	4.30	0.10	50.00	517.40	272.00	5.20	7.50	0.60
111	1.00	1.80	0.00	90.00	737.50	0.00	5.40	7.50	0.70
112	1.00	3.70	3.90	39.00	240.50	93.50	5.40	5.00	0.70
113	1.00	2.20	1.70	38.00	253.60	289.50	5.40	8.00	0.70
114	2.00	1.40	0.00	58.00	150.90	77.70	5.20	6.10	0.70
115	1.25	3.00	2.20	71.00	115.50	69.60	5.10	7.50	0.80
116	0.00	3.40	0.00	39.00	500.10	338.10	5.30	6.80	0.70
117	1.00	5.70	75.50	65.00	65.60	31.00	4.90	6.40	0.60
118	1.00	3.90	8.70	49.00	263.20	87.40	5.10	9.60	0.70
119	0.85	2.80	2.00	41.00	109.90	76.80	5.10	10.30	0.90
120	3.30	2.70	1.20	112.00	419.50	317.10	5.30	6.30	0.80
121	2.50	1.80	1.30	49.00	278.70	104.90	5.40	2.90	0.80

Sample No	Area	OC	AvP	AvK	AvCa	AvMg	pH	Gravel vol	BD
122	1.72	3.70	1.10	60.00	379.20	300.20	5.40	10.70	0.80
123	2.50	3.40	1.00	39.00	561.70	517.90	5.50	8.20	0.70
124	1.25	2.00	1.20	65.00	319.60	231.90	5.50	5.40	0.80
125	2.50	2.60	1.80	46.00	310.00	233.00	5.40	5.00	0.60
126	1.10	2.30	1.50	25.00	152.30	72.50	5.30	4.60	0.80
127	1.50	2.70	1.50	24.00	264.30	95.60	5.30	6.80	0.70
128	1.50	2.60	2.10	46.00	135.10	68.90	5.20	7.80	0.70
129	1.80	3.00	2.30	39.00	459.80	343.10	5.40	8.60	0.60
130	6.00	2.80	2.60	49.00	196.00	79.20	5.40	6.10	0.60
131	1.50	3.80	2.00	68.00	169.10	241.50	5.40	7.10	0.80
132	1.50	2.70	3.20	56.00	273.80	92.00	5.40	8.20	0.60
133	30.00	4.60	6.70	111.00	262.80	100.70	5.30	3.90	0.80
134	30.00	5.00	8.70	65.00	351.50	94.00	5.10	5.00	0.70
135	2.00	2.40	3.00	67.00	125.40	40.40	5.20	6.80	0.70
136	1.50	3.20	1.90	43.00	171.20	54.50	5.20	5.40	0.80
137	20.00	4.00	2.10	63.00	150.40	69.80	5.30	6.40	0.70

Sample No	AWC	Girth	TPD	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg	N index
75	30.30	49.60	3.60	3.70	0.30	1.40	1.10	0.40	0.00
76	37.10	53.10	1.00	3.80	0.30	1.40	1.00	0.50	-1.80
77	29.00	61.70	5.00	4.00	0.20	1.10	1.20	0.40	6.90
78	37.40	60.90	7.00	3.60	0.30	1.60	1.20	0.40	-7.80
79	32.80	55.80	6.00	3.60	0.30	0.50	1.00	0.40	-3.80
80	27.00	63.50	4.00	3.10	0.30	1.40	1.00	0.40	-8.70
81	46.00	62.70	18.00	3.70	0.20	1.40	1.40	0.40	-2.70
82	56.90	56.40	5.00	3.60	0.20	1.20	1.30	0.50	-2.90
83	40.70	58.90	7.00	3.60	0.20	1.10	1.20	0.50	-0.40
84	56.40	63.20	15.00	4.20	0.30	1.30	1.20	0.50	3.00
85	53.40	59.20	18.90	3.60	0.30	1.50	0.90	0.30	2.80
86	49.20	60.00	9.00	3.70	0.30	1.30	1.00	0.30	0.30
87	53.30	57.40	7.00	3.60	0.30	1.30	1.10	0.30	0.90
88	53.30	64.10	2.00	4.00	0.30	1.60	1.00	0.30	3.60
89	53.80	60.80	6.00	3.80	0.30	1.50	0.90	0.30	5.70
90	36.00	53.30	4.00	3.70	0.20	1.30	1.00	0.40	3.00
91	70.20	57.20	6.00	3.50	0.20	1.40	0.90	0.40	1.30
92	41.10	67.80	3.00	3.40	0.20	1.30	1.10	0.30	3.60
93	21.20	64.40	6.00	3.10	0.20	1.20	1.00	0.40	-1.50
94	29.30	62.10	11.00	3.70	0.20	1.60	1.10	0.30	2.90
95	45.90	57.20	24.00	3.20	0.20	1.50	0.90	0.40	5.30
96	53.10	62.20	17.00	3.40	0.30	1.70	1.00	0.40	-7.10
97	74.30	62.20	38.00	3.60	0.30	1.50	1.00	0.40	0.20
98	48.50	56.60	14.00	3.50	0.30	1.60	0.90	0.30	-1.10
99	52.50	51.90	19.00	3.70	0.30	1.60	1.20	0.50	-7.20
100	71.70	52.00	19.00	3.50	0.30	1.50	1.10	0.40	-5.90
101	43.00	63.40	0.00	3.60	0.30	1.50	0.90	0.40	-5.50
102	28.30	52.60	5.00	3.40	0.30	1.60	1.10	0.40	-5.80
103	69.60	53.40	1.00	3.70	0.20	1.40	1.10	0.40	1.20
104	35.50	58.90	4.00	3.60	0.30	1.50	1.00	0.40	-4.60
105	37.80	53.10	1.00	3.60	0.20	1.30	1.40	0.40	-1.10
106	38.00	56.20	4.90	3.10	0.20	1.00	1.00	0.40	-3.60
107	19.30	58.70	10.00	2.90	0.20	1.50	1.10	0.40	-12.70
108	44.20	62.00	2.00	3.20	0.30	1.10	0.90	0.40	-3.70
109	42.30	56.80	3.00	3.10	0.30	1.50	0.80	0.30	-8.20
110	30.50	60.70	2.00	3.40	0.20	1.50	1.00	0.40	-2.30
111	34.10	60.30	5.90	3.40	0.30	1.20	0.90	0.60	-10.40
112	34.50	59.90	3.90	3.30	0.30	1.30	1.10	0.50	-8.70
113	50.40	62.50	6.00	3.90	0.30	1.90	1.10	0.40	-4.80
114	32.60	58.70	14.00	3.90	0.30	1.40	1.00	0.50	-1.60
115	50.20	63.80	1.00	3.20	0.20	1.20	1.10	0.50	-9.20
116	41.20	59.20	5.00	3.90	0.30	1.00	0.80	0.50	5.50
117	136.60	61.30	1.00	3.40	0.20	1.20	1.00	0.50	-3.30
118	49.40	56.90	16.00	3.60	0.20	1.20	0.90	0.40	0.70
119	60.10	54.40	10.00	3.40	0.30	1.90	1.10	0.40	-11.50
120	43.80	53.90	10.00	3.40	0.20	2.00	1.30	0.50	-16.10
121	62.90	60.70	1.00	3.80	0.20	1.30	0.90	0.40	3.00

Sample No	AWC	Girth	TPD	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg	N index
122	50.20	59.30	8.00	3.70	0.20	1.40	0.90	0.50	-2.80
123	28.90	58.50	12.00	3.70	0.30	2.10	0.90	0.40	-3.90
124	27.30	52.00	8.00	3.90	0.30	1.80	1.00	0.40	-3.50
125	19.50	53.30	15.00	3.00	0.20	1.30	0.90	0.40	-6.90
126	46.40	56.00	5.00	3.40	0.30	1.40	1.00	0.50	-9.80
127	69.40	57.90	9.00	3.50	0.20	1.40	1.00	0.40	0.30
128	34.50	54.70	15.00	3.80	0.20	1.40	1.20	0.50	-1.90
129	52.20	64.30	6.70	3.50	0.20	1.20	0.90	0.40	0.40
130	32.70	53.50	1.00	3.60	0.20	1.80	1.10	0.40	-5.40
131	50.60	59.80	23.00	3.60	0.30	1.80	1.00	0.40	-6.10
132	56.60	59.80	15.00	3.80	0.20	1.20	1.20	0.60	-4.70
133	35.00	59.60	3.00	3.60	0.30	1.10	1.10	0.40	1.10
134	55.60	59.70	11.30	4.10	0.30	1.30	0.80	0.40	6.90
135	67.80	62.70	7.00	4.10	0.30	1.10	1.00	0.40	7.70
136	74.10	62.60	9.00	4.00	0.30	1.30	1.00	0.50	1.60
137	63.50	57.40	3.00	4.00	0.30	1.10	0.90	0.40	8.00

Sample No	P index	K index	C aindex	Mg index	Avg.Yield	Ann. Yield
75	-4.80	-0.30	-1.20	6.40	28.52	1018.22
76	-4.90	-2.20	-9.40	18.40	42.49	1517.00
77	-7.10	-15.10	0.60	14.60	32.13	1248.25
78	3.80	2.00	-0.10	2.10	39.50	1534.58
79	-6.20	0.10	-6.40	16.30	35.60	1520.12
80	1.40	2.10	-3.40	8.60	44.65	1906.36
81	-9.40	-1.90	4.90	9.10	32.92	1152.08
82	-11.50	-11.10	6.00	19.50	55.08	1927.86
83	-9.90	-12.40	1.50	21.20	38.18	1336.42
84	-10.70	-8.20	-1.90	17.80	51.59	1787.65
85	-0.50	4.20	-3.30	-3.20	33.44	1158.57
86	7.80	-5.60	-5.60	3.10	30.50	1056.83
87	0.00	-4.10	-0.40	3.70	59.55	2063.41
88	-0.50	5.70	-4.00	-4.80	34.44	1193.26
89	1.20	5.60	-6.00	-6.40	31.62	1095.57
90	-7.80	-3.90	-1.70	10.30	56.81	1968.51
91	-6.00	3.20	-6.40	7.80	38.03	1464.10
92	-11.20	2.80	5.90	-1.00	27.65	1083.88
93	-16.50	0.80	0.10	17.10	26.53	1040.01
94	-11.60	6.40	1.40	0.90		
95	-19.20	6.10	-4.50	12.40	43.13	1690.59
96	-0.60	8.90	-4.00	2.80	32.77	1147.00
97	-4.20	1.20	-3.00	5.70	37.97	1329.00
98	0.40	6.80	-6.30	0.20	30.54	1069.00
99	-2.00	0.80	-0.80	9.20	30.69	1074.00
100	-4.20	1.40	-2.00	10.70	37.86	1325.00
101	0.50	1.50	-9.50	12.90	26.99	944.50
102	-4.20	5.20	-2.40	7.20	29.85	1211.75
103	-10.30	-1.80	-2.20	13.00	46.23	1876.97
104	-1.40	1.90	-5.90	10.00	55.80	2265.48
105	-9.20	-4.80	9.40	5.70	51.00	1999.20
106	-7.40	-10.70	-2.30	24.00	55.10	1793.51
107	-2.40	7.00	0.50	7.60	24.66	975.45
108	3.90	-8.00	-6.30	14.20	34.34	1358.26
109	5.60	7.60	-7.90	2.90	18.22	720.66
110	-14.00	4.60	-1.70	13.50	35.13	1389.28
111	1.70	-12.60	-13.40	34.70	41.02	1449.99
112	-2.60	-4.40	-2.70	18.40	49.04	1956.70
113	-4.80	8.50	-7.20	8.30	60.77	2126.95
114	-7.00	-3.70	-8.40	20.70	29.25	1177.50
115	-15.30	-5.20	-1.10	30.90	42.37	1749.74
116	2.80	-19.50	-12.90	24.10	30.61	1264.19
117	-11.70	-7.00	-4.70	26.60	20.31	753.44
118	-7.20	-5.10	-6.50	18.10	26.81	1013.38
119	-7.40	12.30	-3.60	10.20	27.64	1170.62
120	-17.30	12.10	-0.80	22.10	45.52	1704.60
121	-12.70	-2.50	-7.30	19.40	33.69	1226.32

Sample No	P index	K index	C aindex	Mg index	Avg.Yield	Ann. Yield
122	-13.70	-1.20	-10.70	28.40	35.56	1344.11
123	-10.20	16.20	-12.50	10.30	42.65	1432.89
124	-5.40	8.80	-8.40	8.50	36.55	1279.09
125	-5.60	2.00	-3.00	13.50	32.34	1097.94
126	-7.50	-1.20	-7.70	26.20	45.32	1824.13
127	-12.40	4.50	-3.10	10.60	33.10	1378.62
128	-14.70	-2.00	-1.20	19.70	46.99	1858.36
129	-9.70	-6.80	-5.80	22.00	37.82	1363.49
130	-14.30	9.50	-1.60	11.70	54.62	2198.38
131	-2.30	10.30	-4.30	2.30	32.95	1257.04
132	-13.70	-12.10	-1.10	31.60	45.98	1931.07
133	-1.00	-8.50	0.20	8.20	48.84	1982.97
134	-3.10	-4.60	-12.70	13.60	37.45	1520.47
135	0.40	-15.70	-5.10	12.80	54.47	2001.83
136	-6.00	-9.00	-6.80	20.20	36.59	1306.17
137	-2.80	-10.30	-8.70	13.80	60.46	2475.77

Appendix III

Characteristics of Soil Management Units

Parameter	SMU1	SMU2	SMU3	SMU4	SMU5	SMU6	SMU7
Soil depth	Deep or very deep	Deep or very deep	Moderate	Deep or very deep	Moderate to deep	Moderately deep or shallow	Shallow or moderately deep
Slope	Moderate	Moderate to strong	Moderate	Moderate	Mod steep and strongly sloping	Moderately steep	Steep
Gravel content	Slightly gravely or gravely	Gravely	Gravely or slightly gravel	Gravely	Gravely or slightly gravel	Gravely	Gravely
AWC	Low or medium	Very low or low	Low or very low	Very low or low	Very low or low	Very low	Low
OC stock	Medium	Medium or low	Medium or low	Low or medium	Low or medium	Low	Low

Classes of soil property

Depth(cm):	Slope (%)	Graveliness (%)	AWC (mm)	OC stock (0-30cm)
Shallow- < 50	Moderate 5-10	Slightly 15-35	Very low < 50	Low < 2.5 kg/m^2 soil
Mod. Deep 50-100	Strongly 10-15	Gravely 35-60	Low 50-100	Medium 2.5-5.0 kg/m^2 soil
Deep 100-150	Mod. Steep 15-25	Very gravely > 60	Medium 100-150	High > 5.0 kg/m^2 soil
Very deep >150	Steep 25-33			
	Very steep >33			

GEOSPATIAL ANALYSIS AND SOIL NUTRIENT DYNAMICS OF RUBBER PLANTATIONS IN RELATION TO GROWING ENVIRONMENT

by

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(2009-21-105)

ABSTRACT

of Thesis Submitted in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University, Thrissur

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2013

8. ABSTRACT

Para rubber (*Hevea brasiliensis* Muell. Arg.) grown in varied soil and climate condition in traditional rubber growing regions of India. Variability in soil and climate influences performance of rubber and for this site specific management helps to increase input use efficiency and enhance crop production. Geospatial analysis under GIS environment helps to integrate soil and climate variability and identify the limitations and potential areas for enhancing the rubber production without horizontal expansion of rubber cultivation. Hence the present study was undertaken with the following objectives

1. To develop soil, climate, rubber area and rubber yield database to understand the variability of rubber productivity.
2. To prepare rubber distribution map and delineate productivity constraint area map of rubber in Kanaykumari and Kasargod.
3. To study the soil nutrient dynamics and phenology of rubber in different growing environments.

Objectives of the present study were addressed by conducting two experiments. Under experiment I, two districts - Kanyakumari and Kasargod - were selected and identified 60 holdings in each district distributed over different Soil Management Unit (SMU). Recorded girth and Tapping Panel Dryness (TPD) observations and collected surface soil sample (0-30 cm) from identified holdings and analyzed for major nutrient and physical parameters. Using GPS reading developed holdings soil database and generated soil nutrient map and brought under GIS platform to identify the soil constraint areas. Water balance approach was followed to delineate climate constraint area in each district. Rubber distribution map was developed for each district using satellite image and overlayed with soil and climate constraint map to know the extent of rubber area under soil and climate constraint. Under experiment II, Kottayam district was selected for studying the soil nutrient dynamics of mature rubber plantation in relation to phenology and growing environment. Identified two holdings in each of three elevation classes; 0-100, 100-300 and > 300m. Collected surface soil

samples and recorded rubber phenology at monthly interval. Soil samples were analyzed for pH, OC, nitrogen, exchangeable Al. Recorded annual litter fall and mineralization potential. Rainfall and temperature were recorded at one location in each of the three elevation classes.

Mean soil OC, available P, K, Ca and Mg varied significantly between Kanyakumari and Kasargod district. Soil available P and K were significantly higher in Kanyakumari where as soil OC, available Ca and Mg were significantly higher in Kasargod. Within the district, soil OC, available P, K and Ca showed high spatial variability. Rainfall distribution was distinctly different in two districts. Well distributed rainfall with less dry period and long growing period was seen in Kanyakumari. In Kasargod rainfall was concentrated between June-September, as a result dry period was longer and growing period was shorter. During December to March period moisture stress level was more in Kasargod compared to Kanyakumari. Performance of rubber in terms of girth and rubber yield was better in Kanyakumari compared to Kasargod. Average per tree rubber yield (g/tree/tap) during dry period and annual yield per unit area (kg/ha/year) was significantly higher in Kanyakumari compared to Kasargod. Incidence of Tapping Panel Dryness (TPD) was significantly more in Kasargod compared to Kanyakumari. Leaf nutrient content showed balance level of N, P and K and deficiency of Ca and excess of Mg in Kanyakumari. In Kasargod leaf K was balanced, whereas Mg was in excess and deficiency of nutrient was in the order of P>Ca>N.

Rubber showed a distinct signature compared to other vegetation. Satellite based rubber area was estimated with good accuracy and rubber area was comparable with ground statistics. Overlay analysis indicated that considerable extent of rubber area in Kanyakumari distributed over area without moisture stress but same was not seen in Kasargod. In general all rubber area in Kasargod comes under poor to very poor moisture adequacy during summer compared to only 48 per cent rubber area in Kanyakumari experienced poor moisture adequacy during summer. In Kanyakumari 28 per cent of rubber area distributed over low available P, medium in OC, K and high Ca and Mg followed by 18 per cent over area medium in OC, available P ,K and high in available Ca and Mg. In Kasargod, 61 per cent rubber area distributed over low available P, medium K and high in OC, available Ca and Mg. In Kanyakumari district soil cation (Ca and Mg), and soil health factors showed significant relation with rubber growth and yield. In Kasargod only topography factor showed significant relation with rubber yield.

In Experiment II rubber showed distinct phenological difference over elevation with rubber in high elevation showing early wintering compared to low elevation. Number of new leaf flushes was more in low elevation compared to high elevation. Annual litter addition did not vary along elevation; however rate of litter decomposition was slow at high elevation compared to low elevation. In general maximum and minimum temperature was low at high elevation where as no marked difference in quantity and distribution of rainfall was seen along elevation. Soil OC was significantly higher at high elevation compared to low elevation, but mineralization of soil OC and total N was significantly low at high elevation compared to low elevation. Peak soil total N was observed for short period at high elevation indicating the short growing period compared to low elevation. Wide gap between potential and actual NO_3 and NH_4 nitrogen at low elevation compared to high elevation indicated the loss at low elevation through leaching and denitrification. At low and medium elevation, rubber active growth stage coincided with peak N mineralization whereas peak rubber yield period coincided with low N mineralization. But at high elevation both active growth and peak yield coincided with peak N mineralization. At high elevation, climate factor showed significant positive relation with next month rubber yield indicating the climate limitation at high elevation. At low elevation, climate factor and soil reaction factor did not show significant relation with next month rubber yield indicating mineralization and climate are not limiting at low elevation.