Indian Journal of Agricultural Sciences **89** (12): 2043–7, December 2019/Article
https://doi.org/10.56093/ijas.v89i12.96271

Dendroclimatological approach in plantation management of teak (*Tectona grandis*)

SATISH KUMAR SINHA[1], LAXMIKANTA BEHERA[2], ABHISHEK MEHTA[3] and PRASHANT KUMAR SHRIVASTAVA[4]

Navsari Agricultural University, Navsari, Gujarat 396 450, India

Received: 06 April 2018; Accepted: 07 June 2019

ABSTRACT

Teak (*Tectona grandis* Linn f.) is a commercial timber species which has been widely studied for dendroclimatology. The objective of the investigation was to utilize dendroclimatological approach in plantation management for teak growers. To monitor the effect of climatic factors, viz. rainfall and temperature on the radial growth of teak, 37 core samples from 29 teak trees were collected at three different sites, viz. Ahwa (Dang), Valsad during December, 2012 and Navsari of South Gujarat during January, 2015. It was observed that pre-monsoon showers and high temperature during March and monsoon rainfall during June–July and September of the current year have positive influence on the radial growth of teak at Ahwa site. However, there was positive influence of previous and current year's September–November rainfall on the radial teak growth at Navsari site. At Valsad site, previous year's August rainfall and current year's June rainfall had significant negative correlation with radial growth of teak. Temperature of previous year's October–December and current year's July and September–November months also showed significant negative relationship with radial growth. It was observed that rainfall during March month was positively correlated with radial growth of teak at three sites however, it was significant only at Ahwa site. Hence, it is concluded from the study that for boosting up the radial growth of teak, the growers should give water in the form of light irrigation during March and normal irrigation during active growing period from June–September especially when there is a moisture stress due to deficient rainfall.

Key words: Climate, Dendroclimatological approach, Growth ring, Radial growth, Teak

Tree growth is affected by many climatic factors like sunshine, precipitation, temperature, wind velocity and relative humidity. Besides these, there are other non-climatic factors such as inter tree competition, insect pests and soil nutrient characteristics which may also influence growth (Fritts 1976). The tree-ring width is a function of many variables, including the tree species, tree age, soil nutrient availability and a host of climatic factors. The pattern of radial growth in trees from year to year depends largely on the climatic conditions of different localities (Sinha *et al.* 2011). Whenever tree growth is limited directly or indirectly by some climate variables, that limitation can be computed and dated for dendroclimatic studies. Thus, dendroclimatology is the study of growth-ring formation in trees in response to change in climatic conditions. Most of these studies are limited up to temperate regions of the world. In India, a large part of the tropical forests are under the monsoon climatic regime. It is expected that approximately 25% of total tropical tree species produce growth rings (Sinha 2012). In tropical climate, teak (*Tectona grandis* L. f) and toon (*Toona ciliata*) are found suitable for such studies which show datability of growth rings to the accurate years of their formation. However, teak is pre-dominated in the studies because of its wider distribution and commercial importance. It has been investigated with dendroclimatological approach at several locations of India and abroad (Shah *et al.* 2007, Ram *et al.* 2008, Deepak *et al.* 2010, Sinha *et al.* 2011, Sinha 2012, Pumijumnong 2012, Hlaing 2014, Kumar *et al.* 2014, Ugulino *et al.* 2014, Die *et al.* 2015, Sengupta *et al.* 2018). Hitherto, these dendroclimatological studies in teak have been either carried out to extract the past climatic signals especially monsoon rainfall and temperature from tree ring or to simply establish a climate and tree growth relationships. The objective of the present investigation was to monitor the effect of climatic variables, viz. rainfall and temperature on the radial growth of teak grown at different sites in South Gujarat with a dendroclimatological approach

[1,3]Assistant Professor (sinhafri@gmail.com, aamehta@nau.in), Department of Forest Products and Utilization; [2]Assistant Professor (lkbehera@nau.in), Department of Silviculture and Agroforestry; [4]Professor and Head (pksnvs@nau.in), Department of Natural Resource Management, College of Forestry, Navsari Agricultural University, Navsari, Gujarat.

in plantation management for teak growers.

MATERIALS AND METHODS

Study sites and sample collection: Totally 58 core samples were collected at the breast height using increment borer (5 mm diameter) from the trunk of 34 teak trees at three different sites, viz. Ahwa (Dang), Valsad and Navsari of South Gujarat. The core samples from Ahwa and Valsad sites were collected during December, 2012, whereas core samples from Navsari site was collected during January, 2015. At least one and maximum two core samples per tree were sampled based on the sensitivity of the trees to climate to form variable annual rings. Diseased, rotten and crooked trees and trees from waterlogged areas were avoided during sampling.

Climatic data: Climatic data, viz. monthly rainfall and temperature of Ahwa and Valsad regions available from India Meteorological Department (IMD), Pune were used for the analysis, whereas the climatic data of Navsari recorded at Navsari Agricultural University was used. During analysis, the temperature data of Valsad site was also used for Ahwa site which is 112 km apart from Valsad. The climatic data from AD 1974-2003, AD 1974-2011 and AD 1991-2013 were used for Ahwa, Valsad and Navsari respectively for dendroclimatic analysis.

Sample preparation and tree ring-data measurements: The surfaces of core samples of teak from three sites were smoothened with different grits of sand papers of 120, 220, 360 and 600 successively to expose the growth rings and its structure in such a way that each ring of wood could be easily identified for microscopic analysis. Out of 58 core samples of teak only 37 core samples of 29 trees from three sites were used for annual ring-width measurement based on the datability and sensitivity of growth rings of samples for dendroclimatic analysis. Growth rings of all core samples of teak were counted and cross matched within and between trees from three sites using special cross-matching technique developed by Stokes and Smiley (1968) to detect false rings. After counting the growth ring, ring-widths were measured along the radius of each core sample to the nearest 0.01 mm under a Leica stereo-zoom microscope with LAS live measurement software. Each ring of these radii was dated to the exact year of its formation towards pith from bark. The dating of measured series was re-checked and statistically confirmed with the computer program COFECHA developed by Holmes (1983) to avoid errors in the measurement or dating of the samples.

Finally, corrected measurements of tree-ring sequences along 37 radii of core samples from three sites were selected and the raw mean ring-width data series of 17 core samples of teak from Ahwa and 10 core samples each from Valsad and Navsari sites were prepared for further analysis.

Statistical analysis: The age related trend of raw ring-width data series was detrened or standardized using the options, viz. a negative exponential or cubic spline fit of wavelength equal to 65% N (N is the length of tree-ring series) by the computer program ARSTAN (Holmes 1992). After standardization, a ring-width index chronology was prepared from each ring-width series. Indices were derived by dividing the measured ring-width data with the analogous predicted value of ring-width for each year to extract useful climatic signals. A mean tree-ring-width-index chronology was prepared for each site by averaging all individual index series. The prepared mean tree-ring-width-index chronology of Ahwa, Valsad and Navsari extended from AD 1912-2012, AD 1867-2012 and AD 1991-2015 respectively (Fig 1). Chronology statistics of tree-ring index of teak at Ahwa, Valsad and Navsari of South Gujarat have been derived to understand their suitability for climatic analysis (Table 1).

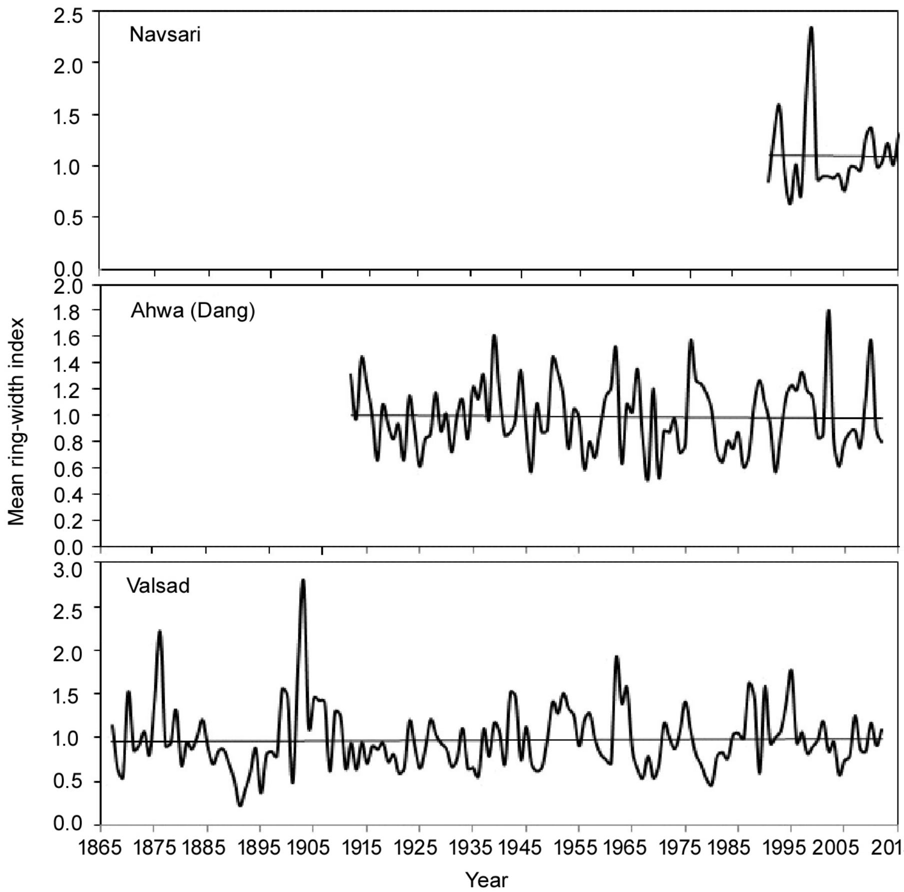

Fig 1 Mean ring-width index chronology of teak from three sites after removal of age-related trend by standardization.

Table 1 Selected statistics of tree-ring index chronologies of *Tectona grandis* at Ahwa (Dang), Valsad and Navsari of South Gujarat

Statistical properties of tree-ring-index chronology	Ahwa (Dang)	Valsad	Navsari
Chronology time span	AD 1912-2012 (101 years)	AD 1867-2012 (146 years)	AD 1991-2015 (25 years)
Number of trees (radii)	11 (17)	8 (10)	10(10)
Mean tree-ring width (mm)	2.49	2.00	6.52
Standard deviation	0.261	0.351	0.320
Mean sensitivity	0.294	0.390	0.273
Autocorrelation order 1	0.052	0.005	0.217
Common interval time span	AD 1938 – 2012 (75 years)	AD 1910 – 2012 (103 years)	AD 1996 – 2015 (20 years)
Number of trees (radii)	9 (15)	4(4)	5(5)
Mean correlation with master chronology	0.477	0.703	0.539
Mean correlation among all radii	0.297	0.562	0.244
Mean correlation between trees	0.285	0.562	0.244
Signal-to-noise ratio	5.592	5.139	1.613
Expressed population signal	0.848	0.837	0.617
Common variance explained %	34.73	67.39	51.58

The chronology suitable for dendroclimatic study should have good correlation between trees, low autocorrelation, high standard deviation, high mean sensitivity, high signal to noise ratio (SNR) and high expressed population signal (EPS) and high value of common variance. The mean sensitivity (MS) was evaluated by making relative difference in ring-width between successive annual rings (Fritts 1976). Its value varies from zero to two. The MS is zero, if there is no variation in adjacent ring-width, and MS is two if a zero value occurs next to non-zero value in a time series. The auto-correlation is the linkage between ring-width of previous year and subsequently formed rings which usually perturb the climate and tree growth relationships (Shah *et al.* 2007). High autocorrelation creates complex modeling and causes trouble in tree-ring analysis. The high value of auto-correlation and low value of mean sensitivity indicate the presence of more low frequency variance in the series. When the case is reverse, the high frequency variance is of more interest for dendroclimatic studies. Auto-regressive modelling removes the high auto-correlation structure in the series and enhances the common climatic signal. The chronologies of three sites contain high autocorrelation at lags of one to two years that was removed from each ring-width series by autoregressive (AR) modeling. Expressed population signal (EPS) decides the association between the mean chronology derived from the core samples and the population from which they are drawn. According to Wigley *et al.* (1984) chronologies with EPS greater than or equal to 0.85 can be acceptable for dendroclimatic analysis. The value of SNR greater than one indicates the strength of climatic signal between trees (Wigley *et al.* 1984). The common variance is an average correlation among all the tree samples over the common interval period. This value indicates the variance due to common forcing factor of a site that may be influence of climatic factors experienced by all the trees over a large area.

Correlation analysis for each tree-ring site was carried out using the monthly rainfall and temperature data from August of previous year to December of current year because the climatic factors of previous years also affect the current year's radial growth in teak. The analyses were based on the time period AD 1974-2003, AD 1974-2011 and AD 1991-2013 for Ahwa,Valsad and Navsari which were common to both meteorological and tree-ring data respectively.

RESULTS AND DISCUSSION

In the present study, moderately high values of standard deviation, mean sensitivity and low auto-correlation after using autoregressive modeling indicate the high dendroclimatic potential of tree-ring index chronologies from three sites of South Gujarat. The value of EPS is nearly 0.85 for tree-ring chronologies of Ahwa and Valsad and 0.62 for the Navsari chronology. The value of SNR is greater than one for all the three chronologies with the highest value of Ahwa chronology (5.592) followed by Valsad (5.139) and Navsari (1.613). The common variance was high for all the three chronologies. These results indicate that tree-ring-index chronologies of three sites have potential for dendroclimatic analysis.

Tree-ring growth and climate relationship: The tree-ring sites, viz. Ahwa, Valsad and Navsari considered in the present investigation are under the influence of the Indian monsoon. The total annual rainfall received during the monsoon season (June-September) is more than 75% and less during post-monsoon season (October–December). Pre-monsoon season (March-May) is usually hot and dry. While pre-monsoon showers during this season play an important role in cambial activity and formation of new cells. Conversely, hot and dry pre-monsoon season creates distinct moisture deficiency which directly influences the radial growth of trees. It indicates that there is significant relationship between radial growth variations of teak and climatic factors, viz. rainfall and temperature (Sinha 2012). However, in most of the cases, it is generally observed that the narrow ring-width (low growth) is significantly linked with deficient rainfall. Normal or exceeding normal rainfall does not show a significant higher growth because of regular moisture present in the root zone of the tree. When the availability of moisture attains a threshold limit, the tree does not respond to the additional moisture, while, less moisture in the root zone causes poor growth of tree. The availability of moisture in the root zone of a tree is primarily the function of monthly rainfall and temperature (Ram *et al.* 2008). The radial growth in teak initiates in March and reaches a peak in June–September and the wood formation gradually declines in October and cease in November. Defoliation starts in December and trees become completely leafless by March (Die *et al.* 2012).

Analysis of tree-growth and climate relationship at Ahwa revealed that rainfall during March and June–July and September of the current year had positive influence on the radial growth of teak (Fig 2a). March temperature during current year also showed positive response with tree growth. A positive relationship between tree growth and climate during March, June–July and September of the current year suggested that the pre-monsoon showers during March and monsoon rainfall during June–September play an important role in the radial growth of teak. March temperature showed significantly positive effect on the radial growth, as it favours initiation of cambial activity by periclinal cell division during wood formation.

Analysis of tree-growth and climate relationship at Navsari showed positive influence of previous and current year's September–November rainfall on the radial growth of teak (Fig 2b). June–August rainfall and temperature did not show any significant relationship at this site. Tree-ring site of Navsari receives higher rainfall than Valsad and Ahwa in June–August and moisture availability is also high in the root zone due to frequent irrigation of agricultural crops nearby tree-ring site. Therefore, it seems that when the moisture availability reaches a certain threshold limit, the tree does not respond to extra moisture and this may be the reason that tree growth did not show any significant relationship with June–August rainfall and it showed positive relationship with September–November rainfall.

Analysis of tree-growth and climate relationship at Valsad showed a significant negative relationship between radial growth and previous year's August rainfall and current year's June rainfall (Fig 2c). Temperature of previous year's October–December and current year's July and September–November months also showed significant negative relationship with radial growth. In case of Valsad tree-ring sampling sites, viz. Dharampur, Kaprada and Nanaponda are located on the sloppy terrain of hilly forest. Though, large amount of rainfall received during monsoon but drained down due to steep topography of tree-ring sites which resulted in moisture stress in the root zone that may have affected the normal growth of trees. High temperature always promotes evaporation and evapotranspiration which produces a severe moisture stress in the root zone causing narrow ring-width in trees. Therefore, rainfall and temperature might have shown negative relationship with radial growth of teak at this site. Similar observation was also recorded in teak by Ram *et al.* (2008) at Sajpur and Bori tree-ring sites located on the slope of the hilly forest of Madhya Pradesh. In case of Navsari and Ahwa sites, the amount of run-off water was comparatively less because of its flat topography that may have resulted in adequate moisture availability at root zone for longer periods although the temperature was high. Consequently, the significant effect of temperature on tree growth was not observed at the Navsari site and only March temperature showed positive influence on the radial growth of teak at Ahwa site.

It is inferred that in general, rainfall during March was positively correlated with radial growth of teak at three sites however, it was significant only at Ahwa site. It is confirmed by several studies that during March, current year's xylem is occupied by only a single row of wide earlywood vessels

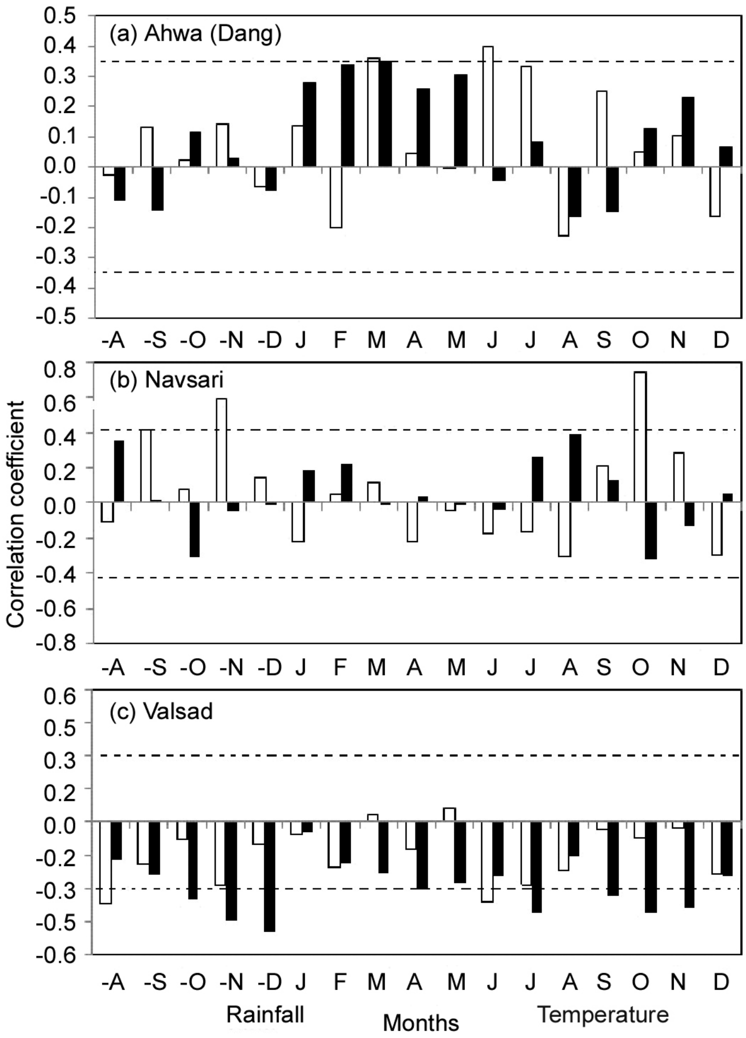

Fig 2 a-c Correlation analysis of tree- ring- index with rainfall and temperature from three sites, Dotted horizontal line indicates significance level ($P < 0.05$) above and below.

with partial wall lignifications except adjacent developing fibres. Therefore, current year's earlywood vessels are not completely functional for water transport in March. This function is fulfilled by latewood vessels of previous year to begin the cambial activity for radial growth (Die *et al.* 2012, Kitin and Funada 2016).

The current study corroborates that pre-monsoon showers, high temperature during March and monsoon rainfall from June–September play an important role in the radial growth of teak. Carry over effect of moisture from the previous year's monsoon as well as post-monsoon also contribute to the variations in teak growth. Low rainfall and high temperature during monsoon (June–September) and post-monsoon (October–November) seasons create moisture stress in the root zone of teak. Consequently, it is concluded that for enhancement of radial growth of teak and future plantation management, the teak growers should give water in the form of light irrigation during March and normal irrigation during active growing period from June–September especially when there is a moisture stress due to deficient rainfall.

ACKNOWLEDGEMENTS

This is to acknowledge that research work was carried out under the aegis of Environment Project in the College of Forestry, Navsari Agricultural University, Navsari, Gujarat.

REFERENCES

Deepak M S, Sinha S K and Rao R V. 2010. Tree-ring analysis of teak (*Tectona grandis* L.f.) from Western Ghats of India as a tool to determine drought years. *Emirates Journal of Food and Agriculture* **22**(5): 388–97.

Dié A, Kitin P, Kouame F N, Bulcke J V, Acker J V and Beeckman H. 2012. Fluctuations of cambial activity in relation to precipitation result in annual rings and intra-annual growth zones of xylem and phloem in teak (*Tectona grandis*) in Ivory Coast. *Annals of Botany* **110**: 861–73.

Die A, De Ridder M, Cherubini P, Kouame F N, Verheyden A, Kitin P and Beeckman H. 2015. Tree rings show a different climatic response in a managed and a non-managed plantation of teak (*Tectona grandis*) in West Africa. *International Association of Wood Anatomists Journal* **36**(4): 409–27.

Fritts H C. 1976. *Tree Rings and Climate*. Academic Press, London.

Kitin P and Funada R. 2016. Earlywood vessels in ring-porous trees become functional for water transport after bud burst and before the maturation of the current-year leaves. *International Association of Wood Anatomists Journal* **37**(2): 315–31.

Hlaing Z C, Teplyakov V K and Thant M N L. 2014. Influence of climate factors on tree-ring growth in teak (*Tectona grandis* L.f.) plantations in the Bago Yoma Range, Myanmar. *Forest Science and Technology* **10**(1): 40–5.

Holmes R L. 1983. A computer assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* **43**: 69–78.

Holmes R L. 1992. Program ARSTAN (Version B-1992). Laboratory of Tree-Ring Research, University of Arizona, USA.

Kumar N P, Devakumar A S, Sheshshayee M S and Mohankumar M V. 2014. Dendroclimatological approach to evaluate *Tectona grandis* L. for moisture stress response. *Trees* **28**(4):1053–63.

Pumijumnong N. 2012. Teak tree-ring widths: Ecology and climatology research in Northwest Thailand. *Science Technology and Development* **31**(2): 165–74.

Ram S, Borgaonkar H P and Sikder A B. 2008. Tree-ring analysis of teak (*Tectona grandis* L.f.) in central India and its relationship with rainfall and moisture index. *Journal of Earth System Science* **117**(5): 637–45.

Sengupta S, Borgaonkar H, Joy RM and Ram S. 2018. Monsoon climate response in Indian teak (*Tectona grandis* L.f.) along a transect from coast to inland. *Theoretical and Applied Climatology* **134**: 1197–05.

Shah S K, Bhattacharyya A and Chaudhary V. 2007. Reconstruction of June-September precipitation based on tree ring data of teak (*Tectona grandis* L.) from Hoshangabad, Madhya Pradesh, India. *Dendrochronologia* **25**: 57–64.

Sinha S K. 2012. Tree-ring width of teak and its relationship with rainfall and temperature. *Indian Journal of Ecology* **39**(1): 1–5.

Sinha S K, Deepak M S, Rao R V and Borgaonkar H P. 2011. Dendroclimatic analysis of teak (*Tectona grandis* L.f.) annual rings from two locations of peninsular India. *Current Science* **100**(1): 84–88.

Stokes M A and Smiley T L. 1968. An introduction to tree-ring dating. The University of Chicago Press, Chicago.

Ugulino B, Latorraca J V F, Filho and M T. 2014. Tree-ring growth response of teak (*Tectona grandis* L.f) to climatic variables in central-west region of Brazil. *Scientia Forestalis* **42**(104): 473–82.

Wigley T M L, Briffa K R and Jones P D. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Climatology and Meteorology* **23**: 201–13.