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Assessing Dendroclimatic Potential of Plantation Grown Teak (*Tectona grandis* L.f) from Nilambur, Kerala

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Abstract

Dendroclimatology is the branch of dendrochronology for the reconstruction of past climate by using tree-rings as a proxy. In this study, cross-sectional discs of 3 trees in a time span of 1949 to 2012 collected from Nilambur by the College of Forestry, KAU were utilized. This study was to look at teak tree ring chronologies in Nilambur, identify the relationship between tree growth and climate, and ultimately assess the dendroclimatic potential of trees. TSAP-Win software in association with LINTAB was used to measure and cross date the ring width. ARSTAN was used to standardize tree ring data using a tool called cubic smoothing spline to remove the non-climatic signals of the series. The climate data was obtained from CRU TS V.3.21. By using PAST software, a bootstrap correlation with moving intervals was done to determine the relationship between tree growth and climate. The study used monthly rainfall and temperature as the climatic parameters. In general, rainfall showed a positive and temperature showed a negative correlation with tree growth. All chronologies exhibited desired levels of SNR and EPS which are the statistical parameters to determine the dendroclimatological potential of trees, and thus proved the site's high dendroclimatic potential.

***Key words*:** *Tectona grandis* L.f, Dendroclimatology, Climate, Nilambur, Teak wood

IPCC defines Climate change broadly as "any change in climate over time whether due to natural variability or as a result of human activity". If we wish to understand the current state of climate change, we must first understand historical climatic circumstances. Trees are alive, natural resources that are sensitive to climatic factors in their surroundings. Tree rings are an incredible accumulator of all types of meteorological data. Rain, temperature, cloudiness, humidity, and other meteorological variables make up our climate system, and tree rings are ideal for preserving this data. Dendroclimatology is a branch of study that employs dendrochronology to recreate past climate conditions. Certain factors are required in dendroclimatology to reconstruct a climate, such as the presence of annual tree rings, limiting climatic factors, and long-lived trees. Multivariate analysis approaches based on yearly tree ring data have demonstrated that they may offer reliable information on the link between tree rings and climate (response function) as well as the nature of the climate itself and its variations over time [1] (Transfer functions).

Dendroclimatology may give a temporal perspective that focuses on environmental changes caused by climate change year to year. As a result, tree ring data can be utilized to recreate paleoclimates spanning decades to centuries [2]. The majority of other paleoclimatic data can only respond to century-long oscillations and cannot resolve annual variations. For a single climate record or several recordings, dendroclimatic reconstructions can be generated. Some of these numerous records can provide information on climatic changes based on geographic variances in tree chronologies [3-5]. Many tree species, particularly in the tropics, have hazy rings or aren't tied to an annual growth cycle, or if they are, there aren't really any evident patterns that may be used to cross date them [6]. On the other hand, tropical forest sites with cross-datable ring species have provided useful chronologies [7].

The world's most important hardwood species is teak (*Tectona grandis* L.f). The wood industry values it highly due to its remarkable mechanical and physical capabilities, as well as its inherent longevity and appealing aesthetic appearance [8]. Tree ring width is one of the most important factors to consider while analyzing tree development pace. Teak is one of the few tropical species with visible growth rings. In connection to mensuration research; Brandis [9] noted growth rings in various

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Indian tropical trees and documented yearly growth rings in teak. This study highlights the potential of teak for the reconstruction of past climate. The major aim of this work is to check the dendroclimatic potential of the plantation-grown teak from Nilambur for the reconstruction of precipitation and temperature. This work deals with the following objectives:

1. To examine teak tree ring chronologies in Nilambur.
2. Determine the link between tree growth and climate.
3. Determine the dendroclimatic potential of ring width for temperature and precipitation reconstruction

MATERIALS AND METHODS

Study site and sample preparation

The main objective of this work is to build and analyze tree-ring chronologies of Nilambur plantation teak to determine the dendroclimatic potential of ring width and teak for temperature and precipitation reconstruction, as well as to examine the tree growth-climate connection. Random samples are taken from the site for this purpose.

The climate of the Nilambur forest division is influenced by the tropical monsoon. The summer season runs from March to May, with the southwest monsoon wet season following from June to September, and the northeast monsoon rainy season following from October to November. December to February is the winter season. Nilambur has substantial rainfall throughout the year, with a brief dry season. The average temperature in this area is 27.7 degrees Celsius. A total of 2666mm of precipitation falls per year.

Teak tree samples (wood discs) from the teak plantation at Nilambur were gathered and kept in the laboratory for this research. The top part of the field-collected basal discs was prepared with a simple hand planer to make the surface equal. The disc surfaces were then smoothed using sandpapers of grit grades 60, 80, 150, 220,320, and 400 in selected 3 to 4 radii to reveal the growth rings for ring width measurement. To calculate the mean vessel area, chosen radii were sanded with grit sizes 600, 800, 1000, and 1500, in that order. After that, the samples were cleaned using a water jet to reveal the vessel lumen.

Measurement of ring width

Tree-ring measuring necessitates a high level of precision and consistency. LINTAB is a tree-ring analysis digital positioning table that can readily perform this operation. LINTAB is user-friendly, durable, and splash-proof. It is possible to measure stem discs as well as increment cores. LINTAB is a powerful tool for tree-ring analysis when used in conjunction with the TSAP program. For tree ring studies, TSAP-Win is a sophisticated software platform. TSAP-Win covers the whole process, from measurement through evaluation of tree ring sequences. TSAP-Win offers a wide range of visual and statistical capabilities, as well as database connections.

After polishing, the growth rings on each disc were numbered and cross-matched on three to four radii. Using a digital camera coupled to a stereomicroscope (Motic), live pictures of the selected rings over the radius were seen on a computer screen, and ring widths were measured using the tree ring measurement platform LINTAB-6. Using TSAP Win software, the ring width of each and every year was calculated from the various radii was digitally recorded with 0.001 mm accuracy.

Cross dating

Cross dating examines the structure of broad and thin rings in a tree to establish the location of actual ring borders based on biometric wood structure. This permits the real age of the specimen to be determined. Tree rings mimic a bar code in this sense, with varying line widths denoting each year. The patterns from one tree may be compared to those of other trees to see if all of the rings are represented in a sample. This method identifies where a sample's rings are missing or where a tree may have generated two or more rings in a single year. Cross dating yields precise dates for each ring in the tree-ring record. The selected radii were cross-dated using Stokes and Smiley's proposed techniques [10]. The removal of fake rings and the insertion of missing rings were done to eliminate measuring inaccuracies.

Cross dating by TSAP Win software

It employs a mix of visual (graphical) and statistical cross-dating techniques. Statistical models are useful for locating potential matches or verifying the dates of pre-dated time data.

Cross-dating parameters

To represent the quality of concordance between time series in dendrochronology, two primary concepts are used: Gleichlaeufigkeit and/or t-values. While the t-statistic is a commonly used test for correlation significance, Gleichlaeufigkeit was created as a unique tool for cross-dating tree-ring series [11]. Different sensitivity to tree ring patterns distinguishes these ideas. T-values are sensitive to extreme values, such as event years, whereas Gleichlaeufigkeit indicates the general agreement of two series. In the Cross-Date Index, a mixture of both is accomplished (CDI). Because the CDI is such a powerful parameter in cross-dating, the potential matches in the TSAP Win result are sorted by descending CDI.

Statistical analysis

Standardization

By applying an appropriate curve fit to the data set and computing a new time series, non-climatic signals such as biological and/or tree disturbances (exogenous) are eliminated from tree-ring data. ARSTAN software was used to de-trend and standardize the raw data for each tree [12]. This was done in order to eliminate biological and geometrical patterns (age and size-related growth trends). To retain the elevated frequency response to climate changes, a cubic smoothing spline was employed with a 50% frequency response cut off of 2/3 mean series length [13]. To eliminate the majority of the first-order autocorrelation, autoregressive modelling was applied to each de-trended ring-width record, and the pre-whitened sequence was then averaged using a bi-weight robust mean to obtain a chronology.

Construction of index values and chronology

Stokes and Smiley's techniques were used to cross-date the specified radii [10]. A ring width chronology was developed using the index values obtained.

$$RI(t) = R(t) / Y(t)$$

Where;

RI (t) - Ring width / Mean vessel area Index value for the year t

R (t) - Measured tree-ring datum for the year t

Y (t) - Expected yearly growth obtained from the smoothing spline

Correlation analysis

For the time period available, the link between climate and tree growth was investigated using high resolution, 0.5 0 x 0.5 0, grid climate data obtained from CRU TS V. 3.21 [14]. Correlation analysis of tree ring data versus monthly, seasonal rainfall, and monthly, seasonal temperature using the statistical package PAST (Paleontological Statistics Version 4.06) was performed. For the analysis, a dendroclimatic year of 18 months from June of the previous year through December of the current year was used. The seven seasons defined were previous southwest monsoon (–JJAS), previous northeast monsoon (–ON), southwest monsoon (June–September; JJAS), post-monsoon or northeast monsoon (October–November; ON), winter (December–February; DJF), summer (March–May; MAM), and annual [15].

The following criteria which are important for dendroclimatological reliability of chronology were calculated using the following equations using Pearson's correlation coefficient (r) and the number of trees/radii (N).

Signal to Noise Ratio (SNR) = Nr/ (1-r)

Expressed Population Signal (EPS) = Nr/ (Nr+1-r)

RESULTS AND DISCUSSION

Measurement of ring width

Nine radii in three discs from three trees were used for this investigation. Tree Ring Station with the help of TSAP Win software was used to measure the widths of the yearly growth rings in the samples. For this investigation, the chronological period studied was 1949–2012. The average ring width measured was 3.555mm. All of the site's ring widths showed an age-related increase tendency. The ring width was wide in the early years of growing, but as it grew older, the ring width shrank. Average raw ring widths for each year from different random sites in Nilambur are shown in (Fig 1).

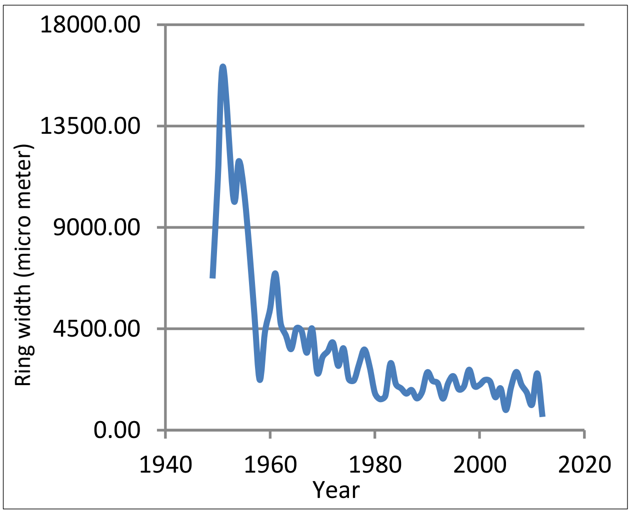

Fig 1 Average raw ring width of the samples from Nilambur

Cross dating

We noticed significant cross-matching between the samples and the reference sample during the software-aided cross-dating process. Only a few instances of false or duplicate rings have been reported. Most of the samples have a strong impact in the beginning. In the majority of the samples, false or duplicate rings are uncommon.

Standardization

The unit less quantity ring width index (RWI) has replaced tree ring width measurement, allowing for comparison with any chronology from any location and at any age group. All tree-ring chronologies perform well. High standard deviation and mean sensitivity scores clearly reflect the species' potential for dendroclimatic study.

Ring width index

We computed the Ring Width Index (RWI) for the chronology to better understand the samples' dendroclimatic potential. The mean correlations among all radii were calculated using this ring width index chronology and found to be 0.6159. For all samples, the ring width index was calculated by dividing the raw ring width value by the smoothed value.

Signal to Noise Ratio (SNR) and Expressed Population Signal (EPS) are two statistical variables that aid in determining the historical climate and dendroclimatic potential of samples. SNR denotes the signal intensity for each chronology era. SNR is defined as the ratio of the desired signal to an unwanted signal or noise. SNR values are frequently quoted as a measure of index quality and have no upper bounds. If the SNR value is >1, it means that the desired signal is greater than the noise. In dendroclimatological studies, SNR values > 1 prove the samples' dendroclimatic potential to reconstruct past climates. The SNR value was 7.81 in this investigation, which is a high ratio for the index chronology.

The Expressed Population Signal (EPS) depicts the relationship between the samples' index chronology and the population from which they were collected. According to Wigely *et al*. [16], if a chronology's EPS value is more than 0.85, it can be considered a credible chronology for dendroclimatic reconstruction. The timeline will be rejected if the EPS value is less than 0.85. In this investigation, the EPS values for the timeline were found to be greater than 0.85, that is, 0.896. As a result, the current index chronologies offer a useful tool for dendroclimatic reconstruction of historical climate for the particular region.

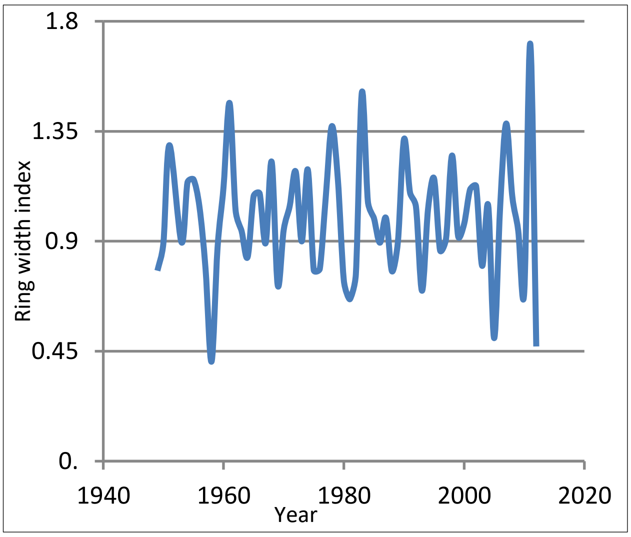

Fig 2 Ring width index chronologies from Nilambur

Table 3 Statistical data of tree ring chronology of *Tectona grandis* from the research area

Chronology time span	1949-2012
Number of trees	3
Number of radii	9
Mean correlation among all radii	0.6159
SNR	7.81
EPS	0.896

Correlation between climate and ring width

Monthly precipitation and ring width

The chronologies from random sites of Nilambur showed a positive correlation with (0.23) June, (0.354) July, (0.385) August, and (0.355) October precipitation of the previous year. However, the chronology revealed a negative correlation (0.482) with the prior year's December precipitation. The current year's (1949-2012) precipitation (0.313) May, (0.324) July, and (0.383) December had a positive correlation with the chronology.

Temperature and ring width on a monthly basis

In the case of temperature, the chronologies showed a negative correlation with (0.307) June and (0.361) December temperatures of the previous year, except with July (0.318) temperatures, which showed a positive correlation. The chronology showed a positive correlation with the (0.332) November temperature of the current year and a negative correlation with the temperatures of March (0.356), April (0.291), and July (0.349) in the current year.

Seasonal climate and the width of the ring

In Nilambur, the previous year's southwest monsoon (pJJAS) had a positive influence on the (0.392) ring-width chronologies and the October-November previous year's precipitation also had a positive correlation (0.272). The current year's October-November precipitation had a positive influence (0.354). In the case of seasonal temperature, the previous southwest monsoon (pJJAS) temperature (0.251), the previous October-November temperature (0.29), and the March-to-May temperature (0.382) had a negative influence on ring-width chronologies. The current year temperature during the southwest monsoon (JJAS) had a positive influence (0.351). Other seasonal temperatures during October-November (0.279) also showed a positive influence.

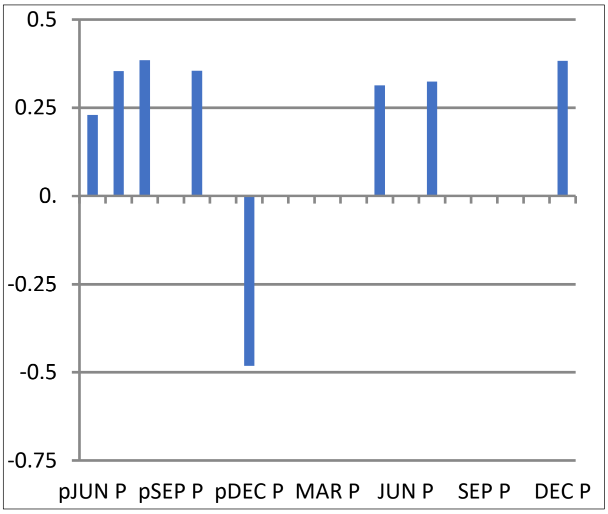

Fig 3 Correlation between precipitation and ring width chronology

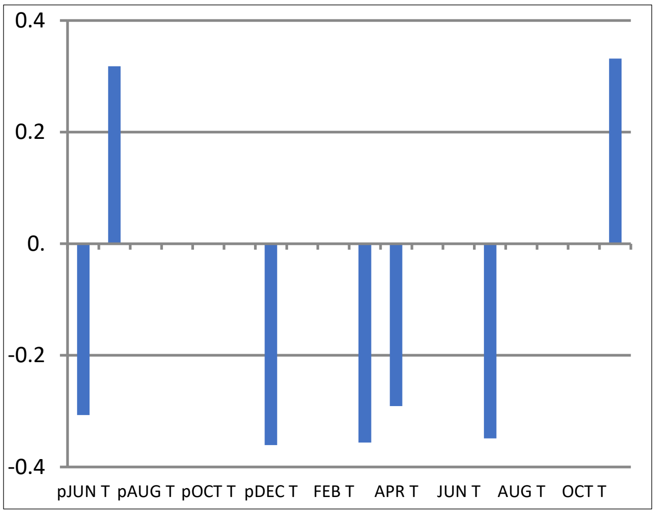

Fig 4 Correlation between temperature and ring width chronology

This study looked into the dendroclimatic potential of teak from selected planting areas in Kerala's Nilambur region. The conclusions of the study, as well as findings from other related studies, are presented below.

Ring width

When it came to ring width, there was an age-related upward trend. That means the average tree ring width of the samples was large throughout their first year of development. The ring's width was steadily reduced during the next year. In their final year of development, they also had a low ring width value. This implies that as the tree becomes older, the ring width of the teak decreases. According to Brookhouse and Brack [17] tree ring width variance was impacted by site characteristics as well as age differences. The locations in Karnataka and Maharashtra have little rainfall compared to Kerala, whereas the ones in Puerto Rican have substantial rainfall [18]. They claimed that the site factor influenced teak growth by 3.14 percent. The average ring width of all the samples obtained from the present study was 3.555 mm. Deepak *et al.* [19] cited 57-year-old teak from Dandeli (2.15mm) and 59-year-old teak from Shimoga as examples of typical raw ring width from other locations in Peninsular India (3.10mm). Sinha *et al.* [20] found that the average raw ring widths of 57-year-old teak from Mundagod (Karnataka) and 130-year-old teak from Chandrapur (Maharashtra) were 2.14mm and 2.97mm, respectively. The average ring widths from these studies were approximately similar to that from the present study.

Tree ring chronology

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 found to be high at 0.6159.

Two statistics are utilized to evaluate the dendroclimatic potential of the sample's index chronology: signal to noise ratio (SNR) and expressed population signal (EPS). SNR has been utilized to evaluate strength of the common variance signal in the indices [13]. There should be more than one SNR to consider whether the chronology is suitable for dendroclimatic reconstruction. The SNR value for the index chronology of the samples under investigation was high at 7.81, indicating that the samples had a strong dendroclimatic potential for past climate reconstruction.

The EPS is used to assess the relationship between the index chronology and the population from which the samples were collected. According to Wigely *et al.* [16], the chronology is appropriate for dendroclimatic reconstruction if the EPS value is equal to or greater than 0.85. The EPS value for this investigation was 0.896, indicating that the samples were suitable for dendroclimatic reconstruction.

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 climates except in winter was revealed by Berger *et al*. [21]. The temperature in the study site had a negative influence on the trees' growth. In the pre-monsoon season, the temperature progressively rises beyond the average yearly value, with May being the warmest month [22]. But there is a very small precipitation amount during the pre-monsoon months. The pre-monsoon season coincides with the early growth period of trees. So, the extreme heating decreases the moisture level, but more precipitation increases the growth of the tree.

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

CONCLUSION

Teak (*Tectona grandis*) is a tropical tree with a high dendroclimatic potential for historical climate reconstruction. Tree rings give long-term meteorological data that may be used to determine previous climatic conditions dating back hundreds of years. The signal-to-noise ratio of teak samples obtained from Nilambur teak plantation was high, indicating that the species present here have a high dendroclimatic potential to reconstruct temperature and rainfall. This knowledge might assist tree farmers in developing a plantation management strategy. We can learn about the timber quality of the trees in these plantations by analyzing historical climatic circumstances that influenced the teak plantation. The current analysis indicated the site's strong dendroclimatic potential, as well as the necessary levels of signal-to-noise ratio and expressed population signal value. The tree-ring width, which was used as a growth metric for this study, was impacted by the site's temperature and rainfall. In Nilambur, the previous year's southwest monsoon (pJJAS) had a positive influence on the ring-width chronologies and the October-November previous year's precipitation also had a positive correlation. The current year's October-November precipitation had a positive influence. In the case of seasonal temperature, the previous southwest monsoon (pJJAS) temperature, the previous October-November temperature, and the March-to-May temperature had a negative influence on ring-width chronologies. The current year's temperature during the southwest monsoon (JJAS) had a positive influence. Other seasonal temperatures during October-November also showed a positive influence. Many additional chronologies from diverse sites may aid in making climate and tree growth projections by providing a broad grasp of previous monsoon variability.

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