RESEARCH REPORT

INTRA-ANNUAL VARIATION IN WOOD DENSITY IN *GMELINA ARBOREA* FROM X-RAY DENSITOMETRY AND ITS RELATIONSHIP WITH RAINFALL

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ABSTRACT

The variation in wood density within growth rings was determined from X-ray negative images of wood samples of *Gmelina arborea*. The within-tree and between-tree comparisons showed that no two growth rings had exactly similar patterns of variation in the radial direction. The proportions of wood in four within-ring density classes were estimated. The variations in the proportions of wood in the four classes with age were nonlinear. On the average, the proportion of low density wood decreased with increasing age, while the proportion of high density wood increased with age. Regression analysis testing different curvilinear models showed that 37 to 99 per cent of the variations in the proportions of wood were associated with variations in age. Maximum and minimum ring density were negatively correlated with dry season rainfall. Variations in the proportion of high density wood and mean ring density were not associated with corresponding variation in dry season rainfall. The proportions of low and high density wood, mean ring density, maximum ring density and minimum ring density were not determined by annual rainfall.

INTRODUCTION

Although an annual ring is formed in one growth season, it is made up of wood cells formed in different periods or seasons of the year. Since environmental factors play some part in the determination of the ultimate structure of the wood, variation in wood properties should be expected (and have often been observed) within growth rings. The magnitude and pattern of such variation should be studied in important species in order to determine the degree of wood uniformity or variability in one year of wood formation. A good way of studying the effect of any environmental factor on a wood property is by within-ring analysis. Nowadays, it is easy to carry out a detailed study of the variation in the density of wood formed in one year by X-ray photography.

Studies on the variation in wood properties within growth rings were regarded in the past as being only of academic interest. There is growing evidence suggesting that this kind of variation may affect industrial processing (Ifju 1969). For example, if growth rings are wide, with very light earlywood and extremely dense latewood, the wood may be rejected by "moulding" manufacturers and perhaps degraded in veneer plants. 2.5 cm boards cut from it would tend to 'cup' from differential shrinkage and would be subject to splitting from nails. Some carpenters do not like 5 cm by 10 cm boards cut from such timber (Echols, 1973).

The objectives of this study were:

(a) To determine the pattern of within-ring density variation in *Gmelina arborea*.
(b) To determine the proportions of wood of different density classes within the rings.
(c) To assess the relationship between within-ring variation in density and rainfall.

MATERIALS AND METHODS

Study Areas and Sampling Technique

Wood samples were obtained from seven-year old *Gmelina* plantations in four different localities in Nigeria; the plantations were established at a planting espacement of 2.44 m x 2.44 m on a square. The natural vegetation at each locality comprising mixed hardwood species, shrubs, herbs, and other humid tropical species was cleared and *Gmelina* seedlings were planted. The study areas were:

(a) Ajebandele, Omo Forest Reserve in Ogun State, a high forest area referred to as 'site 1' in this study. Annual rainfall 2150 mm, altitude 61 m, slope 11°; latitude 6°51'N, longitude 4°23'E. High Forest.

(b) Awi, Oban Forest Reserve in Cross River State, a secondary growth forest, referred to as 'site 2'. Annual rainfall 4030 mm, altitude 229 m, slope 4°; latitude 5°19', longitude 8°34'. Secondary forest.

(c) Ubiaja, Udo Forest Reserve in Bendel State, a derived savanna woodland —'site 3'. Annual rainfall 1870 mm, altitude 168 m, slope 4°; latitude 6°39', longitude 6°23'E. Derived savanna woodland.

(d) Onitsha, Akpaka Forest Reserve in Anambra State, a degraded derived savanna woodland—'site 4'. Annual rainfall 2180 mm, altitude 61 m, slope 6°; latitude 6°12'N, longitude 6°45'E. Degraded derived savanna woodland.

The climate of these study areas is of equatorial type: the rainfall is heavy and the temperature is high and equable. The total annual rainfall of the localities ranged from 1870 to 4030 mm with a similar pattern of seasonal distribution. Temperature conditions are similar in these areas. The mean annual temperature is about 25.5°C, the mean daily maximum is about 31°C and the mean daily minimum between 18°

and 24°C. The mean relative humidity at 9.00 a.m. varies from 80 to 87 per cent.

The following sampling strategy was adopted:

4 Sites
2 Plots (randomly chosen) per site, each plot enclosing about 30 trees
5 Trees (randomly chosen) per plot
3 Billets per tree at 5, 25, and 45 percent of tree height
2 Radial strips (randomly chosen) per billet.

Measurement of Wood Density by X-ray Densitometry

X-ray technique for determination of wood density was used in this study because it is an efficient and rapid method, capable of measuring density at short intervals (as small as 0.01 mm). X-ray densitometry was pioneered by H. Polge and co-workers in France (Polge, 1963, 1965) and it is increasingly popular because of its versatility in wood quality studied.

X-ray film images of radial strips cut from the billets were scanned on a micro-densitometer at intervals of 0.04 mm across each growth ring. The scanning produced optical density values which were transformed to values of physical density (Hughes and Sardinha, 1975; Akachuku, 1980). Radial strips 6 mm wide and 4 mm thick were cut from the billets and dried to equilibrium moisture content (about 12%) corresponding to laboratory conditions of temperature and humidity. Negative images of the radial strips were produced by projecting X-rays onto Kodak X-ray films on which the wood strips were placed.

Sampling for Within-Ring Pattern of Variation

Patterns of within-ring variation in density were determined by obtaining density values of every one-fifth of the ring width from the beginning to the end from the scanning output of the densitometer and plotting these values against radial distance per cent.

Within-ring density variation patterns were determined for:

(i) rings from different radii obtained from the same billet but of the same age or ring number from the pith (Figure 1);
(ii) rings from different billets (or levels) obtained from the same tree but of the same ring number from the pith (Figures 2);
(iii) rings from different trees from different sites but from the same percentage height and the same ring number from the pith (Figure 3).

Sampling for Within-Ring Density Classes

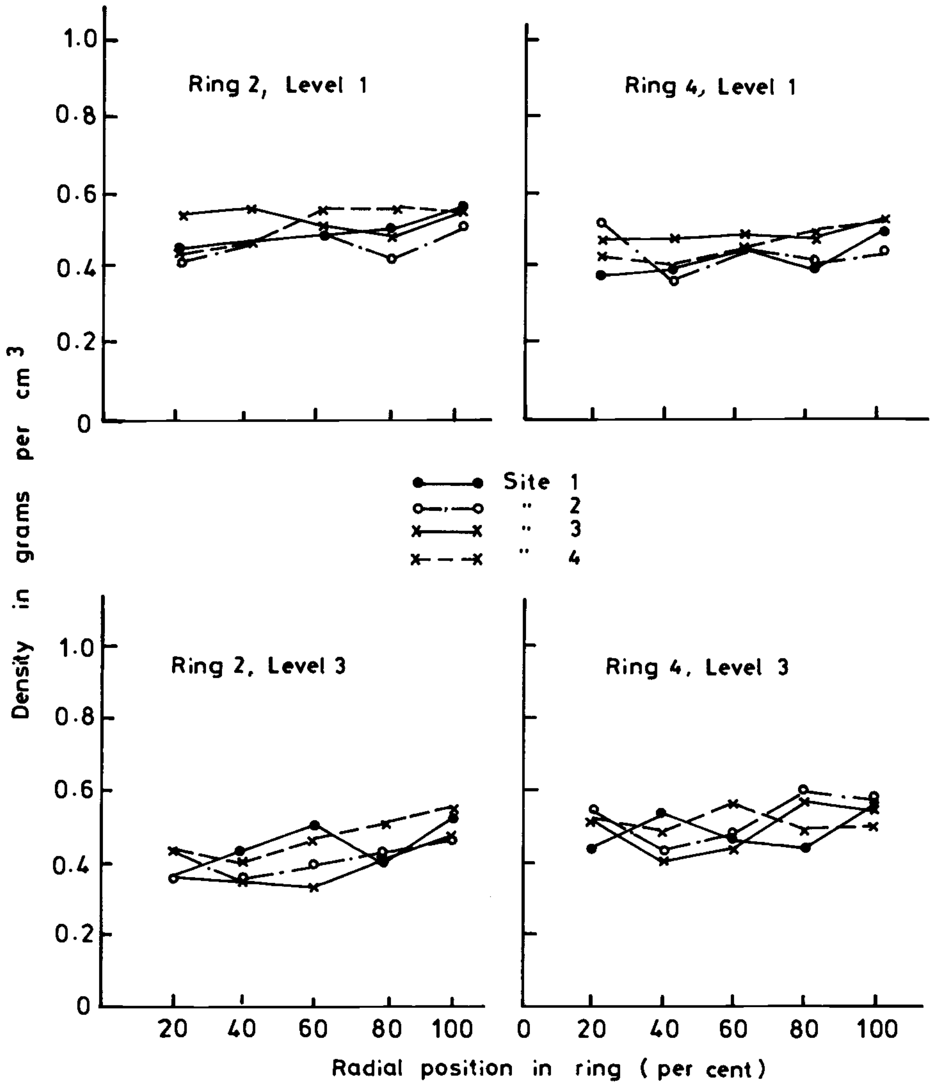

Figure 1. Patterns of within-ring density variation within trees.

At the 5 per cent level of the tree height, where all the sample trees had seven growth rings, the density values for intervals of 0.04 mm within each ring from the pith to the bark were divided into the following density classes:

Class 1: Low density, less than 0.399 gm/cm^3

Class 2: Medium density, 0.400 to 0.499 gm/cm^3

Class 3: Medium-high density, 0.500 to 0.599 gm/cm^3

Class 4: High density, over 0.600 gm/cm^3.

Computations and Statistical Analysis

The following computations were carried out for the within-ring density classes:

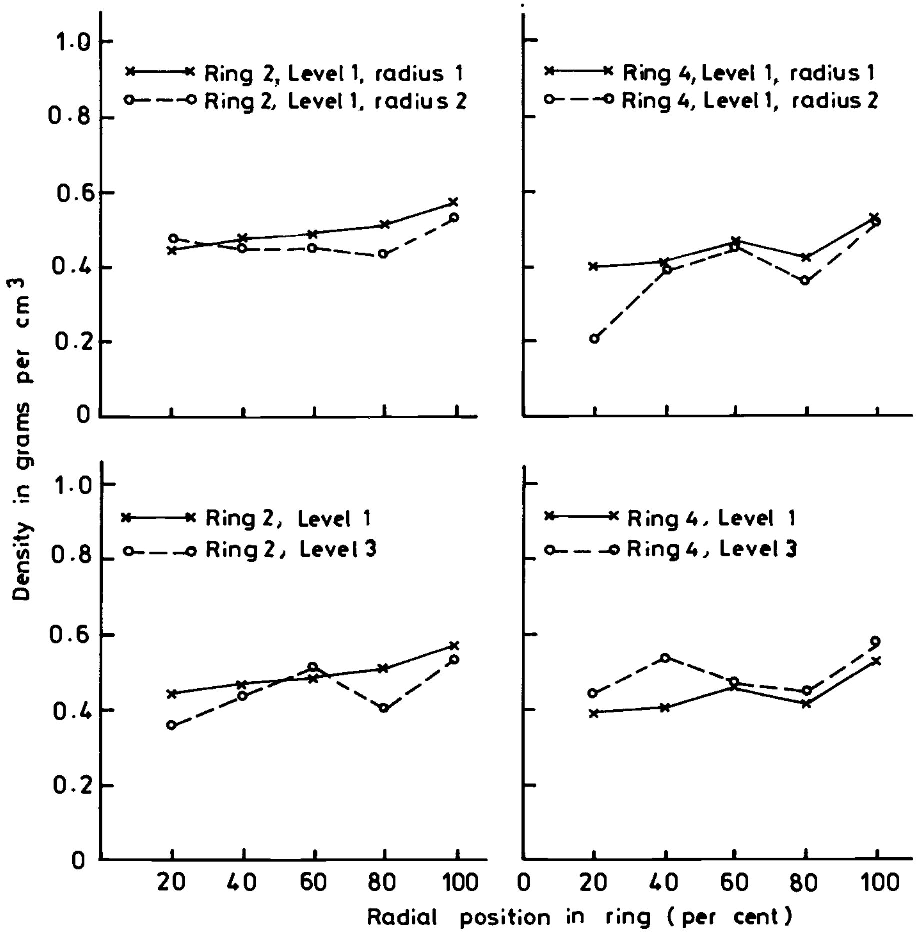

Figure 2. Patterns of within-ring density variation for different sites.

(a) The proportion of wood in each of the classes for every ring, equal to 100 times the width of the density class divided by the total ring width.

(b) The mean proportion of wood of each class in each ring for each site.

(c) The regression of the proportion of wood in each class on cambium age using 12 12 test models (Table 1) to determine the best fit and its coefficient of determination, r^2, or the index of determination, i^2.

The term coefficient of determination (r^2) was used to describe linear relationships between the dependent and independent variables. Curvilinear relationships between dependent and independent variables were described by the term index of determination (i^2). These terms show what proportion of the variation in the values of the dependent variable can be estimated from the concomitant variation in the values of the independent variable. However, because the degrees of freedom for these analyses are limited by the short length of the series, the regression results represent only the best-fit empirical models rather than a basis for estimation on independent data.

Regression analyses were performed to determine the relationship between rainfall and density in site 1, Omo Forest Reserve, where rainfall data were available.

Regression analyses were first carried out to determine the extent to which the total amount of rainfall in a growth season (as the independent variable) explained the

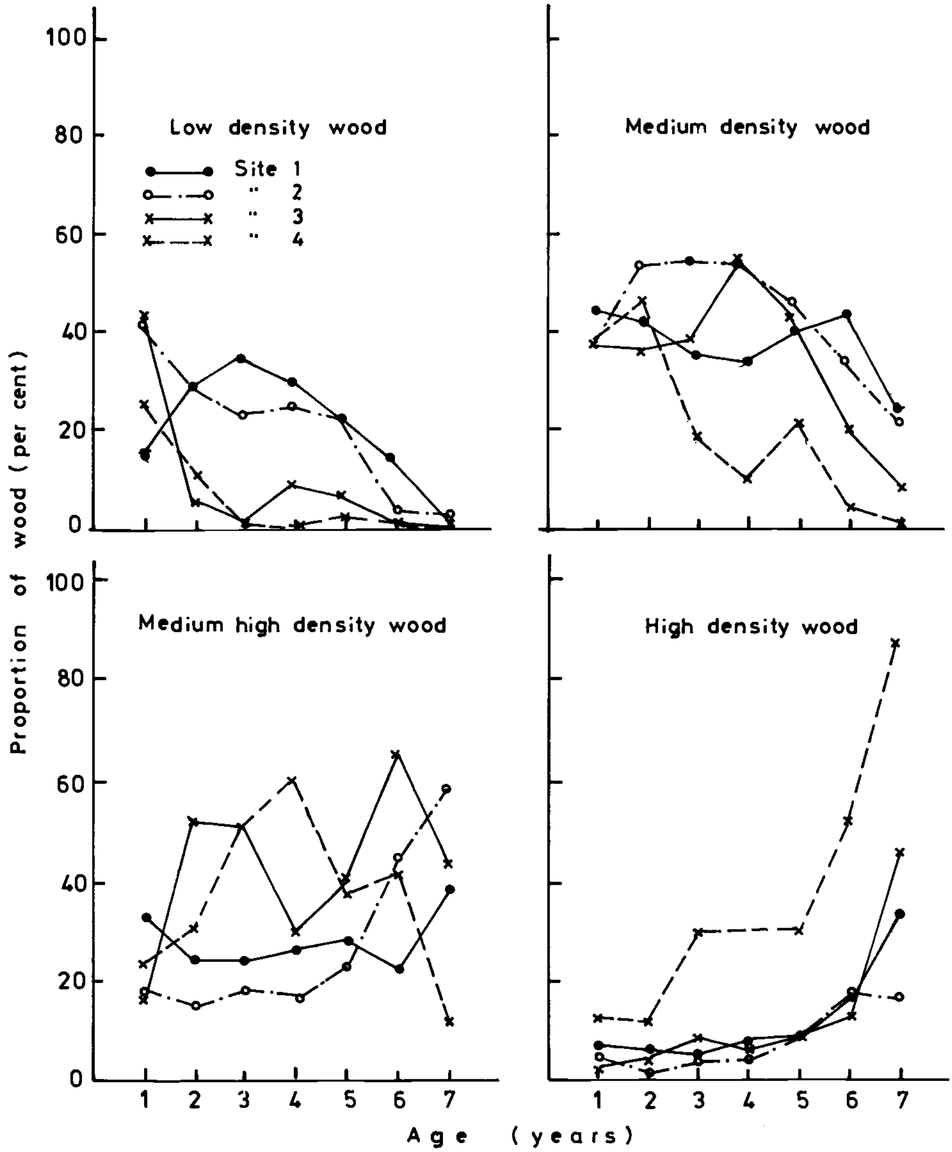

Figure 3. Variations with age in the proportions of wood in within-ring density classes.

following density variables:

(i) proportion of low density wood within the ring,
(ii) proportion of high density wood within the ring,
(iii) mean ring density,
(iv) maximum ring density,
(v) minimum ring density.

The values of r^2 were computed.

Regression analyses were also computed for the linear model to determine how the amount of rainfall in the dry season (that is from November to February inclusive) explained the following density variables:

(i) proportion of high density wood within the ring,
(ii) mean ring density,
(iii) maximum ring density,
(iv) minimum ring density.

RESULTS AND DISCUSSION

Within-Ring Pattern of Density Variation

The within-tree and between-tree comparisons show that no two rings had exactly similar patterns of variation in density in the radial direction. The closest resemblance was found only when two growth rings of the same ring number (or physiological age) were sampled from different radial strips obtained from a billet.

In most of the rings, there was a gradual increase in density from the beginning of the ring till a peak was reached, followed by a gradual decrease and another increase to a higher peak at the end of the ring. In few cases density increased from the beginning of the ring to the end in an irregular manner, or density decreased from the beginning of the ring and gradually rose to a peak but decreased slightly near the end of the ring.

It was clear that the pattern of within-ring density variation was not consistent. This may be an indication of the complexity of the tree's environment during a growth season and the fact that the cambial activity, in response to extrinsic and intrinsic factors, is variable within and between trees. Unlike the case of some species of softwoods in temperate regions where there are well defined patterns of within-ring variation, *Gmelina's* inconsistent pattern makes it difficult to develop a mathematical model relating the density of a piece of wood to its percentage distance from the beginning of the growth ring.

The Proportions of Wood in the Density Classes and Age

On the average, the proportion of low and medium density wood decreased with increasing age (Table 2 and Figure 3). Age had no consistent effect on the proportions of medium density and medium-high density wood (Figure 3). The general tendency was an increase in the proportion of high density wood with age (Figure 3). The regression analyses detected close correlations between the proportions of wood in the different density classes and age for the curvilinear models. However, the proportions of wood in each density class were different for different sites (Table 3). Out of the 12 regression models tested only four gave the best fit in different samples (Table 4).

The decrease in the proportion of low density wood (or the increase in the proportion of high density wood) with increasing age explains why the mean ring density in *Gmelina* usually increases with age.

Table 1. Regression models.

Model Number	Equation
1	$Y = a + bx$
2	$Y = a + b/x$
3	$Y = a + bx + cx^2$
4	$Y = a + be^{-cx}$
5	$Y = a + (1 - e^{-bx})$
6	$Y = a + bx^c$
7	$Y = ax^b$
8	$Y = 1/(a + bx)$
9	$Y = x/(a + bx)$
10	$Y = 1/(a + be^{-cx})$
11	$Y = a(1 - e^{-bx})^c$
12	$Y = x/(a + bx + cx^2)$

Within-Ring Density and Rainfall

Total annual rainfall did not considerably determine the proportion of low density wood (r^2 = 27 per cent, positive), proportion of high density wood (r^2 = 16 per cent, negative), mean ring density (r^2 = 0.8 per cent, positive) and minimum ring density (r^2 = 0.0 per cent).

However, dry season rainfall negatively determined the maximum ring density (r^2 = 83 per cent) and minimum ring density (r^2 = 42 per cent). It only slightly determined the proportion of high density wood (r^2 = 18 per cent negative) and did not determine mean ring density (r^2 = 0.0 per cent).

Although water is very important in wood formation, rainfall *per se* is not the only factor that controls wood density. The poor or negligible correlations between the density and rainfall variables were therefore likely to occur.

A decrease in the amount of dry season rainfall (that is, an increase in the severity of dryness) increased the ring maximum density because the two variables were observed to be negatively correlated. This should be expected because the latewood, usually formed during the time of water deficit, has a higher density than the earlywood, formed when there is sufficient water. However, wood formation is controlled by complex biochemical and physiological processes which are influenced by several intrinsic and extrinsic factors.

Table 2. Proportion of wood in four density classes within rings in *Gmelina arborea.*

Year of formation	Density Class			
	Low	Medium	Medium-High	High
		Site 1		
1967-68	14.8	45.4	32.6	7.2
1968-69	28.5	41.6	23.6	6.2
1969-70	34.3	36.3	24.0	5.5
1970-71	30.1	34.2	27.4	8.3
1971-72	22.7	39.6	29.1	8.6
1972-73	15.4	43.5	22.5	16.7
1973-74	3.1	25.1	39.3	32.5
Mean	21.3	38.0	28.4	12.1
		Site 2		
1967-68	40.3	37.1	18.1	4.6
1968-69	28.7	53.8	15.8	1.4
1969-70	23.0	55.1	18.3	3.6
1970-71	25.1	53.5	16.8	4.5
1971-72	23.3	45.9	23.3	7.6
1972-73	4.1	33.7	44.7	17.5
1973-74	2.9	22.0	58.5	16.6
Mean	21.1	43.0	27.8	8.0

Other environmental factors such as light, temperature and biotic factors control wood formation and structure (Kramer and Kozlowski, 1960; Kozlowski, 1964; Panshin and De Zoeow, 1970; Kozlowski, 1971; Fritts, 1976) and consequently wood density, which is an index of wood quality.

CONCLUSIONS

1. Wood formed in one growth year was not of uniform density. That is, within-ring variation in density was observed.
2. The pattern of within-ring variation in density in the radial direction was not consistent; it varied with positions within trees, among trees and sites.
3. The proportions of wood in within-ring density classes were different in different years of wood formation in different sites.
4. Density and rainfall variables were not closely correlated except for dry season rainfall and maximum ring density, which were negatively correlated.

Table 2. continued.

Year of formation	Low	Density Class Medium	Medium-High	High
		Site 3		
1967-68	43.8	36.6	16.8	2.8
1968-69	6.1	37.2	51.8	4.9
1969-70	1.4	39.2	50.8	8.6
1970-71	8.7	54.6	30.0	6.8
1971-72	6.5	43.9	40.2	9.3
1972-73	1.1	19.6	66.2	13.1
1973-74	0.0	9.0	44.3	46.8
Mean	9.6	34.3	42.9	13.2
		Site 4		
1967-68	25.8	37.9	23.6	12.6
1968-69	11.1	45.9	31.4	11.6
1969-70	0.2	18.5	51.4	29.9
1970-71	0.0	9.9	59.6	30.5
1971-72	3.2	21.5	38.3	31.3
1972-73	0.0	5.2	42.0	52.8
1973-74	0.0	0.0	12.4	87.6
Mean	6.0	20.0	37.2	36.8

Table 3. Overall mean values (in %) of the proportions of wood in four within-ring density classes for the four sites.

Site	Low	Density Class Medium	Medium-High	High
1	22.9	37.5	27.9	11.6
2	21.1	43.0	27.8	8
3	9.7	34.3	42.9	13.2
4	6.0	37.2	37.2	36.8

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Table 4. Results of regression of within-ring density classes on age.

		Density Class			
		Low	Medium	Medium-High	High
Site 1	Model	3	3	12	12
	i^2	95%	37%	54%	99%
	Model	-	-	3	3
	i^2	-	-	54%	95%
Site 2	Model	3	3	3	12
	i^2	87%	95%	97%	90%
	Model	-	-	-	3
	i^2	-	-	-	88%
Site 3	Model	6	3	2	12
	i^2	96%	82%	40%	99%
	Model	3	-	-	3
	i^2	68%	-	-	93%
Site 4	Model	3	3	3	12
	i^2	88%	77%	83%	97%
	Model	-	-	-	3
	i^2	-	-	-	93%

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