Tree growth – climate relations of plantation grown teak (*Tectona grandis* L.f.) from selected sites of Thrissur district, Kerala

By

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(2016-20-024)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

B.Sc.-M.Sc. (Integrated) CLIMATE CHANGE ADAPTATION

FACULTY OF AGRICULTURE

Kerala Agricultural University

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KERALA, INDIA

2021

DECLARATION

I, Sandra M L, (2016-20-024) hereby declare that this thesis entitled "**Tree growth- Climate Relations of plantation grown teak (*Tectona grandis* L.f.) from Selected Sites of Thrissur District, Kerala**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar titles, of any other University or Society.

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CERTIFICATE

I, hereby certify that the thesis entitled "**Tree growth-climate relations of plantation grown teak (*Tectona grandis* L.f.) from selected sites of Thrissur district, Kerala"**is a record of research work done independently by Ms. Sandra M L (2016-20-024) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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ACKNOWLEDGEMENT

First and foremost, I extend my deepest sense of gratitude and obligation to the chairman of my advisory committee, **Dr. E. V. Anoop** (Major Advisor) Dean, College of Forestry, Vellanikkara for his valuable guidance and suggestion for thesis work. I would also like to thank him, for his advice and assistance in keeping my progress on schedule.

I wish to extend my profound gratitude to my advisory committee members **Dr. P. O. Nameer**, Dean, College of Climate Change and Environmental Science for his indispensable moral support and crucial assistance during critical point of thesis correction and submission.

I wish to acknowledge the help provided by **Dr. Sreejith Babu** for lab work, for giving more knowledge about my topic and for the valuable assistance all through my thesis work. His indefatigable effort and patient attitude was a deep sense of relief to me period from a place across the ocean is highly and deeply acknowledged.

I express my sincere thanks to **Dr. A. V. Santhosh Kumar**, Professor& Head, Dept. of Silviculture& Agroforestry, KAU and **Dr. T.K. Kunhamu**, Professor and Head, Dept. of Silviculture& Agroforestry, COF who were the able members of my advisory committee for their timely cooperation and valuable support extended during the period of my M.Sc. project work.

I extend my heartfelt gratefulness and sincere regard to **Dr. M. C. Aneesh** and **Dr. Pavin Praize Sunny** (Faculty of COF) for the support they ensure during by Project time.

I would also like to extend my huge, warm thanks to everyone at **College of Climate Change and Environmental Science**, teaching and non-teaching staves who at some point of my project period had played crucial roles.

I am thankful to my major advisor, faculty at **COF** and other staff for providing good lab and library facilities for completing my research work.

Finally, I must convey my very deep gratitude to my **family** and to my classmates **(2016 batch-Campeones)** for providing me with abiding support and incessant encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Sandra M L

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SYMBOLS AND ABBREVIATIONS

°C - Degree Celsius

IPCC - Intergovernmental Panel on Climate Change

m - Meter

mm - Millimeter

SNR - Signal -to-Noise Ratio

EPS - Expressed Population Signal

MS - Mean Sensitivity

TAR - Third Assessment Report

ENSO - El Nino Southern Oscillation

PDO - Pacific Decadal Oscillation

NAO - North Atlantic Oscillation

cm - Centimeter

CDI - Cross Date Index

RWI - Ring Width Index

JJAS - Southwest monsoon (June, July, August, September)

ON - Northeast monsoon (October, November)

-JJAS - Previous southwest monsoon

-ON - Previous northeast monsoon

DJF - Winter season (December , January, February)

MAM - Summer (March, April, May)

$_{P}$June - Previous June

INTRODUCTION

CHAPTER 1

INTRODUCTION

The global climatic condition is changing day to day. Since climate change is a global problem which affects the entire balance of the planet, it has a greater influence in various sectors like agriculture which is the major livelihood for tropical and subtropical countries, fisheries, forestry etc.So, a clear understanding about the climate change and its reasons are necessary to solve the problems faced by our society.

To understand the trend of present climatic change, it is necessary to know about the studies on past climatic conditions according to Intergovernmental Panel on Climate Change (IPCC). The study of past climate prior to instrumental record is known as Paleoclimatology (Bradley, 1999). The climatic data from the instrumental record is available only for a period about 100-150 years. This limited data is not sufficient for understanding or studying the past climatic conditions for millions of years ago. So such information can be obtained through the sources like ice cores, sediments of lake, pollen grains, tree rings etc. Among these, tree rings are a major proxy for extending the existing instrumental climate records (Bradley, 1999).

The study of past climate using tree ring as a proxy is called dendroclimatology which is a branch of dendrochronology (Fritts, 1976). It consists of various methods to check the response of climatic factors (temperature, precipitation, relative humidity etc.) on tree ring factors (ring width, wood density etc.) for a particular period which are instrumentally recorded. The climatic information prior to the instrumental record can be determined by using response function analysis.

Dendroclimatology is the branch of dendrochronology. The word 'dendro' originated from a Greek word 'dendron' which means tree and chronology is a branch of science which gives name time and date to the events.

Most of the climate factors like precipitation, temperature, sunlight, relative humidity etc. will affect the growth of the tree. Not only the climatic factors, the non climatic factors like insect pests, soil nutrient characteristics etc. are also influence the tree growth.

Each year the tree produces one ring. This single ring is called annual ring. The annual ring consists of one light ring and one dark ring. Formation of the annual ring in each year shows the growth of the tree and it is greatly influenced by the climatic condition. During favorable climatic condition, trees form a wider ring. Similarly, they form narrow rings during unfavorable or stressful conditions. Sometimes the tree forms irregular missing and false rings in the stressful condition. So by analyzing the characteristic of rings, the dendroclimatologists can explain the climatic condition existed during the growing period of that tree. So, due to these reasons tree rings can be used as a better proxy for past climate detection.

Teak (*Tectona grandis* L.f.) is one of the better tree species which can be used for the Dendroclimatological studies in Asian tropics. The area with an annual rainfall of 800-3750 mm and maximum and minimum temperature of 39-43°C and 13-17°C respectively and having an elevation below 1000m is suitable for the growth of teak plantation (Zaw, Z. *et al*. 2020). Teak is a ring porous species which is well suited to Dendroclimatological research because they show distinct annual rings.

After the collection and preparation of the tree ring samples, the chronologies are prepared. These chronologies should have high signal-to-noise ratio (SNR) and Expressed Population Signal (EPS) and high value of common variance and mean sensitivity (MS), high standard deviation, low autocorrelation etc. (Fritts, 1976).

The major aim of this work is to check the dendroclimatic potential of the plantation grown teak from selected sites of Thrissur for the reconstruction of precipitation and temperature. This work deals with following objectives;

1. To develop and analyze the tree ring chronologies of teak in Thrissur district
2. To assess the relationship between tree growth and climate
3. To find out the dendroclimatic potential of ring width and wood density for the reconstruction of temperature and precipitation

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Dendroclimatic investigations were started in India since the end of 1970. Inorder to predict the climatic extremes like drought, flood etc. it is necessary to require the meteorological data of longer series (Yadav, 1992).

There are numerous proxies were suitable for determining past climate. For example: coral reefs, ice core, sediments, pollen grains, archaeological materials, tree-rings etc. (Borgaonkar *et al*. 2010). Among the proxies, tree-rings were found to be a better, precisely dated and also annually resolved proxy for past climate studies (Mann, *et al.* 1990).

By understanding tree growth-climate relationship from the tree-ring and climatic factors, the environmental information can be obtained (Fritts, 1976; Hughes, *et al*. 1982; Cook & Kairiukstis, 1989).

Dendroclimatology – climate relationship in a wide scale started only a few years back. Intergovernmental Panel on Climate Change (IPCC) cited the climatic reconstruction using tree-rings in their Third Assessment Report (TSR) (Holmes, 1983).

There are a number of studies were done on multidecadal fluctuations like El Nino-Southern Oscillation (ENSO) , variation in timing and intensity of monsoon and of multidecadal fluctuations in Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO) (Gaire, *et al*.2018). The realization about these fluctuations is limited because the instrumental meteorological records available for these phenomena are only less than 100 years long. Study of Hughes (2002) focused the tree-rings as natural archives of past climate which gives a long term records about these phenomena.

Hughes (2001) showed the evidence of the scientific application of dendroclimatic science by supporting the finding of 20th century that the reconstruction of surface temperature variation and 1990 the uniquely warm year in last 1000 years (Briffa *et al*. 2001; Jones *et al*. 2001; Mann *et al*. 1990.

A striking improvement in the field of dendroclimatology was started since the end of 1970s. These sensational improvement were made in several regions like Southern hemisphere, Canada, the British Isles (Hughes *et al*. 1982), the Eastern United States (Chowdhury, 1940), Mediterranean region (Serre-Bachet *et al*. 1992) etc.

Annual maps of seasonal temperature, precipitation and sea-level pressure back to AD 1602 produced by Fritts *et al*. (2015) by using the first sub continental network of ring width series.

Development of climatic information by the application of modern tree-ring researches were started not long ago (Pant, 1979, 1983; Pant & Borgaonkar, 1983).

Indian climate is influenced by seasonal wind patterns and also variation in the precipitation and temperature. A seasonal wind pattern consists of northeast and south west monsoon. But the instrumental record of climate data is only available for a limited period, which is not enough to predict the climate and to understand the Indian climate in an extended aspect. The past climatic condition of India can be therefore reconstructed using tree-ring proxy for understanding the climate of several last centuries (Bhattacharryya & Shah, 2009).

Tree-growth – climate relationship study was started with the work of Chowdhury (1940a, 1940b). Later by using the tree-ring data of short time, the relation between tree-rings and climate were studied in Western Himalaya (Pant, 1979). The study of climate using tree rings is known as dendrochronology and its branch which deals with the reconstruction of past climate is known as dendroclimatology (Fritts, 1976).

Dendroclimatic studies are more applicable in temperate trees in the world. Because a huge part of tropical forest in India lie under the monsoon climatic regime (Sinha *et al*. 2019).

Until now these Dendroclimatological studies were done to find the tree growth – climate relationship and also to determine the past climatic conditions.

The chronology which have low auto correlation, high mean sensitivity (MS), high standard deviation, high Signal-to-Noise ratio (SNR) and Expressed Population Signal (EPS) and high common variance are only suitable for dendroclimatological studies (Fritts, 1976).

Auto correlation is the relation between previous year's ring width and current year's ring width. High auto correlation will upset the relation between tree growth and climate (Shah *et al*. 2007).

Mean sensitivity is the difference between the ring width of one year and that of next year. Value of MS varies from zero to two (Fritts, 1976).

Low auto correlation and high MS shows the presence of high frequency variance necessary for dendroclimatic studies. The high auto correlation can be removed by a technique called auto regressive modeling (Shah *et al*. 2007).

The linkage between the mean chronology and population from where the samples are taken is called expressed population signal. If the EPS value is equal or greater than 0.85, then the chronology is suitable for the dendroclimatic investigations (Wigley *et al*. 1984). According to Wigley *et al*. (1984) the SNR should always greater than one.

The average correlation among the samples is called common variance. If this variance is high, the samples are more correlated and this is a necessary factor for dendroclimatological studies (Fritts, 1976).

Numerous studies in countries like India, Thailand, Indonesia, Myanmar etc. revealed teak as a crucial proxy for determining past climate or dendroclimatic investigation (D'Arrigo *et al*. 1989, 2006).

Teak is used for the Dendroclimatological studies in various locations of India because it is widely distributed (Shah *et al*. 2007; Ram *et al*. 2008; Deepak *et al*. 2010; Sinha *et al*. 2019; Pumijimnong, 2012; Die *et al*. 2015)

Analysis of tree-ring for a longer time span started at the end of 1980s. After that so many studies were performed to find the relation between climate and tree-rings in Indian subcontinent (Bhattacharryya & Shah, 2009). Birbal Sahini Institute of Paleobotany, Uttarpradesh, Indian Institute of Tropical Meteorology, Pune and Physical Research Laboratory at Ahmadabad are the three research institutes performing a number of tree-ring researches now.

Abies pindrow, Cedrus deodara, Picea smithiana, Pinus gerardiana, Pinus roxburghii and Pinus Wallichiana are the conifers which are found suitable for tree-ring based studies by Bhattacharryya *et al*. (1988).

Abies pindrow were used by Hughes (1982) for reconstructing mean temperature of spring (April – May), late summer of August – September and precipitation of the growing season (April – September0 by considering the tree-ring width and density.

Cedrus deodara was found as a better proxy for pre monsoon temperature reconstruction. This specie is growing in Joshimath, Uttaranchal (Borgaonkar *et al*. 1996; Yadav & Singh, 2002a).

Reconstruction of non-monsoon months (prior October to current May) back to AD 1171 revealed the wettest and driest months in the 14th and 13th centuries (Singh & Yadav, 2005).

Cedrus deodara and *Pinus gerardiana* were the two species found to be suitable for the drought reconstruction for long period because they exhibit narrow ring formation during less rainfall (Bargaonkar, *et al*. 2007).

The northeast and northwest Himalayan trees were analyzed to understand the suitability of those sites for the tree-ring studies (Shah & Mehrotra, 2017).

Cedrala toona were found suitable for reconstructing variation in monsoon and drought event existed in the past (Bhattacharryya *et al*. 1992).

Since some species in Himalayan and Peninsular region in India shows variation in the temperature and precipitation, they are well suited for the tree-ring research and climatic reconstruction. Monsoon reconstruction data are only for the central part of India. Major part of India lie under tropical forests. The tree-ring studies were not carried out in other species except teak and toona in India. The main tree-ring parameter used for the dendroclimatic study in India is ring width (Bhattacharryya and Shah, 2009).

In India dendroclimatic studies done on the sites like moist deciduous Thane, Maharashtra (Pant & Borgaonkar, 1983; Bhattacharryya *et al*. 1992), dry deciduous forest in Korzi, Andhra Pradesh (Yadav & Bhattacharryya, 1996), Western Ghats of Kerala (Bhattacharryya *et al*. 2007; Borgaonkar *et al*. 2010), upper Narmada river basin in Central India and dry deciduous forest of Madhya Pradesh (Shah *et al*. 2007). Besides India, other countries like Thailand (Buckley *et al.* 2005) and Indonesia (D'Arrigo *et al*. 1989).

Western Ghats of India is one of the crucial sites for Dendroclimatological investigation due to the variation in monsoon precipitation. Some northern Western

Ghats areas having heavy rainfall followed by long dry spells but the amount of annual rainfall are less in the regions near the equator (Preechamart *et al*. 2018).

2.1 Tropical trees

A major part of tropical forest lies under monsoon climatic regime. And annual rings are produced by about twenty five percentage of tropical trees. Teak and toona are the two species which are found suitable for dendroclimatic studies due to the formation of datable growth rings (Sinha *et al*. 2019).

Dendroclimatological investigations are slow in tropics because of the lack of seasonality. Even though it is necessary to analyze the tropical tree-rings to understand the tropical phenomena like inter tropical convergence zone and southern oscillation which have a crucial influence in global climate. Due to the lack of seasonality the tropical trees does not exhibit well defined growth rings. Growth rings form only if there exists enough seasonality (Yadav, 1992).

Major part of the Indian geographical area experience monsoon climate. If monsoon is deficient in an area, there exhibit a periodic water stress and it causes distinct seasonality of tree growth which produces different growth zones which are differentiated by various anatomical features (Chowdhury, 1964).

The potential for the dendroclimatic analysis increased by the accessibility of teak ring width data (Bhattacharryya & Yadav, 1989).

Table 1: showing the tropical trees having ring porous and semi ring porous annual rings

Anatomical feature of annual rings	Tropical trees
Ring porous	*Tectona grandis, ,* *Melia azedarach, Lagerstroemia speciosa*
Semi ring porous	*Cedrela toona,* *Pterocorpus dalbergioides* *Pterocarpus marsnpium,* *Juglans regia*

Source: Bhattacharya and Yadav (1989)

2.2 Temperate trees

There are distinct growth rings formed in conifer species growing in temperate to sub alpine forests in India. The chronologies of *Pinus roxburghii* which is a specie grown in area where moisture supply is provided by the summer precipitation is used to know about the past monsoon character. But due to the over exploitation of the tree for the resin, old trees are difficult to get for the studies (Buntgen *et al*. 2008).

The chronological study of *Pinus gerardiana* from Jammu and Kashmir by Bhattacharryya *et al*. (1988) showed the dendroclimatic potential of the species to reconstruct temperature and winter precipitation in the area as they show low autocorrelation, high mean sensitivity and high common variance and they observed 300-400 years old trees in the natural forests are the common factors.

Cedrus deodara has high dendroclimatic potential due to its durability and ecological importance. This species grown in Western Himalaya extends from 1200-3300 m altitude (Bhattacharryya *et al.* 1988; Bhattacharryya & Yadav, 1989).

2.3 Tree growth and climate

In recent years it is very necessary to understand the climatic variability for making future projections through the understanding of different internal influences on the climate. So tree-rings are one of the best proxies to recognize the past climate changes (Carrer & Urbinati, 2004).

The information about the influence of large scale climate on ring growth can be identified by analyzing the large scale variation in tree-ring pattern first identified by Laxton & Smith (2009).

The climatic factors have great influence in the annual growth. During spring and summer seasons, the xylem cell growth is very fast if they receive minimum moisture (Fritts, 1976). During the early period of growth, an important source of moisture is from precipitation in the form of rain or snow while the growth remains dormant throughout the winter.

The climate – tree growth relationship can be understand by a method called response function analysis (Fritts, 1976). Besides the climatic factors like temperature, precipitation, relative humidity, wind velocity etc. there are some non - climatic factors such as insect pests, soil nutrients, inter tree competition etc. also influence the growth of the tree (Fritts, 1976).

The growth rate of tree can be measured by using width of the tree-rings. The radial growth pattern will change annually in association with the climatic condition of the area. The climate variability has the power to limit the growth and that variability is called as limiting factors. The limitation can be observed and cross dated for further dendroclimatic studies (Sinha *et al,* 2019).

The ring width and density of the tree species from a higher elevation site without moisture stress have a linear relationship with surface temperature in all of the growing season. Since the site chronologies from an area near the ecological range of specie has only single climatic factor response when compared to the greater response to the climate by those from the central range of the specie (Shi *et al*. 2020).

The relationship between variation in tree growth parameters and regional climate were obtained by Hughes (1992) by using *Abies pindrow* and *Picea smithiana*. Summer climate of Srinagar were reconstructed by Hughes (1992) using ring width chronologies and ring density of *Abies pindrow*.

The dendroclimatic analysis of *Cedrus deodara* in Uttar Pradesh was reported by Bhattacharryya & Yadav (1992).

The temperature gradually increases above the annual average value in the pre monsoon season and May is considered as the hottest month. But there is a very small precipitation amount during the pre monsoon months. The pre monsoon season coincide with the early growth period of trees. So extreme heating decreases the moisture level but more precipitation increases the growth. Thus summer climate affects the tree growth (Borgaonkar *et al*. 1996).

The heat index of the previous year and tree growth are negatively correlated. As a result the enhancement of the tree growth during the successive growing season get affected (Shah *et al*. 2007).

In comparison to a single climate, Ram & Borgaonkar (2016) found that seasonally averaged climate had a significant impact on tree growth. Tree-ring records from places near glaciers can be used to determine the glaciers' temporal fluctuations.

Rapid growth of the tree can be initiated by high temperature in winter and early spring through increasing net photosynthesis and physiological activity.

2.4 Tree-rings

High resolution climate proxies are provided by the tree-rings for predicting past climate (Cook *et al*. 2010).

Countries like Thailand (Buckley *et al*. 2007; Pumijimnong, 2010), India (Shah *et al*. 2007; Borgaonkar *et al*. 2010), Indonesia (D'Arrigo *et al*. 2006), Vietnam (Sano *et al.* 2009) used tree-ring as a proxy for dendroclimatic studies.

A number of local to regional drought and several mega droughts were observed using drought reconstruction using tree-rings (Sano *et al*. 2009; Cook *et al*. 2010).

Tree-ring proxies give long term information for the reconstruction of climate. To reconstruct different aspects of past climate variability, relationship between the growth of the species which respond to the seasonal variability and climate should be known. Towards the end of 1970s only the modern tree-ring based studies were started (Pant, 1979, 1983).

Table 2: Trees forming annual rings

Type of Forest	Name of Trees
Wet Evergreen Forest	*Cedrela toona,* *Cinnamomum cedidodaphne*
Semi Evergreen Forest	*Terminalia citrina,* Gmelina arborea, Magnolia spp., *Michelia spp., Syzygium spp.* *Pterocarpus dalbergioides,* *Alianthus excels, Tectona grandis*
Dry Evergreen Forest	*Azadirachata indica,* *Pterospermum suberifolium,* *Gmelina arborea*
Dry Deciduous Forest	*Melia azedarach, Santalum album,* *Pistacia integerrima, Anogeissus latigolia,*

	Tectona grandis, Tamarix articulate, Feronia elephantum
Moist Deciduous Forest	*Tecona grandis,* *Meliosma dilleniaefolia*
Littoral and Swamp Forest	*Carapa molluccensis*
Thorn Forest	*Ziziphus jujube, Acacia catechu*

Source: Bhattacharya and Yadav (1989)

2.5 Teak (*Tectona grandis*)

One of the major hardwood species across the world is teak (*Tectona grandis* L. f.). Teak wood is ring porous and semi ring porous. In Asia, the dendroclimatic potential of teak is being studied by measuring the width of their tree-ring and understanding their patterns. In countries like Thailand (Nash, 2002), India (Murphy, 1989) etc. the dendroclimatic potential of teak are being studied. Those studies showed the high potential of teak to predict the climatic patterns like temperature, rainfall, drought etc.

Teak is a tropical, light demanding and deciduous specie native to countries like India, Thailand, Laos and Myanmar. The area with annual rainfall of 800-3750 mm, maximum temperature of 39–43 °C, minimum temperature of 13–17 °C and elevation below 1000 m are suitable conditions for teak growth and they exhibit distinct annual rings (Berger *et al*. 1979).

In tropical regions, less precipitation and warmer temperature cause extreme drought condition by decreasing tree growth by reducing the xylem productivity (Valmore & LaMarche, 1974). This indicates the radial growth of teak is influenced by precipitation and temperature during dry season.

Moisture availability is one of the major factors affecting the teak growth. So if the drought condition and increasing temperature will reduce the enhancement of teak forest in tropical regions of south East Asia (Borgaonkar *et al*. 2008). This shows the greater potential of teak to study the changes in the climate.

The current year development of teak growth is influenced by the availability of moisture in post monsoon period of previous year (Ram *et al*. 2008).

Teak usually forms annual rings but sometimes false rings may form (Chowdhury, 1964). Physiological disturbances and insect defoliation were found out as the reason for this false ring formation (Chowdhury, 1964; Priya & Bhat, 1988).

Teak growth was influenced by previous year rainy season and also rainy season in the current year (D'Arrigo *et al*. 1989). So moisture level in the soil before the beginning of growing season is an important factor for teak growth.

The pre monsoon showers of October-December have crucial role in the formation of cells in teak. Contrarily a distinct moisture deficiency caused by the hot and dry pre monsoon affects the radial growth directly. Hence this proved the significant relationship between variation in growth and climatic factors (Sinha *et al*. 2019).

Low rainfall will cause reduced tree growth in case of teak but a normal or higher rainfall will not increase the growth because of the presence of regular moisture in the root zone. The moisture availability in the root zone is a function of monthly rainfall and temperature (Ram *et al*. 2008)

In teak during the month of March, the radial growth initiates and during the month of June – September it reaches at the top and then formation of wood decreases and stop at November. In the month of December defoliation starts and by March the tree become completely leafless (Die *et al*. 2015).

Radial growth of teak was influenced by high temperature and pre monsoon showers and monsoon rainfall. The moisture availability of teak from previous year's monsoon and also from post monsoon also provides growth variation in teak. But the moisture stress of teak at the root zone is caused by the high temperature and low rainfall during monsoon (June – September) and post monsoon (October – November) (Sinha *et al*. 2019).

The increase in moisture and rainfall especially in monsoon months have an influence in the ring width in the area. So moisture and rainfall are the major factors affecting teak growth and its relationship with the climate. Thus tree-ring chronology of teak can be used as a high resolution proxy for investigating dendroclimatic potential (Ram *et al*. 2008).

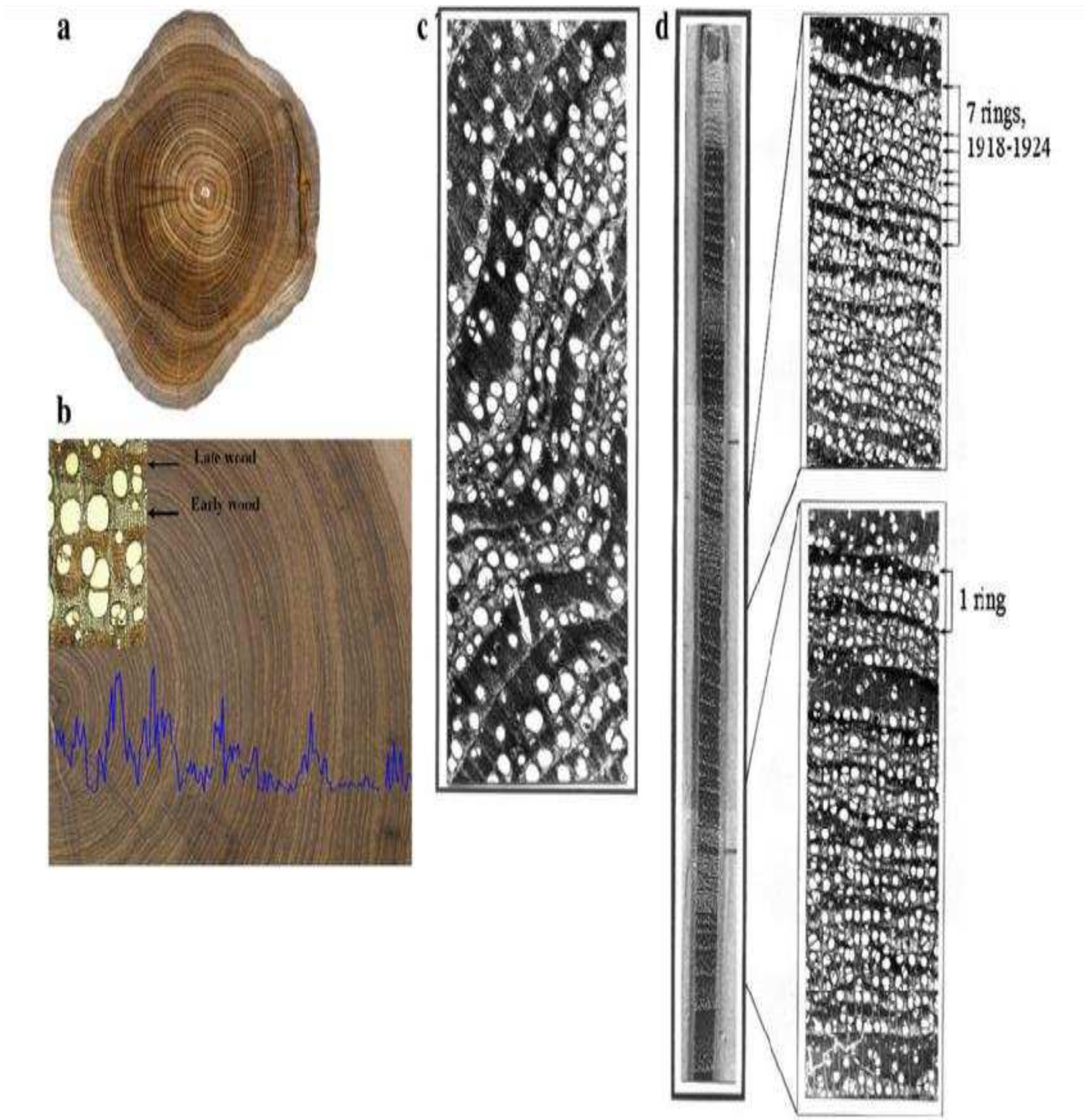


Figure1: Photographs of teak features. **a**) A teak disk,**b**) teak tree-ring width, **c)** teak surface with wavy rings and **d**) the complicated ring.

Source: Pumijimnong *et al.* (1995)

2.6 Dendroclimatology in Asia

Due to the lack of seasonality in tropics, the dendroclimatological studies are difficult in tropical trees. So the tree-ring records of Asian tropics are very few (Worbes, 1995; Jacoby, 1989)

The climate records extend only upto 150 years in tropical and subtropical Asia. It consists of tree-ring records (Buckley *et al*. 1995; D'Arrigo *et al*. 1994; Pumijimnong *et al*. 1995), coral reefs (Urban *et al*. 2000), ice cores (Thompson, 2001).

The rainfall anomalies in Asia due to the variation in monsoon precipitation cause extreme droughts and floods in Asia, especially in agrarian parts. Asian monsoon is influenced by the surface temperature variability over global ocean and over high latitude Asian landmass (Die *et al*. 2015).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The study was conducted to find whether teak (*Tectona grandis* L.f.) samples collected from plantation grown teak from selected sites of Thrissur district, Kerala have dendroclimatic potential to reconstruct temperature and precipitation by preparing their chronologies and thereby understanding the climate-tree growth relationship. The process of dendroclimatic investigation consists of a hierarchy of steps such as site selection followed by sample collection and preparation of the sample, then measurement of ring width, cross dating, chronology building, standardization and finally reconstruction through dendroclimatic analysis.

3.1 Site selection

Site selection is the back bone of the dendroclimatic studies. Because the environmental conditions of the site have a major role in the growth of trees in that site. Reconstruction of climatic variability depends upon the limiting factors present in the study site. That is, in a site where temperature is a limiting factor, the tree rings of the trees growing in respective site can be used for reconstructing temperature. Similarly, precipitation can be reconstructed from the trees from a site where moisture availability is a limiting factor. If the selected sites have proofs of disturbances such as fire, earthquakes, wind, human interventions, volcanic eruptions etc., then the trees in those sites show missing rings or false rings instead of normal tree rings. This abnormality in tree rings will affect the dendroclimatic study. So sites in Thrissur with minimal disturbances were selected for better result in dendroclimatic investigations. Long term meteorological data were also available for these sites for precise reconstruction of climate existed very long years ago.

3.2 Sample collection

For this study the teak (*Tectona grandis* L.f.) tree ring samples collected from plantation grown teak in selected sites of Thrissur district, Kerala by College of Forestry, KAU, Vellanikkara, Thrissur were used. From each log one basal disc with a thickness of 10-15 cm were cut using a chain saw.

3.3 Sample preparation

The surfaces of the sample discs were smoothened using sand papers with grit sizes 60, 80, 150, 220, 320, 400, 1000 and 1500 until the annual rings on the discs were clearly exposed for the measurements. The smoothening was done on three radii in each disc.

3.4 Measurement of ring width

Ring width of a tree means the perpendicular distance between late woods of two consecutive years or it can also be explained as the amount of growth that has taken place for a tree in one year. In favorable climatic condition, trees grow faster and produce wider rings. But in stressful period, tree growth will be slow and form narrow rings. So, the ring widths can also indicate the climatic conditions existed during the growth periods of the tree.

Ring widths of the prepared samples were measured by using a tree ring measuring station called LINTAB-6 which is a moving platform. The polished wood discs were placed over the platform of LINTAB – 6. The live images of the tree rings across the selected radius were taken using a stereomicroscope (Motic) which consists of a digital camera attached to it. The annual tree ring widths across the radii were obtained from pith to bark by moving the platform containing wood discs and were recorded digitally with the help of software known as TSAP Win with a precision of 0.001 mm. The growth rate of the treewas calculated from the measurements obtained from the TSAP Win software by analyzing the number of annual rings per cm.

Figure2: Sample Preparation by smoothening process using sand paper

Figure3: Measurement of sample ring width using LINTAB – 6 at COF, KAU at Thrissur.

3.5 Cross dating

Cross dating is a process which is done to ensure each individual ring is assigned its exact year of formation by eliminating the errors in the series like false rings, missing rings etc. A basic and traditional technique suggested by Stokes and Smiley (1968) was used for the cross dating process. This technique is called skeleton plotting. This method is reliable but time consuming. So statistical methods with the help of software were also used for cross dating called software assisted cross dating was used.

3.5.1 Cross dating principle

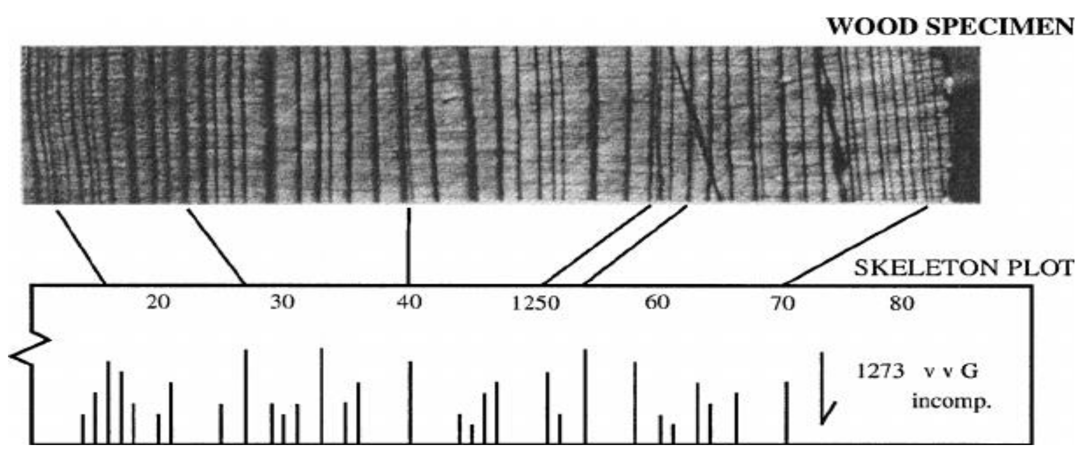
Cross dating is being considered as the fundamental principle of dendrochronology. Cross dating procedure make use of the presence and absence of the tree rings. A tree will add one growth ring per year. But in stressful years cause the trees fail to develop a ring and as a result in that year the ring will be absent (missing rings). Trees may develop double ring or false rings due to the transition of early wood and late wood cells by the phasing in and out of favorable conditions.

The cross-dating parameters hang on the geographic and climatic factors and their consequences on the tree growth. Trees growing in same region under same climatic conditions will have uniform rings because of the uniform influence of climatic signals affects them. Along with climatic factors, other factors like competition, insect attack etc. may also influence the tree growth.

Cross dating consisted of the following techniques.

3.5.2 Skeleton plotting

The graphic representation of ring width of a tree to compare and find the missing and false rings and assign the exact year of formation of the ring is called skeleton plotting. In this technique, the narrow rings of the tree sample are plotted on a strip of graph paper. This is called a skeleton plot. These skeleton plots are then compared and matched with master chronologies which are developed by sampling hundreds or thousands of trees in same or different sites.



Source: Nash, S. E. (2002)

Figure4: A schematic view of a skeleton plot, which is a graphic representation of ring-width variability that emphasizes narrow rings and other ring characteristics.

3.5.3 Cross dating by the assistance of software

The exact year of formation for the tree rings can be obtained with the help of TSAP Win software which uses the amalgam of both visual and statistical cross dating. Visual cross dating is truly graphical and statistical cross dating is used to confirm the pre dated time series.

In this process the ring width data were given as input to the software. The software consists of working stacks and reference stacks in the window. Here the samples with a greater number of rings were taken as the reference stack and rest of the samples as working stack.

When we select the cross date option, the software will compare each sample in the working stack with the reference sample and finally give the best matching series with respect to the reference series. The possible matching series from the working stack were selected based on a parameter called Cross Date Index (CDI).

CDI value is the value which decides the correlation significance and cross dating. When we cross date each sample with reference sample, the CDI value can also be seen in the window for each sample series. The highest value of CDI represents the best matching series. So, the possible matches were ordered according to the descending values of CDI.

3.5.4 Parameters of cross dating

Gleichlaeufigkeit and t-value are two concepts applied in dendrochronological investigations for understanding the quality of conformity between the time series. Gleichlaeufigkeit is a special tool for the cross dating of tree rings and t-value is widely used for testing correlation significance. The sensitivity to the patterns of tree rings was valued for both these concepts. Gleichlaeufigkeit shows the overall agreement of two series. But the t-values are sensitive to extreme values. Cross Dating Index (CDI) is a combination of both these concepts, which is a strong parameter in the cross dating process. A descending CDI in the TSAP Win output is the one which order the possible matches of the series.

3.6 Chronology building

Chronologies are represented by a mean time series. That is, the average values of different time series. Only cross dated time series are used for the chronology building.

In this process, the cross dated time series were analyzed and took the mean of all the ring width values in respective years. Finally got the average values of ring widths for each year from 1959 to 2009 which is the time span selected for the study. Using these mean values, the chronology was built for 1959 to 2009.

3.7 Standardization

Standardization is one of the important steps in dendroclimatological studies which are done to extract the climatic signals. It is a process of removing non climatic signals of biological or other tree disturbances from tree ring data by applying appropriate curve fitting technique to tree ring data series.

In this process the series of raw data were detrended and standardized using ARSTAN software which is FORTRAN based software (Cook *et al*., 1990). The tool used for this purpose was cubic smoothing spline with a frequency 50% and response cutoff of 2/3 mean series length to maintain the high to medium frequency response to climatic variability. The first order autocorrelation was removed from the detrended ring width series by performing autoregressive modeling and the pre whitened series were finally averaged using a bi weight robust mean to produce the chronology.

The resultant values get after the smoothing spline technique are called as the predicted values or expected values. These predicted values were used for calculating Ring Width Index (RWI) values that were required for the further processes of reconstruction. The resultant index series were free from noises or non-climatic signals.

The Ring Width Index values were obtained for 1959 to 2009 by dividing the actual tree ring data by predicted tree ring data by ARSTAN using cubic smoothing spline. The equation for obtaining ring width index value is,

$$RI_t = R_t/Y_t$$

Where,

RI_t -Ring width Index value for the year t

R_t -Measured tree-ring width value for the year t

Y_t - Predicted yearly ring width obtained from the smoothing spline for year t

3.8 Correlation analysis

In this process the relationship between tree growth and climate was analyzed for the available time span by using a high resolution 0.5^0 x 0.5^0, grid climate data obtained from CRU TS V.3.21 (Harris, *et al.*, 2014). Correlation analysis between tree growth and monthly seasonal rainfall and monthly seasonal temperature were done by using the PAST software (Paleontological statistics version 4.06).

Correlation analysis was done by comparing the climatic influence on tree growth in previous and current years. A dendroclimatic year of 19 months starting from June of previous to December of current year was used. The climate data and tee ring data were given as input to the software. The software correlated the temperature and precipitation during these 19 months with the ring width indices in the corresponding years and gave the average correlated values. These correlated values reveal how the monthly temperature and precipitation influence the tree growth. If the correlated values are positive, that means the climate has positive influence on tree growth and negative value shows the negative influence of climate on tree growth.

The correlation of ring width indices in each year with annual precipitation and temperature of previous and current year gave the seasonal relationship of climate with tree growth. The defined seven seasons such as previous southwest monsoon (-JJAS), previous northeast monsoon (-ON), winter (DJF), summer (MAM) and annual (Ram *et al*., 2008) were considered for this study.

3.9 Dendroclimatic analysis

Dendroclimatic analyses were done to find out the dendroclimatic potential of the samples for climatic reconstruction. Dendroclimatic potential is actually the capability of the samples and the site to reconstruct past climate using available data.

The dendroclimatic reliability of the samples was determined by using some statistical parameters such as Signal to noise ratio (SNR) and Expressed Population Signal (EPS). The desired levels of these parameters reveal the dendroclimatic potential of the samples.

The equations used for calculating the parameters are the following;

$$\text{Signal to Noise Ratio (SNR)} = Nt/ (1-r)$$

$$\text{Expressed Population Signal (EPS)} = Nt/ (Nt+1-r)$$

Where,

N – Number of trees / radii

r – Pearson's correlation coefficient

3.9.1 Signal to Noise Ratio (SNR):

SNR was calculated for obtaining only the desired climatic signals by knowing how many climatic signals are present in the chronology. According to Wigely *et al* (1984), if the value of SNR >1, then the sample have dendroclimatic potential for the past climatic reconstruction.

3.9.2 Expressed Population Signal (EPS):

EPS shows the association between index chronology and population or locality from where the samples were taken. Desired level of EPS means, if the index chronology is found to be reliable for climatic reconstruction, then the population or site where the samples were collected are also fit for the reconstruction purpose.

According to Wigely *et al* (1984), if the EPS value ≥0.85, then the sample is dendroclimatic potential.

RESULTS

CHAPTER 4

RESULTS

Results obtained through the dendroclimatological investigation on teak grown plantation in Thrissur district is presented in this section. It helps to understand the tree growth – climate relationship and also the dendroclimatic potential of the teak species here.

4.1 Measurement of ring width

For this study 9 radii were selected in 3 discs from 3 trees. Widths of the annual growth rings in the samples were measured by using Tree Ring Station with the help of TSAP Win software. The chronology time span considered for this study was from 1959 to 2009. The ring width measured by the TSAP Win is raw ring width. The average ring widths for each year for all samples obtained were 4.595 mm.

Average raw ring width series for a period from 1959 to 2009 showed an age-related growth trend. The chronology taken here had some non-climatic signals like age of the tree, local and regional disturbances and climatic factors other than temperature and precipitation. Because of these reasons, chronology showed a great difference in ring width. During the initial growth year they showed a high ring width (14,168.33 micrometer) and on the followed years the ring width alternatively decreased and increased. But from the comparison between initial and last years of growth, it was observed a large decrease in ring width.

Actually ring width of an younger tree will generally produce wider rings than an older tree. So the ring width will generally decrease with the increasing age of the tree. In the present study also it was clear that the resultant chronology showed an age related growth trend.

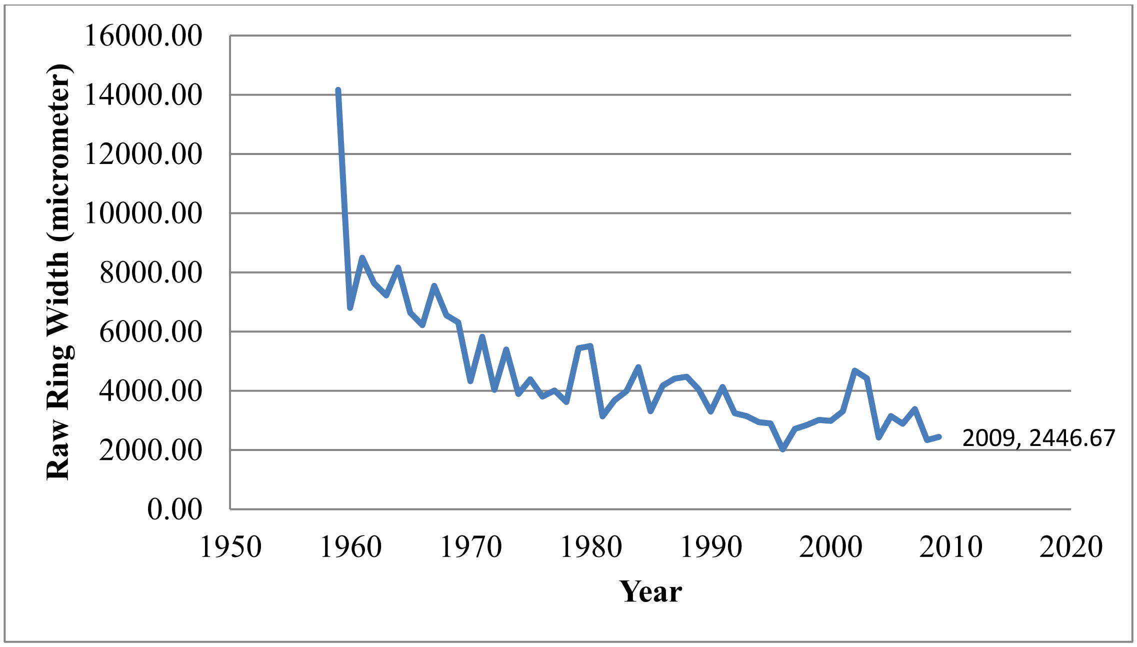


Figure5: Graph showing average raw ring widths measured for 1959 to 2009

4.2 Ring width index

Ring Width Index (RWI) for the chronology was calculated for understanding the dendroclimatic potential of the samples and the relationship between climate and tree growth. From this ring width index chronology, mean correlations among all radii were obtained as 0.5855. Mean correlation among all radii were calculated to understand the similarities among the ring widths of the total 9 radii and how its trend vary and how they are related to each other. This value was obtained by using the PAST software. The series of ring width index for all samples have been obtained by dividing raw ring width value by corresponding smoothed value.

Expressed Population Signal (EPS) and Signal to Noise Ratio (SNR) are two statistical factors which helps to obtain the understanding about the past climate and dendroclimatic potential of the samples.

SNR indicates the signal strength for each period of chronology. SNR can be explained as the ratio between desired signal to unwanted signal or noise. If SNR value is >1, then it means that desired signal is more than noise. In dendroclimatological studies, the SNR value >1 proves the dendroclimatic potential of the samples to reconstruct the past climate. In this study, the SNR value was 7.24 which is a high value for the index chronology.

Expressed Population Signal (EPS) shows the association between index chronology of the samples and the population from which they are drawn. Wigely *et al*. (1984) suggested that if the EPS value of a chronology ≥ 0.85, then it can be considered as a reliable chronology for dendroclimatic reconstruction. If EPS value < 0.85, the chronology will be unaccepted. EPS values for the chronology in this study were obtained as 0.878. So, the present index chronologies have the dendroclimatic potential for reconstructing past climate

Since the ring width index chronology were standardized and free from noises, ring width index chronology from 1959 to 2009 was not showed an age-related growth trend like average raw ring width series.

The Ring Width Index value of 1 represents the normal tree growth and value greater than 1 represents an increased growth rate of the tree.

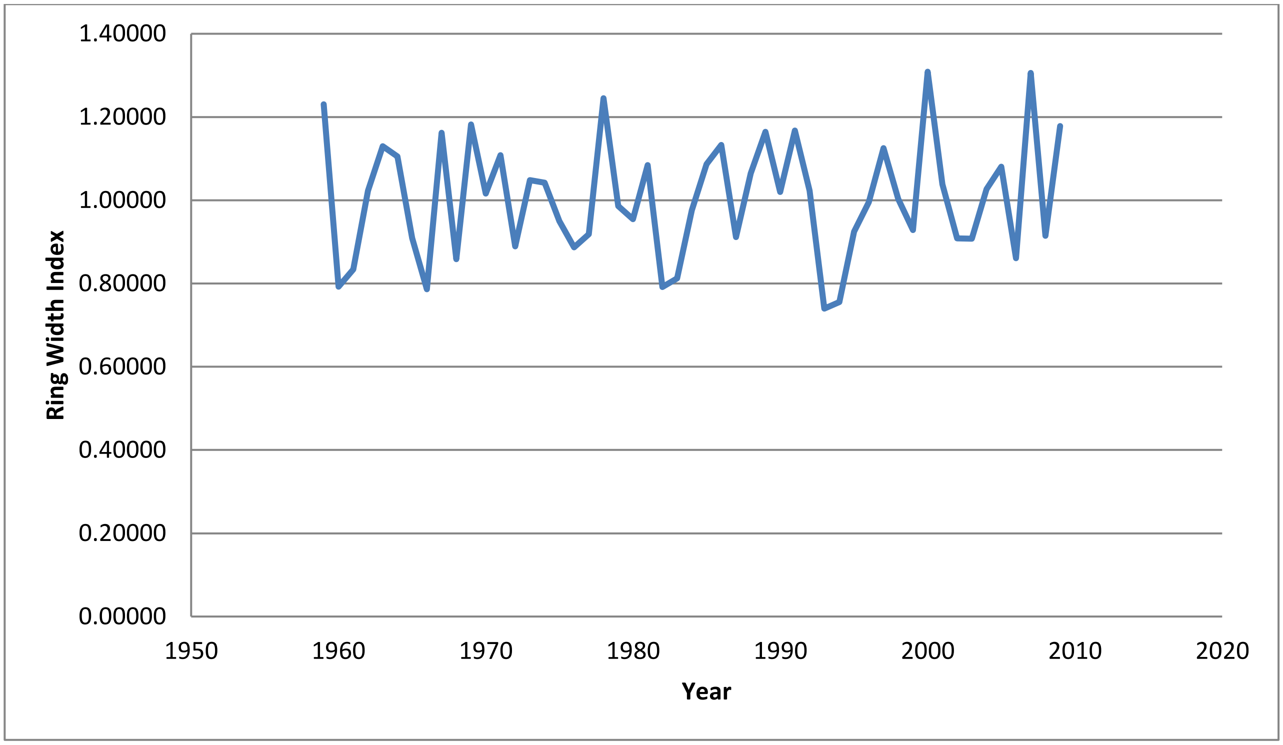


Figure6: Graph showing ring width index calculated for 1959 to 2009 tree-rings

Table3: Statistics of Tree ring Chronology of *Tectona grandis* from the Study Area

Chronology time span	1959-2009
Number of trees	3
Number of radii	9
Mean correlation among all radii	0.5855
SNR	7.24
EPS	0.878

4.3 Correlation between climate and ring width

4.3.1 Monthly Rainfall and Ring Width

The tree ring width chronologies from the Thrissur teak plantation sites showed a positive correlation with precipitation in June (0.339), July (0.204) and September (0.37) of the previous year. That means, the moisture availability during these months increased the ring widths of the tree. More growth of the tree due to the precipitation occurred in current July and previous September.

By correlating the ring width chronologies with the current year precipitation, it was observed that a positive correlation of chronology with April (0.293), May (0.33), July (0.376) and September (0.235) precipitation and a negative correlation with January (-0.257) and March (-0.248) precipitation. That means, a negative influence of climate was observed on the tree growth, even there was precipitation during those months. It reveals that the current January and March precipitation did not make any enhancement in ring formation.

In general, the monthly precipitation had a positive influence on tree growth.

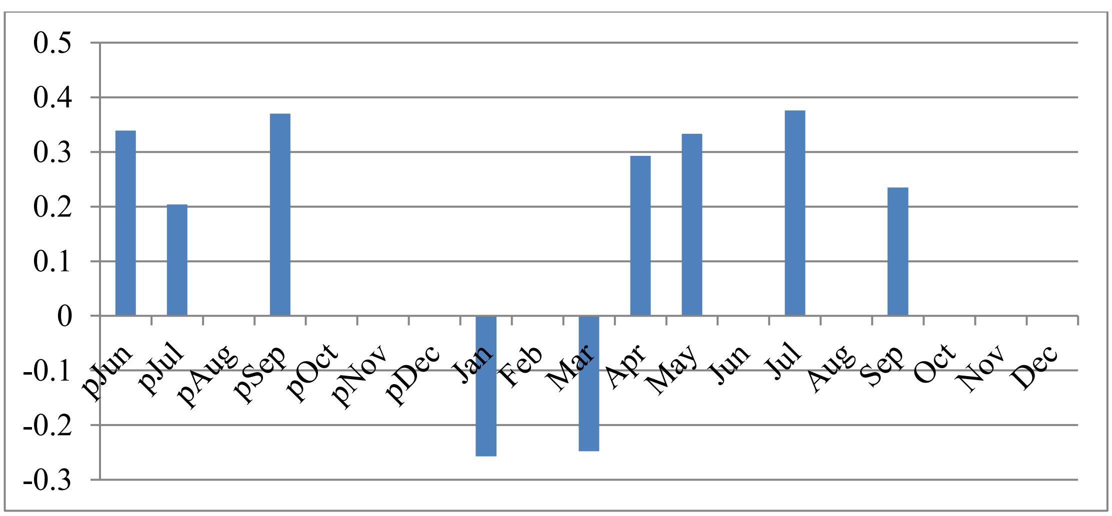


Figure7: Correlation between precipitation and ring width index chronology

4.3.2 Monthly Temperature and Ring Width

The resultant chronology showed a negative correlation with temperature during the months of June (-0.322), July (-0.203) and August (-0.274) months of previous year and June (-0.401). That means, the effect of temperature hindered the tree growth during these months and as a result, the ring width were narrow. But in previous November (0.395) and current February (0.302) a positive influence was observed especially in previous November, which indicated that the tree had a significant amount of growth even the influence of temperature was there.

So in general, a negative influence was observed on the tree growth by monthly temperature except in previous November and Current February.

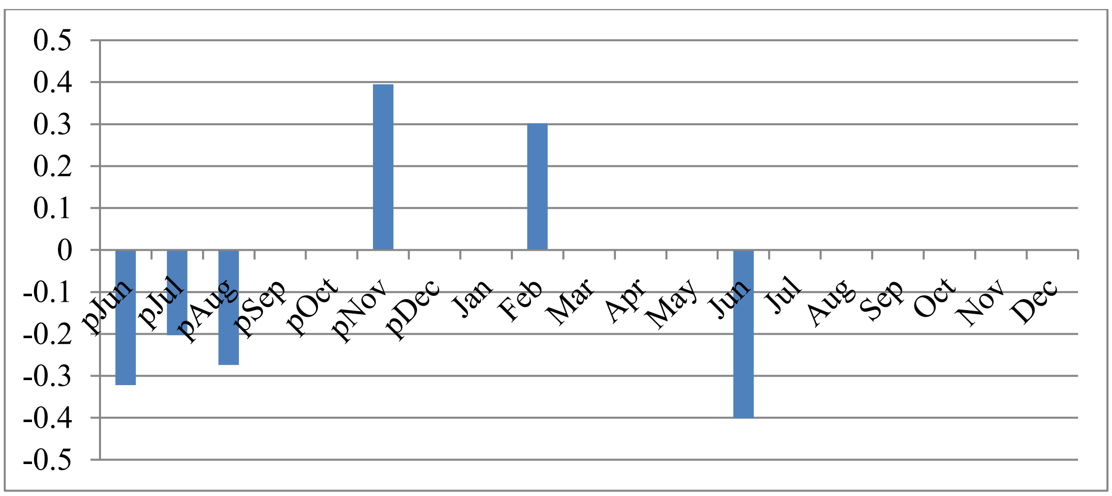


Figure8: Correlation between temperature and ring width index chronology

4.3.3 Seasonal Climate and Ring Width

The correlation analysis of chronology with annual precipitation showed a positive correlation of chronology with precipitation in previous (0.419) and current (0.347) southwest monsoon (JJAS). During the northeast monsoon (October and November) also they showed a positive correlation with previous year precipitation. The chronology showed a positive correlation with current year precipitation during winter (DJF) (0.267) and summer (MAM) (0.227) seasons. This means that, the annual precipitation during these seasons will increase the ring formation and growth of the tree in a significant manner.

Correlation analysis of index chronology with annual temperature showed a significant negative influence on tree growth during the southwest monsoon (-0.361) and summer season (-0.346) of the current year, which means that there were no improvement in ring width and growth of the tree. But during the previous southwest and northeast monsoon, it had a positive influence on tree growth. At that time, the tree growth was not hindered by the temperature and showed an enhancement in growth. More growth was occurred in previous northeast monsoon. So in general, the annual temperature hindered tree growth except in southwest and northeast monsoon seasons of previous year.

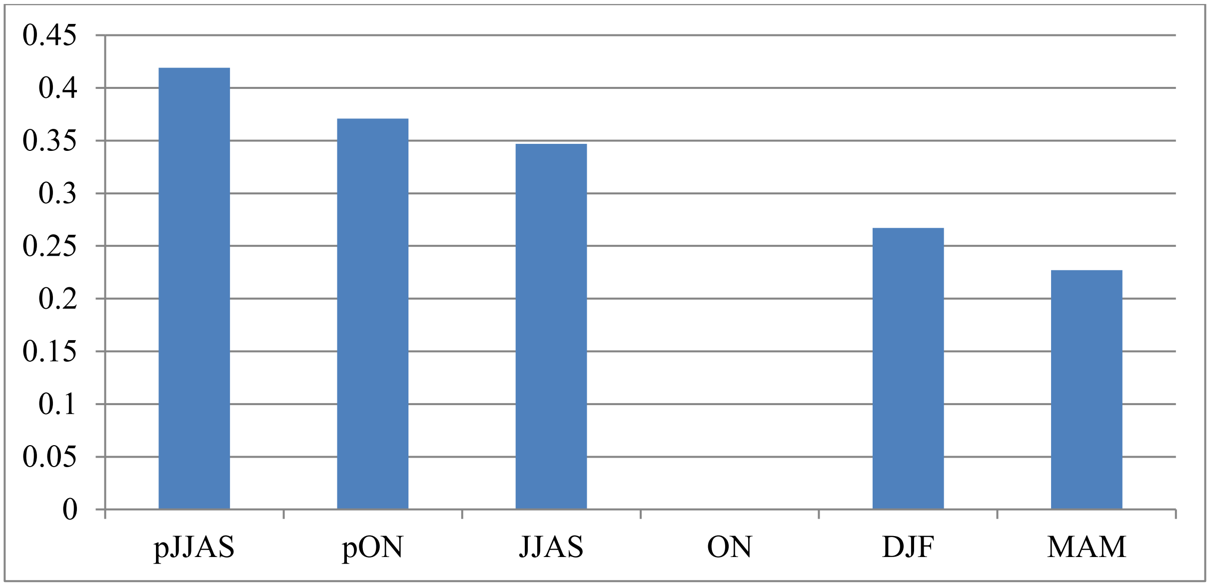


Figure9: Correlation between annual precipitation and ring width index chronology

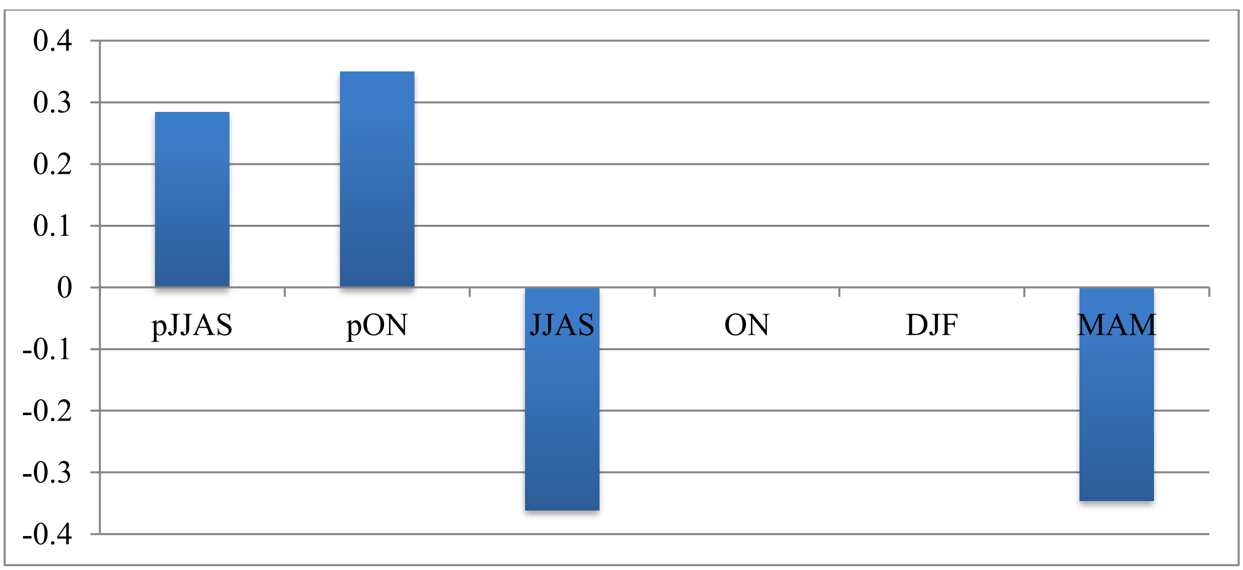


Figure10: Correlation between annual temperature and ring width index chronology

DISCUSSION

CHAPTER 5

DISCUSSION

Dendroclimatic potential of the teak from selected plantation sites in Thrissur district of Kerala was studied in this investigation. The findings got from the study and also the findings from other related studies are presented here.

5.1 Ring width

There was an age-related growth trend observed in case of ring width. That means, during the initial year of growth, the average tree ring width of the samples were large. Gradually ring width decreased in the followed year. And at the final year of growth, they showed a low ring width value. This means that the ring width of the teak decreases with age of the tree. The average ring widths of all samples were measured as 4.524 mm.

Brookhouse and Brack (2008) suggested that the tree ring width variation influenced by the characteristic feature of the site and variation in their age. Compared to Kerala, the sites in Karnataka and Maharashtra have a low rainfall but Puer to Rican site have a high rainfall (Purkayastha and Satyamurthi, 1975). They suggested that a variability of 3.14% in teak growth donated by the site factor.

A study conducted in *Rhizopora mucronata* which is a growth ring less species by Verheyden *et al*., (2004) on the polished discs proved the presence of early wood (brown) and late wood (light) rings. The age of the tree and growth rate could be determined by observing these rings.

5.2 Tree ring chronology

5.2.1 Ring width index chronology:

Ring width index chronologies from the study site were analyzed to obtain the dendroclimatic potential of teak. By analyzing the Ring width index chronology, the mean correlation among all radii was to be high (0.5855).

Signal to Noise Ratio (SNR) and Expressed Population Signal (EPS) are two of the statistics used to estimate the dendroclimatic potential of the index chronology of the sample. According to Cook and Kairiukstis (1989), SNR has been used to estimate the relationship strength of the common variance signal in the indices. The value of SNR should >1 for accepting that chronology as acceptable for dendroclimatic reconstruction. The SNR value for the index chronology of samples under study was high 7.24 which mean the samples have high dendroclimatic potential for the past climatic reconstruction.

The EPS is used to evaluate the association between the index chronology and the population from which the samples are taken. According to Wigely *et al*. (1984) study, if the EPS value is equal or greater than 0.85, the chronology is suitable for dendroclimatic reconstruction. The EPS value for the present study ere 0.878 which showed the acceptability of the samples for the dendroclimatic reconstruction.

5.3 Correlation between climate and ring width

Rainfall had a positive influence on the tree growth in the study site in all seasons. The great influence of precipitation on tree growth in wet and cold Mediterranean climate except in winter was revealed by Berger *et al*. (1979).

The temperature in the study site had a negative influence on the tree growth. The study of Borgaonkar *et al*., (1996) suggested that the temperature gradually increases above the annual average value in the pre monsoon season and May is considered as the hottest month. But there is very small precipitation amount during the pre-monsoon months. The pre monsoon season coincide with the early growth period of trees. So, the extreme heating decrease the moisture level but more precipitation increases the growth of the tree.

In the studies of Corlett, (2016), revealed that in tropical regions, less precipitation and warmer temperature cause extreme drought condition which decreases the tree growth. This indicates the radial growth of teak is influenced by precipitation and temperature during dry season. In the present study also observed a negative correlation of temperature on tree growth during the dry season (MAM).

The present study revealed that the previous year temperature in June, July and August were negatively correlated with tree growth. The study of Shah *et al*., (2007) revealed that the heat index of the previous year and tree growth are negatively correlated. As a result, the enhancement of the tree growth during the successive growing seasons was affected.

According to Ram *et al*., (2008), low rainfall will cause reduced tree growth in case of teak, but a normal or high rainfall will increase the growth because of the presence of regular moisture in the root zone. The moisture availability is a function of monthly rainfall and temperature.

In the present study, precipitation had a positive influence on tree growth during the pre-monsoon season. In case of temperature, there was a positive influence was found during the month of November in previous year. Sinha (2019) revealed that the pre monsoon showers of October to November have a crucial role in the formation of new cells in teak. Contrarily a distinct moisture deficiency caused by the hot and dry pre monsoon affects the radial growth directly. Hence this proved the significant relationship between variation in tree growth and climatic factors.

As per the study of Die *et al*., (2015) on teak, during the month of March, the radial growth initiates and during the month of June to September, it reaches at the top and then formation of wood decreases and stop at November. In the month of December, defoliation starts and by March the tree become completely leafless. In the present study, the tree had no growth during the month of March due to the precipitation in current year and during the month of June to September, precipitation increased the tree growth but there was a hindrance in growth occurred by the influence of temperature.

The present study revealed a significant relationship of tree growth and climatic factors like temperature and precipitation. In general, a positive influence was observed for tree growth in case of precipitation and a negative influence was found on the growth by the temperature. But during the month of current year February and previous year November, growth was positively influenced even there was the significant presence of temperature. This is because of the influence of moisture from previous year precipitation. The study of Sinha *et al*., (2019) also show that the radial growth of teak influenced by high temperature and pre monsoon showers and monsoon rainfall. The moisture availability of teak from previous year's monsoon and also from post monsoon provides growth variation in teak. But the moisture stress of teak at root zone is caused by the high temperature and low rainfall during monsoon and post monsoon seasons.

CONCLUSION

CHAPTER 6

CONCLUSION

Several important observations obtained from the different stages of this study are presented in this section. These conclusions may help to get into more studies about this subject.

Teak (*Tectona grandis*) is a tropical species which has a high dendroclimatic potential for the reconstruction of past climate. Tree-rings provide a long-term meteorological data which are useful for determining past climatic conditions for hundreds or thousands of years. The teak samples collected from the teak plantations of Thrissur district showed high value of signal to noise ratio which proved that the species found here have high dendroclimatic potential to reconstruct temperature and rainfall. Teak species in the Thrissur plantations showed high dendroclimatic potential to reconstruct temperature and rainfall. This understanding may help the farmers for preparing a management plan for the plantation. By understanding the past climatic conditions that affected the teak plantation, We get information about the timber quality of the trees in these plantations.

The present study revealed the desired levels of signal to noise ratio and expressed population signal value and high dendroclimatic potential of the site. The temperature and rainfall of the site influenced the tree-ring width which is a growth parameter that was selected for this study.

The tree growth – climate relationship from this study revealed that a positive influence of rainfall in previous and current year southwest and northeast monsoon and in current winter and summer seasons on the ring formation or growth of the tree. But temperature have a negative influence on tree growth or ring formation during current year southwest monsoon summer seasons except in southwest and northeast monsoon of the previous year.

Many more chronologies from various site may help us to make predictions on climate and tree growth relation through the understanding of past monsoon variability in a wide manner.

SUMMARY

CHAPTER 7

SUMMARY

Dendroclimatic investigation on tree growth – climate relationship of plantation grown teak (*Tectona grandis*) were done in 9 samples from 3 trees of age 51 from the randomly selected sites of Thrissur district of Kerala. The investigation was conducted in Department of Wood Science, College of Forestry, Kerala Agricultural University, Vellanikkara at Thrissur.

7.1 Tree-ring data

Wooden discs of teak (*Tectona grandis*) from different sites of Thrissur, Kerala which were collected by College of Forestry, KAU, Vellanikkara have been used in the analysis. With this set of teak samples, I did all dendrochronological analysis in the laboratory, including sanding of wooden discs, measurement of ring width, cross dating. This was an important aspect of my project program to learn the basic dendrochronological techniques. Ring width measurement has been used for efficient and accurate measurement of ring widths. The samples have been microscopically examined at various stages of processing, cross-matching and examination of anatomical details of anomalous rings to detect the false and double rings.

7.2 Chronology development and its dendroclimatic potential

Ring width series indicate the resultant annual growth patterns of the trees, representing the aggregate effect of many internal and environmental signals including climatic and non-climatic factors like biological aging, local endogenous disturbances due to competition among the trees and exogenous disturbances caused by fire, pests, disease, pollution etc. Appropriate detrending method called cubic spline smoothing have been applied to the individual ring width series to minimize non-climatic signals. The ring width series, thus filtered out, are called the index series and contain large variance due to climatic influences. Site chronologies have been prepared by averaging all the index series from a particular site. Statistics studied to evaluate dendroclimatic potentiality of the samples were Signal-to-Noise Ratio (SNR) and Expressed Population Signal (EPS). The present chronology show more SNR (7.24) and EPS (0.878) which indicates high dendroclimatic potentiality of the samples.

7.3 Tree growth-climate relationships

The standardized index series contain large climate signal compared to those of raw ring-width series. These index chronologies are correlated with regional climatic parameters to study the association between tree growth and climate. The main purpose of the study is to find out reliable relationship between tree-ring variations and various climatic parameters (temperature & precipitation) which are statistically significant, to establish the equations which can be used for the reconstruction of these parameters over the earlier period to the instrumental record.

In the development of the relationship between climate and tree growth, the correlation analyses have been used. For this purpose, data of monthly temperature and precipitation from different sites of Thrissur district along with the corresponding tree-ring chronologies have been used. I have also used CRU grid point data of monthly mean temperature and rainfall index for a period from 1959-2009. Many times observatory station data are far away from the tree-ring site location, in such cases, the data of CRU grid close to tree-ring site is can be used for comparison and better understanding of tree growth climate relationship. A dendroclimatic year of 19 months starting from June of previous to December of current year was used for the analysis. In general the correlation analysis of tree ring width with climatic parameters (monthly temperature & monthly precipitation) showed that, tree growth had a negative influence by the temperature and a positive influence by the precipitation.

The results are summarized below.

1. The average raw ring width obtained from measured ring width value using TSAP Win software was 4.524 mm.

2. There were 9 radii taken in 3 discs. Mean correlation among all radii of the ring width index chronology were 0.5855.

3. The signal to noise ratio value was high for the index chronology (7.24) revealing the high dendroclimatic potential for the sites for the past climatic reconstruction.

4. The value of expressed population signal was also moderately high for the index chronology revealing the reliability of the population for further dendroclimatic analysis.

5. Rainfall always had positive influence on tree growth during the southwest and northeast monsoon of previous and current years and also in winter and summer season of the current year.

6. Temperature had negative influence on tree growth in summer season (MAM) and southwest monsoon season(JJAS) of the current year but a positive influence was observed during the previous year southwest and northeast monsoon seasons.

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Tree growth – climate relations of plantation grown teak (*Tectona grandis* L.f.) from selected sites of Thrissur district, Kerala

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(2016-20-024)

THESIS

Submitted in partial fulfillment of the

requirements for the degree of

B.Sc.-M.Sc. (Integrated) Climate Change Adaptation

Faculty of Agriculture

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2021

ABSTRACT

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Dendroclimatology is the branch of Dendrochronology for the reconstruction of past climate by using tree-rings as a proxy. Instrumental records of the climate are not available for a long period. Since trees can live for hundreds or thousands of years, they can extend the meteorological records for thousands of years back and that is why trees are a better proxy in dendroclimatic studies. This field has a crucial role in this recent climate scenario to predict the climate in future by using the past climatic information.

In the present study, three trees in a time a span of 1959 to 2009 were collected from random plantation sites in Thrissur district collected by College of Forestry, KAU, Thrissur. The discs were smoothened and ring widths were measured by using LINTAB – 6 with the help of TSAP Win software. Then they were precisely cross dated. The non – climatic signals of the series were removed by an important method called standardization using ARSTAN program using a tool called cubic smoothing spline. Ring width index (RWI) values were calculated for correlation purpose. The tree growth-climate relationship was obtained by correlating the RWI value with climate data obtained from CRU TS V.3.21 by using PAST software. Monthly seasonal rainfall and monthly seasonal temperature were the climatic parameters used for the study. In the general observation, rainfall showed a positive correlation with tree growth and temperature showed a negative correlation with tree growth. Signal to Noise Ratio (SNR) and Expressed Population Signal (EPS) were the statistical parameters considered for the study. These parameters showed desired levels in the chronologies and it confirmed the good dendroclimatic potential of the selected site.

Keywords: Dendroclimatology; Teak plantation; Climate; Annual rings