

Wood-growth zones in *Acacia seyal* Delile in the Keita Valley, Niger: Is there any climatic signal?

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ABSTRACT

Acacia trees are a key element in Sahelian semiarid ecosystems, being some of the few tree species surviving in such extreme environments. Understanding their growth dynamics represents a fundamental step to improve forest sustainable management. Dendroclimatology, the study of tree rings and their relationships with climate, could help in understanding how changing climatic conditions may impact these ecosystems. We studied *Acacia seyal* Delile trees growth in Keita Valley, in the Sahelian zone of Niger. Wood from 8 trees of known age was sampled to study the relationships between growth zones, i.e. ring patterns, and climatic conditions. We present herein, a study based on cross sections instead of cores. Wood-anatomical and dendrochronological analyses enabled us to evaluate the relationships between age and ring formation, and to confirm that one tree ring for rainy season is formed. Moreover, surprisingly for a species growing at such latitudes, acacia tree rings have a climatic signal, mainly due to the precipitation falling during the rainy season but also influenced by the average seasonal temperature.

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1. Introduction

The Sahel is an arid to semiarid region located between Sahara and Sudan, laying from Senegal to Chad, characterized by 250–500 mm summer rainfall. Overall, with some local exceptions, it is characterized by semi-desert grassland, shrublands and wooded grasslands, in which acacia species play a dominant role. In the recent decades the overexploitation of soils, closely linked to the increase in population, has led to soil exhaustion and to lower productivity, further enhanced by limited rainfall that is becoming more and more sparse and irregular as a result of climate changes. Drought, in conjunction with overexploitation, is leading to a quick and often irreversible degradation of natural resources. The primitive agricultural techniques have stimulated a non-sustainable exploitation of soil, with important and serious consequences for local human populations, being agriculture and forestry often the only source of income (Le Houérou, 1996). In this context, forests have a crucial importance in preserving soil and limiting desertification, providing food and energy for people, fodder for animals,

and offering additional income to local populations. Acacias, in particular, supply high-protein forage, good quality timber, high value non-timber products (gums and tannins) and improve soil fertility thanks to their root symbiotic nitrogen-fixing bacteria (Wickens et al., 1996).

Assessing the age of trees enables the evaluation of tree-productivity rates and is essential for a thorough understanding of ecosystem dynamics (Martin and Moss, 1997). Knowledge on growth rates of the main tree species are fundamental prerequisites for avoiding their overexploitation and degradation. Furthermore, understanding the relations between tree growth and climatic conditions is particularly important for understanding how ecosystems will react to future climate change and for their sustainable management.

Not only in temperate regions but also in the tropics, counts and measurements of tree rings can offer a reliable way for assessing site-specific growth rates (Eckstein et al., 1981; Gourlay, 1995b; Tarhule and Hughes, 2002; Worbes, 1995). Even if recently some dendrochronological studies were carried out in different African countries (February et al., 2006; Fichtler et al., 2004; Gourlay, 1995a; Gourlay et al., 1996; Milton et al., 1997; Steenkamp et al., 2008; Trouet et al., 2001), an important gap of knowledge exists about semi-arid Sahel areas (Cherubini et al., 2003). Only few studies have focused on Western Sahel and its typical trees (Eshete and Stahl, 1999; Mariaux, 1975; Martin and Moss, 1997), because of

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several different reasons i.e. difficulties to get funds, harsh environment, among which the main one is probably the difficulties encountered identifying tree rings because of the indistinct nature of rings boundaries (Gourlay, 1995a) induced by peculiar climatic conditions. Nonetheless, anatomical studies showed that it is possible to identify ring boundaries in acacias, using for example marginal parenchyma bands, although difficult to be distinguished, being often of less than five rows of cells (Gourlay and Kanowsky, 1991; Mariaux, 1975). These bands are often associated with rhomboidal crystals of calcium oxalate (Gourlay, 1995a; Gourlay and Grime, 1994) that may be used as indicators of rings edges. These results enabled several authors to investigate more closely the relationships between wood formation and seasonal climatic trends, in particular, its climatic signal (Cook and Kairiukstis, 1990). Tree rings formed during the rainy season have been used to understand tree growth under different water availability in several species including some acacias (Eshete and Stahl, 1999; February et al., 2006; Martin and Moss, 1997; Steenkamp et al., 2008), yet the relationships are sometimes difficult to interpret, as growth limitations or changes in growth patterns are not well known.

In this study the relationships between climatic variables and growth-ring patterns were investigated in *Acacia seyal* Delile, one of the main species in the Sahel. The studied trees came from forestry interventions made by a long-term project of rural development launched in the Sahel (Project Keita in Keita district, Niger). In fact, twenty five years of soil conservation and reclaim interventions makes Keita an open-air laboratory where it is possible to carry out studies on the environmental and socio-economic impact of management actions against desertification. The work described here aimed at studying the growth patterns of *A. seyal* according to site-specific climatic characteristics. To achieve this result we identified the growth rings in *A. seyal*, we measured the ring width and we assessed the climatic response of trees growing in the area.

2. Study area and climatic data

The Keita Valley, part of the Tahoua Region, is located 600 km East of Niamey, in the centre of the Republic of Niger, between 5° 20' and 6° 35' E Longitude and 15° 10' and 14° 20' N Latitude, covering an area of more than 4860 km².

It belongs to the Ader Doutchi-Maggia basin in the north of the Sahelian region. Because of its particular orography and its milder climate, represents a natural barrier against desert advancing. The area is composed of highlands (*plateaux*) with rocky slopes and valleys, forming a complex system of watersheds subjected to strong winds and water erosion. Sandy soils and dunes are the most common edaphic conformation but lateritic surfacing is often present.

The natural vegetation is mainly formed by woodlands dominated by acacias and bushy steppe (*brousse tigrée*) but is characterized by a strong degree of anthropization due to the several environmental reclaim interventions in the last three decades. Indeed, this region was strongly impacted by the drought in 1972–73 and 1984–85, which resulted in a progressive degradation of natural vegetation and agricultural lands. Within the Keita Project more than 19 millions of trees have been planted since 1985. They were part of an integrated approach intervention for water conservation to stop the accelerated erosion triggered by the drought-induced disappearance of the previous natural vegetation cover. Plantations have been realized on *plateaux*, on rocky hills, on *glacis* (sandy-loamy soils of moderate and uniform slope with low permeability), and in valleys. In this study only plantations on the *glacis* have been considered because of their impact in terms of surface and productivity (Di Vecchia et al., 2007) and their great importance for the rural community (they represent a successful example of agro-forestry-breeding integration).

The climate is soudano-sahelian with unimodal distribution of precipitation falling in a short rainy season from May–June to September–October. The average annual precipitation of the last 30 years is 463 mm and the average temperature is 29.12 °C. Climatic data (daily rainfall, mean monthly temperatures) of the Keita weather station (Lat 14° 46' 12"; Long 5° 46' 12") have been provided by the Niger National Meteorological Service.

3. Material and methods

The two sampling sites are located in the Keita district, nearby the villages of Sakarawa-Facko and Ibohamane, approximately 10 km apart, so that it can be expected that they are approximately under the same climatic conditions. Even so, sampling sites showed peculiar environmental characteristics (e.g., slope, soil moisture, exposure). To ensure the independence of tree-ring data, particular attention was taken to select trees with crowns isolated or having enough space between each other (Bascietto et al., 2004).

Wood samples from planted acacias were obtained from trees pruned for this survey and trees collected in 2003 for similar purposes. All trees were planted between 1985 and 1987. Tree height, diameter at 1.30 m and weight (aboveground woody biomass) were measured and recorded. A total of 8 trees were felled and studied. For each tree two discs were cut near the base (30–50 cm) and at breast height. The analysis was conducted with standard dendrochronological techniques (Pilcher, 1990). Discs were dried in a fresh dry-air store, sanded with four grades of grit and finely polished to a high level of clearness. The radii, 2–4 on each disc, were examined under a stereo-microscope (Leica, Germany) at magnification ranging from x10 to x50.

Before ring-width measurements, the presence of the marginal parenchyma bands and rhomboidal crystals was verified according to Gourlay and Kanowsky (1991). Microtome sections of approximately 15 µm thickness were taken and analysed under a light microscope (Leica, Germany) equipped with Cell^A Software Imaging System. Afterwards, microscopic observations have been used to determine ring boundaries and widths. Discs were later analysed under the stereo-microscope to check potential anomalies (i.e., eccentricity, wedging rings) in the tree-ring structure. Ring-widths were measured using LINTAB equipped with TSAP-Win software (Rinntech, Heidelberg, Germany) to the nearest 0.01 mm from bark to the pit. The next step was building the chronology. Ring width was measured along two radii on each disc. First, a visual cross-dating among radii of the same disk was done for identification of errors during the measurements and of potential missing or double rings (Bascietto et al., 2004; Cherubini et al., 2003; Worbes, 1995). Then, the accuracy of measurements was statistically checked using the programme COFECHA (Cook and Holmes, 1999). Curves of each tree were visually and statistically cross-dated and averaged into a site-specific mean chronology (Fichtler et al., 2004). Synchronization between sites was possible and the master chronology (mean for both sites) was used in the correlation analysis with the moisture-related variables. Characteristics of sampling and chronology were reported on Table 1.

Subsequently, a linear regression analysis was done to investigate the relationships between known age of sampled trees and ring

Table 1

Characteristics of sampling and Ibohamane's and Sakarawa-Facko's ring-width series. OVL is the overlap period and r-value is the Pearson's correlation coefficient.

Site	Trees	Cores	Chrono length	OVL	r-value
Ibohamane	5	10	15	12	0.53
Sakarawa-Facko	3	6	20	14	0.73

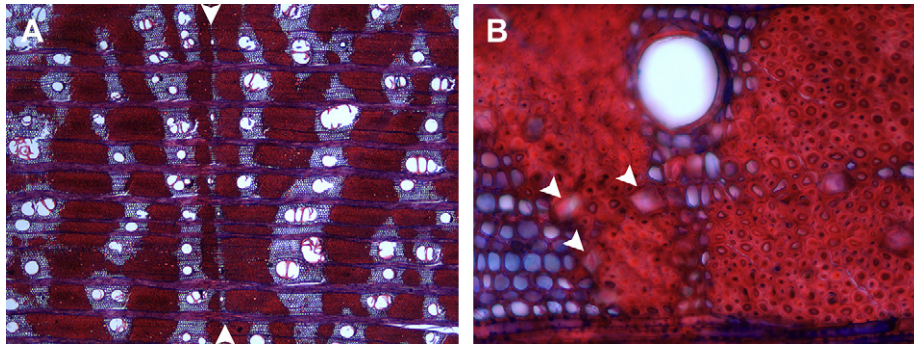


Fig. 1. Transverse sections of *A. seyal*. A: (x 16 magnification) the arrows indicate the parenchyma band (the ring edge) appearing between the aliform-confluent parenchyma. B: (x 25 magnification) large rhomboidal crystals (arrows) along the parenchyma band.

counts. Classic last-square method was used in the regression technique.

To allow the statistical comparison between tree-ring series and their relationship with climatic data, a standardisation of the individual curves is necessary (Cook and Kairiukstis, 1990). Time series were transformed into index-series using the ARSTAN program by detrending and applying an estimation of the mean value function. Based on tree-ring measurements, ARSTAN produces three different tree-wise indexes containing the maximum common signal and the minimum amount of noise (Cook and Holmes, 1999). For the detrending procedure a negative exponential curve was fitted through ring series. Indices were computed dividing measurements by curve value, and the variance were stabilized for each detrended series. We taken absolute deviation from the mean and we fitted negative exponential or regression line fit. Chronology computation was done by means of a biweight robust mean estimation.

Seasonal precipitation, beginning, end and length of the rainy season, mean seasonal temperature and Thornthwaite's P-E (Precipitation-Effectiveness) index were used in the analysis. Rainy season's parameters have been calculated using daily rainfall using the specific methods for Niger described by Sivakumar (Sivakumar et al., 1993). In few cases climatic missing values were computed using those from neighbouring stations of Garhanga (Lat 14° 33' Long 5° 36') and Tamaské (Lat 14° 49' Long 5° 39'). Correlation involved both a visual exploration and a formal computation (Eshete and Stahl, 1999) with a 5% significant level. The investigation was carried out for the common interval of the series, from 1993 to 2006.

4. Results

Anatomical analyses enabled us to detect distinctive growth bands delimited by marginal parenchyma (Fig. 1). Tree-ring wood anatomical anomalies such as double, missing or partial rings are often present but easy to be detected by observing the whole sample disc. Parenchyma cells in the wood structure had regular shape with very thin cell walls. They are often linked with vessels (paratracheal parenchyma) forming irregular tangential bands with a variable width. Fibres form a very dense and undifferentiated tissue, without a clear pattern between earlywood and latewood. Ring boundaries are revealed by marginal parenchyma bands regularly formed by 3–8 rows of cells, frequently hidden by aliform-confluent parenchyma as described by Gourelay and Kanowsky (1991), as shown in Fig. 1A. However, the presence of several large rhomboidal crystals of calcium oxalate (Gourelay, 1995a; Gourelay and Grime, 1994) facilitates the location of rings edges (arrows in Fig. 1B).

The annual ring width varies from less than 2 mm to more than 16 mm with an overall mean of 6.47 mm, i.e. an annual diameter increment of around 13.00 mm. The standard curves for both sites and master standard chronology are showed in Fig. 2.

For trees at Sakarawa-Facko cross-dating was successful for all discs. Total length of series was 20 years with an optimum common interval of 13 years. Cross-dating for the Ibohamane samples was successful for 9 out of 10 radii. The total length of the chronology was 15 years, with a common interval 1994–2003. To build the master chronology a total of 15 series were employed (derived from 8 trees). The time span of the master curve was from 1987 to 2006. The common interval analysis of detrended series was established in a time span from 1993 to 2006 and then dendro-climatological analyses were conducted within this period. Table 2 illustrates the statistics of the two local series and the statistics of the master series in detail.

The relationship between ring counts and known age was detected by the last-squares regression technique forcing a linear trend-line through the origin. This kind of interpolation is useful to represent the annuality of rings but is not completely correct in a statistical sense (Martin and Moss, 1997). The regression analyses without constriction ($\alpha=0.05$) showed a lower slope with an intercept value close by 10 (data not shown). However a slope of 1.15 of the trend-line, according with the results reported by Eshete and Stahl (1999), shows that one tree-ring per year is formed.

The response of trees to climate was investigated testing all the variables separately. Table 3 gives all the Pearson's values of the correlation analysis. For the considered period, results show that the strongest signal in the chronology is due to the seasonal precipitation (Fig. 3) with a Pearson's coefficient of 0.653. Significant correlation was also found with the P-E Index with an r-value of 0.660 (the minimum significant Pearson's coefficient at $\alpha=0.05$ for the considered period with 8 trees is 0.632).

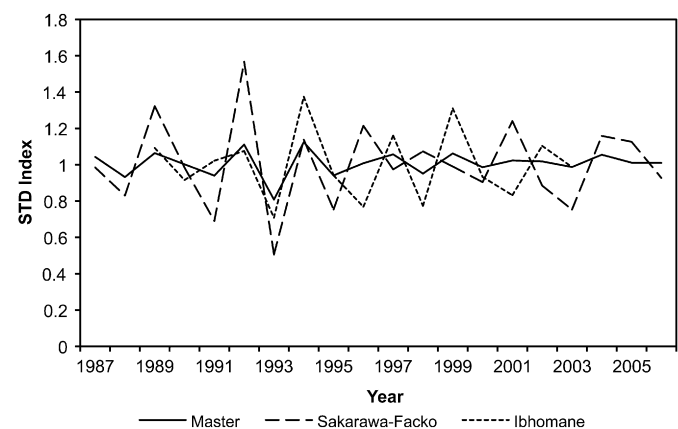


Fig. 2. Standard (STD) index chronologies for *A. seyal* from Sakarawa-Facko and Ibohamane (dotted lines). The continuous line represents the Master series.

Table 2

Statistics of the standard chronologies. In order to quantify the master chronology's strength the Signal to Noise Ratio (SNR) and the Expressed Population Signal (EPS) were used as described in Cook and Kairiukstis, 1990.

Local chronologies			
Statistics	Sakarawa F.	Ibohamane	
Mean	1.001	1.005	
Mean sensitivity	0.351	0.324	
Standard deviation	0.241	0.206	
Mean corr. among all radii	0.549	0.500	
Mean corr. radii vs mean	0.780	0.725	
Variance in first eigenvector	64.79%	55.86%	
Master chronology (time span 1987 to 2006)			
Statistics	STNDRD	RESID (AR2)	ARSTAN
Mean	1.007	1.010	1.003
Mean sensitivity	0.103	0.032	0.174
Standard deviation	0.071	0.038	0.111
Master chronology common interval (time span 1993 to 2006)			
Mean correlations	detrended series	residuals (white noise)	
Among all radii	0.706	0.547	
Between trees	0.642	0.545	
Within trees	0.961	0.917	
Radii vs mean	0.763	0.609	
SNR	6.704	1.226	
EPS ^a	0.856	0.808	
Agreement with population chron	0.843	0.714	
Variance in first eigenvector	78.39%	71.18%	

^a for the EPS Wigley et al. (1984) suggested a minimum value of 0.85 in order to obtain a sufficiently replicated chronology.

5. Discussion

Despite several dendrochronological studies have been conducted on acacia species (February et al., 2006; Gourlay, 1995a; Gourlay, 1995b; Gourlay and Kanowsky, 1991; Mariaux, 1975; Martin and Moss, 1997; Robbertse et al., 1980; Steenkamp et al., 2008) only few authors (Eshete and Stahl, 1999; Tarhule and Hughes, 2002) have studied (marginally) *A. seyal*, one of the most widely distributed tree in Sahelian arid environments. Also, most works are based on trees from natural stands, lacking the background information necessary to reconstruct the tree-life history (Gourlay, 1995a). In this study, the use of samples of known age and known management history enabled us to confirm the dendrochronological potential of *A. seyal*. Although some constraints caused by the specific wood-anatomical features (some ring anomalies, aliform-confluent parenchyma), ring boundaries are through the marginal parenchyma bands clearly visible and reliable for assessing tree age univocally. The mean annual radial increment (6.34 mm/year) agrees perfectly with values reported in other studies of acacia species growing in similar ecosystems (Gourlay, 1995a; Gourlay, 1995b; Gourlay and Kanowsky, 1991; Mariaux, 1975).

The regression line describing age against ring count confirms that one ring per year should have been formed (age = 1.15 ring count). Discrepancies found in some cases could be explained by several different reasons such as the actual physiological tree age at the planting time (the seedlings in rare cases may have been 2 year

Table 3

Correlation between the master chronology and climatic data of the Keita district. Ring width is significantly correlated with precipitation and P-E index of the current year (Curr. year).

Precipitation	Rainy season		Mean Temperature		Aridity		
Curr. year	Prev. year	Beginning	End	Length	Curr. year	Prev. year	P-E Index
0.653	-0.265	-0.206	0.230	0.299	-0.209	0.115	0.660

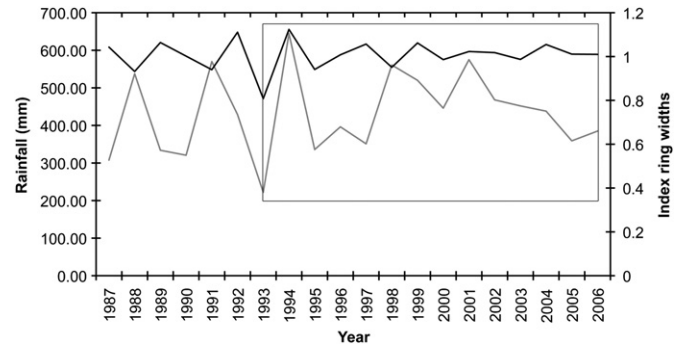


Fig. 3. Master chronology (black line) plotted against the seasonal precipitation (grey line). For the investigated period (highlighted by the box) a correlation coefficient of 0.653 was found.

hold instead of 1), the sampling height, undetected missing, double or false rings. Further complication may arise from the extreme variable phenological behaviour of this species, strongly related to soil moisture (Bremen and Kessler, 1995; Cissé, 1980).

The standard chronologies were obtained averaging the detrended tree-ring index series by a biweight robust mean to remove effects of endogenous disturbances or the growth trend and should show a climatic signal, if present. Successful cross-dating among trees indicate that trees were influenced by a common limiting factor. This is confirmed by the similar statistical parameters found for the site-specific curves (see Table 2). For example, the high mean sensitivity, showing strong interannual variability, suggests that tree growth is strongly influenced by some environmental factors that impact all trees in a similar way.

Precipitation, during the rainy season, seems to be the most important climatic factor that influences ring-width growth.

Unlike other studies (Eshete and Stahl, 1999; Fritts, 1962) introducing a lag of 1 or more years in the index chronology entails a decrease in correlation.

Also the Thornthwaite's P-E index shows a very high value of Pearson's coefficient (0.660) confirming the strong role of evapotranspiration on tree life cycle at these sites.

The response of tree growth to the mean seasonal temperatures and to the rainy season's features seems to be weak, pointing out in every case not statistically significant correlations.

In conclusion, we can confirm that *A. seyal* forms one tree ring per year, i.e. annual rings. This allowed us to detect a climatic signal in tree-ring series, i.e. the influence of the precipitation of the current year's rainy season, and to state that *A. seyal* has dendrochronological potential even in the Sahel.

The analysis presented here is based on a relatively small number of sample trees with a short time period covered by the chronosequences. We preferred to cut trees in order to analyse cross section rather than cores (Eshete and Stahl, 1999), but cutting trees in this region should be restricted to a minimum for conservative purposes. Moreover, the studied ecosystem is of recent formation because of very heavy anthropogenic impact, with consequences on the age of the trees (25 years are the maximum).

To improve the reliability of the results found here, further long-term studies are necessary. Understanding the growth dynamics and their interactions with climate in such region is fundamental for developing adequate strategies in environmental reclaim actions, there, where desertification begins.

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