

**ALLOMETRIC MODELS FOR ESTIMATING SITE INDEX OF TEAK (*Tectona grandis* Linn F.) IN KANYA FOREST PLANTATION, KEBBI STATE, NIGERIA**

**ABSTRACT**

This study was conducted in order to develop site index for Teak (*Tectona grandis*) in Kanya Forest Plantation, Nigeria. Site index is defined as the total height of the dominant or co-dominant trees at an arbitrary index age, it is a method used for quantifying site quality for pure even aged stands which is essential in growth and yield modeling. The data used in this study were obtained from six different age classes. Five sample plots each were selected across all age classes in which a total of 712 trees were measured, variables measured include total height, diameter at the base, middle, top, and diameter at the breast height were taken from 30 temporary sampled plots of 25x25m approximately from the center, 180 dominant trees were selected from 712 trees. Basal area and volume of sampled trees were computed. Yield values obtained from the dominant trees are (B=249.312m<sup>3</sup>/ha, D=196.128m<sup>3</sup>/ha, F=134.976m<sup>3</sup>/ha, C=119.328m<sup>3</sup>/ha, E=100.320m<sup>3</sup>/ ha and A=86.976m<sup>3</sup>/ha). The results showed that B was the best and A was the poorest. Seventeen models were generated and paired sampled t-test was used for model validation, comparing the actual and predicted height. Two out of 17 were rejected (significant P<0.05). The first model  $Hd=12075.346-354.809(\text{Age})+3.448(\text{Age})^2-135193.126(1/\text{Age})$  is the recommended height estimation of Teak in Kanya Forest plantation for its best performance.

**Keywords:** Site; Site Index; Site Quality; Dominant Trees; Teak.

**1. INTRODUCTION**

Site index is defined as the average total height of dominant and co-dominant trees (site trees) at a specified reference or base age, which is commonly selected to lie close to the rotation age [1]. The top height is the arithmetic mean height of the 100 trees ha<sup>-1</sup> with the greatest diameters [2]. However, the most common objective of site index is to determine the height development pattern that a stand is expected to follow throughout rotation [1]. It is little affected by varying densities and species composition, relatively stable under varying thinning intensities and is strongly correlated with volume.

Site index is a quantitative measure of site quality, and it is generally a reflection of the potential timber productivity of a stand of trees [3]. Dominant and co-dominant trees are used to describe

34 site index because they are assumed to have grown freely throughout their life; thus, the growth  
35 of these trees is somewhat independent of other vegetation. A base age is usually used as a  
36 reference so that stands of different site quality can be compared. These characteristics of  
37 plantation forest - uniformity of crop, intensity of production, high density, fast growth rate and  
38 high productivity have raised concerns that many of the sites on which the plantations are  
39 established may be incapable of sustaining their productivity [4]. Site quality assessment is the  
40 evaluation of innate productive capacity of an area of forest land for one or more tree species.  
41 Site quality assessment is very important in forest management because a site could support one  
42 species excellently, while supporting another species poorly.

43 According to 2000-2005 Global Forest Resources Assessment of the Food and Agricultural  
44 Organization of the United Nation (FAO), Nigeria has the world's highest annual deforestation  
45 rate of primary forest at 55.7%. The country is one of the largest losers of annual natural forest in  
46 Africa at 11.1%. Nigeria's annual deforestation rate of natural forest is the highest in the world  
47 and put it in the pace to lose virtually all its primary forest within few years. There is a growing  
48 concern about the uncontrolled exploitation of Nigeria's forest resources in accordance to the  
49 recent observations that deforestation poses a great risk to sustainable land use and the wellbeing  
50 of the people [5].

51 For more than 100 years, site index has remained the world's most widely used measure of site  
52 productivity, many decisions in forestry rely on estimates of the land's inherent ability to grow  
53 trees and yield timber. These site productivity estimates serve as a baseline for land-use  
54 decisions, land appraisals, silvicultural investment analyses, and growth and yield predictions.  
55 The importance of site quality assessment remains imperative in quantitative forestry, simply for  
56 its potential and possibility of determining the productive capacity of the plantations area for

57 sustainable management [6]. The main objective of this research is to develop site index for Teak  
58 (*Tectona grandis* Linn F.) in Kanya Forest Plantation

## 59 **2. MATERIALS AND METHODS**

### 60 **2.1 The Study Area**

61 The study was conducted in Kanya Forest Plantation in Danko Wasagu Local Government,  
62 Kebbi State is located on Latitude 11.339<sup>0</sup>N to 11.348<sup>0</sup> and Longitude 5.606<sup>0</sup>E to 5.641<sup>0</sup>E,  
63 occupying about 4,208km<sup>2</sup>. It is bordered in the South by Sakaba Local Government, in the West  
64 by Zuru Local Government both in Kebbi State and in the North by Bukkuyum Local  
65 Government Area of Zamfara State. Danko Wasagu has an estimated population of about  
66 265,271 people [7]. The vegetation falls under Northern Guinea Savannah. The topography is  
67 said to be flat or low land with fertile soil covered by sandy soils, sometime coarse in texture  
68 with fadama and alluvial plain suitable for agricultural activities. The weather is marked by  
69 single rainy season and long dry season; the average rainfall is 720mm, the rainy season is about  
70 four to five months, the mean temperature ranges from 31<sup>0</sup>C and 38<sup>0</sup>C. From the month of  
71 November to February cold weather is usually experienced due to the dry harmattan wind and  
72 from March to May, the weather is generally hot and wet as in the tropics [8].

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### 76 **2.2 Sampling Procedure**

77 The area was stratified in to different age classes based on the years of establishment (1979,  
78 1980, 1981, 1982, 1983, and 1989) on which five temporary sample plots of 25 x 25m

79 (0.0625ha) were marked at random from each age block close to the center. Measurements were  
80 taken on all trees within the selected plots. Stand age was obtained from plantation records.

### 81 **2.3 Data Collection**

82 The data obtained include: Counting and recording of individual trees per plot, Measuring the  
83 total height of six dominant trees in all selected plots using Haga Altimeter (this represented the  
84 100 largest trees per ha), Diameter at breast height (DBH) of all individual trees was measured at  
85 1.3m above ground level. Flexible measuring tape was used to determine the circumference of  
86 the boles, Diameters at three different points (Base, middle, Top) were determined with the aid  
87 of Spiegel Relascope.

### 88 **2.4 Development of Site Index Equations**

89 After due consideration of the rotation age and the age of culmination of mean annual increment  
90 as recommended by various researchers [9,10,11] 30 years was adopted as the appropriate base  
91 age for the determination of site index of Teak plantations in the study area. Among the various  
92 techniques for developing site index equations, the proportional or guide curve method was  
93 adopted for this study because the data were obtained from temporary sample plots, thus  
94 permitting only the use of this method [1,12]. Various linear and non-linear equations commonly  
95 used for site index studies in forestry were selected from forestry literature  
96 [13,14,15,16,11,17,18,19]. These equations or models followed the order as follows.

$$97 \quad Hd = a_0 + a_1 (\text{Age}) + a_2 (\text{age})^2 + e_i \quad (4)$$

$$98 \quad Hd = a_3 + a_4 (\text{Age}) + a_5 (1/\text{Age}) + e_i \quad (5)$$

$$99 \quad Hd = a_6 + a_7 \ln (\text{Age}) + e_i \quad (6)$$

### 100 **2.5 Model Selection and Validation**

101 Different criteria for choosing the best model are available; the highest coefficient of  
102 determination ( $R^2$ ) and the lowest root mean square error (RMSE) were considered appropriate

103 criteria in selecting the best model. Model validation was achieved by dividing the data into two  
 104 sets; (75%) of the data to calibrate the models and the other set (25%) to validate the models,  
 105 testing for the significant differences in mean predicted and observed values of the dependent  
 106 variables in all cases was achieved using paired sample T-test.

### 107 3. RESULTS

108 The summaries of growth and yield characteristics of 180 sampled dominant trees are presented  
 109 in Tables 1 and 2. Mean, minimum and maximum values of Dbh, height, BA and volume are  
 110 recorded for all the age series. The standard error of the mean was also attached to all the mean  
 111 values in order to see the variability distribution of the sampled data from the population.

112 **Table 1: Summary Statistics of Dominant Trees (Sampled Trees)**

Age (years)	Plots	Trees	Dbh (cm)			Height(m)		
			Min	Max	Mean*	Min	Max	Mean*
38	5	6	12.51	36.98	23.77±0.29	9.85	15.25	15.61±0.44
37	5	6	20.53	27.05	25.10±0.75	11.30	19.60	15.19±0.51
36	5	6	19.26	37.91	26.62±0.93	10.70	20.00	15.58±0.42
35	5	6	16.23	37.91	30.07±1.39	11.55	19.60	22.61±0.46
34	5	6	19.89	48.09	24.91±0.89	18.80	28.25	15.07±0.39
28	5	6	16.87	39.15	25.59±0.41	12.90	19.80	16.06±0.29

113 \*Mean± standard error

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119 **Table 2: Summary of yield characteristics of Dominant Trees (Sites Trees)**

AC	P	Trees	Basal Area (m <sup>2</sup> )				Volume (m <sup>3</sup> )			
			Min	Max	Mean	Mean BA/ha	Min	Max	Mean	Mean volume/ha
A	5	6	0.01	0.11	0.04±0.01	4.29	0.240	0.980	0.906±0.04	86.976

B	5	6	0.03	0.06	0.50±0.03	8.03	0.410	1.310	2.597±0.20	249.312
C	5	6	0.29	1.11	0.11±0.04	10.34	1.260	5.630	1.243±0.18	119.328
D	5	6	0.02	1.11	0.08±0.01	7.20	0.480	5.470	2.043±0.18	196.128
E	5	6	0.03	0.18	0.05±0.01	4.70	1.150	5.300	1.045±0.08	100.320
F	5	6	0.02	0.12	0.14±0.02	13.14	0.580	2.290	1.406±0.08	134.976

120 \*Mean± standard error

### 121 3.1 Site Index Parameter Models.

122 Different model forms/structures were considered in developing site index equations and  
 123 estimated regression parameters are presented in Table 3.

**Table 3: General models**

Model Expression		Estimated parameters			
		a	b	c	d
1	Hd = a + b (Age)	23.84	-0.225	-	-
2	Hd = a + b (Age) <sup>2</sup>	20.821	-0.004	-	-
3	Hd = a + b ln (Age)	38.441	-6.311	-	-
4	Hd = a + b ln (Age) <sup>2</sup>	27.990	-0.948	-	-
5	Hd = a + b (Age) + c (Age) <sup>2</sup>	-238.092	15.996	0.248	-
6	Hd = a + b (Age) + c (1/Age)	597.471	-9.017	9225.302	-
7	Hd = a + b (1/Age) + c (Age) <sup>2</sup>	296.410	-5903.004	-0.089	-
8	Hd = a + b (1/Age) + c ln (Age)	2716.098	-19260.413	-604.20	-
9	Hd = a + b (Age) <sup>2</sup> + c ln (Age)	-772.306	-0.129	266.731	-
10	Hd = a + b ln (Age) + c ln (Age) <sup>2</sup>	-3452.704	2004.657	-289.249	-
11	Hd = a + b (Age) + c (1/Age) + d (Age) <sup>2</sup>	-238'183	15.999	10.00	-0.248
12	Hd = a + b (Age) + c(1/Age) + d ln (Age)	-1349.746	-17.299	15.000	555.0.78
13	Hd = a + b (Age) + c ln (Age) + (Age) <sup>2</sup>	-545.676	-23.907	15.000	110.529
14	Hd = a + b (Age) + c ln (Age) <sup>2</sup>	-544.228	-23.919	110.729	-
15	Hd = a + b (1/Age) + c ln (Age) <sup>2</sup>	1287.809	-14801.435	-66.976	-
16	Hd = a + b (Age) + c ln (Age) <sup>2</sup>	-3427.703	1990.238	-287.173	-
17	Hd = a + b (Age) + c (Age) <sup>2</sup> + d (1/Age)	12075.346	-354.809	3.448	1351.126

124 Hd = dominant height, a, b, c, d = Regression coefficients, Age = Age of the plantation

### 125 3.2 Model Evaluation and Validation

126 Fifteen equations were ranked based on some statistics generated in the course of modelling.

127 Models with the highest coefficient of determination (R<sup>2</sup>) and Smaller Root mean square error

128 (RMSE) were considered as the better fit models and were subsequently ranked higher than those

129 with lower R<sup>2</sup> and higher RMSE values (Table 4). The selected candidate models were equations

130 1,2, and 3 based on ranking with equation 1 having the highest R<sup>2</sup> and lowest RMSE of 0.760

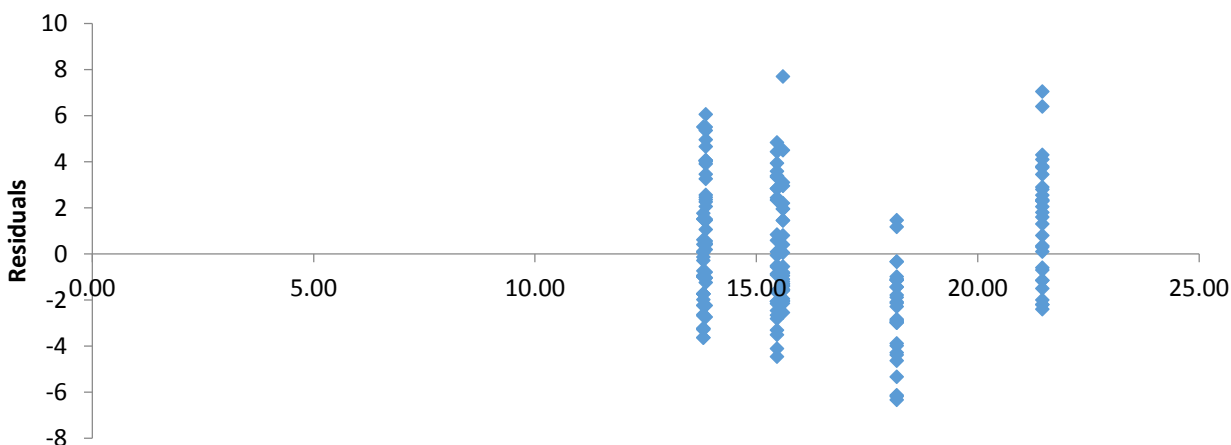
131 and 1.384. Furthermore, plots of residual values of dominant height for the selected models are

132 shown in Figures 1, 2, and 3. The selected models have their scatter plot normally distributed  
 133 having perfect prediction of the estimated dominant height.

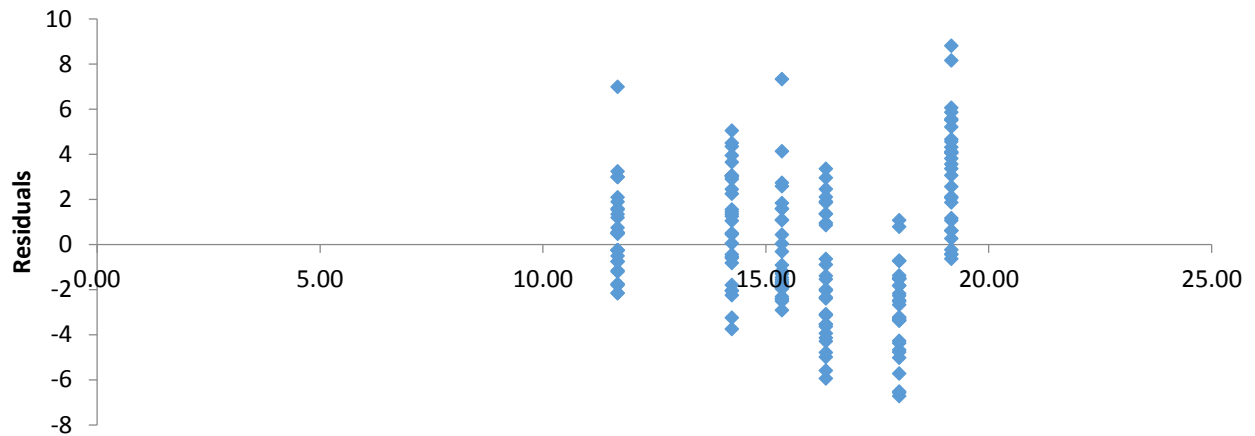
**Table 4: General Equations Developed for Site Index Estimation**

Developed Equations	R <sup>2</sup>	RMSE	Ranking
Hd = 12075.346 - 354.809 (Age) + 3.448 (Age) <sup>2</sup> - 135193.126 (1/Age)	0.760	2.384	1
Hd= 2716.098 - 19260.413 (1/Age) - 604.020ln (Age)	0.634	3.592	2
Hd = 1287.809 - 1401.435 (1/Age) - 66.976ln (Age) <sup>2</sup>	0.632	3.607	3
Hd= - 3452.704 + 2004.657ln (Age) - 289.249ln (Age) <sup>2</sup>	0.627	3.657	4
Hd = - 597.471 - 9.017 (Age) - 9225.302 (1/Age)	0.627	3.660	5
Hd = - 3427.703 + 1990.238ln (Age) - 289.173ln (Age) <sup>2</sup>	0.626	3.695	6
Hd = 296.410 - 5903.004 (1/Age) - 0.089 (Age) <sup>2</sup>	0.620	3.730	7
Hd = - 1349.746 - 17.299 (Age) + 15.00 (1/Age) + 555.078ln (Age) <sup>2</sup>	0.620	3.745	8
Hd = - 772.306 - 0.129 (Age) <sup>2</sup> + 266.731ln (Age)	0.613	3.794	9
Hd = - 238.092 + 15.996 (Age) - 0.248 (Age) <sup>2</sup>	0.607	3.860	10
Hd = - 238.183 + 15.999 (Age) + 10.00 (1/Age) - 0.248 (Age) <sup>2</sup>	0.607	3.882	11
Hd = 20.821 - 0.004 (Age) <sup>2</sup>	0.071	9.055	12
Hd = 23.884 - 0.225 (Age)	0.055	9.216	13
Hd= 27.990 - 0.498ln (Age) <sup>2</sup>	0.045	9.315	14
Hd = 38.441 - 6.311ln (Age)	0.041	9.352	15

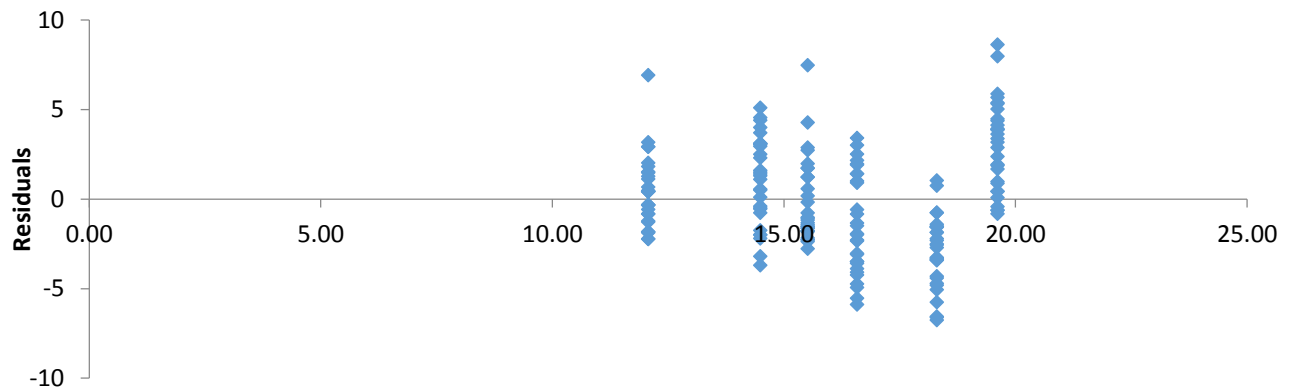
134 Hd = dominant height (m) Age = Age of the plantation, R<sup>2</sup> = coefficient of determination, RMSE = Root mean square error.



135 **Figure 1: Residual plots for dominant height using first equation**  
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138 **Figure 2: Residual plot for dominant height using second equation**



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140 **Figure 3: Residual Plot for Dominant Height using third Equation**

141 In order to validate the selected models, paired sample T-test was carried out comparing heights  
142 of dominant trees measured from the field and the estimated values from the equations generated  
143 (Table 5). Pairs that showed non-significant difference were considered as valid models for  
144 application, while pairs that yielded significant differences were rejected ( $p < 0.05$ ).

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**Table 5: Results of Model Validation for Site Index Estimation**

Paired Samples	Mean difference	T-Value	P-Value	Decision
Hd(m) v Eqn 1	0.00789	0.028	0.978 ns	Accepted
Hd(m) v Eqn 2	0.12022	0.425	0.671 ns	Accepted
Hd(m) v Eqn 3	-0.00193	-0.007	0.995 ns	Accepted
Hd(m) v Eqn 4	-0.00203	-0.007	0.994 ns	Accepted



Hd(m) v Eqn 5	0.31456	1.391	0.166 ns	Accepted
Hd(m) v Eqn 6	0.00181	0.008	0.994 ns	Accepted
Hd(m) v Eqn 7	0.00033	0.001	0.999 ns	Accepted
Hd(m) v Eqn 8	0.29726	1.319	0.189 ns	Accepted
Hd(m) v Eqn 9	0.00039	0.002	0.999 ns	Accepted
Hd(m) v Eqn 10	-0.42848	-1.908	0.058 ns	Accepted
Hd(m) v Eqn 11	0.01019	0.045	0.96 ns	Accepted
Hd(m) v Eqn 12	-3.59844	-16.004	0.00 sig	Rejected
Hd(m) v Eqn 13	-49.59120	-199.945	0.00 sig	Rejected
Hd(m) v Eqn 14	0.01658	0.074	0.941 ns	Accepted
Hd(m) v Eqn 15	-0.00152	-0.007	0.995 ns	Accepted
Hd(m) v Eqn 16	0.00317	0.140	0.989 ns	Accepted
Hd(m) v Eqn 17	-0.30048	-1.454	0.145 ns	Accepted

147 Hd = Dominant height (m), Eqn = Equations, Ns = No significant different, Sig.= Significant difference.

## 148 4. DISCUSSION

### 149 4.1 Site Index Models

150 The parameter and statistics of regression models 1-17 generated are being presented. Parameters  
151 (a, b, c, d,) varied with the model. The selected height-age models are presented according to  
152 criteria for selecting the most suitable prediction model, model 17 (Ranked 1st) performed better  
153 than all for height-age prediction in Kanya Forest Reserve having highest  $R^2$  and the lowest  
154 RMSE of 0.760 and 2.384. Although, the  $R^2$  value was higher than that reported by [20] in  
155 height-diameter models and slightly lower  $R^2$  in volume-Dbh models  $R^2 = 0.51$  and  $R^2 = 0.85$   
156 respectively. The result implies greater accuracy for dominant height prediction due to higher  
157 modeling efficiency. [18] carried out similar study on Site Index Equation for *Pinus caribaea*  
158 Plantation in Erosion Prone Enugu Ngwo, Nigeria having  $R^2_{adj}$  0.911 and RMSE 0.023  
159 respectively. [21] Site Quality Assessment for *Tectona grandis* Linn.F Plantations in Gambari  
160 Forest Reserve, Nigeria reported  $R^2$  value of 0.95 and SEE value of 0.0835 this shows higher  
161 accuracy than the best model in this research. A study by [22] on Site Quality Assessment of  
162 Degraded *Quercus fraianetto* stand in central Greece obtained slightly higher  $R^2$  values (0.799,  
163 0.788, and 0.700) for the first two equations and the third equation reporting lower  $R^2$  value, two

164 of the equations have higher accuracy than the best equation in this study and the third equation  
165 having low accuracy in predicting dominant height than what was presented in this study. Paired  
166 sampled t-test was used to validate the models by comparing the height estimated by the  
167 equations and actual height measured. The validation showed mean differences, T-value, P-value  
168 and also decisions on the accepted and rejected models. All equations with higher P-values  
169 ( $P > 0.05$ ) showed no significant difference between the actual measured and estimated dominant  
170 height and are accepted, while those with P-value ( $P < 0.05$ ) showing significant differences were  
171 automatically rejected. [20] also used paired sampled t-test to validate the models comparing  
172 actual measured and estimated volume of the stand recording three equations that were  
173 significantly different ( $p < 0.05$ ).

## 174 **5. Conclusion and Recommendation**

175 From the results of the study, it can be concluded that the index age of 30 was used to determine  
176 the site index of *Tectona grandis* in Kanya Forest Planation, Nigeria. Similarly, the site index  
177 equation developed was appropriate for the determination of the site quality of the *Tectona*  
178 *grandis* plantation, and thus can be relevant in assessing the productivity of the Teak stand. This  
179 will enhance the proper management of the stand for sustainable timber yield production.  
180 It is therefore recommended based on the that: Equation 1.  $Hd = 12075.346 - 354.809 (Age) +$   
181  $3.448 (Age)^2 - 135193.126 (1/Age)$ , should be used for site index estimation of teak plantation in  
182 Kanya Forest Plantation for its best performance and simple structure

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