Source: Maaten-Theunissen M, Spiecker H, Gärtner H, Helle G, Heinrich I (Eds.) (2011): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 9. GFZ Potsdam, Scientific Technical Report STR 11/07, Potsdam, p. 143 - 148.

# Exploring climatic signals in stable isotopes of *Sclerocarya birrea* tree ring chronologies from the Sahel region in West Africa

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## Introduction

The instrumental record of climate is just too short to understand how climate changes in Africa. Although a number of proxy data series have been developed from temperate and subtropical regions to trace the course of environmental and climatological fluctuations, precise palaeo-climate records from the tropics, notably from Africa, are still sorely lacking (Gebrekirstos 2009a). Therefore, it is central to identify potential climate proxies that could provide empirical data regarding past climatic events and its impact on important agroforestry species.

Tree ring widths and stable isotopes in tree rings have been successfully used as climate proxies in temperate regions. Recently some progress has been reported with regard to the potential of tree rings as climate proxy in semi-arid Africa (Gebrekirstos et al. 2009b, Gebrekirstos et al. 2011, Trouet et al. 2006, Fichtler et al. 2004, Wils et al. 2010). Gebrekirstos et al (2009b) demonstrated the potential of $\delta^{13}C$ in tree rings of Acacia species to reflect physiological responses to environmental and climate changes as a tool for paleoclimatic reconstructions in Ethiopia. High correlations (up to r = -0.82) were found between the $\delta^{13}C$ chronologies and precipitation data, which demonstrates their potential to reconstruct precipitation in semi-arid tropics. Wills et al (2010) also demonstrated the use of $\delta^{13}C$ in *Juniperus procera* by reconstructing the flow of the Blue Nile River.

In this context, we extend the study to West Africa in Burkina Faso (Sahel region) and East Africa in Tanzania (Miombo woodland). The overall purpose of the study is to establish large-scale correlation patterns between tree growth, precipitation and temperature that are affected by the Indian Summer Monsoon (ISM) and the West African Monsoon (WAM) in East and West Africa, respectively. This knowledge will help us to explore local and regional climate processes. In this paper we present preliminary pilot results that indicate the potential of stable oxygen and carbon isotopes in tree rings of *Sclerocarya birrea* from the Sahel region in Burkina Faso as a climate proxy.

## Methodology

*Study site and climate*

Six samples of stem disks were collected from Sahel region in Burkina Faso (Tugure), (N13°22'17,5" W00°28'16,7") (Fig. 1). The rainfall distribution of the study region is uni-modal within a rainfall range of about 500 to 600 mm (Fig. 2). The rainy season starts in May and extends to September, with the wettest month in August. Mean annual temperature is 37 $^{o}$C with the hottest months from March to May (about 40 $^{o}$C). Burkina Faso has three major climate regimes, the Sahel in the north, the Sudan Guinea zone in the south and the Sudano Sahel in transition (Fig. 1). The Sahel zone climate is influenced by the Sahara desert and the WAM.

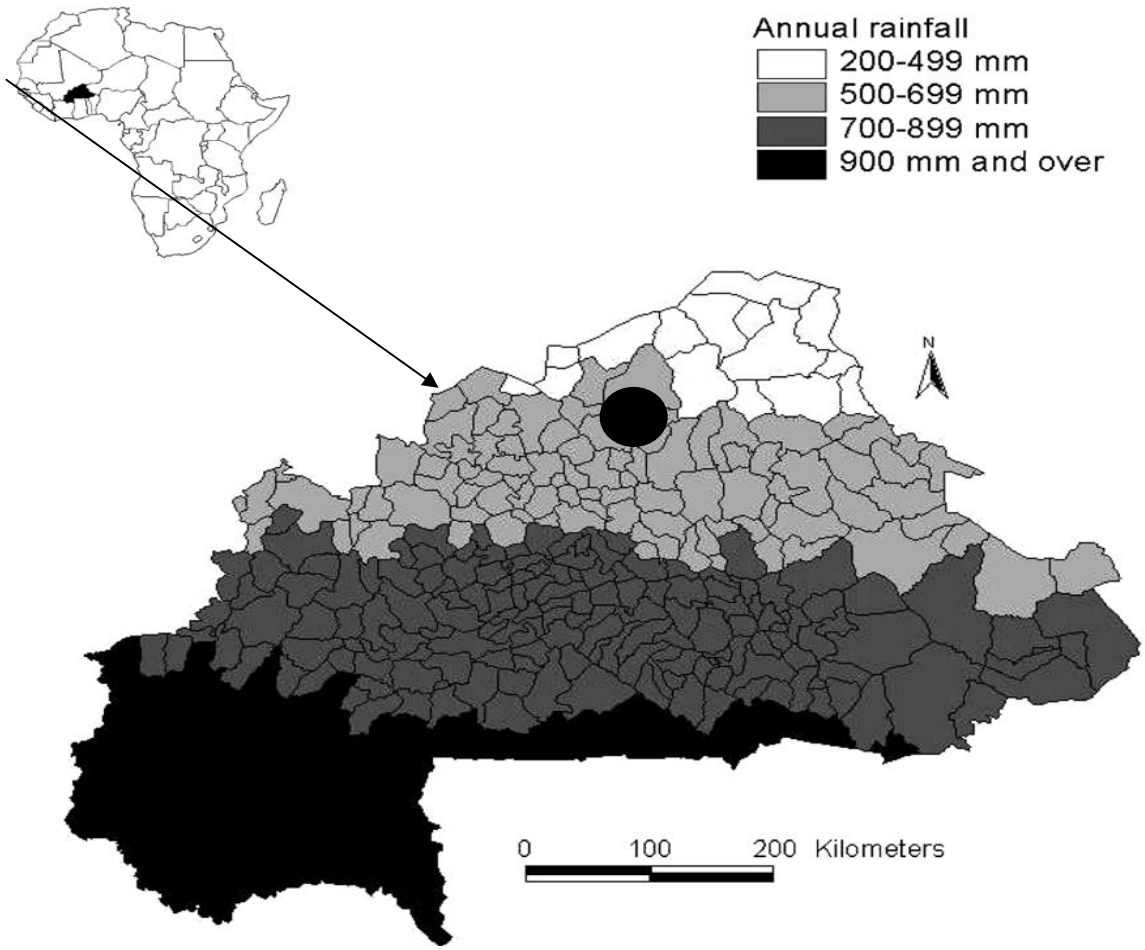


*Figure 1: Location of the study area Burkina Faso in West Africa. The circle indicates the location of the study site (village Tugure)*

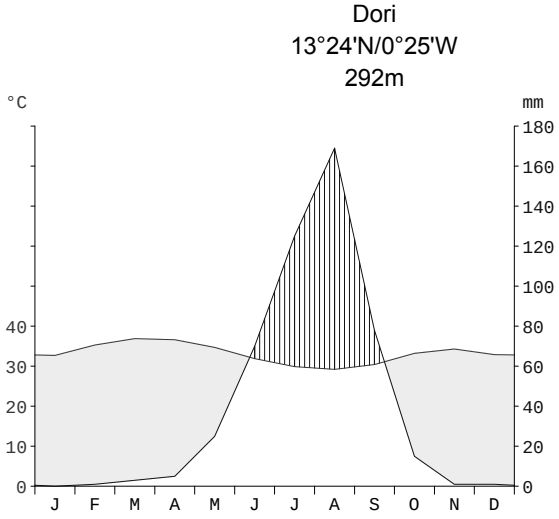


*Figure 2: Climatic diagram from Dori station drawn according to Walter (1973). Rainfall (mm) and temperature (°C) data (1987–2007) were obtained from Burkina Faso Meteorological Agency.*

*Study species and measurement of stable isotopes*

For the $\delta^{13}C$ and $\delta^{18}$ O pilot measurements, we selected two stem disks of *Sclerocarya birrea* that had been dated using standard dendrochronological procedures. *Sclerocarya birrea,* a deciduous tree that belongs to the family Anacardiaceae, is found in most parts of Africa. It grows to a height

of about 20 m.The $\delta^{13}C$ and $\delta^{18}$ O analyses were performed for each individual at one-year resolution from 1983 to 2007. Powdered samples were produced from two to three radii of each tree using a drill width of 0.5 mm (Fig. 3b). The powders were pooled into tin capsules and homogenized with a metal stick to represent the whole ring. The disk was cleaned with compressed air after collecting each sample to avoid cross contamination. We used bulk wood for this investigation. From each sample, 1 mg and 0.2 mg of powdered wood was used for the $\delta^{13}C$ and $\delta^{18}$ O measurements, respectively. This was carried out at the Center for Stable Isotope research and Analysis, Forest Ecosystem Research, University of Gottingen, Germany.
The trend in $\delta^{13}C$ series related to the decline in atmospheric $\delta^{13}C$ values was removed following the method described in Mc Carroll & Loader (2004). To determine the relation between the $\delta^{13}C$ and $\delta^{18}$ O values and climate variables, we used precipitation (monthly and annual), Palmer Drought Sensitivity Index (PDSI), mean relative humidity, sun shine hours, maximum temperature and evapo-transpiration. The climatic data were obtained from Burkina Faso Metrological Agency, except for PDSI data which we obtained from Dai et al. (2004). We used the climatic data from Dori station, which is the closest available station to our study site. STATISTICA for windows (Version 6.0) was used as a tool for the data analyses. Unless stated otherwise, results are statistically significant at $P<0.05$.

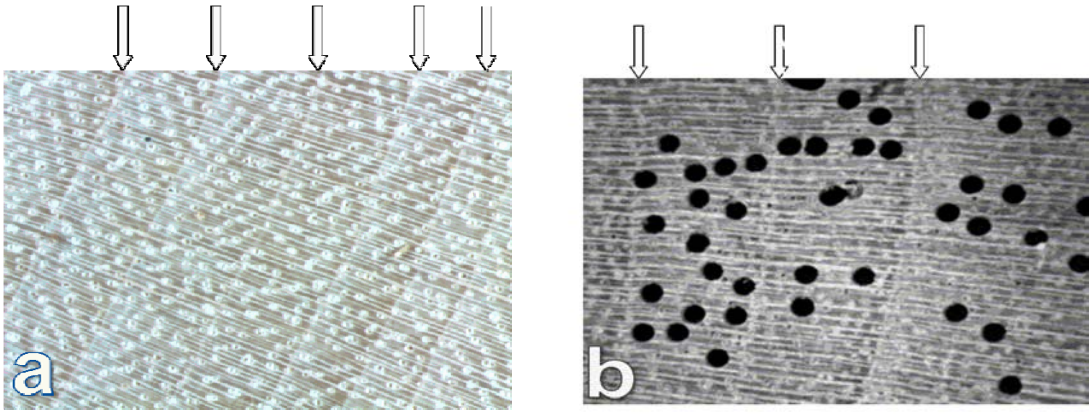


*Figure 3: Cross-sections of Sclerocarya birrea a) arrows indicate annual growth boundaries b) method of sample preparation. Black dots represent holes drilled for obtaining wood material for stable isotope analyses.*

## Results and Discussion

### *Formation of growth boundaries*

This pilot study explores the formation of growth boundaries and potential of stable isotopes in tree rings of *S. birrea* for climate reconstruction in the Sahel region. *S. birrea* forms very distinct rings characterized by marginal parenchyma bands, which run around the entire stem disc (Fig. 3a). This is in agreement to the phenology of *S. birrea,* which is a drought deciduous species that sheds its leaves during the dry season. The study area is marked by uni-modal rainfall distribution and about eight months of dry season that triggers formation of annual growth boundaries. Compared to the drought deciduous *Acacia* species in Ethiopia (Gebrekirstos et al 2008), ring formation in *S. birrea* is very distinct.

### *Inter annual $\delta^{13}C$ and $\delta^{18}$ O variations*

The preliminary results showed that the inter-annual patterns of $\delta^{13}C$ and $\delta^{18}$ O ratios in tree rings of *S. birrea* are uniform between the two individual trees indicating that marked fluctuations in stable isotope ratios are synchronous. This is further confirmed by cross-correlation analyses of the species mean $\delta^{13}C$ series ($r = 0.42$) and $\delta^{18}$ O ($r = 0.62$). The $\delta^{13}C$ and $\delta^{18}$ O values range from -24.6‰ to -26.7‰ and 21.24‰ to 25.45‰, respectively. However it is worth noting that the

statistical correlations we mentioned in the following are still preliminary and might change as a result of increasing sample length and depth in the future.
$\delta^{13}C$ and $\delta^{18}$ O mean values also showed similar variation patterns and significant positive correlations (r = 0.53). The similar pattern within and between $\delta^{13}C$ and $\delta^{18}$ O ratios indicate that external factors affected isotope fractionations in a similar way.

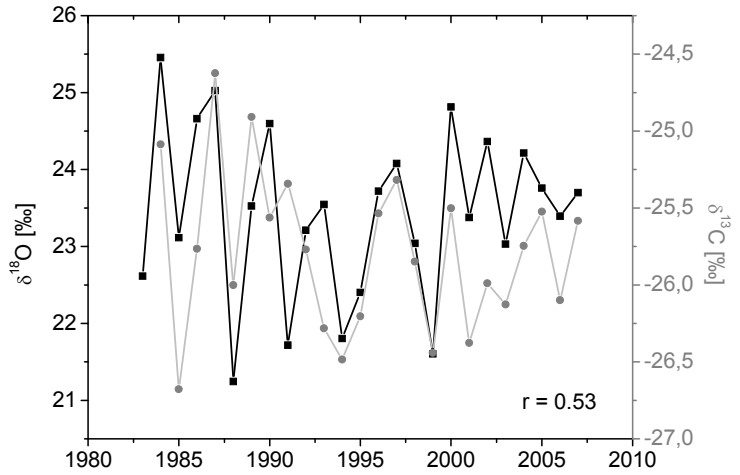


*Figure 4: Sclerocarya birrea $\delta^{13}C$ and $\delta^{18}O$ patterns and correlations*

## *$\delta^{13}C$ , $\delta^{18}$ O and climate*

*Sclerocarya birrea* responded to the short rains that normally started around May and showed significant correlations to the rainy season (July-September). In general, both $\delta^{13}C$ and $\delta^{18}$ O showed negative correlations with rainfall, humidity and PDSI. In the contrary they showed positive correlations with sun shine hours, maximum temperature and evaporation. Furthermore, precipitation in August (the wettest month) proved to have a stronger influence on the $\delta^{13}C$ and $\delta^{18}O$ isotopic variations than annual precipitation.
Some of the relationships mentioned are explained by the covariance of some climatic factors, e.g. high rainfall would mean higher relative humidity and PDSI. Consequently, stomatal conductance would be enhanced that leads to the depletion of $\delta^{13}C$. In dry years moisture stress would lead to stomata closure and enrichment of the heavier isotopes (e.g. Gebrekirstos et al. 2009b, Wils et al 2010). Similarly, negative correlations with $\delta^{18}O$ also reflects that $\delta^{18}O$ in tree rings of *S. birrea* records dry and moist years. During drier conditions it will be harder for the heavier isotopes to evaporate and hence heavier concentration of $\delta^{18}O$ that indicated drought years. In contrast, depletion of the heavier isotope $\delta^{18}O$ indicates moist years. Treydte et al. (2010) reported that $\delta^{18}O$ in tree rings primarily record the source water information. Hence, the significant correlation of $\delta^{18}O$ with precipitation amount in the rainy season would also reflect that the main source of water for the growth of *S. birrea* is soil water.

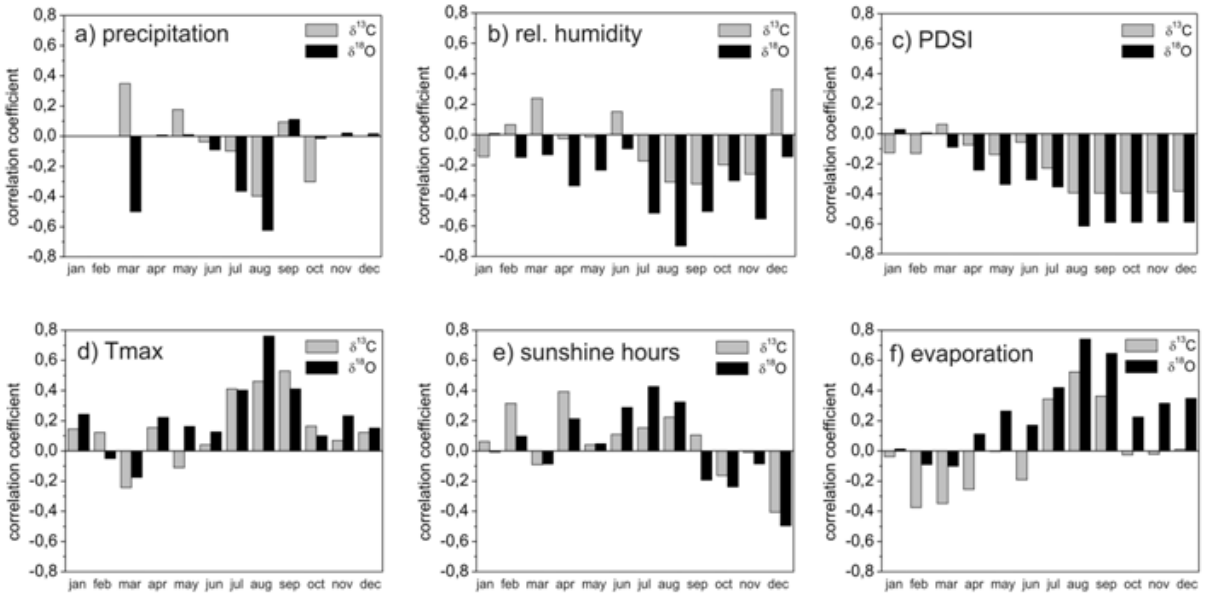


*Figure 5: Correlation between Sclerocarya birrea $\delta^{13}C$ and $\delta^{18}O$ and climate parameters*

## Outlook

The pilot measurements showed the potential of stable isotopes in tree rings of *S. birrea* as climate proxy. The oldest tree we found in Tugure (the present study site) is about 130 years. Our ultimate objectives are 1) to develop longer tree ring chronology from different agro- ecological zones influenced by different climate regimes to put the short instrumental record including the Sahel drought events into a longer perspective. 2) to investigate the impact of climate variability on the growth and water use of the species in the face of climate changes.

## Acknowledgments

We are grateful to BMZ and GTZ for funding the projects in Burkina Faso (ALUCCSA) and Tanzania (ReACCT). Our sincere thanks to Dr Jules Bayala and Jonas Koala for their help during the field work in Burkina Faso, and Reinhard Köpp for polishing the wood samples.

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