SCIENTIA
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Tree-ring growth response of teak (*Tectona grandis* L.f.) to climatic variables in central-west region of Brazil

Resposta dos anéis de crescimento de árvores de teca (*Tectona grandis* L.f.) à variáveis climáticas na região centro-oeste do Brasil

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Abstract

Through a non-destructive method, four core wood samples were taken at DBH of fifteen trees from an unmanaged teak (*Tectona grandis* L.f.) stand in Cáceres, Mato Grosso, Brazil. Wood core samples were prepared for anatomical analysis, digitized and growth ring widths were measured using image analysis software. Growth rings were large and well defined in the juvenile phase, reflecting the fast-growing character of the species. Three types of false growth rings were identified. Types I and II occurred in the earlywood and type IV in the latewood zone. The occurrence of false growth rings was higher in juvenile wood than in mature wood. The relationship between growth ring width of teak trees and climate was explored using data of monthly temperature and rainfall. It was found that high temperatures during the rainy season had a significant negative effect on tree growth. On the other hand, a rainfall event during the dry months could affect the growth positively. The correlations found between growth rings and climate factors help understand and predict the local climate influence on teak tree growth for this area in Brazil.

Keywords: False rings, Mato Grosso, Brazil, Tree-ring analysis.

Resumo

Através de um método não-destrutivo, quatro amostras do lenho foram retiradas na altura do peito do tronco de quinze árvores de uma plantação de teca (*Tectona grandis* L.f.), sem manejo, localizada em Cárceres, Mato Grosso, Brasil. As amostras do lenho foram preparadas para análise anatômica, digitalizadas e em seguida a largura de cada anel foi mensurada através de um programa de análise de imagens. Os anéis de crescimento anuais foram largos e bem definidos na madeira juvenil, refletindo a característica de rápido crescimento da espécie. Três tipos de falsos anéis de crescimento foram identificados, sendo que os dos tipos I e II que ocorreram no lenho inicial e o tipo IV no lenho tardio. A ocorrência dos falsos anéis de crescimento foi maior na madeira juvenil do que na madeira adulta. A relação entre a largura dos anéis de crescimento das árvores de teca e clima foi explorada usando dados de temperatura e precipitação mensais. Verificou-se que altas temperaturas durante a estação chuvosa teve um efeito negativo e significativo sobre o crescimento das árvores. Por outro lado, um evento de precipitação durante os meses secos poderia afectar o crescimento de foma positiva. As correlações encontradas entre a largura dos anéis de crescimento e os fatores cimáticos contribui para o entendimento e a predição sobre o efeito do clima local no crescimento das árvores de teca para esta região do Brasil.

Palavras-chave: Falsos anéis, Mato Grosso, Brasil, Análises dos anéis de crescimento de árvores.

INTRODUCTION

The state of Mato Grosso has the largest area of teak (*Tectona grandis* L.f.) plantations in Brazil with approximately 65,000 hectares (FAMATO, 2013). The planting of teak, in this state, began in the 1970s, with the purpose of reducing the pressure on native species. Early growth results of trees stimulated the expansion of teak plantations in the region (MATRICARDI, 1989). However, little is known about the influence of local climate on the radial growth of these trees.

Growth rings are anatomical structures of the wood that represent one year of their life or other seasonal periods of tree growth (FRITTS, 1976; JACOBY; D'ARRIGO, 1989). The tree growth can be affected by many factors, e.g., environmental factors, physical spaces, edaphic

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conditions, topographic features and competitive factors (ZANON; FINGER, 2010). The influence of these factors is recorded in the width and density variation in growth rings, as well as in their anatomical structure (FRITTS, 1976; JACOBY; D'ARRIGO, 1989; WORBES, 1995; WORBES et al. 2003). In tropical zones, seasonal patterns of wood growth are generally related to water availability (BHATTACHARYYA et al., 2007; COOK et al., 2010; D'ARRIGO et al., 2011; SHAH et al., 2007; WORBES, 1999). Many tropical areas have at least 2 months of arid conditions (WORBES, 1992, 1995, 1999), a dry season or a rainy season with a break in rainfall during mid-season (PRIYA; BHAT, 1998), permitting one to use dendrochronological methods developed for temperate zones (SCHWEINGRUBER, 1988). According to several studies, teak has shown to be sensitive to climatic variations (e.g. D'ARRIGO et al., 2011; DIÉ et al., 2012; PRIYA; BHAT, 1998; PUMIJUMNONG, 2012; RAM et al., 2008; SHAH et al., 2007). In Brazil, the sensitivity of the teak to climatic variations was demonstrated by Tomazello Filho and Cardoso (1999). However, false rings may cause measurement errors in tree ring research. The false ring formation is triggered by specific environmental conditions (COPENHEAVER et al., 2006). A drought during the growing season (EWEL; PARENDES, 1984; FRITTS, 1976; YAMAGUCHI, 1991), unusually high levels of air pollution, periodic flooding and mild frosts experienced in late spring and early summer (KOZLOV; KISTERNAYA, 2004; KURCZYNSKA et al., 1997; YOUNG et al., 1993) are some of stressful conditions which promote the formation of a false ring.

Furthermore, the discovery of seasonal growth cycles in tropical and subtropical species make tree-ring analysis a promising tool for studying the structure and especially the dynamics of these forests (BRIENEN; ZUIDEMA, 2005; PUMIJUMNONG, 1999; WORBES, 1995, 1999). Due particularly to the increasing number of reforestation programs in tropical regions, this knowledge becomes very useful for better forest management. Moreover, large-scale reforestation with fast-growing genotypes like teak, is likely to shorten rotations in the near future (KOUBAA et al., 2005). Thus, the aim of this study was to characterize the growth rings of teak and relate their formation to climatic factors such as temperature and rainfall.

MATERIAL AND METHODS

Study Area

The study area is located in the Instituto Federal de Educação, Ciência e Tecnologia do Mato Grosso, Campus de Cáceres, Mato Grosso, Brazil (16°13′53″S, 57°32′40″ W) at 118 m asl (Figure 1). The area is characterized as flat terrain and the soil classified as dystrophic red-yellow Latosol (OLIVEIRA, 2008). The teak plantation was established in the period 1970-1980 and then left without tending.

The climate is characterized by a dry season with a mean monthly rainfall of 37.8 mm from April to September. The months of January and July have the highest and lowest total mean monthly rainfall, with 237 mm and 14 mm respectively (Figure 1). The mean annual temperature is 25.2°C, with a lower temperatures season from May to August, with average temperatures of 21.9 and 23.9°C in July and August respectively (Figure 1). Meteorological data of daily temperature were provided by two stations of Instituto Nacional de Meteorologia (INMET) (16°05′S e 57°68′W, 118 m asl and 15°S e 56°W, 184 m asl) and daily rainfall data by the Agência Nacional de Águas (ANA) located in the municipality of Cáceres, Mato Grosso, Brazil (16°04′33″S, 57°42′08″W, 108 m asl).

Sample collection and preparation

Fifteen trees were selected taking into account phytosanitary aspects in the study area. Four wood radial samples were taken from each tree, all comprising the pith, using the non-destructive Pressler auger method (5.15 mm diameter, Haglöf) at a height of 1.30 m from the ground (DBH). The increment cores were cut using a large sliding microtome obtaining cross-sectional samples with an average thickness of 1.6 mm. The cross-sectional surfaces were polished with increasingly finer sandpaper from grain 120 up to 400.

Tree-ring analysis

Wood samples were examined under a stereomicroscope, which allowed identifying and demarcating the growth rings. Narrow rings were used as indicator years during visual cross dating of the cores (YAMAGUCHI, 1991). False rings identified by visual cross dating process were subsequently checked by the program COFECHA (HOLMES et al., 1986). Thus, false rings were classified according to Priya and Bhat (1998), who identified four types of false ring formations in teak from Nilambur (Kerala), India. Types I and II occur in the earlywood zone and types III and IV in the latewood zone. The type I false ring is characterized by a zone similar to earlywood with one or more rows of parenchyma, large vessels and thin wall fibers preceded by thick wall fibers. An abrupt change from the thin walled earlywood fibres to a band of thick walled fibres with diffuse parenchyma and vessels characterizes the type II false ring. In the latewood zone, type III is defined by one or two rows of parenchyma cells with small vessels scattered nearby. Type IV is characterized by aggregations of multiple radial vessels with paratracheal parenchyma cells. Palakit et al. (2012) also identified false rings similar to those described by Priya and Bhat (1998) in teak wood. These authors classified two types of false rings as type I and II in earlywood and latewood respectively. False ring type I has one or more rows of axial parenchyma associated with large vessels at the beginning of the annual ring, as type I described by Priya and Bhat (1998). False ring type II is divided into two groups based on their characteristics. The first group had an aggregation of large vessels associated with paratracheal parenchyma while the second group did not have any paratracheal parenchyma.

These wood cross sections were then digitized by a scanner at a resolution of 1600 dpi (Epson Perfection V700 Photo). The width of the growth rings (from pith towards bark) was measured using WinDENDRO™ software (version 2009b). The ring width data were then read by the COFECHA program (HOLMES et al., 1986). A spline cubic filter 50% wavelength cut-

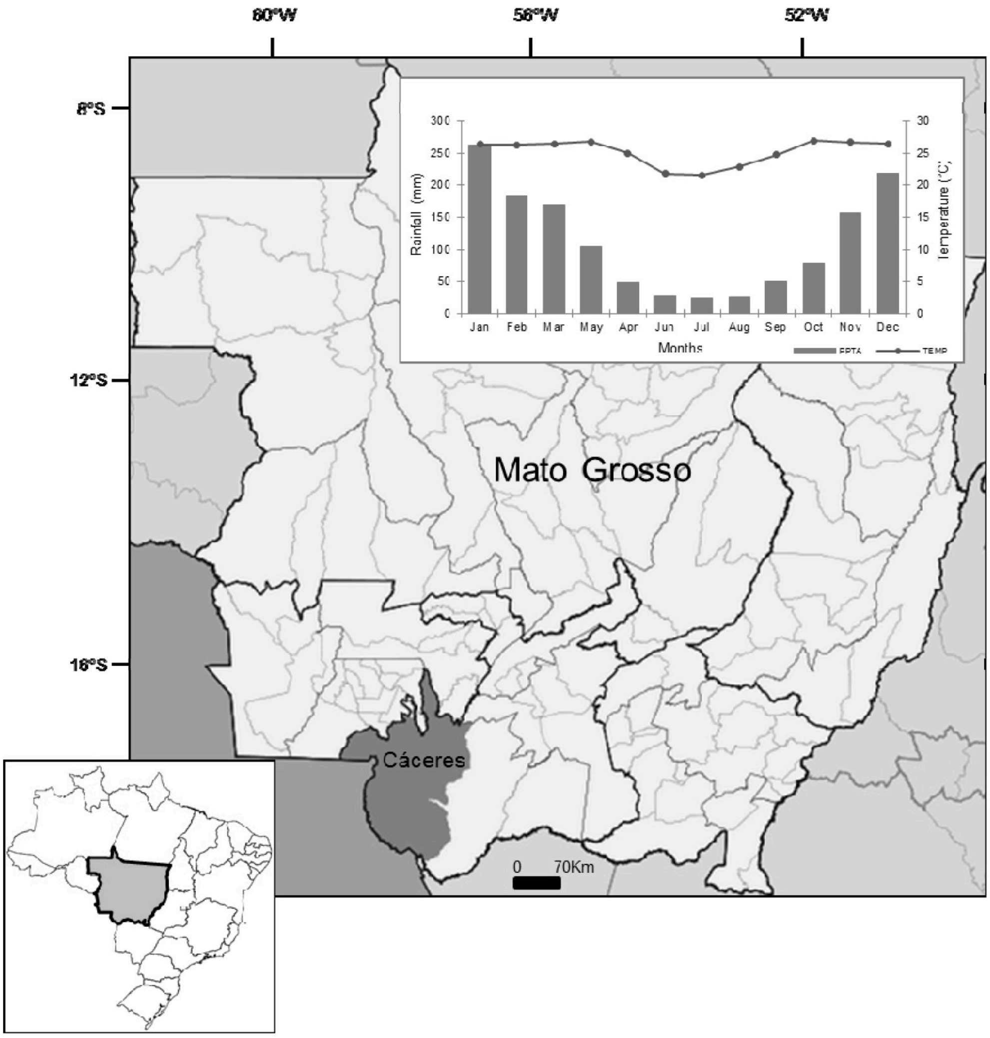

Figure 1. Location map of the study area, Instituto Federal de Educação, Ciência e Tecnologia do Mato Grosso, Campus de Cáceres, Mato Grosso, Brasil. The graph on the right top shows the means monthly temperature and precipitation at Cáceres, Mato Grosso, Brazil based on the data from 1980 to 2009.

Figura 1. Mapa de localização da área de estudo, o Instituto Federal de Educação, Ciência e Tecnologia do Mato Grosso, Campus de Cáceres, Mato Grosso, Brasil. O gráfico no canto superior direito mostra as médias mensais de temperatura e precipitação em Cáceres, Mato Grosso, Brasil, com base nos dados do período de 1980 à 2009.

off of 32 years, with 20-year segments lagged by 10 years and a critical correlation of 0.5155 were applied. The quality control was carried out and the synchronization of growth ring width series was verified, initially among the four radii of the same teak tree and then between teak trees. Once the master series of all trees had been obtained, low frequency trends were removed from the data on growth ring widths, thereby maximizing the common signal of the series, forming a master series representing the series that make it up. Trends were removed from the ring series by adjusting a spline curve; the value of growth ring width was then divided by the adjusted curve. The software thus calculated the Pearson's correlations between individual series in relation to the master series. The analysis of the correlation values enabled to observe that some series did not adjust well to the master series and therefore were excluded from the analysis in order to ensure compliance of the final synchronization. Some of these series were obtained from samples with the presence of an irregular grain, many false growth rings and/or a probably site-specific influence. Therefore, of 15 (60 radii) trees of teak correlated, only 12 (17 radii) were used in the final synchronization of growth rings (Table 1).

Tabela 1. Statistics of tree-ring chronology of teak at Cáceres, Mato Grosso, Brazil.
Table 1. Estatísticas da cronologia dos anéis de teca em Cáceres, Mato Grosso, Brasil.

Chronology time spam	1981-2008
Number of cores (trees)	25 (15)
Mean	0.977
Mean sensitivity	0.306
Standard deviation	0.420
Autocorrelation order 1	0.237
Common interval time spam	1983-2008
Number of cores (trees)	17 (12)
Mean correlation between trees	0.301
Mean correlation radii vs mean	0.576
Signal-to-noise ratio	7.438
Expressed population signal	0.880
Variance explained in first eigenvector (%)	37.78

With the aid of the ARSTAN program (COOK; HOLMES, 1996), a regression curve was fit to the ring width series, the non-climatic growth trends for the set of teak trees were removed and then index were estimated. Ring width data were standardized using a cubic smoothing spline method of the ARSTAN program. This method was a better option than other detrending methods for smoothing age trends in width values. According to Fritts (1976), tree-ring chronologies with higher values of mean sensitivity, standard deviation and mean correlation among all trees and lower values of autocorrelation are indicators of high dendroclimatic potential of a species.

The residual chronology generated by the ARSTAN program were correlated to the monthly averages of mean temperature and total rainfall (period: 01/1980 to 10/2009), using RESPO software (HOLMES et al., 1986). RESPO transformed these climatic parameters into main components and then performed a regression where the chronology of growth rings becomes the dependent variable, and climatic parameters (temperature and rainfall) become the independent variables. The result was a response function for the chronology, which expressed the independent relationship between tree growth and climate.

RESULTS AND DISCUSSION

Growth rings and false rings

The growth rings of teak from Caceres are characterized by large and numerous pores in earlywood and by small and scarce pores in latewood, and the presence of bands of axial parenchyma marginal with a lighter color in relation to the fibers (Figure 2a). This anatomical structure of teak growth rings is mentioned in the literature (e.g. CHOWDHURY, 1939; GOVAERE et al. 2003; PRIYA; BHAT, 1998; RICHTER; DALLWITZ, 2000; SUDHEENDRAKUMAR, et al. 1993; TOMAZELLO; CARDOSO, 1999).

The cross dating technique allowed the identification of false rings. The presence of false growth rings was observed both in the juvenile and mature wood; however, there was a higher occurrence in the juvenile wood. According to Chowdhury and Rao (1949), the occurrence of false growth rings is more frequent in juvenile teak trees. Younger trees and trees with faster growth rates are also more prone to false ring formation (VOGEL et al., 2001). Inside the growth rings, the presence of false rings was observed in both earlywood and latewood. False rings types I, II and IV (Figure 2b, c and d) were identified in the present study, according to the classification of Priya and Bhat (1998). Types I and II occurred in the earlywood zone and type IV in the latewood zone. According to these authors, rainfall events during the dry season and drought during the growing season contribute significantly to the frequency of false rings in teak. Moreover, the location of the false ring within the annual ring correlates to the timing of the mechanism that triggers the false ring to form in *Pinus banksiana* (COPENHEAVER et al., 2006).

The analysis of teak wood samples showed variability in growth ring width, where wide and narrow growth rings could be observed. This behavior is due to the fact that teak shows a rapid growth in the first years, and as the tree matures this growth rate tends to decrease (FIGUEIREDO, 2005); a characteristic of this species that is well documented in the literature (e.g. CALDEIRA, 2004; CENTENO, 2001; GOVAERE et al., 2003; THULASIDAS et al., 2006). This variability in growth ring width indicates, among other factors, the sensitivity of these trees to environmental conditions.

Crossdating

By observing the data on growth ring width, some similar trends in tree growth can be found. Tree rings with a similar trend in most of the radii studied were used as indicator years, such as 1991, 1993 and 1995. The year 1993, for example, showed a narrower ring in relation to the other years, this was observed in all correlated radii (Figure 3). This narrow ring was used as indicator years during visual cross dating of the cores.

The period 1990-1993 is characterized by the occurrence of the El Niño, with strong intensity. According to some authors, the occurrence of the phenomenon in the Central-West region of Brazil does not show a significant impact on the region's climate (RAO; HADA, 1989; ROPELEWSKI; HALPERT, 1987). However, Grimm et al. (1998), when studying the influence of El Niño-related events on rainfall in the Central-West region of Brazil found that abnormal persistent and consistent droughts occur during the summer in the western part or this region, where the municipality of Cáceres is located. The analysis of the total annual rainfall (mm) and average annual temperature (°C) for the period 1980-2009 in the region of Cáceres-MT shows that total annual rainfall of 983 mm and 949 mm were recorded in 1993 and 1994 respectively. These values were much lower compared to the previous year (1438 mm) and following year (1510 mm). Dry summers and high rainfall variability over the year are unfavorable factors for plant growth (MITRAKOS, 1980). The smallest increments between 1991 and 1993 could be explained by the intensification of the El Niño in the period surveyed. However, no regression analyses were done to confirm this possible correlation.

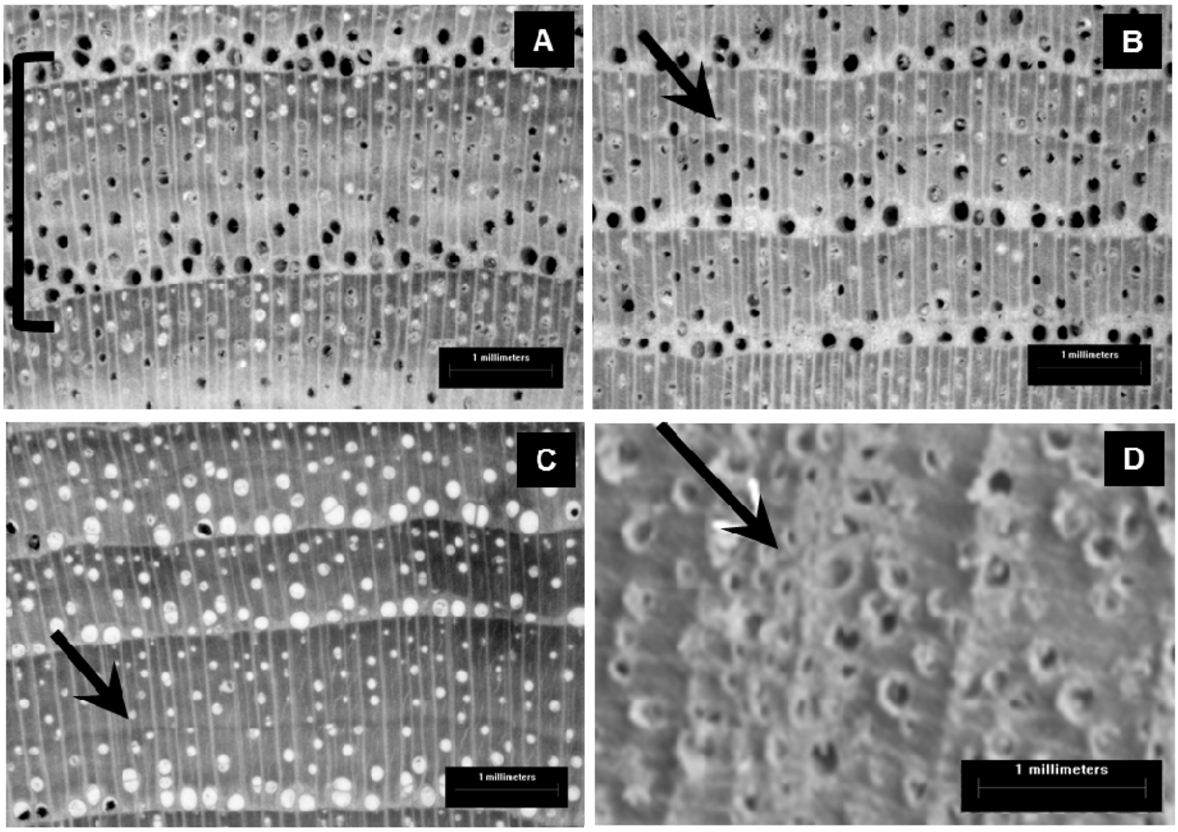

Figure 2. (A) Example of growth rings in teak trees (10x), (B) False growth ring type I (10x); (C) False growth ring type II (10x), (C) False growth ring type IV (40x).

Figura 2. (A) Exemplo de anéis de crescimento em teca (10x), (B) Anel de crescimento falso tipo I (10x); (C) Anel de crescimento falso tipo II (10x), (D) Anel de crescimento falso tipo IV (40x).

The chronology statistics of teak from present study showed moderates values of mean sensitivity, standard deviation, good correlation between trees and high signal noise ratio (Table 1). These results helped to establish that the common features observed in these series represent the response of teak trees to a similar seasonal cycle of diametrical growth, proving suitability of this chronology for the analysis of climate-growth relationship.

Tree-growth and climate

The residual chronology of teak, obtained in the ARTSAN program (Figure 4), was correlated with the climatic data of mean monthly temperature and total monthly rainfall in the RESPO program. A twelve month long dendroclimatic year was set to derive from growth-climate relationship extending from August of the previous year to the July growing season of the next growing season for the period 1980-2009. The multiple correlation coefficient was r=0.7887 and the total variance explained through the main component was 62.21%. Statistically significant (at 95% level), negative correlations between tree-growth and temperature were found for October of the previous year and February of the current year (Figure 5). The mean temperature in the region increases from September to March (highest average temperature months), and it is between these months that temperature and growth show a negative correlation, except during November of the previous year. According to Pumijumnong et al. (1995) high temperatures can increase the evapotranspiration rate and thus expose the teak trees in northern Thailand to water stress. Shah et al. (2007) assumed that increased precipitation during hot summer accelerates the rate of evapotranspiration, which might have caused the water stress conditions for teak trees in Hoshangabad, Madhya Pradesh, India.

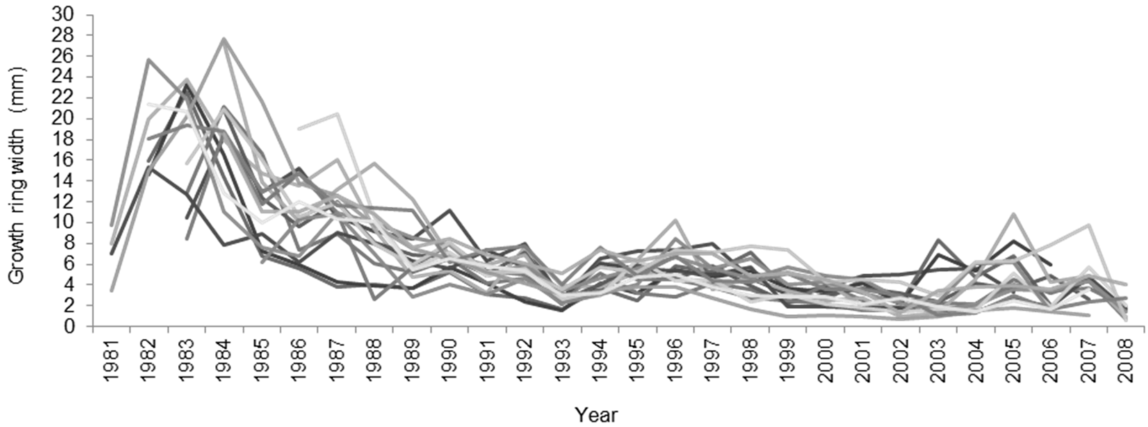

Figure 3. Series of teak trees growth ring width used in the COFECHA program.
Figura 3. Série de anéis de crescimento das árvores de teca usado no programa COFECHA.

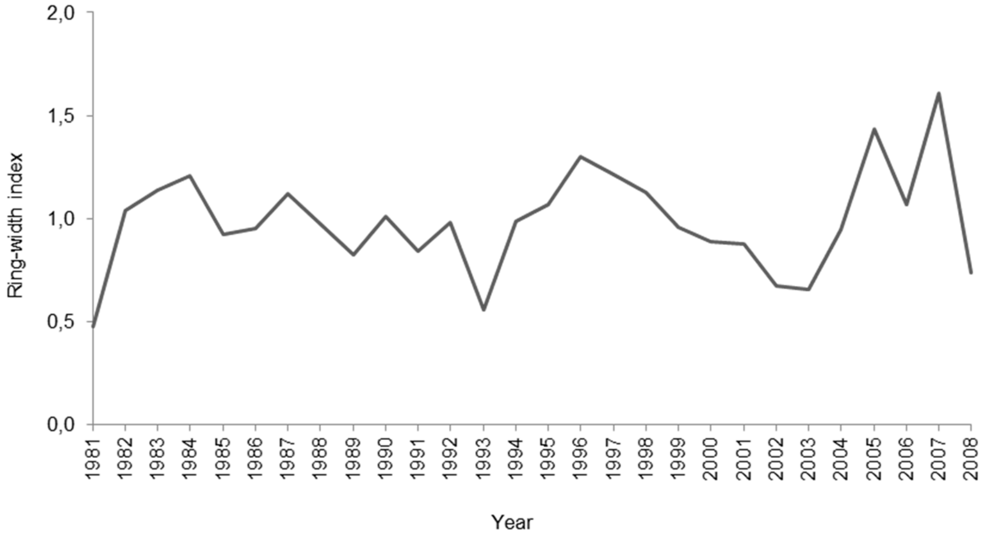

Figure 4. Tree-ring width index chronology of teak from Cáceres, Mato Grosso, Brazil.
Figura 4. Índices de largura dos anéis da cronologia da teca em Cáceres, Mato Grosso, Brasil.

Moreover, high plant evapotranspiration may cause consumption of available food at a rate that exceeds replenishment of food stocks (FRITTS, 1976), resulting in reduced radial growth (White et al. 2014). Thus, the negative correlation found between the temperature and the growth of teak trees in the present study could be due to the combination of excessively high temperatures and increased precipitation resulting in a high rate of evapotranspiration in this period.

In terms of rainfall, a significant positive correlation between growth and rainfall was observed in June of the current year (Figure 5). The dry season in Cáceres region starts in May lasting to September, when rainfall rates begin to increase again. The fact that the month of June has a low total rainfall (22 mm) suggests that a rainfall event during the dry season could stimulate the tree-growth. Berlage (1931) by correlating Java teak tree chronology with climate also found a positive correlation between teak-ring width and the June to October period, which corresponds to the dry season in that region. Likewise tree growth has been found to be limited by the low monsoon precipitation in Hoshangabad, Madhya Pradesh, India (SHAH et al., 2007). Moreover, rainfall is the environmental factor that has the most influence on teak tree-ring width in Southeast Asia (PUMIJUMNONG, 2012). According to the review paper made by that author, this variable indeed differs between rainy and dry season, and it has been shown that the transition between dry seasons' end and the beginning of the rainy season affects teak growth the most.

CONCLUSION

The main conclusions are: (i) the wood samples allowed to identify and characterize the annual growth rings of teak trees, due to the seasonality of cambium activity; (ii) the presence of false growth rings was higher in the juvenile wood; (iii) high temperature during the rainy season suggests a negative influence on the tree-growth; (iv) similarly a rainfall during the dry season affects positively and significantly the growth of the trees in the study area; (v) knowledge of the factors which affect the growth (high evapotranspiration in hot summers and extended periods without rain) is useful for defining best silvicultural practices for teak plantations in the study area.

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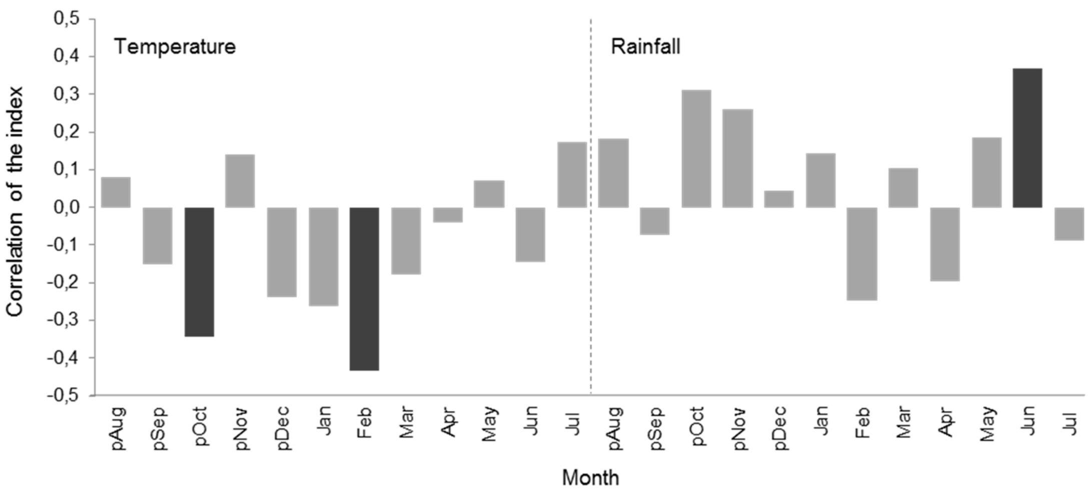

Figure 5. Correlation coefficients between mean monthly temperature, total monthly rainfall and ring-width index. Months with a "p" prefix indicate values from the previous year.
Figura 5. Coeficientes de correlação entre temperatura média mensal, precipitação total mensal e índices de largura dos anéis de crescimento. Meses com um prefixo "p" indica os valores do ano anterior.

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