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Research Article

VARIATIONS IN ANNUAL GROWTH RINGS OF *TECTONA GRANDIS* AND *TERMINALIA TOMENTOSA* AND THEIR CORRELATION WITH RAINFALL AND TEMPERATURE

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ABSTRACT
Variations in annual plant growth are dependent on variations in different climatic parameters. Growth ring study was conducted during the present investigation to understand the growth pattern in *Tectona grandis* and *Terminalia tomentosa* trees during past few decades and to correlate the variations in growth rate with variations in annual rainfall and mean annual maximum and minimum temperature. In the study, the growth rings in *Tectona grandis* and *Terminalia tomentosa* were observed in two stumps of each species. Width of various growth rings was measured to find out the correlation of the tree growth with climatic variables viz., temperature and rainfall. The individual rings represented tree growth in different years. The counting of total annual rings on the stumps was done to assess the age of the felled trees. Average thickness of annual growth rings varied from minimum 1 mm to maximum 8 mm in *Tectona grandis* and from minimum 2 mm to maximum 10 mm in *Terminalia tomentosa*. The mean maximum temperature varied from 29.5°C in the year 2003 to 33.9°C in the year 2010. The mean minimum temperature varied from 17.4°C in the year 2013 to 21.3°C in the year 1967. The annual rainfall witnessed large variations with minimum rainfall of 480 mm in the year 1965 to 1490 mm in the year 2013. The growth ring study revealed that tree growth is better in years when the difference in maximum and minimum temperatures is more. As far as the impact of rainfall is concerned, it is not only the total rainfall during the current year but also during the preceding years which have profound impact on the tree growth due to the residual effect of rainfall on the retention of soil moisture in the root zone of trees. It was interfered that rainfall during the current year and previous two years and range of temperature variations during the current year are the decisive factors for tree growth.

Keywords: *Annual Growth Rings, Tree Growth, Variations, Climate Change, Temperature and Rainfall*

INTRODUCTION
Average atmospheric temperature is rising as a result of increase in concentration of greenhouse gases due to a phenomenon known as 'greenhouse effect'. In alpine, sub-alpine, temperate and sub-tropical regions, global warming is going to create more favourable temperature conditions for tree growth. Further, increased concentration of carbon dioxide (CO_2) in the atmosphere is expected to accelerate photosynthesis, thereby resulting in faster rate of growth. However, in tropical and equatorial regions, the situation may be different. Equatorial regions are characterized as areas with higher temperatures and heavier rainfall. Climate change is expected to make these regions still warmer and wetter beyond the optimal requirements of several species. Thus, the expected sub-optimal climatic conditions may be counter productive to survival and growth of climate vulnerable species. In tropical regions, which are cooler and drier as compared to equatorial regions but warmer and wetter as compared to subtropical and temperate regions, the impact of climate change on tree growth could be positive for certain species but negative for others. Long term studies monitoring tree growth of different species in different climatic regions is desirable to understand the impact of climate change on tree growth (Ryan, 2010).

A growth ring can be defined as a tangential part of the secondary xylem tissue where one or more axial cellular components exhibit modifications along the dimension of radial growth: radial elements can also exhibit alterations in the same sense; each ring is recognized by the presence of two (or less frequently three or more) contrasting regions produced by radial variation in morphology or in the frequency of cellular components of the secondary xylem; these regions correspond to the early- and latewood, or the presence of tissues analogous to them; each growth ring corresponds to a portion of tissue produced during a growth period of the stem determined by a pause in cambial activity, or less frequently by alteration in its activity (Silva *et al.*, 2019).

Growth rings of tree are important to understand the events like fire, insect attack, climate change and so on, that happened in the past (Deepak *et al.,* 2010). Growth of a tree depends on the prevailing edaphic and climatic conditions. Each species has its specific requirements of soil, water and temperature for optimal growth. In general, tree growth is better in warmer and wetter conditions. Therefore, climatic change is certain to impact tree growth. Plant growth may also be affected by changes in troposphere ozone concentrations, deposition of nitrogen, elevated CO_2 levels and land use changes that have a combined positive or negative effect on growth (Amedie, 2013).

Growth rings are distinct in trees of temperate regions. Unlike trees of temperate regions, most of tropical trees have been excluded from dendrochronology studies because of lack of seasonality and the absence of a clear dormancy of the cambial activity failing to produce distinct growth rings. Growth rings are undulating, distinct due to concentric layers of parenchyma in between late and early wood (Chowdhary, 1997).

Growth of trees is not uniform throughout the year due to change in weather conditions. Plants require optimal levels of temperature, soil moisture and sunshine for optimal growth. Any deviation from these optimal conditions results in sub-optimal growth. When the deviation is still wider beyond a certain limit, the growth may altogether stop resulting in ‘zero growth’ condition. Since there are seasonal variations in temperature, rainfall, sunshine hours, etc., the growth rate of plants also varies in different seasons of the year. In colder regions, the growth almost stops in winter season, whereas in warmer regions, it is just reverse. In these regions, peak summer season is too hot and dry to allow any growth in plants. So, we can say that growth in plants stops when it is too hot or too cold or too dry. The season in which tree growth takes place is called the ‘growing season’.

Due to seasonal variations in growth, annual growth rings can be seen on tree stumps in many species. These rings grow under the bark and the bark is pushed out while the tree is growing. The inner part of a growth ring is formed early in the growing season when growth is fast and is known as ‘early wood’. The outer portion is the ‘late wood’ and it is denser than the early wood. Colour of early wood is lighter whereas it is darker in case of late wood. This difference in colour enables differential in growth rings of adjoining years. Many trees in places with hot summers and cool winters make one growth ring in a year. Normally, there is one ring for each year. However, switching in between bad and good weather conditions more than once in a year can result in several rings also. Growth rings usually grow wider in warm and wet years and they are narrower in a cold and dry year.

The study of growth rings in the tropics is much more complex than in temperate regions due to the greater number of species, diversity of habitats, behaviour of cambial activity and phenology, anatomical markers for growth rings and their respective degrees of distinction and mainly the absence of well-defined seasons (Borchert, 1994; Borchert and Rivera, 2001; Schongart *et al.,* 2002; Worbes and Fichtler, 2010; Slik *et al.,* 2015; Tarelkin *et al.,* 2016; Silva *et al.,* 2017).

However, Brandis (1879) pointed out growth rings in several Indian tropical trees in relation to mensuration studies and reported annual growth rings in Teak. In our study, we have taken Teak (*Tectona grandis*) and Saja (*Terminalia tomentosa*) among the major tropical species to identify the variations in annual growth rings over a different span of time with respect to its correlation with rainfall and temperature. There are many researchers who have conducted research on annual growth rings of tree to find out the age, variation in growth per year, etc. Gamble (1902) studied growth rings in a large number of tropical trees as annual rings. Even in species where the rings were distinct, age determination by counting their growth rings was considered unreliable (Coster, 1927).

Study on growth rings by Chowdhary (1939 &1940) revealed that about 25% percent of the total number of tree species produce growth rings. The science of reconstructing past climate by use of tree-rings is known as dendroclimatology which is a branch of the more general discipline of dendrochronology (Fritts, 1976). It is not only the high species diversity of tropical regions which contributes to the greater structural variability of growth rings but also the greater complexity of the secondary xylem of the angiosperm species which dominate these environments, as compared to that of the gymnosperms (Worbes and Fichtler, 2010; Islam and Brauning, 2018).

After Chowdhary's initial work on growth ring formation in relation to climate, limited work has been carried out in teak from the point of view of dendroclimatology at several sites of India. As far as Madhya Pradesh in concerned study conducted by Shah *et al.,* (2007) and Somaru *et al.,* (2008) were found to be closely relevant to our study as their studies were limited to dry deciduous forest regions of Madhya Pradesh. Apart from these two studies on growth rings of Teak, available earlier studies are very few. So this study will help us to assess the past climate events on the basis of fluctuations in annual ring width (if any). However, an attempt was made by Deepak *et al.,* (2010) to analyze the growth rings of Teak (*Tectona grandis*) in relation to rainfall pattern, mostly the drought years at two sites in Western Ghats of India.

Tectona grandis is a ring porous to semi ring porous wood. Rings are clear and distinguished by the pore size. These are usually annual but false rings also occur in saplings and mature trees. False rings are those rings which do not produce any complete or continuous growth marks all around the circumference. It was earlier reported that false rings were formed in several Teak trees due to physiological disturbances and insect defoliation (Chowdhary, 1964; Priya and Bhat, 1998).

Terminalia tomentosa is a large deciduous tree, 20-35 m high The bark is rough and dark. However, the annual growth rings in *Terminalia tomentosa* are not very clear and distinguished by the pore size much like *Tectona grandis*. It needs proper cleaning and then stem bark or stump is needed washing thoroughly to remove the soil and adhering materials and dried in shade.

Growth rings in these trees or usually in any tropical trees are formed during each growth season as new water and food conducting tissues (tracheids) and these tissues are added around the perimeter of the tree trunk. Rings are formed because of the change in the growth speed through different seasons. One ring usually makes the passage of one year in the life of the tree. Enough moisture and a long growing season results in a wide ring. A dry year may result in a very narrow ring.

MATERIALS AND METHODS

Study area

The study area was South Sagar Division of Sagar Forest Circle, in Madhya Pradesh, India. The site for the study of variations in annual growth rings were selected in felling coupes of Selection-cum-Improvement Working Circle of Gopalpur and Sejpur beats of Gaurjhamar Range in South Sagar Division.

Two felling coupes viz. IX Gopalpura and IX Sejpura in Gourjhamar Range of South Sagar Forest Division were selected for the study. In coupe IX Gopalpura, two stumps of Teak (*Tectona grandis*) trees and in coupe IX Sejpura, two stumps of Saja (*Terminalia tomentosa*) trees, were selected for the growth ring study. Information about the location and total number of growth rings in the studied stumps is given in Table- 1.

As can be seen from Table-1, the age of trees in whose stumps this study was carried out, varied from 58 to 90 years. The growth rings in these studied stumps were observed with the help of a magnifying glass. Before starting the study, the stumps were sawn to get a smooth flat surface. Two perpendicular lines were drawn on the stump from pith to the periphery with the help of a scale and a color pencil. Rings were counted from the periphery towards the pith. The first ring at the periphery is the growth ring of the first year and as we move from the periphery towards the centre (pith), older annual rings are encountered.

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Table 1: Information about the stumps selected for the study of growth rings

Division	Working circle	Coupe No. & Felling series	GPS Location	Species	Stump No.	No. of growth rings counted
South Sagar Division	Selection - cum-Improvement	IX Gopalpur	Latitude 23°29.511’N Longitude 79°58.310’E	Teak	1	90
					2	58
		IX Sejpur	Latitude 23°33.687’N Longitude 79°01.850’E	Saj	1	80
					2	62

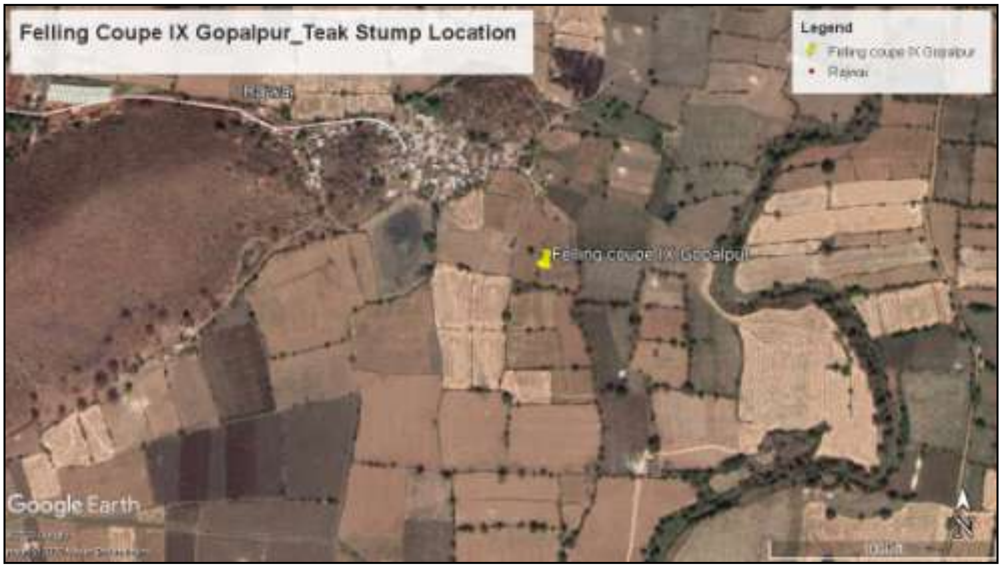

Figure 1: Google imagery of location of felling coupe Teak in Gopalpur

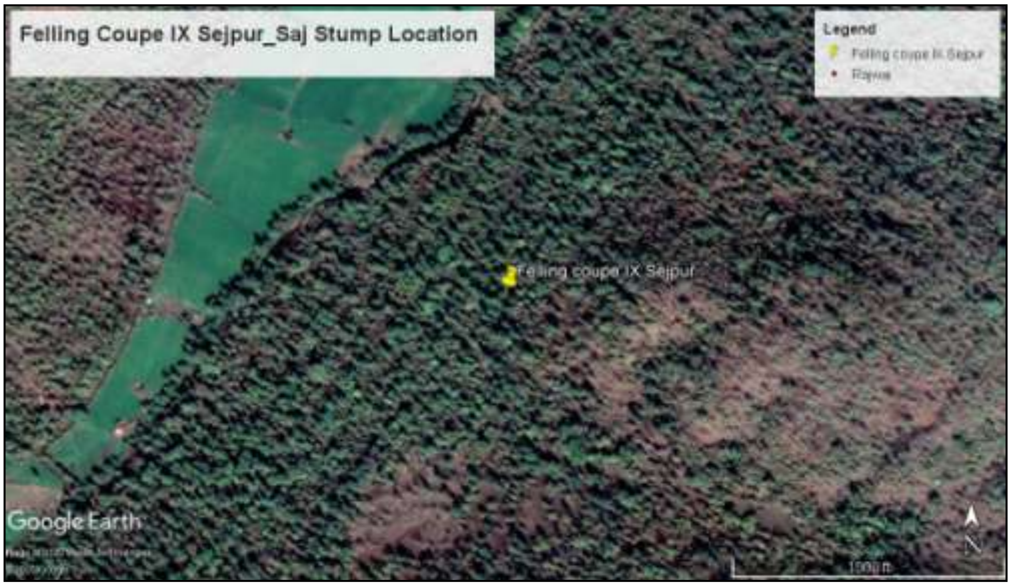

Figure 2: Google imagery of location of felling coupe Saja in Sejpur

For example, if the outermost ring is of the year 2017, the fifth ring (from the periphery) will be of the year 2013. After each 10 rings, a pin was inserted on the stump to mark the end of a decade. Insertion of pins facilitates counting and identification of a particular ring with the year of its growth. Thickness of each growth ring was measured in millimeters in the two perpendicular directions with the help of a scale and average of the two observations was recorded as the thickness of that particular ring. Google imagery of both felling coupe locations of Teak (*Tectona grandis*) and Saja (*Terminalia tomentosa*) are given in Image-1 and 2, respectively.

Methodology

Annual rings on the tree stump and the expanse between two growth rings were measured with the help of a scale and magnifying glass to know the variations in formation of growth rings every year. This field data was used to know the correlation of tree growth with annual temperature and/ or rainfall. Every single annual ring was counted and its growth (in mm) was measured. This was done with the help of a measuring cloth tape of length 1 m and a steel scale. However, particular growth rings (either very thin or very wide) were closely observed to find out the correlation of ring width with temperature.

South Sagar Forest Division was selected for the practical exercise, as in this division fellings operations were ongoing in timber felling coupes during the study period. The annual rainfall of South Sagar Forest Division ranges between 491.6 mm to 2191.6 mm with average annual rainfall 1275.70 mm. The mean maximum temperature is 31.3°C while mean minimum temperature is 19°C. So, the mean maximum and minimum temperature ranges between between 19-37.3°C (Chaturvedi, 2009).

To correlate the width annual growth rings of tree with climate data, annual data on mean maximum and minimum temperatures and annual rainfall is required therefore, climate data on these variables were collected for 57 years between 1960 to 2017 *(Source: IITM, Pune).*

RESULTS AND DISCUSSION

The temporal variation in tree growth rate could be attributable to only climatic factors as the other factors-edaphic and physiographic are supposed to have more or less remained unchanged. As is well known, a tree requires an optimum range of temperature and adequate soil moisture in its root zone for its proper growth. Availability of soil moisture in the root zone is determined by the amount of water percolating to reach the subterranean soil layer adjoining the root zone, which, in turn, is dependent on the amount of rainfall and the soil texture. Since the soil texture at a place remains almost unchanged for quite a long time, the only variable responsible for the temporal variations in the available soil moisture in root zone could be the amount of rainfall. Since there is a residual effect of rainfall on the sub terranean soil moisture for a period longer than a year, it is not only the amount of rainfall during the current year but also during the previous two years, which matter to affect the tree growth. Table- 2 shows thickness of annual growth rings of the Teak stump number 1, along with climatic data on annual mean maximum and minimum temperatures and annual rainfall in different years during the study period (from the year 1960 to 2017).

Table 2: Annual growth ring data of Teak stump no. 1

Growth ring no.	**Year of growth**	**Average thickness of the growth ring in mm**	**Mean max. temp. in °C**	**Mean min. temp. in °C**	**Average rainfall in mm**
1	2017	2	33.2	21.3	503
2	2016	1.5	32.9	20.9	583
3	2015	2	32.8	20.9	810
4	2014	2.5	32.8	21.1	690
5	2013	2	32.6	17.4	1490

6	2012	4	31.9	20.8	950
7	2011	2	33.6	17.9	1270
8	2010	8	33.9	17.5	910
9	2009	6	33.7	18.5	750
10	2008	5	32.5	19.0	999
11	2007	4	32.2	18.5	630
12	2006	1.5	30.8	19.6	830
13	2005	1	30.6	20.6	1180
14	2004	1	31.4	18.4	760
15	2003	0.5	29.5	17.5	1160
16	2002	1	32.8	20.7	680
17	2001	1	32.0	20.1	850
18	2000	1	32.0	20.0	640
19	1999	2	31.4	19.9	1120
20	1998	2	31.4	20.1	601
21	1997	1	30.5	19.3	980
22	1996	2	31.9	19.8	810
23	1995	1.5	31.7	19.0	720
24	1994	2	31.4	18.4	1330
25	1993	2	32.0	19.6	790
26	1992	2	32.0	19.9	980
27	1991	1.5	31.8	20.0	976
28	1990	2.5	30.9	19.8	1430
29	1989	1	32.1	19.0	449
30	1988	1	32.2	20.0	820
31	1987	1.5	31.9	20.0	1260
32	1986	1	31.3	19.6	830
33	1985	1.5	31.4	19.9	960
34	1984	2	30.9	19.0	920
35	1983	1	30.4	18.9	1110
36	1982	1	30.4	19.8	1110
37	1981	1.5	31.6	20.1	710
38	1980	2	31.8	20.4	1140
39	1979	5	31.8	20.0	470
40	1978	2.5	30.8	19.6	1260
41	1977	2	31.3	18.7	1010
42	1976	3	32.1	19.1	770
43	1975	1.5	30.8	19.6	920
44	1974	4	31.4	19.4	780
45	1973	6	31.6	19.5	980

46	1972	4	30.2	18.4	790
47	1971	2	29.9	18.6	1440
48	1970	2	31.3	18.8	710
49	1969	2	30.6	19.4	1180
50	1968	1.5	30.8	19.6	840
51	1967	2.5	32.2	21.3	1340
52	1966	1.5	31.3	18.6	740
53	1965	2	30.6	18.4	480
54	1964	2	30.9	18.5	850
55	1963	2	32.2	19.6	870
56	1962	1	31.3	20.6	880
57	1961	1	30.7	19.5	1270
58	1960	1.5	31.3	19.9	1010

From the perusal of climatic data given in Table- 2, it can be seen that there have been significant variations in mean maximum and minimum temperatures and lot of fluctuations in annual rainfall. The annual mean maximum temperature has varied from 29.5°C in the year 2003 to 33.9°C in the year 2010 with a range width of 4.4°C. Similarly, the annual mean minimum temperature has also varied from 17.4°C in the year 2013 to 21.3°C in the year 1967 and 2017, with a range width of 3.9°C. As far as annual rainfall is concerned, large scale fluctuations have witnessed in this climatic parameter. The annual rainfall has varied from as little as only 449 mm during the year 1989 to as much as 1490 mm during the year 2013, with a range width of 1041 mm. Thus, it is the amount of rainfall which might have affected the tree growth to a greater extent than the variations in temperature.

Study of the annual growth rings on Teak stump no. 1.

As per the data of 58 annual growth rings of Teak stump no. 1 given in Table- 2, it can be seen that there have been large variations in the thickness of annual growth rings on teak stump no. 1. It varied from only 0.5 mm in the year 2003 to 8 mm in the year 2010, with the average width of 2.19 mm during the whole study period (from the year 1960 to 2017).

The other years in which the annual growth rings were found comparatively thicker (years of fast growth) are 2009 (6 mm), 1979 & 2008 (5 mm) and 1972, 1974, 2007 & 2012 (4 mm). Let us try to find out the possible reasons for this exceptionally good growth.

In the year 2010, the year of the fastest growth, the annual mean maximum temperature was recorded as 33.9°C, the highest during the whole study period. The annual mean minimum temperature was recorded as 17.5°C which is very close to the lowest value of this parameter (17.4°C). Thus, the difference between the annual mean maximum and mean minimum temperatures was 16.4°C which is the highest during the study period. This wide range of variation in temperatures could be the prime reason for the accelerated growth. As far as annual rainfall is concerned the year witnessed an average rainfall of 910 mm, adequate to ensure the maintenance of necessary soil moisture for the tree growth. Thus, wide temperature range between maximum and minimum temperature and fair amount of rainfall might have created conditions conductive for the exceptionally good tree growth (as reflected in the width of the annual growth ring) during the year for Teak stump no. 1.

To examine the factors inhibiting the plant growth, the slowest growth ring was observed. The slowest tree growth during the study period was observed during the year 2003 in which the average thickness of the annual growth ring was only 0.5 mm. The annual mean maximum and minimum temperatures were recorded as 29.5°C and 17.5°C, respectively during the year with a difference of 12.0°C

Although the year had a good rainfall of 1160 mm, the previous three years at a stretch were poor rainfall years with the annual rainfall recorded as 680 mm, 850 mm and 640 mm during the years 2002, 2001 and 2000, respectively. Continuous rain deficiency for a long period might have cumulatively created near-drought conditions. Therefore even good rainfall during the year 2003 could not have overcome the residual effect of desiccated soil conditions in the root zone as a result of near drought conditions prevailing during the previous three years as the rain water taken some time to percolate through the soil to reach the subterraneous layers near the root zone.

Study of the annual growth rings on Teak stump no. 2

Table 3 shows the annual growth ring data of Teak stump no. 2 along with climate data.

Table 3: Annual growth ring data of teak stump no. 2

Growth ring no.	Year of growth	Average thickness of the growth ring in mm	Mean max temp. in °C	Mean min temp. in °C	Average rainfall in mm
1	2017	1.5	33.2	21.3	503
2	2016	2	32.9	20.9	583
3	2015	2	32.8	20.9	810
4	2014	4	32.8	21.1	690
5	2013	5	32.6	17.4	1490
6	2012	3	31.9	20.8	950
7	2011	2	33.6	17.9	1270
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15	2003	6	29.5	17.5	1160
16	2002	4	32.8	20.7	680
17	2001	2	32.0	20.1	850
18	2000	3	32.0	20.0	640
19	1999	2.5	31.4	19.9	1120
20	1998	3	31.4	20.1	601
21	1997	2	30.5	19.3	980
22	1996	3	31.9	19.8	810
23	1995	3	31.7	19.0	720
24	1994	3	31.4	18.4	1330
25	1993	4	32.0	19.6	790
26	1992	4	32.0	19.9	980
27	1991	3	31.8	20.0	976

28	1990	2	30.9	19.8	1430
29	1989	2	32.1	19.0	449
30	1988	2.5	32.2	20.0	820
31	1987	2	31.9	20.0	1260
32	1986	2	31.3	19.6	830
33	1985	3	31.4	19.9	960
34	1984	4.5	30.9	19.0	920
35	1983	4	30.4	18.9	1110
36	1982	4	30.4	19.8	1110
37	1981	5	31.6	20.1	710
38	1980	8	31.8	20.4	1140
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44	1974	3.5	31.4	19.4	780
45	1973	3	31.6	19.5	980
46	1972	2	30.2	18.4	790
47	1971	2	29.9	18.6	1440
48	1970	2	31.3	18.8	710
49	1969	2.5	30.6	19.4	1180
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51	1967	2	32.2	21.3	1340
52	1966	2	31.3	18.6	740
53	1965	1	30.6	18.4	480
54	1964	1	30.9	18.5	850
55	1963	1.5	32.2	19.6	870
56	1962	2	31.3	20.6	880
57	1961	1.5	30.7	19.5	1270
58	1960	1	31.3	19.9	1010

From the perusal of the data given in Table-3, it can be seen that the thickness of annual growth rings varied from the minimum 1 mm during the year 1960, 1964 & 1965 to the maximum 8 mm during the year 1980. The other years of relatively faster growth reflected in thickness of annual growth rings were 1976, 1979 & 2004 (7 mm), 1977 of 2003 (6 mm) and 1975, 1978, 1981 & 2013 (5 mm).

During the year 1980, the year of the fastest growth, the difference between the annual mean maximum temperature (31.8°C) and the annual mean minimum temperature (20.4°C) was 11.4°C which is reasonably good. Besides, the year also received good rainfall of 1140 mm. Although its immediately preceding year (1979) was a rain-deficient year with only 470 mm rainfall, whereas its previous year (1978) had received excellent rainfall (1260 mm). Thus, residual effect of exceptionally good rainfall in the year 1978 and again, a good rainfall in the year 1980 must have been helpful in maintenance of good

soil moisture level in the root zone in spite of the poor rainfall during the year 1975 and these conditions, combined together, must have created conditions conducive for the exceptionally good plant growth.
Poor growth rates during the years 1964 and 1965 could be ascribed to deficient rainfall during the period from the year 1962 to 1965. During this period, the annual rainfall ranged between 480 and 880 mm only as continuous low rainfall for a long period results in desiccation of soil**.** Obviously, the consistent and good rainfall in previous years built up a good soil moisture reserve in the root zone. This together with favorable temperature range contributed in creating favorable conditions for tree growth.
Annual growth rings on Teak stump number 1 and 2, can be seen in Image 3 and 4, respectively.

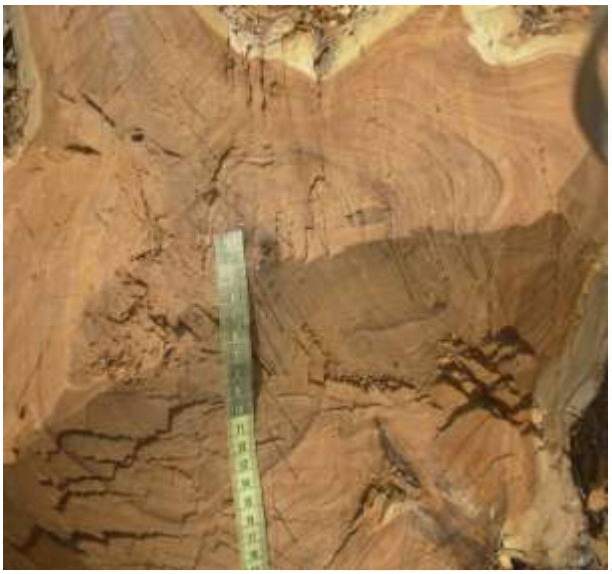

Figure 3: Teak stump no. 1

Figure 4: Teak stump no. 2

Study of the annual growth rings on Saja stump no.1
Table 4 shows the annual growth ring data of Saja stump no. 1 along with climate data.

Table 4: Annual growth ring data of saja stump no. 1

Growth ring no.	**Year of growth**	**Average thickness of the growth ring in mm**	**Mean max. temp. in °C**	**Mean min. temp. in °C**	**Average rainfall in mm**
1	2017	4	33.2	21.3	503
2	2016	4	32.9	20.9	583
3	2015	3	32.8	20.9	810
4	2014	3	32.8	21.1	690
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25	1993	7	32.0	19.6	790
26	1992	8	32.0	19.9	980
27	1991	10	31.8	20.0	976
28	1990	7	30.9	19.8	1430
29	1989	7.5	32.1	19.0	449
30	1988	8	32.2	20.0	820
31	1987	5	31.9	20.0	1260
32	1986	4	31.3	19.6	830
33	1985	4	31.4	19.9	960
34	1984	3	30.9	19.0	920
35	1983	3	30.4	18.9	1110
36	1982	3	30.4	19.8	1110
37	1981	2	31.6	20.1	710
38	1980	3	31.8	20.4	1140
39	1979	2	31.8	20.0	470
40	1978	2.5	30.8	19.6	1260
41	1977	2	31.3	18.7	1010
42	1976	4	32.1	19.1	770
43	1975	2	30.8	19.6	920
44	1974	3	31.4	19.4	780
45	1973	3	31.6	19.5	980
46	1972	2	30.2	18.4	790
47	1971	5	29.9	18.6	1440
48	1970	8	31.3	18.8	710
49	1969	3.5	30.6	19.4	1180

50	1968	2	30.8	19.6	840
51	1967	2.5	32.2	21.3	1340
52	1966	3	31.3	18.6	740
53	1965	3	30.6	18.4	480
54	1964	3	30.9	18.5	850
55	1963	3	32.2	19.6	870
56	1962	2.5	31.3	20.6	880
57	1961	2	30.7	19.5	1270
58	1960	2	31.3	19.9	1010

From the perusal of data given in Table-4, it can be seen that the thickness of annual growth rings in Saja stump no-1 varied from 2 mm in the years 1960, 61, 68,72,75,77 and 81 to 10 mm in the year 1991. If we compare these figures with the corresponding figures for teak, it is evident that the annual girth increment in Saja is more than that in teak in which the height growth is faster. Besides the year 1991, other years of relatively faster rate of growth in Saja stump no-1 have been 1970, 1988, 1992 & 1994 with growth ring thickness 8mm, year 1989 with growth ring thickness 7.5mm and the yeas 1990, 1993, 1995 and 1997 with growth ring thickness 7mm.

During the year 1991, in which the studied Saja tree registered the fastest rate of growth, the annual mean maximum and minimum temperature, were recorded as 31.8°C and 20.0°C, respectively. The difference between the maximum and minimum temperature was 11.8°C which is quite substantial. Rainfall during the year was 976 mm which is only slightly better than average annual rainfall during the study period (919 mm) but the previous year (1990) had an exceptionally good rainfall (1430 mm) and the effect of the surplus rainfall in the year 1990 must have persisted in next year (1991) also. Thus, more than average rainfall in the current year and heavy rainfall during the previous year must have created conditions of saturation of soil moisture in the root zone resulting in exceptionally fast growth during the year.

The slowest growth was recorded during the years 1960, 1961, 1968, 1972, 1975, 1977, 1979 and 1981. If we study the climate data of these years, we find that either these years (or their immediately previous years) were poor rainfall years (with some exceptions, of course) or the temperature range was not optimum for the growth.

Study of the annual growth rings on Saja stump no.2

In continuation to observe annual growth rings on Saja stump no. 2, total annual rings along with average thickness and climate data are shown in Table-5.

Table 5: Annual growth ring data of Saja stump no. 2

Growth ring no.	**Year of growth**	**Average thickness of the growth ring in mm**	**Mean max. temp. in °C**	**Mean min. temp. in °C**	**Average rainfall in mm**
1	2017	3	33.2	21.3	503
2	2016	3	32.9	20.9	583
3	2015	2	32.8	20.9	810
4	2014	3	32.8	21.1	690
5	2013	3	32.6	17.4	1490
6	2012	4	31.9	20.8	950
7	2011	6	33.6	17.9	1270

8	2010	6.5	33.9	17.5	910
9	2009	6	33.7	18.5	750
10	2008	7	32.5	19.0	999
11	2007	8.5	32.2	18.5	630
12	2006	7	30.8	19.6	830
13	2005	6	30.6	20.6	1180
14	2004	5	31.4	18.4	760
15	2003	2	29.5	17.5	1160
16	2002	5	32.8	20.7	680
17	2001	3	32.0	20.1	850
18	2000	3	32.0	20.0	640
19	1999	2	31.4	19.9	1120
20	1998	2	31.4	20.1	601
21	1997	2	30.5	19.3	980
22	1996	3.5	31.9	19.8	810
23	1995	3	31.7	19.0	720
24	1994	4	31.4	18.4	1330
25	1993	5	32.0	19.6	790
26	1992	4.5	32.0	19.9	980
27	1991	5	31.8	20.0	976
28	1990	2	30.9	19.8	1430
29	1989	3	32.1	19.0	449
30	1988	4	32.2	20.0	820
31	1987	3	31.9	20.0	1260
32	1986	3	31.3	19.6	830
33	1985	2	31.4	19.9	960
34	1984	2	30.9	19.0	920
35	1983	3	30.4	18.9	1110
36	1982	3	30.4	19.8	1110
37	1981	2.5	31.6	20.1	710
38	1980	3	31.8	20.4	1140
39	1979	3	31.8	20.0	470
40	1978	3	30.8	19.6	1260
41	1977	4	31.3	18.7	1010
42	1976	5	32.1	19.1	770
43	1975	3	30.8	19.6	920
44	1974	2	31.4	19.4	780
45	1973	2	31.6	19.5	980
46	1972	3	30.2	18.4	790
47	1971	2	29.9	18.6	1440

48	1970	3	31.3	18.8	710
49	1969	2	30.6	19.4	1180
50	1968	2	30.8	19.6	840
51	1967	3	32.2	21.3	1340
52	1966	2.5	31.3	18.6	740
53	1965	2	30.6	18.4	480
54	1964	2.5	30.9	18.5	850
55	1963	3	32.2	19.6	870
56	1962	3	31.3	20.6	880
57	1961	2	30.7	19.5	1270
58	1960	2	31.3	19.9	1010

From the perusal of data given in Table-5, it can be seen that the thickness of annual growth rings in Saja stump no. 2 varied from 2 mm in the years 1960, 61, 65, 68, 69, 71, 73, 74, 84, 85, 90, 97, 98, 99, 2003 and 2015 to 8.5 mm in the year 2007. The other years of relatively better growth are 2006 & 2008 (7mm); 2010 (6.5 mm) and 2005, 2009 and 2011 (6 mm).

During the year 2007, the annual mean maximum and minimum temperatures were recorded as 32.2°C and 18.5°C, respectively with a large difference of 13.7°C. This wide range of variation in temperature might have been mainly responsible for the widest annual growth ring in the year. The rainfall during the year was below average (only 630 mm), although previous two years were better in rainfall. The annual rainfall during the year 2006 had been recorded as 830 mm (only slightly less than average), whereas its previous year (2005) had received good rainfall (1160 mm).

During the year 2010, the annual mean maximum and minimum temperature were recorded as 33.9°C and 17.5°C, respectively, with a difference of 16.4°C between the two. The rainfall recorded during the year was 910 mm. significantly wide range of variation in temperature and near average rainfall might have contributed to good growth during the year.

Figure 5: Saja stump no 1

Figure 6: Saja stump no 2

Very good rainfall during the year 2005 (1180 mm) and 2011 (1270 mm) must have helped in fairly good growth during these years. Vast difference of 15.2°C between the annual mean maximum and minimum temperatures might have been contributing factor for good growth during the year.
Conversely, the narrow range of difference in temperature appears to be responsible for poor growth rate with annual growth ring thickness of only 2 mm during the years 1960, 61, 71, 73, 74, 84, 85, 90, 97, 99 and 2003. The range of variation in temperature during these years varied between 11.2°C and 12.1°C. On the other hand, the main factor for poor growth rate was deficient rainfall during the years 1965 (480 mm), 1968 (840 mm), 1998 (601 mm) and 2015 (810 mm).
Annual growth rings on Saja stump number 1 and 2, can be seen in Image 5 and 6, respectively.

CONCLUSION

From the observation of annual growth rings on the studied stumps, it can be seen that there are large variations in the thickness of annual growth rings. Some rings are quite thicker in comparison to other rings. As the thickness of an annual growth ring represents the growth in a tree in that particular year, it is quite obvious that the growth is not uniform in different years and there are temporal variations in the rate of growth.
From the analysis given in foregone paragraphs, it is obvious that variations in climatic parameters are mainly responsible for variations in annual plant growth. Wider range of variation in temperatures and good rainfall, not only during the current year but also during the previous years, are helpful in creating climatic conditions conducive to growth. Conversely, narrow range of variation in temperature and continuous rain deficiency inhibit plant growth. Thus, climate change is certainly going to impact the tree growth; although climate vulnerability could be species specific. It is likely to be different in fast growing Vs slow growing, light demanding Vs shade tolerant and deep rooted Vs shallow rooted species. Moreover, the impact of climate change is likely to be different in different regions. In equatorial and tropical regions, the global warming may cause adverse impact on plant growth as the temperatures may rise above the optimum range. On the contrary, colder areas in sub-temperate, temperate, sub-alpine and alpine regions may be benefitted because of global warming. Detailed long-term studies by establishing permanent sample plots in different agro-ecological zones are required to understand the complex relationship between the plant growth and different climatic variables. Very narrow and very wide tree rings, in the different species indicates that a climatic signal may be present in growth patterns (Cherubini *et al.*, 2003).
Growth of a tree depends on the prevailing edaphic and climatic conditions. Each species has its specific requirements of soil, water and temperature for optimal growth. In general, tree growth is better in warmer and wetter conditions. In our study, the growth rings of *Tectona grandis* were observed in two stumps. Average thickness of annual growth rings varied from minimum 1 mm to maximum 8 mm. The mean maximum temperature varied from 29.5 °C in the year 2003 to 33.9 °C in the year 2010. The mean minimum temperature varied from 17.4 °C in the year 2013 to 21.3°C in the year 1967. The annual rainfall witnessed large variations with minimum rainfall of 480 mm in the year 1965 to maximum of 1490 mm in the year 2013. The growth ring study revealed that tree growth is better in years when the difference in maximum and minimum temperatures is more. As far as the impact of rainfall is concerned, it is not only the total rainfall during the current year but also during the preceding years also that impacts the growth in trees due to the residual effect of rainfall on the retention of soil moisture in the root zone of trees.
Gradual increases in atmospheric temperature as a result of global warming, together with the consequent disruption in rainfall pattern, especially the menacing trend of continuous reduction in annual rainfall observed during past few years, are bound to cause significant impacts on soil moisture, phenology, natural regeneration, especially of certain climate vulnerable species, forest composition, growth and productivity of forests. Climate change also has potential to trigger invasion of new species,

disappearance of vulnerable species and increased incidences of pests and diseases. The common low rainfall years at the study sites matched with most of the drought years of India (Deepak *et al.,* 2010).

Climate change influences forest, including soil properties, tree growth, and disturbance regimes, range shifts, the occurrence of diseases and insect dynamics. Change in tree growth may be determined by how much the climate warms. Hence, higher temperature increases may lead to growth reductions, but the plant growth may also be affected by changes in troposphere ozone concentrations, deposition of nitrogen, elevated CO_2 levels, and land use changes that have a combined positive or negative effect on forest growth (Evans and Perschel, 2009) Climate warming has increased tree diameter growth and moved the forest line forward in the Laotudingzi Mountains. The tree ring index, which is the ratio of the actual width of tree rings to the expected one, has increased at an average rate of 0.01 per year and this upward trend is consistent with the temperature change in this region over the last 30 years (Wang *et al.*, 2004) In the humid tropics, where climate is only slightly seasonal, trees mostly fail to form wood with distinct yearly growth layers (Dorby and Kyncl, 1992).

A growth ring in a cross-section of a tree corresponds to an increment in tree growth, in other words to a layer of wood apparently produced during one growing season. It is called an “annual growth ring” when it corresponds to one year’s growth (Mariaux, 2016).

Temperature effects on tree growth might also come from an understanding of the effects of temperature on cell division and expansion, which are generally more sensitive to environmental variability than are photosynthesis and respiration (Ryan, 2010).

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