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Assessment of Some Inter - Tree Competition Measures for Predicting Individual Stem Volume of Tectona Grandis (Lin.F.) Stands in Ibadan, South Western Nigeria

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ABSTRACT

Competition among trees within a stand occurs when resource availability is insufficient to meet the total requirements of a tree population for optimal growth. The occurrence of natural thinning in forest stands is a function of the competition stress of such trees, necessitated the need to carrying out of this research. Assessment of inter-tree competition is very important in growth and yield studies at individual tree level as it provides detailed information and flexibility for evaluating alternative use options and stand treatments. The incorporation of competition indices in predicting stem volume of Tectona grandis stands have not been properly researched in the forest stands of Ibadan metropolis, Ibadan, and hence, the need for this research.

Nineteen temporary sample plots of dimensions 25 m x 25 m were laid and used for this study. Within each plot, there was complete enumeration. The tree growth variables measured were diameters at breast height, stump, middle and top, total and merchantable heights, crown length, crown diameter and distance of target trees from neighboring trees. The other derived variables include tree volume, basal area and stand density. Four distance- dependent competition indices were employed and named as CI_1 to CI_4. The tree volumes of each stand were assessed independently. Fourteen linear regression models were fitted and evaluated by using the adjusted coefficient of determination (R^2), root mean squared error, Akaike Information Criterion (AIC) and residual variance (resVar).

The data was analyzed using descriptive statistics, correlation and regression analyses. Amongst the fourteen models developed and evaluated, the model with adjusted coefficient of determination of 0.82, root mean square of 0.29, Akaike Information Criteria of -23.98 and residual variance of 0.087 gave the best fit and predictive ability. Therefore, it is recommended that the model can be used by forest managers for updating and calibration inventory data for sustainable stand management of forest resources in Ibadan metropolis.

Keywords: *distance-dependent model, correlation, inter-tree, competition indices, Teak.*

INTRODUCTION

Tree competition has been a subject of substantial scientific interest in much of forestry research. Variables employed hereto represent competitive effects that explain diameter, basal area, and other growth traits of individual trees. These variables however, characterize the vigor and competitiveness of the chosen subject tree through its absolute or relative dimensions, while other variables account for the amount of competition exerted on the subject tree by surrounding trees. The variables reflecting potential tree competitiveness are primarily individual tree characteristics, some of which are relative to the tree's neighbors. Some of these variables include diameter, basal area, height, crown class, projected crown area, and portion of the crown exposed to direct sunlight.

Research related to individual tree growth is crucial in light of the often employed silvicultural practice of crop tree management, by which individual high-quality trees from predetermined species are selected fairly early in the life of the stand with the intention to be kept throughout the rotation. An understanding of the influence of neighboring trees on the growth of the crop tree is critical. Providing the most favorable growing conditions through silvicultural operations to these crop trees during the rotation requires prior knowledge of the inter-specific and intra-specific competition effects that may exist. Competition among trees within a population occurs when adjacent trees are forced to share limited resources in a restricted area (Tilman 1982, Shainsky *et al.*, 1992). Due to the competition that occurs, trees in populations usually exhibit large variations in growth (Harper 1977). Understanding this variation in growth is central to forest ecology because of its significance to the forest structure, mortality, and biomass (Peet *et al.*, 1987, Nishimura *et al.*, 2002, Coomes *et al.*, 2007).

In order to understand competitive dynamics, several competition indices (CI) have been developed through time to assess the competitive intensity taking place either in whole stand, size-class or acting on individual trees. Whole stand models use stand-level parameters such as stand density (e.g., trees/acre or hectare), stand basal area, quadratic mean diameter, site index, and stand age to predict timber yields for the stand. Research related to competition effects on tree growth is based on two broad types of models (Munro 1974); distance-independent models where the predictor variables represent mostly stand-level or plot-level characteristics, including density and basal area of all trees, or the basal area of only the trees with height or diameter above a Certain threshold (Martin *et al.*, 1984, Daniels *et al.*, 1986, Wykoff 1990, Wimberly *et al.*, 1996) and distance-dependent models developed to better account for the variation found in stand conditions with heterogeneous species composition, density, and spatial structure (Dimov, 2004, Biging *et al.*, 1995). These distance-dependent models range in their degree of complexity from some simpler ones that use inter-tree distances or competitor size (Daniels, 1976, Martin *et al.*, 1984, Biging *et al.*, 1992). The distance-independent and distance-dependent models in the literature vary in their performance in accounting for tree growth with neither type having a clear advantage over the other. Various size variables are used including DBH, total tree height (Corral-Rivas *et al.*, 2005), stem volume (Weiner, 1985) and crown cross-sectional area (Biging *et al.*, 1992). DBH is frequently used as the size variable because it is commonly available and other variables are not vastly superior (Corral *et al.*, 2005). Size-ratio indices calculate sums of ratios of subject tree dimensions (diameter at breast height (DBH), total height, and basal area) to competitor tree dimensions, and are often weighted by distances of the subject tree to its competitors. The resulting size ratios are often weighted by the distances between subject and competitor trees so that the closer ones have greater influences (Wang *et al.*, 2012).

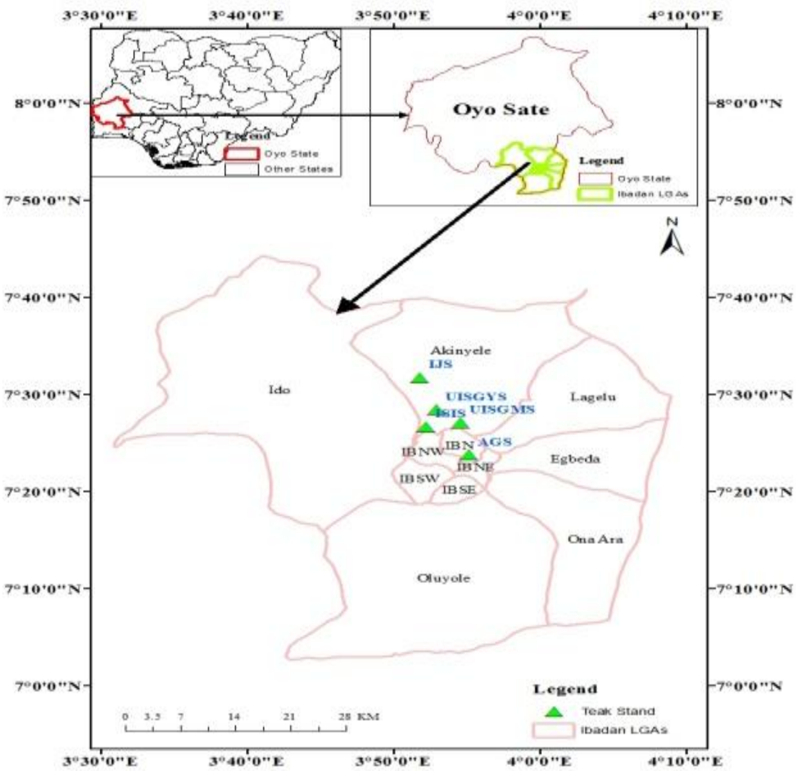

Figure1. *Map of Ibadan showing the teak stands used for the study*

Key to the abbreviations

IJS – Ijaiye Stand

UISGYS – University of Ibadan Second Gate Young Stand

UISGMS **-** *University of Ibadan Second Gate Mature Stand*

ISIS – International School Ibadan Stand

AGS – Agodi Gardens Stand

METHODOLOGY

The sites include University of Ibadan second gate plantations, Agodi Gardens, Ijaiye and International School Ibadan. Agodi Garden is located in Ibadan North Local Government Area of Oyo State. It lies between latitudes 7^0 24.421′N and 7^0 24.623′N; and longitudes 3^0 53.725′E and 3^0 53.878′E. The University of Ibadan mature teak plantation is located at Northeast corner of the university campus situated between latitudes 7^0 45.106′N and 7^0 45.834′N; and longitudes 3^0 90.942′E and 3^0 90.508′E, while the young plantation is located between latitudes 7^0 45.79′N and 7^0 45.834′N; and longitudes 3^0 90.392′E and 3^0 90.508′E. The *Tectona grandis* stand situated at the International School, University of Ibadan is located between latitudes 7^0 26.097′N and 7^0 26.136′N; and longitudes 3^0 53.775′E and 3^0 53.821′E. The privately owned teak plantation located off Ijaye road was established in 1996. The site has a gentle slope and is surrounded by a shallow swamp. It is located between latitudes 07^0 32.379′N and 07^0 32.449′N; and longitudes 3^0.53.358′E and 3^0.53.459′E.

Data Collection

Within the Teak plantations however, the direct observation technique was employed and it involved the assessment of five sample plots of dimension 20m × 20m within each stands resulting to a total of nineteen sample plots that were examined.

Sampling Procedure

Since the plantation is of same species and located on different sites, basically consisting of teak trees, the Stratified Random Sampling technique was used. This method yields an unbiased estimate of the population mean and also provides information to assess the sampling error.

Tree Measurement

The variables measured include circumference at breast height (CBH), circumference at base (CB), diameter at middle (DM) and diameter at the top (DT), total height (THT), merchantable height (MHT), crown length, crown diameter, search radius and distance of competitor trees from the subject trees.

Data Analysis

Stand Density Computation

Stand density can simply be defined as the degree of crowding of standing trees within a specified area. Basal area is the cumulative cross-sectional area per hectare of tree stem at Dbh (usually 1.3m above ground level). Basal area is thus calculated using:

$$A = \frac{\pi D^2}{4} \dots\dots\dots\dots\dots\dots\dots.. \qquad (5)$$

D = Diameter at breast height (DBH), A = basal area, Where π is 3.142 or 22/7

Computation of Stem Volume

Newton's formula was used in the computation of stem volume. This is an analytical method of tree volume estimation and parameters such as Diameter at breast height (Dbh), Diameter at the base, Diameter at the top and Diameter at the middle.

Where,

$$V = {}^{\pi h}/_{24}\ (D_b{}^2 + 4D_m{}^2 + D_t{}^2) \qquad (6)$$

Table1. *Distance-dependent competition indices investigated*

Variable name	Equation	Equation number	Variable abbreviation	Index type
Lorimer (1983)	${}^{Dj}/_{Di}\ (\sqrt{\sum_{i=1}^{n} {}^{Di^2}/_{n}})$	7	Cl_1	Canopy layer
Castegneri (2008)	$\sum_j = \ln\left[\left({}^{CPA_j}/_{CPA_i}\right)^2 .(distij + 1)\right]$	8	Cl_2	Local neighbourhood
Alemdag (1978)	$\sum\left\{\pi\left[Lij \times \frac{Di}{(Di+Dj)}\right]\right\}^2 \times$	9	Cl_3	Growing space

	$\left[{(Dj/Lij)}\Big/{\sum \frac{Dj}{Lij}}\right]$			
Hegyi (1974)	$\sum_{i \neq j}^{n} \frac{D_j}{D_i(Distij\ +1)}$	10	Cl_4	Size ratio

Where Di, diameter at breast height (Dbh) of subject tree i (m); Dj, Dbh of competitor trees (j ≠ i) (cm); Distij: distance of subject tree i to competitor j (m), ; Lij: distance of subject tree i to competitor j (m); CPA_j is the neighbor tree crown projection area (m^2); CPA_i is the target tree crown projection area (m^2); $dist_{tj}$ is the distance (m) between the neighbor j and the target tree t.

Regression

$$y = b_o + b_i X_1 + \varepsilon i \qquad (11)$$

Where y = dependent variable

bo is the point where the line crosses the Y axis

bi is the regression coefficient

X1 is the independent variable

εi is the error variable

However, multiple linear regression equation can be represented as:

$$= b_o + b_i Xi + b_2 X^2 + \varepsilon i \qquad (12)$$

Where X2 is the value of the independent variable raised to the power of two.

The models formulated were evaluated with a view of selecting the best estimator for tree volume. The models were selected based on adjusted coefficient of determination(R^2_{adj}), root mean squared error (RMSE), Akaike Information criterion, and residual variance (resVar).

$$R^2_{adj} = \frac{(n-1)\ \sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n-p)\ \sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (13)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}} \qquad (14)$$

The Akaike Information Criterion (Akaike, 1974) is defined as:

$$AIC = N.\ln\left(\frac{SSE}{n}\right) + 2p \qquad (15)$$

The residual variance (resVar) is the residual variance that cannot be accounted for by the model. Spiess and Neumeyer (2010), defined the residual variance as:

$$resVar = \frac{SSE}{n-P} \qquad (16)$$

Where: y_i = the observed SV, $\hat{y}_i$ = predicted SV, $\bar{y}$ = average SV, n = total number of observation used to fit the model, p = number of parameters to be estimated, k = p + 1, SSE = sum of squared of residual from the non-linear least squares fit.

Results

The resultant map in the Figure 1 reveals that a total number of five *Tectona grandis* plantations were assessed.

The data used in this study comprise of tree growth variables measured from 19 Temporary Sample Plots (TSP) of *Tectona grandis* stands in Ibadan metropolis, Nigeria. A total of 190 trees were measured and the summary statistics presented in Table 2. The distribution of Dbh ranged from 4.77 to 67.47 cm, squared Dbh ranged from 0.23 to 45.53 m, lnDbh ranged from -304.2 to -39.34, THT ranged from 4.0 to 28.0 m, lnTHT ranged from 1.44 to 3.33 m, SV ranged from 0.0024 to 3.23 m^3, lnSV ranged from -6.03 to 1.17 m^3, CI_1 ranged from 0.5 to 2.69, CI_2 ranged from -6.66 to 30.01, CI_3 ranged from 4.98 to 777.8 and CI_4 and ranged from 0.16 to 4.37.

Competition index class below indicates the set of trees dominating others in the stand. This was broadly classified into three; trees dominating others (TDO), trees mildly stressed (TMS) and trees severely stressed (TSS), these were shown in Table 3 below. About 57.4% of the trees were dominating others in the stand while trees mildly dominated were about 22% but the severely suppressed trees were approximately 21% of the whole population.

Table2. *Summary of Statistics of the Tree growth variables*

Tree variables	Descriptive Statistics			
	Minimum	**Maximum**	**Std. Dev.**	**Mean ± S.E**
Dbh (cm)	4.77	67.47	14.38	27.94 ± 1.04
Dbh^2 (cm)	0.23	45.53	8.64	9.86 ± 0.63
InDbh (cm)	-304.2	-39.34	62.77	-144.35 ± 4.55
THT (m)	4.00	28.00	4.71	15.54 ± 0.34
lnTHT (m)	1.44	3.33	0.33	2.69 ± 0.024

SV (m^3)	0.0024	3.23	0.70	0.63 ± 0.05
In SV (m3)	-6.03	1.17	1.57	-1.34 ± 0.11
CI_1	0.5	2.69	0.30	1.061 ± 0.02
CI_2	-6.66	30.01	4.89	12.38 ± 0.35
CI_3	4.98	777.8	106.99	93.31 ± 7.76
CI_4	0.16	4.37	0.72	1.42 ± 0.05

Source: *field data (2013)*

Summary of statistics is represented in Table 3 where; Dbh (cm) = diameter at breast height, Dbh^2 (cm) = squared diameter at breast height, In Dbh (cm) = Natural Logarithm of diameter at breast height SV (m^3) = stem volume, In SV (m^3) = Natural Logarithm of stem volume stem volume, CI_1 = competition index, CI_2 = local neighborhood, CI_3 = area potentially available and indices CI_4 = size-ratio indices.

Table3. *Degree of dominance in the sampled site*

	TDO	TMS	TSS
CI>(0.95-1.05)	109	-	-
CI >(1.06-1.25)	-	42	-
CI >(1.26)	-	-	39
TOTAL	57.37%	22.1%	20.53%

Source: *field data (2013)*

Where: CI < (0.95 - 1.05) = Trees that are dominating others

CI > (1.06 - 1.26) = Trees that are mildly stressed

CI > 1.26 = Trees that are severely stressed

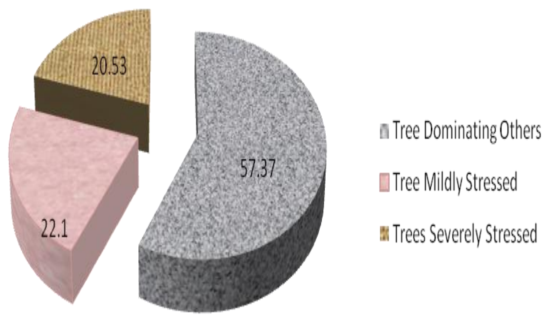

Figure2. *Competition indices of the sampled trees*

Table 4 showed the result of Pearson's product-moment correlation analysis between Dbh, Dbh^2, In Dbh, CI_1, CI_2, CI_3 and CI_4. The result revealed that both the stem volume (SV) and the natural logarithm of the stem volume are significant and negatively correlated with all the competition indices except the local neighborhood index (CI_2). The tree growth variables investigated had high correlation with SV and ln SV.

Table4. *Correlation of the growth variables*

	Dbh	Dbh^2	InDbh	CI_1	CI_2	CI_3	CI_4
SV	0.87*	0.91*	0.77*	-0.39*	-0.01	0.60*	-0.54*
In SV	0.95*	0.87*	0.97*	-0.38*	0.12	0.52*	-0.60*

** Correlation coefficient is significant at the 0.05 level (2-tailed), N=190, where: Dbh (cm) = diameter at breast height, Dbh^2 (cm) = squared diameter at breast height, In Dbh (cm) = Natural Logarithm of diameter at breast height SV (m^3) = stem volume, In SV (m^3) = Natural Logarithm of stem volume stem volume, CI_1 = competition index, CI_2 = local neighborhood, CI_3 = area potentially available and indices CI_4 = size-ratio indices*

Table5. *Fit indices of the tested models*

Models	Model type	α	β_1	β_2	β_3	RMSE	adj R²	AIC	Resvar
1	$\boldsymbol{SV = \alpha + \beta_1 Dbh^2 + \beta_2 \ln Dbh + \beta_3 CI_3}$	**0.39**	**8.78**	**-0.15**	**-0.001**	**0.29**	**0.82**	**-223.98**	**0.087**
2	$SV = \alpha + \beta_1 Dbh + \beta_2 \ln Dbh + \beta_3 CI_1$	-3.06	8.42	-1.02	-0.129	0.30	0.82	-220.76	0.090
3	$SV = \alpha + \beta_1 Dbh + \beta_2 CI_2$	-0.40	4.29	-0.014	-	0.34	0.76	-197.02	0.118
4	$\ln SV = \alpha + \beta_1 Dbh^2 + \beta_2 \ln Dbh + \beta_3 CI_3$	1.71	2.37	2.22	-0.001	0.37	0.95	-182.94	0.134
5	$\ln SV = \alpha + \beta_1 \ln Dbh + \beta_2 CI_4$	2.21	2.37	-0.09	-	0.37	0.94	-182.15	0.138
6	$\ln SV = \alpha + \beta_1 Dbh + \beta_2 Dbh^2 + \beta_3 CI_1$	-5.07	20.01	-16.84	-0.19	0.37	0.94	-180.15	0.138
7	$SV = \alpha + \beta_1 \ln Dbh + \beta_2 CI_1$	2.12	0.88	-0.018	-	0.45	0.60	-147.37	0.199
8	$SV = \alpha + \beta_1 \ln Dbh + \beta_2 CI_2$	2.09	0.81	-0.28	-	0.45	0.59	-146.89	0.200
9	$SV = \alpha + \beta_1 \ln Dbh + \beta_2 CI_4$	1.92	0.77	-0.13	-	0.44	0.59	-146.42	0.201

10	$lnSV = \alpha + \beta_1 Dbh + \beta_2 CI_3$	-4.31	11.34	-0.002	-	0.48	0.91	-134.45	0.228
11	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_3$	-2.87	17.78	-0.002	-	0.76	0.76	-45.42	0.582
12	$SV = \alpha + \beta_1 lnDbh + \beta_2 CI_3$	1.49	0.70	0.002	-	0.76	0.62	-45.42	0.582
13	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_4$	-2.35	14.36	-0.28	-	0.78	0.76	-44.45	0.588
14	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_2$	-3.18	15.70	0.02	-	0.78	0.76	-42.37	0.601

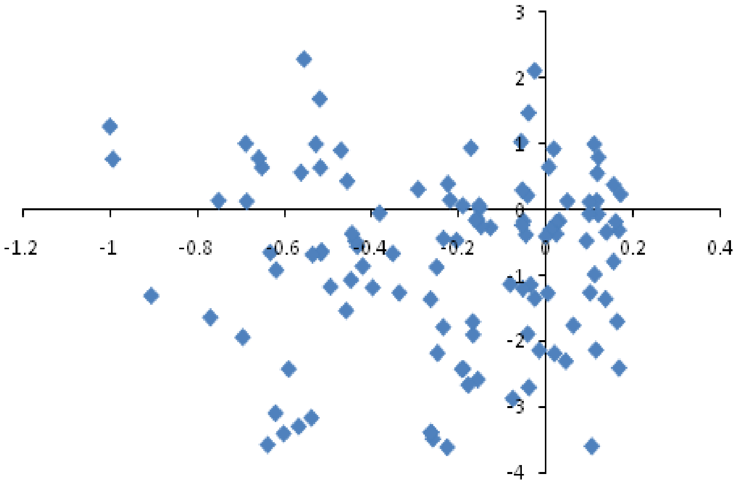

Figure3. *Residual dispersal against predicted SV using the selected model 1*

Several models were tested and arranged based on the estimated values of Adjusted R^2, root mean squared error, Akaike Information Criterion (AIC) and residual variance obtained the total variation in observed stem volume values explained by the fourteen developed models. The RMSE values ranged from 0.29 to 0.78, the Adj.R^2 values ranged from 0.59 to 0.95, AIC values range from -223.98 to -42.37 and the residual variance range from 0.087 to 0.601. The first model gave the Adjusted R^2 value of 0.82, RMSE value of 0.29, AIC value of -223.98 and the residual variance value of 0.087. however, the third, fourth and fifth models had the highest adjusted R^2 of 0.95, 0.94 and 0.94 values respectively, all other fit indices were lower than those of the first model. Hence, Model 1 (semi-logarithm) was selected as the best followed by model 2 (Semi logarithm) and so on. Figure 3 shows the dispersal of residuals against the predicted natural logarithm of stem volume.

The Table 6 revealed the significant values of the parameter estimates developed in the study. All the included parameters in the selected model had significant p-values (Table 6) ranging from 0.000 to 0.047 at alpha level of 0.05. The other parameter estimates of other models listed below had a few insignificant parameter values.

Table6. *Models tested and their P-values*

Models	Model type	α	β1	β2	β3
1	$SV = \alpha + \beta_1 Dbh^2 + \beta_2 \ lnDbh + \beta_3 CI_3$	0.010	0.000	0.041	0.047
2	$SV = \alpha + \beta_1 Dbh + \beta_2 \ lnDbh + \beta_3 CI_1$	0.000	0.000	0.000	0.103
3	$SV = \alpha + \beta_1 Dbh + \beta_2 CI_2$	0.000	0.000	0.008	-
4	$ln\ SV = \alpha + \beta_1 Dbh^2 + \beta_2 \ lnDbh + \beta_3 CI_3$	0.000	0.000	0.058	-
5	$ln\ SV = \alpha + \beta_1 \ lnDbh + \beta_2 CI_4$	0.000	0.002	0.000	0.025
6	$ln\ SV = \alpha + \beta_1 Dbh + \beta_2 \ \mathrm{Dbh}^2 + \beta_3 CI_1$	0.000	0.000	0.000	0.054
7	$SV = \alpha + \beta_1 lnDbh + \beta_2 CI_1$	0.000	0.000	0.008	-
8	$SV = \alpha + \beta_1 lnDbh + \beta_2 CI_2$	0.000	0.000	0.019	-
9	$SV = \alpha + \beta_1 lnDbh + \beta_2 CI_4$	0.000	0.000	0.025	-
10	$lnSV = \alpha + \beta_1 Dbh + \beta_2 CI_3$	0.000	0.000	0.000	-
11	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_3$	0.000	0.000	0.002	-
12	$SV = \alpha + \beta_1 lnDbh + \beta_2 CI_3$	0.000	0.000	0.000	-
13	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_4$	0.000	0.000	0.004	-
14	$lnSV = \alpha + \beta_1 Dbh^2 + \beta_2 CI_2$	0.000	0.000	0.041	-

The standard error of the parameter estimates (Table 7) of all the investigated models were shown below. The choice model had significantly lower errors associated with their parameters when compared to the associated errors of other tested models used in the study.

Table7. *Standard errors of the parameter estimates*

Models	S.E (α)	S.E (β_1)	S.E (β_2)	S.E (β_3)
1	0.151	0.605	0.071	0.000
2	0.349	0.555	0.126	0.079
3	0.080	0.175	0.005	
4	0.187	0.750	0.089	0.000
5	0.071	0.053	0.047	
6	0.156	0.789	1.321	0.098
7	0.124	0.052	0.007	
8	0.124	0.056	0.117	
9	0.085	0.065	0.056	
10	0.078	0.315	0.000	
11	0.084	0.897	0.001	
12	0.112	0.060	0.000	
13	0.203	0.806	0.097	
14	0.164	0.653	0.012	

Discussion

In this study, tree growth data were collected and processed. The benefits of this information are important for many purposes but within the scope of this study, competition indices of the individual trees were reported. Growth of forest trees depends on their ability to compete for potentially limited resources such as moisture, nutrients, and light.

The resources for which neighbouring individuals compete depend on the type of resource and whether the competition is mediated by depletion or the preventive actions of the resources (Nord-Larsen *et al.,* 2006). Competition indices for each individual tree depend on the mathematical formulation of relationships between the variables chosen and on the method used to define neighbouring trees as competitors.

The observed correlation of the stem volume and its natural logarithm with diameter at breast height for the Teak plantation cannot be overemphasized. This relationship simply means that trees with larger diameter will likely have larger stem volume. This association of the diameter at breast height enormously contributes to trees total volume. The sign of the correlation coefficient depends on the competition index used (Wang *et al.*, 2012).

As the Alemdag index focused on measuring the subject tree's growing space, a positive correlation with stem volume was shown. However, for the Hegyi and competitive index, negative correlations was shown with basal area, and volume which was similar to the observations in the studies carried out by Wang *et al.,* (2012). Pearson product moment correlation coefficients measure assumes no correlation between the local neighbourhood index and the independent variables and it also show no significance that is, it has a p-value greater than the probability level of 0.05.The overall degree of dominance affects the stand density and growing space which led to the various canopy layers and individual tree volume (Wang *et. al.*, 2012).

According to Wang *et al*, 2012, thinning effect on the competition indices showed that the overall competitive stress suffered for all trees was subject to the stand density and the overall competitive stress became less rigorous after thinning.

In effect, the observed radial growth for a tree is completely inconsistent from competition with neighboring trees which was noticed in the growth pattern of the stands (Canham *et al.,* 2004). Competitive effect of a neighbor scales to the DBH of the neighbor, was similar with many previous studies that assume that competitive effect scales linearly with DBH (Bella 1971; Hegyi 1974; Biging *et al.,* 1995). Success of these indices was probably due to the correlation existing between DBH and stem volume. Moreover, diameter is related to the age and past competition history of the tree (Fox *et al.,* 2007). Conversely, self-thinning dynamic in the more naturally developed because competition indices can be efficiently model dominance-related tree variables (Canham *et al.,* 2004). To assess the performances of the competition indices in predicting individual tree volume, a growth prediction without a competition index was established (Wang *et al.,* 2012). This was because a strong positive correlation exists between the merchantable volume as dependent variable and Distance and DBH as independent variables (Shamaki *et al.,* 2013, Wang *et al.,* 2012). Therefore, using Distance, DBH, Basal area etc. alone can give good estimates of volume. Also, logarithmic transformation gives better results compared with other untransformed values and this is because of high variability within and among species in terms of their size and height (Shamaki *et al.,* 2013).

The criteria adopted for ranking the models was through comparison of adjusted R^2 and SEE which is one of the standard ways of ranking and validating models (Shamaki *et al.,* 2013). The stem volume models were used to evaluate the contributions of competition indices to individual tree growth; this was because the consistency of the empirical competition indices with their theoretical relationships had to be checked (Daniels *et al.,* 1986; Wang *et al.,* 2012).

As shown above, they produce very good results by explaining more than 90% of the variance of the volume. Akindele (1985) and Odunlami (1992) confirmed that the higher the adjusted R^2 values the better and the lower the SEE the better.

This indicates that the variation in tree volume can be explained by the variation in tree diameter and competition indices.

In all the volume prediction models however, the best among the competition indices studied was CI_3 of the Alemdag growing space index. Past studies have shown that superiority of distance-dependent competition indices is not a rule (Biging *et al.,* 1995). Competitive influence on spatial structure is complicated by the confounding effect of spatial micro-site variability and possible human activities, leading mis-interpretation of individual competition indices (Fox *et al.,* 2007).

Conclusion

This study found that stem volume could be predicted from tree stem diameter and competition indices of the *Tectona grandis* plantation in Ibadan metropolis. Furthermore, stem volume of *T. grandis* species in the study locations can be estimated from Dbh using the logarithmic function.

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