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Variation of Rate of Growth in Teak (*Tectona Grandis L. F.)* Derived from within Tree Systematic Internodal Sampling.

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Abstract

Rate of growth is one of the most important economic end-use properties of living trees and their timbers. A very fast rate of growth (wide annual ring width) connotes a poor timber yield while a very slow rate of growth (narrow annual rings) suggests a very dense and refractive timber This paper examines the variation in rate of growth (ring width) within and between teak *(Tectona grandis L.f)* trees grown in Ibadan Nigeria. The inter and intra tree variation in growth rate were evaluated using the systematic within tree internodal sampling techniques first used by Duff and Nolan (1953) on softwoods. Since hardwoods, such as teak does not show visible annual internodes on the bole, this was achieved by counting the annual growth rings within the trees at different levels from apex to base in order to determine the nodal positions. The study found that the average rate of growth (ring width) within the teak trees vary significantly from tree to tree depending on the position in the tree canopy. The sub-dominants trees grew slower than the co-dominants and the dominant trees. There is however, no significant difference in the mean ring width of the co-dominant and the dominant trees. The effects of canopy class, position within trees and the interaction of trees with position were significant on ring width (rate of growth), the effect of canopy class being of least significance. Differences were found in the rate of growth with the various systematic directions within the tree. In all, the within tree variation in rate of growth (ring width) was greater than between trees.

Key Words: Rate of growth; ring width; canopy classes; systematic sampling

Introduction

In a given tree, the ring width tends to follow certain patterns of variation in the horizontal and vertical directions. This variation is systematic. The classic work of Duff and Nolan (1953) established the systematic variation of ring width with the position of the crown in *Pinus resinosa (*Duff and Nolan, 1953).

The present study is an attempt to demonstrate the practicability of applying the technique of intermodal sampling suggested by Duff and Nolan (1953) on teak (*Tectona grandis L. f*), a tropical hardwood which does not have visible annual internodes on its bole. This involves, by counting the annual rings at each level from apex to base of the tree.

Generally there are three main types (patterns) of variation within a tree based on the intrinsic and extrinsic factors controlling cambial growth. These patterns were first observed by Duff and Nolan (1953) while working on red pine. They are in fact the horizontal and vertical organization of growth within the tree: (Figure 1).

Duff and Nolan (1953) observed that there are three main factors acting as controls on tree growth responsible for these three patterns of variation. These factors are:

(1) Systematic factors or complexity of factors, which operate to induce certain uniformity or pattern in the distribution of growth activities in the tree no matter what the circumstances of growth may be.
(2) Systematic factors or complexity of factors operating to induce regularity in the distribution of growth activity which however is not the same under all circumstances but varies with variation in such conditions as site and stand density.
(3) Random factors, the action of which tends to produce irregularity and fluctuations in the distribution of growth activity.

In order to isolate and assess the effects of these three types of variation discussed above, the authors suggested a consideration of the activities of the cambium forming the wood. Thus, they proposed the following three sequences, each identifiable with the three main patterns of variation within a tree.

(1) Variation 1: Sequence type 1: A cambium operating as a single sheath from tip to base therefore shows the effect of increasing cambial age operating in a common calendar year. This sequence is oblique.

(2) Variation 2: Sequence type 2: A cambium progressively in age from pith to bark in a radial horizontal therefore shows the effect of increasing cambial age at concomitant progression of calendar year. This sequence is radial.

(3) Variation 3: Sequence type 3: Cambia of common physiological age, operating at progressively increasing calendar years. This sequence is vertical.

The first and second patterns of variation show the intrinsic factors of growth within the tree. The third sequence, however, shows the extrinsic (environmental) factors which control the configuration (form) of the cambial growth and wood formation. According to Duff and Nolan (1953) and Richardson (1961), non-systematic variation is indicated by the extent to which the plotted points depart from a smooth curve and is termed "configuration". The cambium along this vertical sequence is progressively affected by climatic conditions at the time of wood formation, hence the variation in this sequence has been found to be correlated with extension growth (Richardson, 1961).

The description of these two within-tree systematic patterns and some random patterns have been confirmed by many researchers working with conifers and hardwoods, by using additional wood properties apart from the ring width used by Duff and Nolan, such as density, tracheid length and fibre length (Richardson, 1961; Dinwoodie, 1963; Sanwo, 2006).

It is common in literature to discuss these patterns along the two main directions of variation in the tree: radial which is similar to sequence 2 and vertical or axial direction which incorporates sequence 1. This approach has been adopted in this paper but in the subsequent analysis in this study, sequences have been properly isolated. The reasons for adopting this method here is because literature on broadleaf species seldom refers to these sequences as they have so far been mainly used only with conifers.

The purposes of this study are as follows:

(1) To estimate the relative magnitude and importance of the main sources of variation associated with rate of growth (ring width). These sources are as follows:
   (i) the effects of canopy class (Ci)
   (ii) the effects of differences between trees (Tij)
   (iii) the effects of differences between sampling positions within trees (P_k)
   (iv) the effects of the interaction of trees and position within trees (TPijk).

(2) To examine the patterns of variation in the rate of growth (ring width) between and within trees.

Material and Methods

Wood samples were obtained from a 27 – year – old teak plantation growing at the University of Ibadan Campus (Lat. 07^o 20^{1}N and Long 03^o 50^{1}E). The area lies within the drier part of the tropical rain forest of Southern Nigeria, the climate of the area is of the equatorial type with two distinct seasons; rainy (wet) (April – October) and dry (November – March). Under this type of condition, teak produces clear annual growth rings which are visible to the naked eye (Rudman and Da Costa, 1959; Renes, 1978, Sanwo, 2006). The initial spacing of the stands examined was 2.3 x 2.3m and the stands were not known to have had any programmed management. At the time of sampling, the productivity of the sample plot was: volume 96.15m^3/ha, mean annual increment (MAI) 3.70^3/ha/annum, average stocking 524 trees/ha and mean basal area, 39.97m^2/ha.

In the study plot, which was 40m x 100m (0.4hectare) in size, three growth rate classes were tested based on dbh. ob measurements; fast, dominants; medium, co-dominants and slow, sub-dominants. There were 208 trees in the selected sample plot and from this the best nine trees were selected – two from the dominants, five from the co-dominants and two from the sub-dominants representing the proportion of trees found in each of the three canopy classes. A detailed explanation of the sampling and testing procedure is given in Sanwo, (1986 and 2006).

Within each of the nine trees sampled, systematic sampling as suggested by Richardson (1961) following the pattern of Duff and Nolan (1953) was carried out. Twenty samples were isolated from common positions in each tree (Figure 1). The data for all the nine trees were combined. Sampling difficulties precluded the use of the topmost sampling position in one tree. Hence the total number of samples was 178 (i.e. 20 x 9 - 2).

Results and Discussion

Ring width was measured with a transparent ruler. This saved time and because the ring width boundaries in teak are normally very distinct, accuracy was not seriously jeopardized. All measurements were made to the nearest 0.5mm, which was considered adequate for this investigation. The ruler employed was a transparent mapping ruler and this was placed directly on a diameter line running through the pith on the end section of the sample bolt. The measurements were made on both sides of the pith and recorded with proper ring identification number. When required, mean ring width for each ring was calculated on the basis of two measurements on the two opposite radii, taken on each ring.

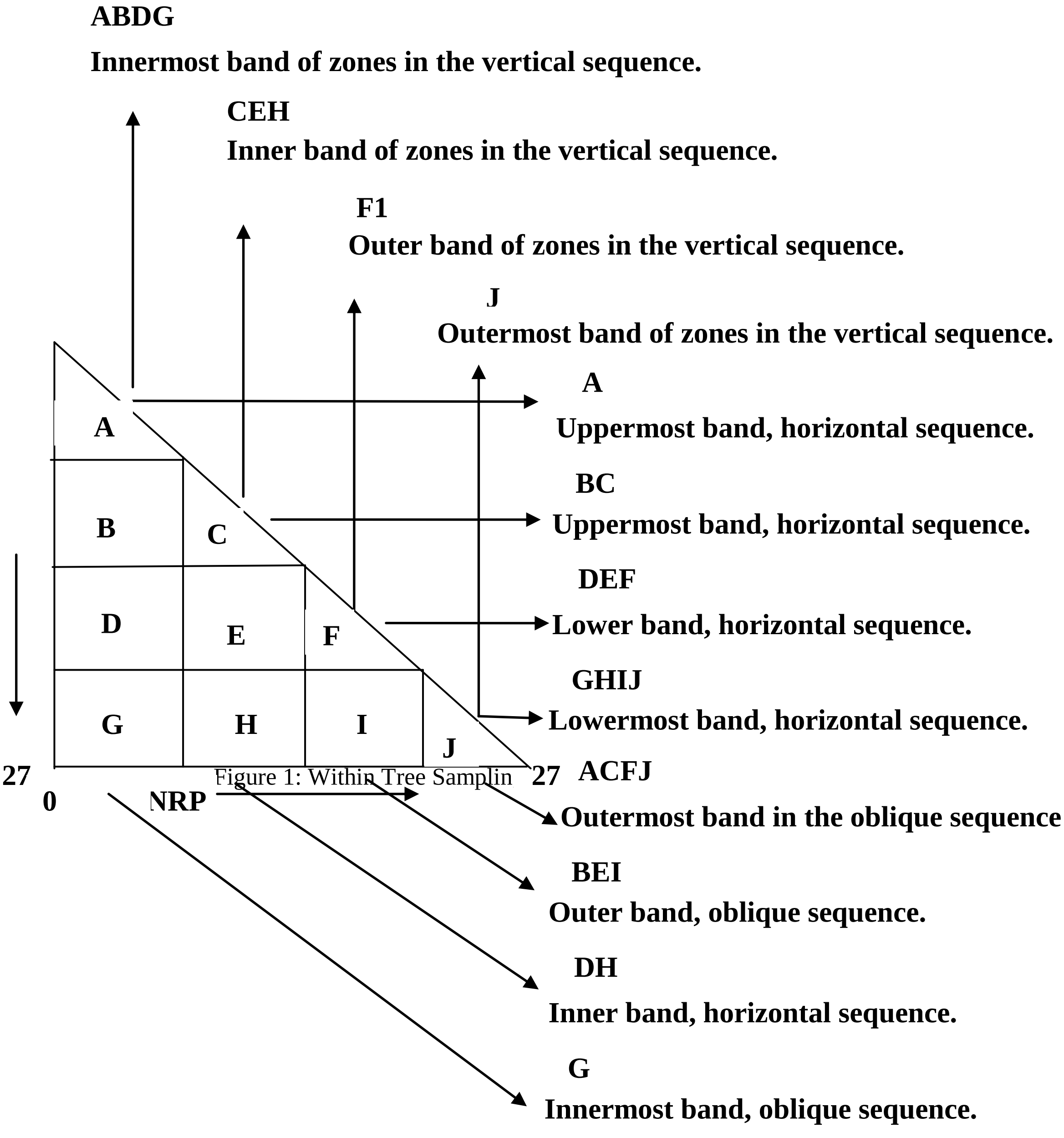

Figure 1: Within Tree Samplin

The method of data presentation is as follows:

(a) A table of the summary of test results is presented, on which the ring width value for each of the 10 sampling positions within the tree can be seen as well as the whole-tree statistics (mean, standard error of the mean, and the coefficient of variability) (Table 1). Table 1, also shows the overall ring width for the sample plot and for all the crown classes combined trees data. This table makes it easy to quantify and observe the pattern of variation of ring width between trees and groups of trees. The use of the coefficient of variation or coefficient of variability as it is sometimes called is justified because it is a commonly used index of the extent of relative variation in biological research (Zar, 1974) and in wood properties assessment (Brazier and Lavers, 1977; Dinwoodie, 1981). The coefficient of variability (CV) is expressed as follows:

$$CV\% = \frac{SD}{X} \times 100$$

Where:

CV = coefficient of variability (expressed in %)

SD = standard deviation of the property

$\bar{X}$ = mean of the property.

The higher the CV, the higher the magnitude of variation of the property.

(a) The data presentation is followed by a discussion of the analysis of variance carried out on the ring width. The ANOVA table has been presented and the level of statistical significance of the main sources of variation associated with this study has been indicated. The analysis of variance was carried out with the all trees combined data (CTD) (trees 1-9).

Table 1: Within – tree Pattern of Ring Width (mm) Distribution

Tree no.	Canopy class	Position within-tree (n=2)										Whole-tree statistics			
		A	B	C	D	E	F	G	H	I	J	X	± S.E	C.V. (%)	N
1	DOM	3.63	3.50	4.88	7.20	6.13	4.63	9.00	4.88	2.63	3.75	5.02	0.472	42.03	20
2	DOM	0.78	2.13	2.50	6.13	4.03	2.48	13.25	7.50	4.38	2.90	4.61	0.857	83.20	20
CD	DOM	2.21	2.82	3.69	6.68	5.08	3.56	11.13	6.19	3.51	3.33	4.81	0.484	63.59	40
3	CDOM	3.25	6.13	2.50	4.13	2.63	1.88	12.38	3.38	2.13	2.00	4.04	0.767	85.05	20
4	CDOM	3.25	4.50	3.75	4.75	3.25	2.63	6.63	5.50	3.13	3.00	4.04	0.329	36.40	20
5	CDOM	7.13	4.75	6.00	4.13	3.00	1.88	8.25	5.00	3.75	3.50	4.74	0.476	44.92	20
6	CDOM	3.25	7.00	4.25	5.50	3.75	5.50	8.88	4.25	6.00	3.75	5.21	0.474	40.68	20
7	CDOM	2.43	1.50	2.88	4.13	2.75	3.53	6.13	4.38	4.13	4.43	3.76	0.32	36.10	18
CCD	CDOM	3.86	4.78	3.88	4.53	3.08	3.08	8.45	4.50	3.83	3.34	4.37	0.43	51.75	98
8	SDOM	1.63	3.13	1.50	3.25	1.75	1.38	7.25	3.75	1.75	1.63	2.70	0.420	70.30	20
9	SDOM	1.03	3.75	2.13	3.88	2.38	3.25	5.70	3.13	2.88	3.38	3.15	0.330	46.56	20
CSD	SDOM	1.33	3.44	1.82	3.57	2.07	2.32	6.48	3.44	2.32	2.51	2.93	0.267	57.77	40
CTD	CTD	2.93	4.04	3.38	4.79	3.29	3.01	8.61	4.64	3.42	3.15	4.14	0.183	58.90	178

Key: D = Dominants,; CDOM = Co-domunants. SDOM = Sub-dominants;
CD = Combined co-dominants; CCD = Combined co-dominants;
CSD = Combined sub – dominants; CTD = Combined total data.

(b) There were 178 observations plus 2 values estimated in the programme representing those missing in zone A of tree 7, making the total number of observations employed for the analysis to be 180.

The analysis of variance indicates the level of statistical significance of the different sources of variation and throughout this paper; the following convention has been adopted:

*** indicates significance at 0.1% probability level
** indicates significant at 1.0% probability level
* indicates significant at 5.0% probability level
….indicates not significant at the 5.0% probability level.

A summary of the ring width measurements within each tree is presented in Table 1, and it shows that the average ring width of the combined data (CTD, n=178) is 4.14± 0.183mm. In terms of rate of growth, this gives a rate of about 6 rings per inch. A summary of the analysis of variance carried out on ring width is presented in Table 2.

In the analysis of variance (Table 2), the crown class effect examined. It was found that the variation in ring width associated with differences between the canopy classes was statistically significant at the 5% probability level. Out of the 4 factors ('main' and interaction effects) considered, the canopy class effect was the least significant. Application of the Newman-Keuls multiple range test (Zar, 1974) showed the average ring width of the sub-dominants (2.93mm) to be significantly different from those of the co-dominant (4.37mm) and the dominants (4.81mm), at the 5% probability level. The result of this test, which is presented below, shows that the significant effect of crown class is confined to the differences between the sub-dominant and the other classes considered (Table 3).

Between- Tree Variations in Ring Width (Tree Effect)

In the analysis of variance (Table 2) the differences between tree mean ring width were significant at 0.1 per cent probability level. The individual tree mean ring width value varies from 2.70mm for the sub-dominant tree 8 to 5.02mm for the dominant tree 1. The large variation in ring width is understandable, since the trees were selected from 3 different canopy classes. (Table 3)

Table 2: Variation of Ring Width: An Analysis of Variance of 9 Trees from 3 Canopy Classes.

Source of Variation	df	S. S.	M. S.	Test Vs Entry	Fcal	F0.95	Remarks
1 Between canopy classes (Ci)	2	80.8636	40.4318	1 Vs 2	6.7499	5.14	*
2. Residual 1	6	35.9400	5.9900				
3. Between trees (Tij)	8	116.8036	14.6005	2Vs 5	3.6759	2.07	**
4. Between Positions (Pk)	9	470.8829	52.3203	4 Vs 5	13.1761	2.02	***
5. Residual 2 (TP ijk)	72	285.9008	3.9708	5 Vs 6	1.8708	1.46	**
6. Residual 3 (µijkm)	88	186.7808	2.1225				
Total	177	1060.3680					

Table 3: Pattern of Ring Width (mm) Distribution among Canopy Classes.

Rank of Canopy class means	Canopy class	Mean ring width (mm)	Size of samples (n)
1	Sub-dominant	2.93	40
2	Co-dominant	4.37	98
3	Dominant	4.81	40

(Any two means not underscored by the same vertical line are significantly different at the 5% probability level).

Application of the Newman-Keuls multiple range test showed significant differences between some of the trees at the 5% probability level. (Zar, 1974). Sub-dominant tree 8 was significantly different from all the other trees except sub-dominant tree 9, and co-dominant trees 7, 4 and 3. The largest tree mean ring width (co-dominant tree 6) differs significantly from the smallest (sub-dominant tree 8). (Table 4)

Within-trees Variation (Positional Effect)

The positional effect within trees, which is significant at the 0.1% level, is pre-dominant and this result might be anticipated upon examination of Table 1, on within-tree pattern of ring width distribution. Table 5 shows the average ring width distribution by position (all trees combined data). From this Table, the positional effect is clearly demonstrated. Positions A, B, D and G are all close to the pith, all show high values for ring width and they also emphasize calendar year effect shown in the vertical sequence since zone G was laid before zone D, B and A in that order. Vertically down the tree, ring width decreases as ring age increases, from C E H to F I and finally to J. (Figure 1).

Newman – Keuls multiple range tests was applied on the mean ring width values of the 10 positions within the tree. The results of this test are summarized are presented on Table 5. From this table, it can be seen that zone G nearest to the pith and at the tree base, is significantly different form the rest of the zones in the tree. In the analysis of variance (Table 2) it was shown that there is a general difference somewhere amongst the ten zones examined in the tree ($P \leq .01$). It is now clear that at the 0.5 level, the significant effect of positions/zones is confined to the difference between zone G and other zones in the tree. Ring width was observed during the sampling stage of this investigation to be generally low in the outer sheaths of the trees.

Table 4: Pattern of Ring Width (mm) Distribution Amongst Trees

Rank of tree means	Tree No.	Canopy Class	Mean Ring Width (mm)	Size of Samples (n)
1	8	Sub-dominant	2.70	20
2	9	Sub-dominant	3.15	20
3	7	Co-dominant	3.76	18
4	4	Co-dominant	4.04	20
5	3	Co-dominant Dominant	4.04	20
6	2	Co-dominant	4.61	20
7	5	Dominant	4.74	20
8	1	Co-dominant	5.02	20
9	6		5.81	20

(Any two means not underscored by the same vertical line are significantly different at the 5% probability level).

Table 5: Average Ring Width Distribution by Position (Zones) within the Tree (Combined Data)

Rank of zone means	*Zone Label*	*Mean Ring Width of Zones (mm)*	*Size of Samples (n)*
1	A	2.93	16
2	F	3.01	18
3	J	3.15	18
4	E	3.29	18
5	C	3.38	18
6	I	3.42	18
7	B	4.04	18
8	H	4.64	18
9	D	4.79	18
10	G	8.61	18

(Any two means not underscored by the same vertical line are significantly different at the 5% probability level).

Conclusion

The present study has clearly demonstrated the practicability of applying the technique of intermodal sampling on hardwoods with distinct regular annual growth rings. This study can easily be replicated in other analysis of tropical hardwoods such as teak growing in equatorial regions of the World with regular rainfall patterns. From the foregoing, the following can be concluded:

(1) The mean ring width (rate of growth) varies significantly from the sub-dominant crown class compared with the co-dominant and the dominant classes. The latter two canopy classes are not significantly different in their mean ring width.

(2) The effects of canopy class, position within trees and the interaction of trees and position were significant on ring width, the effect of crown class being of least predominance.

(3) In the oblique sequence (sequence type 1), ring width decreases sharply from tree apex to about the 9th internode from the apex, then it increases gradually towards the tree base with further increase in the number of internodes from apex.

(4) In the horizontal sequence (sequence type 2), ring width decreases sharply with pith to about the 9th ring from the pith and thereafter it increases gradually towards the tree periphery.

(5) In the vertical sequence (sequence type 3), ring width decreases with increasing year of wood formation from year of planting, 1952 to about 1969, and thereafter ring width is maintained or alternatively decreases further.

(6) Variation of rate of growth within and between trees can only be successfully studied by isolating and comparing wood formed by cambium of similar physiological ages operating under similar environmental conditions.

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