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RELATING *Acacia senegal* (L) willd. GROWTH TO RAINFALL IN NORTH EASTERN NIGERIA USING TREE RING ANALYSIS

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ABSTRACT

Many tropical regions showed one distinct dry season. Often, this seasonality induces cambial dormancy of trees, particularly if these belong to deciduous species. This will often lead to the formation of annual rings. This study analysed Annual tree ring formation and climate-growth relationships and examined its dendrochronological potentials. Ring widths were assessed on stem discs of a total of six (6) trees selected from two zones (Nguru and Gujba) in Yobe State, Nigeria. Ring width and monthly rainfall data were collected to provide the annual character of the tree rings for the study species. Annual character was assessed by counting rings on trees of known age and by radiocarbon dating. Data collected were subjected to descriptive statistics and correlation matrix. It was revealed that the mean annual radial growth rate was 3.6 mm/year in Nguru and 8.13 mm/year in Gujba. Ring width index showed annual patterns similar to seasonal precipitation in both provenances. Correlations of the ring widths and precipitation showed that tree growth was significantly positively correlated with the precipitation in the arid region. *A senegal* in the two provenances showed a different response to precipitation. The pattern of sensitivity showed a slightly different response to precipitation. Cross dating of annual ring width growth was successful within and among selected *Acacia senegal* trees, which indicates that this species forms annual rings and that growth responds to an external climate variability. The result demonstrated that tree rings from the species of two zones can be successfully applied in the tropics.

Keywords: *Acacia senegal*, Annual tree ring, Dendrochronology, Climate–growth relation and Radiocarbon dating.

INTRODUCTION

Acacia genus mainly growing in the arid and semi-arid environments of Africa, the Middle East and the Sub-continent of India (Beyene, 1993, Gorain, 2014) and with most of them produce natural gum of different types. *Acacia senegal* and *Acacia seyal* are observed to be of commercial importance (Beyene, 1993, Coppen, 1995, Abdel Magid *et al.*, 2014). The highest quality gum Arabic yet, is obtained from the grey-barked *Acacia senegal*. *A senegal* is highly tolerant to rainfall and temperature variations. In Nigeria, it grows mainly in North Eastern region (Omokhafe *et al.,* 2007, Ibrahim *et al.*, 2014), where annual average precipitation falls between 180 mm and 350 mm (Abaje *et al.*, 2012). One of the most important environmental threats to agricultural production responsible for a reduced yield is drought stress (Bartels and Phillips 2010, Bibi, 2014). Droughts have been occurring in North Eastern Nigeria for decades (Abaje*et al.*, 2011, 2013, Kayode and Francis 2012, Bibi *et al.,* 2014) and it is a reoccurring phenomenon in this area.

One way of recreate past climatic conditions and assess tree responses to climatic changes are through tree-ring studies (dendrochronology) (Schöngart, *et al.*, 2006). Many studies had shown that tree-ring data are very useful for the assessment of past climatic variations (Worbes, 2002, Hughes 2002, Gebrekirstos *et al.*, 2008, García-Suárez *et al.*, 2009). Tree growing on more favourable site may exhibit little tree ring response to climatic variation. However trees growing on severely limiting sites often have significant growth responses to drought (Maingi, 2006). Tree ring studies represent an important approach to understanding the long term impact and dynamics of climatic variations (Tarhule and Hughes, 2002) at species, community and land scape levels. (Abrams *et al.*, 1998).

In the temperate region trees had been revealed to only record the growing season (Harley*et al.*, 2012, Galván *et al.,* 2014) and show to be a dependable mean of assessing tree growth rate (Worbes, 2002, Mousseau *et al.,* 2013). Unlike the temperate regions trees in tropical regions grow all year round and therefore show no real obvious annual growth rings (Schweingruber, 1988 and Brienen, 2005), and the absence of annual growth ring (Lieberman *et al*., 1985) was believed to be due to a non-existence of clear seasonality (Brienen, 2005). Tree ring in the tropical tree species are frequently anatomically less distinct than those of the temperate area (Brienen, 2005). Three features impaired tree ring formation in dry tropical environments (Wils *et al.,* 2011) ,''First, tree rings are often discontinuous along the circumference of the tree (partial rings), Second, the response to environmental conditions tends to vary strongly between species and individual trees, depending on variability in for instance wood anatomical structure, habitat, nutrient availability, rooting depth and growth history. Third, and most profoundly, many trees do not experience true dormancy''.

Tree ring width varies among and within species from year to year in response to climate fluctuation during the growing season. Some growth rings are easy to identify, while others are nearly invisible and the distinctiveness is determined by seasonal variation in cell-diameter and cell wall thickness and by the distribution of different kinds of cells within the wood (Hoadley, 1990). Annual tree ring formation in the tropics occurs in area where trees experience cambial dormancy in one period of the year due to environmental conditions (Worbes, 1999). A dry period of at least two months with less than 50 mm of rain would be required to expect annual rings in tropical tree species (Worbes, 1999) and small annual variation in rainfall occurring under ever wet conditions may trigger ring formation (Fichtler *et al.,* 2003). In arid and semi-arid of sub-Saharan Africa of where droughts is a reoccurring phenomenon, annual tree ring growth may still be detected (Jacoby, 1989); also increasing drought will reduce plant productivity cause ring boundary formation (Wils *et al*., 2011), furthermore studies have successful reported correlations between tree ring and climatic variable (Therrell *et al*., 2006; Trouet *et al*., 2006, 2010).

Studies of *Acacia* spp. had showed that tree rings are present (Eshete and Ståhl 1999; Gebrekirstos*et al*., 2008 and Wils,*et al*., 2011). Annual rings in Acacia spp growing under bimodal rainfall conditions were sometime double with a wider and narrower ring corresponding to the long ring boundaries in African Acacia species are delimited by long calcium oxalate crystal chains and repeatedly marginal parenchyma cells (Eshete and and Ståhl, 1999; Nicolini *et al.,* 2010 andWils, *et al.,* 2011). However such studies have never been report in the arid and semi-arid environments of North Eastern Nigeria. To enjoy the benefits of sustainable management of acacia woodlands, a better understanding of their dynamics is important and of the fundamental element in this regard is the knowledge of growth rate and yield of main tree species (Eshete and Ståhl, 1999). This study will also help to understand species dynamics and ecology, including response to climate variability and change.

The relationship between climatic variables and growth-ring patterns were investigated for *A senegal* (L) Willd. in two contrasting areas in North Eastern Nigeria. The aim was to establish whether or not one tree-ring per year could be expected and to determine the correlation between tree-ring and moisture-related variables in the region.

MATERIALS AND METHODS

Study area

This study was undertaken in two contrasting areas, Nguru (arid) 12.53°N, 10.28°E alt. 343m and Gujba (semi-arid) 11.30°N, 11.56°E alt 456m, the two locations chosen provide differences in climatic parameters with different soil type, representing two Gum Arabic growing areas in Yobe State, one of the states within the sahelian zone (Fig.1), it has a land area of 4715.3 ha, and is located between lat. 10.5° N and 13° N and long. 9.5°E and 13°E (Fig 1), it is characterized by semi-desert grassland, shrub lands and wooded grasslands, in which acacia species play a dominant role.

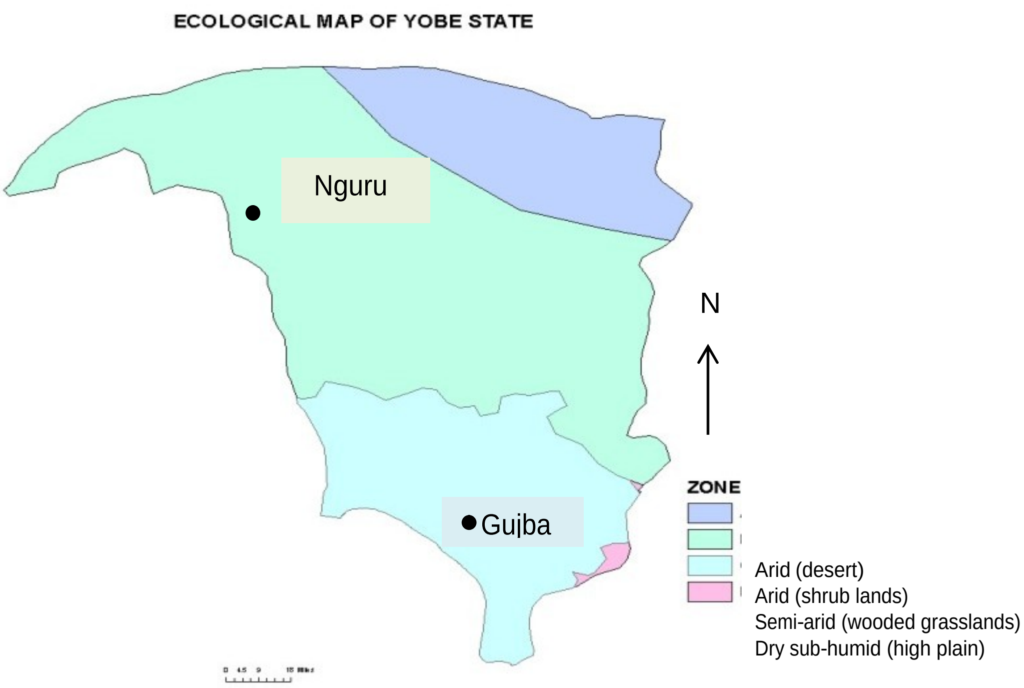

Figure1. Ecological map of Yobe state, showing the sites locations

Climatic data

The Weather data for Gujba and Nguru were obtained from the Nigerian Meteorological Agency (NIMET) Abuja and covered a period of 40 years (1970-2010). The data include total monthly precipitation and monthly means of daily maximum and minimum temperatures for those years. The climate in Gujba is characterized by a distinct dry season with no rain between November and April, while the rainy period occur from May to October with an annual drops ranging between 300mm to 500mm, lasts 120 to140 days, the average temperatures during the hottest periods of the year is 35°C and in Nguru it is characterized by a distinct long dry season with no rain between October and May, and a rainy period occurring from June to September, the rainfall lasts between 80 to 100 days with annual drops ranging between 200mm to 500mm, with average temperature during the hottest periods of the year recording over 40°C. The average monthly distribution of precipitation and temperature for Gujba and Nguru sites are shown in Figure 2a and b.

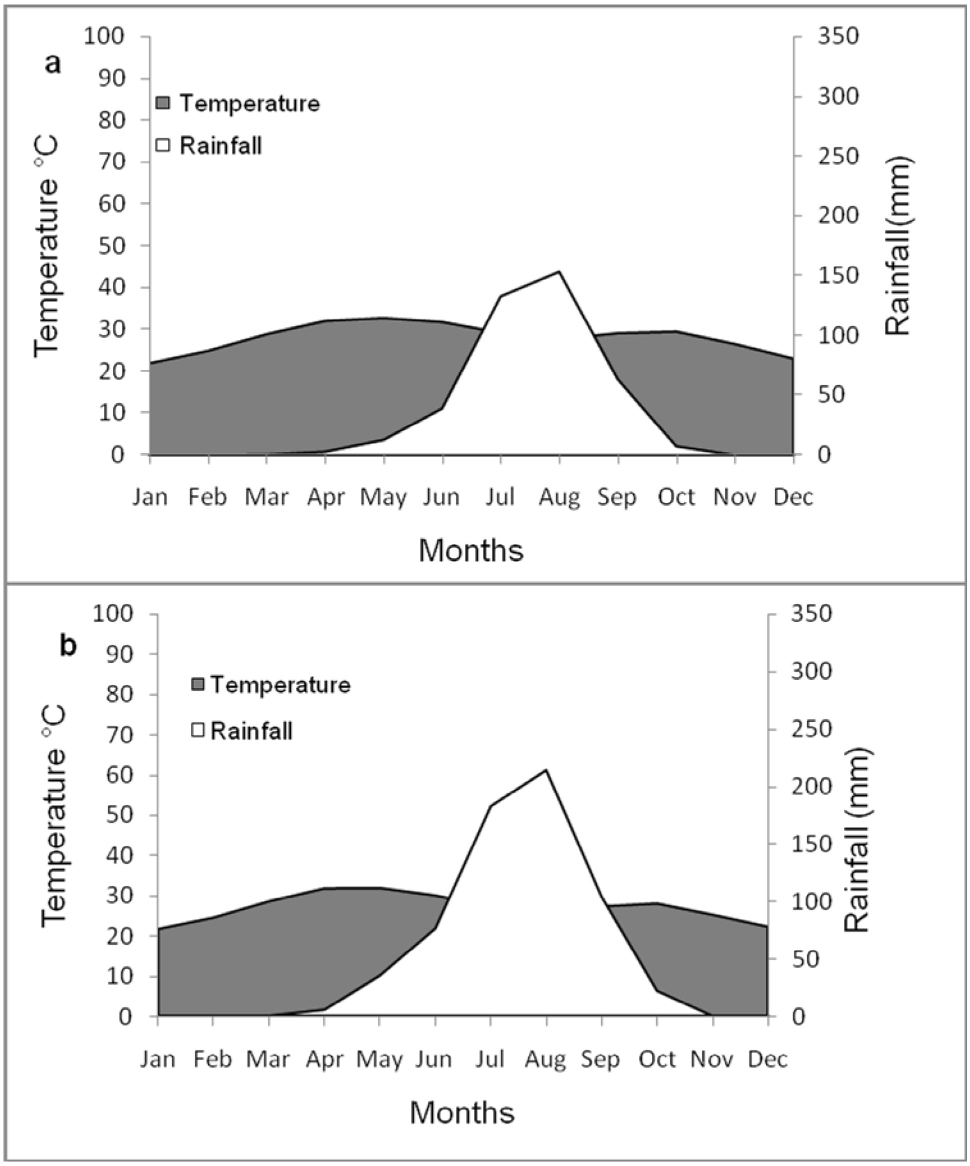

Figure 2a and Figure 2b. Climate diagrams of (a) Gujba and (b) Nguru, rainfall and temperature for 1971-2010. The dry period (curve; November-April), the rainfall period (curve; May- October)

Samples

A total of 6 trees were felled and collected in 2011for this study, wood samples were taking from *A senegal* trees of known age for each tree, a cross-sectional wood disc was taking with a chainsaw for about 0.3 to 0.5 m above ground this was to maximize the estimation of the tree age as the number of rings decrease with height, all samples were then labelled and air dried. The prepared and examine of the disc was a challenge because of lack of an on-site facility for surfacing the samples. The samples collected from the study area were not polished and examined for their rings until the specimens arrived at University of Aberdeen UK. On arrival in Aberdeen, the stem discs were mechanically surfaced and then manually polished with a series of successively finer grades of sandpaper until the structure was clearly visible and analyse for tree ring (Figure 3a and b).

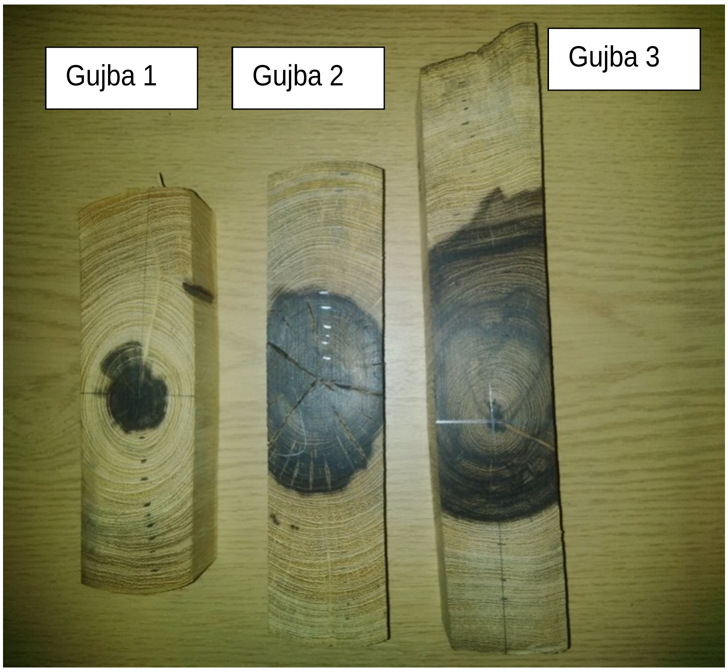

Figure 3a: Mechanically surfaced and manually polished stem discs for Gujba provenances of different age (Gujba1 = 10-12 years, Gujba 2 = 15-20 years, Gujba 3 = 25-30 years).

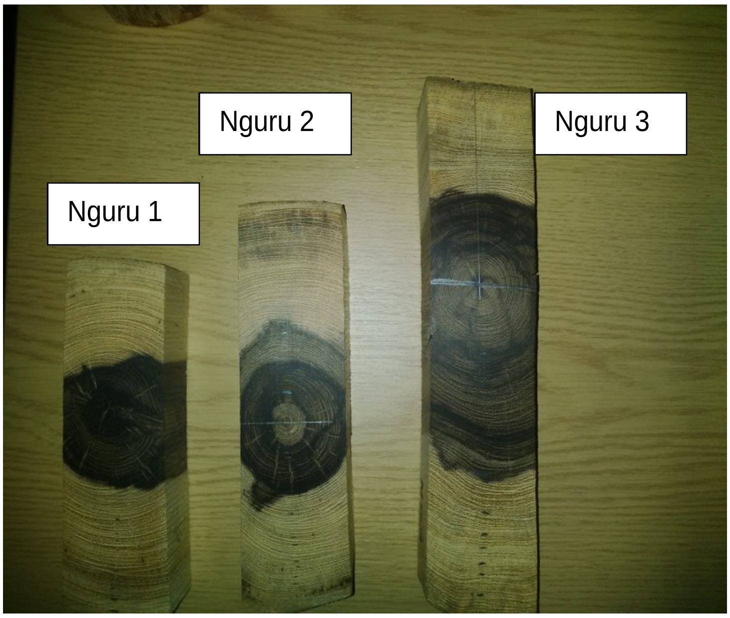

Figure 3b: Mechanically surfaced and manually polished stem discs for Nguru provenances of different (Nguru1 = 10-12 years, Nguru 2 = 15-20 years, Nguru 3 = 25-30 years).

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The ring boundary for each year was examined and verified circumferentially between two radii of each disk and the presence of the marginal parenchyma bands was verified. Total ring widths were measured to the nearest 0.001 mm by using a Digital position meter ring width analyser interfaced with a computer (Figure 4), measurements from the bark to pith form the north and south directions averaged, at magnification ranging from x10 to x50, to determine ring boundaries and widths. Cross-dating was conducted between samples from the same site. After verification of successful cross-dating, digital images were made using digital camera. The digital image acquired was then employed to asset annual tree ring formation and for the measurement of ring width by using software from ImageJ (Rasband, 2014). A ring width index was created for each core by dividing the yearly measured growth value by the base year value (Veblen *et al.*, 1991).

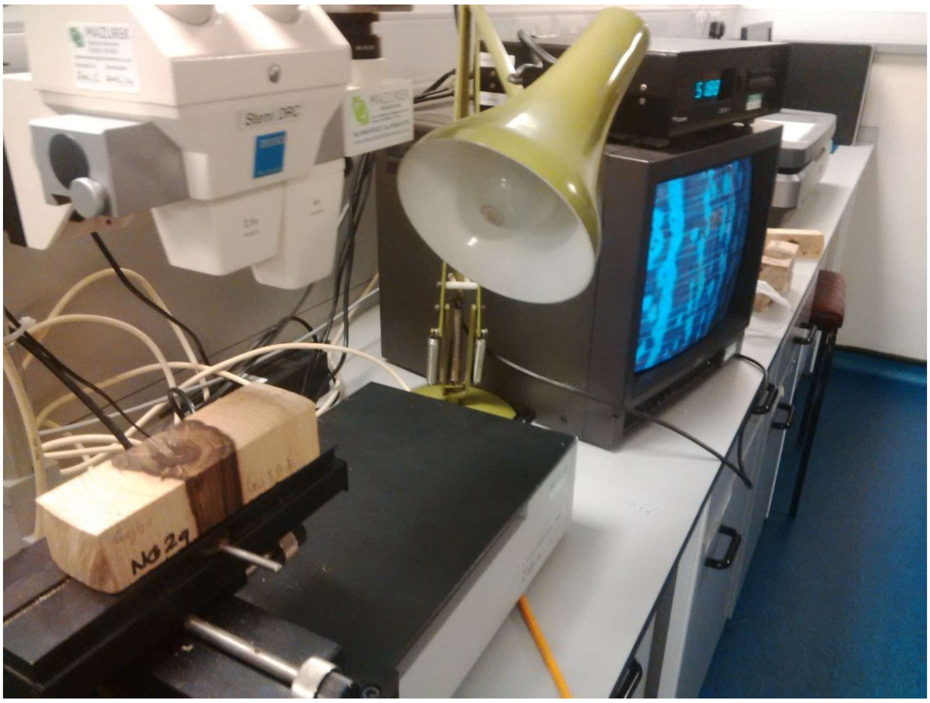

Figure 4: A Digital position meter ring width analyser interfaced with a computer.

Data Analysis

Various parameters were calculated to assess their liability of the chronologies. Pearson's correlations between pairs of chronologies were used.

RESULTS

Samples collected from two different sites showed variation in ring visibility. Distinctness of ring were identifiable but with difficulty in some samples and uncertainty in identifying ring boundaries in other samples, making some growth ring characteristics difficult. The border of ring is presented like single circular line. *A senegal* form distinct tree-ring boundaries (Figure 5).

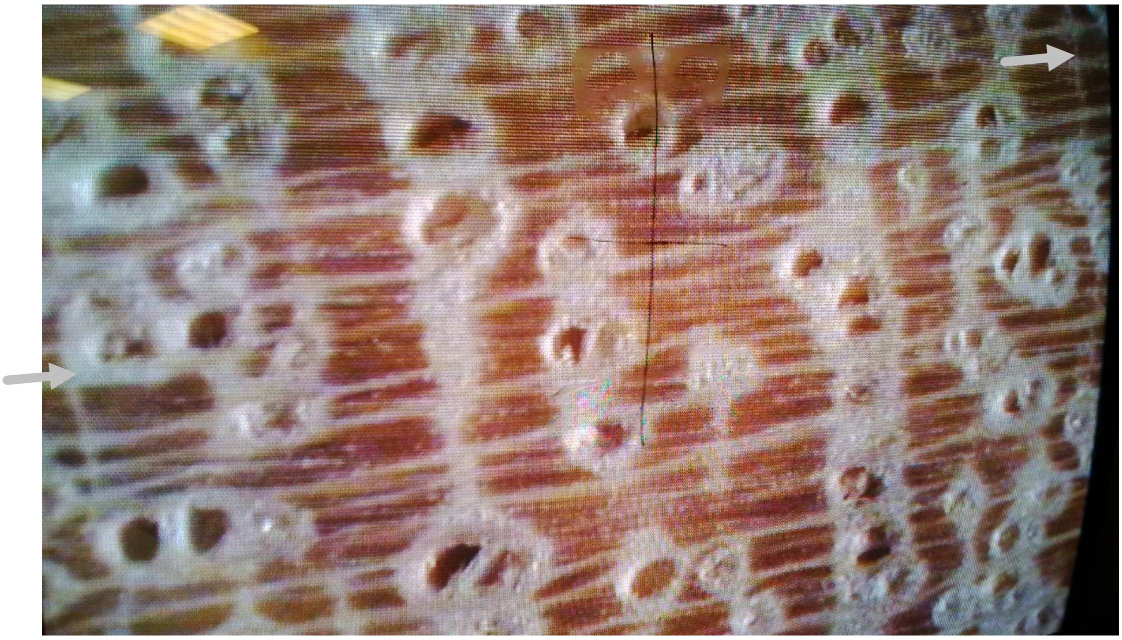

Figure 5: Wood anatomy of *A.senegal* showing growth rings in a disc sample boundaries of annual rings are indicated by arrows. Tree-rings are characterized by marginal parenchyma bands.

Cross-dating

Since no previous dendrochronological studies have been carried out anywhere in the Study area, it was necessary first, to identify if *A. senegal* produced discernible rings. Cross-dating of annual ring width growth was successful within *A senegal* trees, in Gujba (figure 6) and Nguru (figure 7), which indicates that this species forms annual rings and that growth responds to an external climate variability. Successful cross-dating among trees indicate that trees were influenced by a common limiting factor.

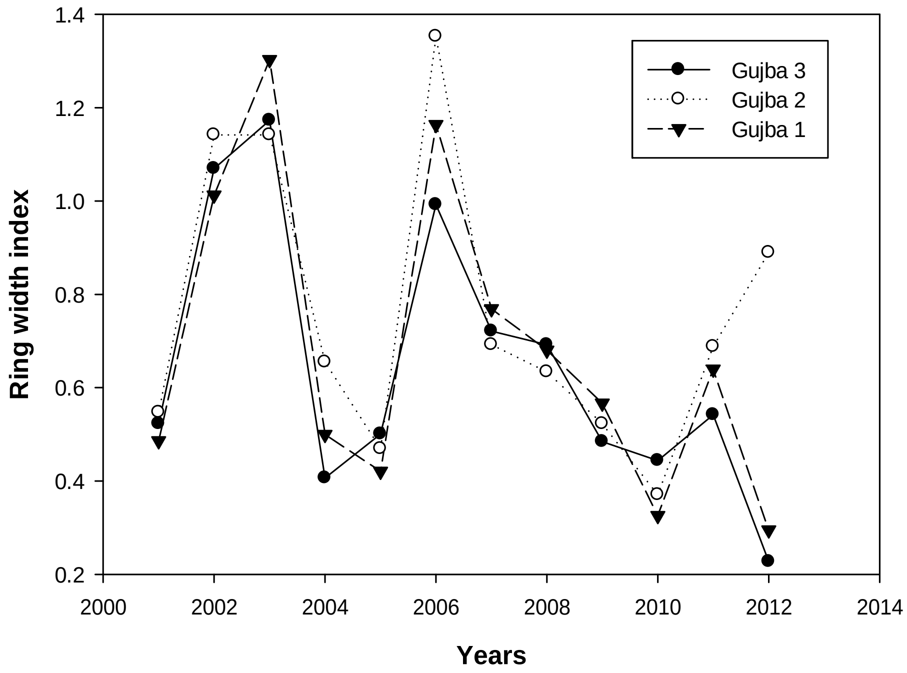

Figure 6: Cross-dating of annual ring width growth within *A senegal* trees, in Gujba provenances of different age, using ring width measurement.

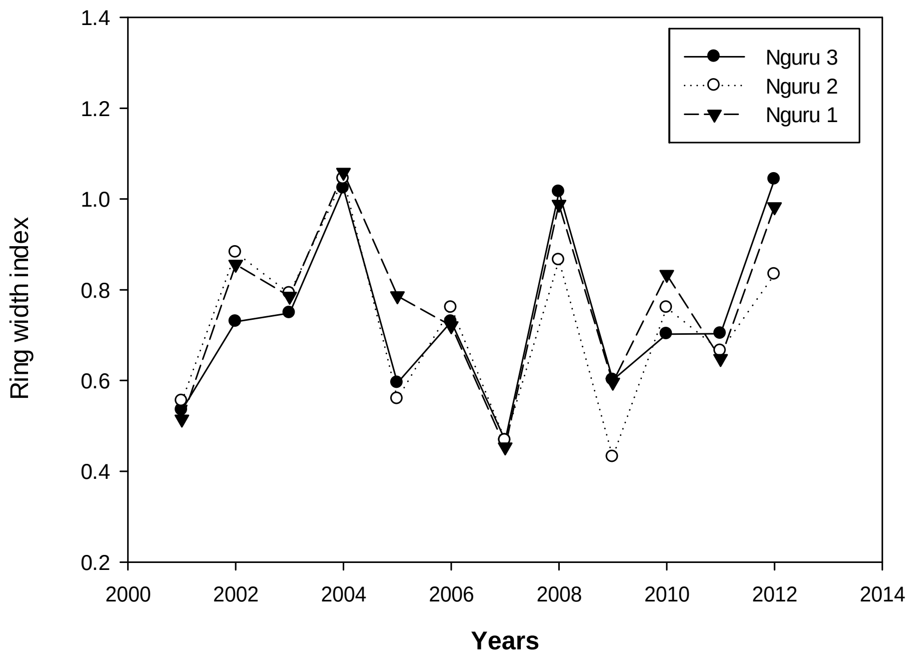

Figure 7: Cross-dating of annual ring width growth within *A senegal* trees, in Nguru provenances of different age using ring width measurement.

Ring width index showed annual patterns similar to seasonal precipitation in both provenances. The high similarities are evident in the graphs between season (years) precipitation data and mean ring width index (figures 9 and 8).

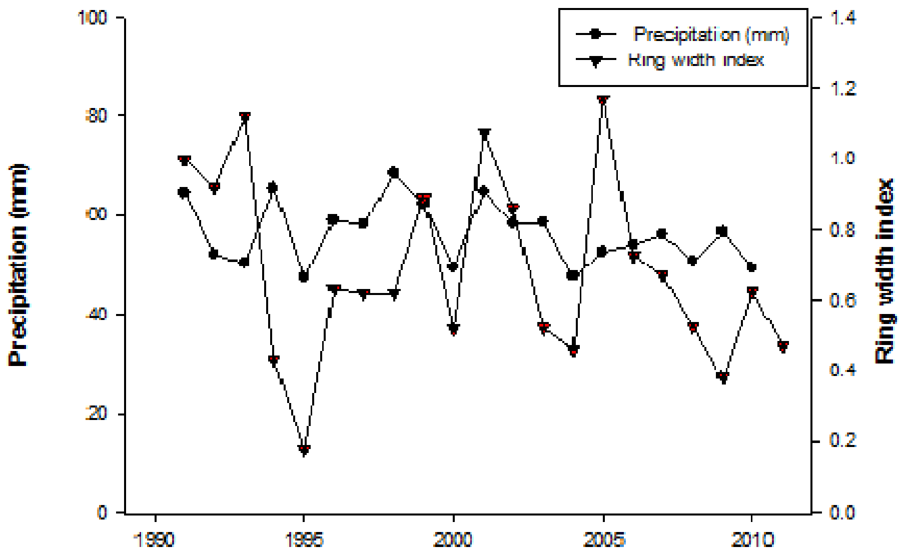

Figure 8: Annual ring width index and precipitation against time 1990-2010 in Nguru (arid).

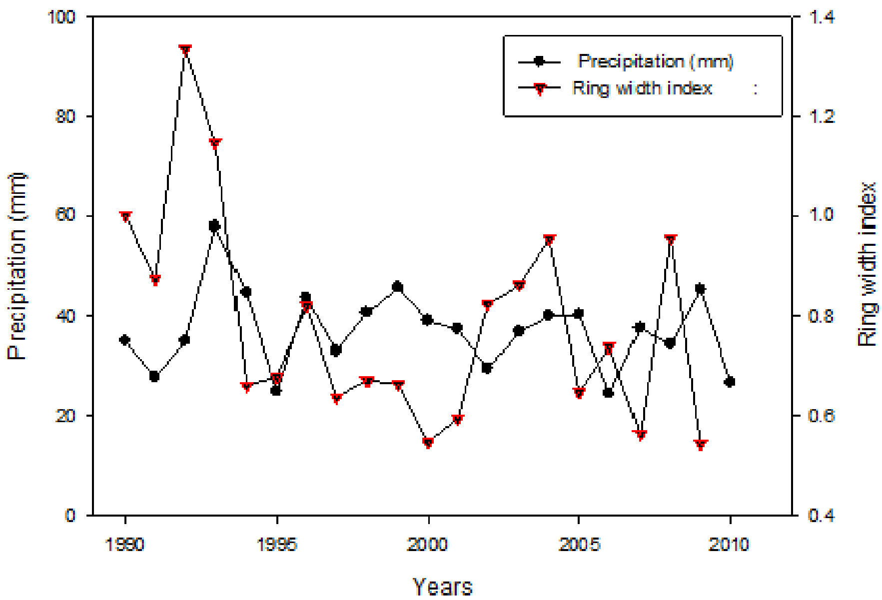

Figure 9: Annual ring width index and precipitation against time 1990-2011 in Gujba (sami-arid).

Correlations of the ring widths and precipitation showed that tree growth was significantly positively correlated with the precipitation (Figure 10). Growth of these trees is clearly limited by drought, as indicated by the strong positive relationship between tree-ring index values and annual precipitation in Nguru provenances. Growth was not correlated with the precipitation in the Gujba provenances

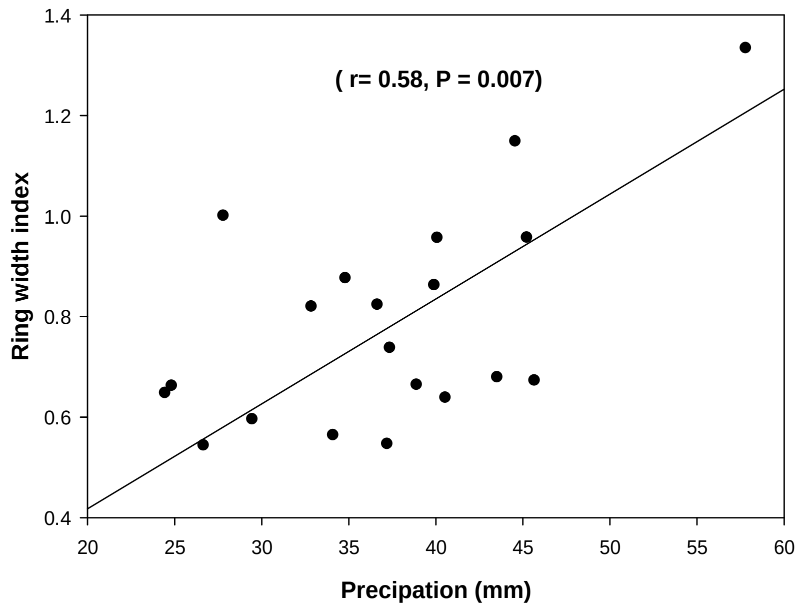

Figure 10: Relationship between precipitation and the ring index for *A senegal* in the Nguru. On the x axis, the ring width index during the period of the highest correlation Precipitation.

DISCUSSION

The findings from this study indicate that *A. senegal* species does form annual tree rings and that these rings are useful in determining growth rates. Annual growth rings were observed in all samples. Ring-width patterns of individual tree from the same study site have been successfully cross-dated. However the tree rings were delimited by wood anatomical patterns characterized by marginal parenchyma bands (Worbes, 1989). The form of repeated patterns of parenchyma and fibre bands and variations in wood density were more difficult to distinguish. The radiuses are wide and the growth border was characterized by marginal parenchyma bands. Ring-width patterns of individual tree from the same study site have been successfully cross-dated. This indicates that trees were responding similarly to common environmental factors (Fekedulegn *et al*., 2003, Worbes, 1995) which is the seasonal precipitation.

Generally, these anomalous rings were successfully detected through differences in the anatomy of the ring and by checking the continuity of rings over the entire stem disc. Annual rings are clearly distinguishable at larger diameters. The annual ring width varies from less than 2 mm to more than 8 mm with an overall mean of 5.63 mm in the Nguru and 3 mm to more 15.36 mm an overall mean of 8.13 in the Gujba. This corresponding to an annual diameter increment of 6–7 mm/year reported for Acacia species growing in arid and semi-arid environments (Gourlay, 1995). Annual ring width was higher in those years were relatively precipitation are higher and was lower when they were relatively precipitation low (Brienen, 2005). When compared to other year's declines in radial growth in *A senegal* in the Nguru provenances corresponded to the declines in precipitation in year 1995, 2000, 2004 and 2009. This suggested that precipitation seems to be the most important climatic factor that influences ring-width growth (Nicolini *et al.*, 2010).

The findings from this study also demonstrate a positive correlation between precipitation and annual ring-width growth (r = 0.58) in Nguru (arid) in this appeared to be most sensitive to major rainfall season fluctuations with the highest correlation coefficient in Gujba where there was no correlation = -0.154 P-Value = 0.542. *A senegal* in the two provenances shows a different response to precipitation. The pattern of sensitivity shows a slightly different response to precipitation, with the highest sensitivity to the precipitation in Nguru (arid) and no significant effect in Gujba (semi-arid).

CONCLUSION

Based on these results, rings of *A senegal* are annual and show good potential for the development of climate sensitive chronologies and the rings can be dated precisely. The growth of this species is sensitive to precipitation which is influenced by climate. It has been established that *A senegal* can be used for tree-ring analysis in North East Nigeria. The presented mean tree-ring index is the first chronology of its kind in North Eastern Nigeria. Such studies will help to better comprehend the varying growth responses to extreme weather conditions, in particular drought. There is also a need for further investigation into the physiological reactions of this *A senegal* to extreme weather conditions in the region.

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