Nigerian Journal of Ecology (2016) 15(1):82-90.

ISSN: 1116-753X

Evaluation of selected competition indices for predicting tree growth attributes in *Tectona grandis* stands

***Peter O. Adesoye and Stephen Aina**
Department of Forest Resources Management, University of Ibadan, Nigeria

* Corresponding Author: Email: adesoyepet@yahoo.com

(Accepted 20 April 2016)

ABSTRACT
This study was aimed at evaluating the potentials of variants of competition indices in explaining variations in selected tree biometric attributes. Twenty-five sample plots of size 20m × 20m were established from five (5) stands of Tectona grandis of different ages (i.e. 16, 17, 19, 20 and 22). Diameter at breast height (dbh), total and merchantable heights, crown diameter and length were measured. The effects of neighborhood competition on individual tree were calculated using tree-specific search horizon. Data obtained were analyzed using linear and nonlinear regression equations. Model precision was assessed using coefficient of determination (R^2), Root Mean Square Error (RMSE) and Akaike's Information Criterion (AIC). The non-spatial measure of competition gave the best fit (AIC of 359.69) and was statistically significant and negatively related to Dbh under nonlinear equations compared to the spatial measures. The results also showed that inclusion of spatial information in competition measure does not provide significant improvement in Dbh and stem volume equation. Nonlinear relationship was found most suitable for predicting Dbh and stem volume. The best candidate model for predicting Dbh is given as $Dbh = 1 + e^{(1.251-0.165DICI)}$ *with R^2 of 98.7% and RMSE of 0.34.*

Key words: Competition index, spatial measure, non-spatial measure, *Tectona grandis*, Tree size

INTRODUCTION
Tree growth is a complex process. It is influenced by an intricate network of below and above-ground competition which is defined to include the spatial arrangement of local competitors. Many physical and biological components are exerting influence on forest trees (Murphy, 1992). Differences in stand conditions (e.g. density) affect the distribution of diameter which can consequently affect the stem profile and thus stem volume (Andrew *et al.*, 2007). Diameter and height vary with planting spacing. Competition is an important factor in forest management and has been investigated in several growth studies (e.g. Biging and Dobbertin, 1992; De Luis *et al*, 1998; Radtke *et al*, 2003).
A tree cannot be in competition with itself. Therefore, it stands to presume that surrounding trees within specific radii around the subject tree called competitor trees, will exert certain competitive influence on the subject tree. Measures of stand density being used in the tropics provides information on the degree of crowding of stems per unit area. Models developed from the stand measure usually

generate little information and generally insufficient for predicting important tree characteristics at individual tree level. Basic understanding of competitive interaction and spatial interdependency of trees is still generally insufficient (Wichmann, 2002). However, competition index allows researchers to quantify and express several attributes of plant competition including competition intensity and importance, competitive effects and responses and outcome of competition (Alexandra and Peter, 2003).

A competition index is a mathematical formulation derived to represent or describe competition from adjacent trees that could be affecting the growth of any considered tree (Schreuder and Williams, 1995; Woodall *et al.*, 2003). According to Munro (1974), there are two classes of competition index. Those which utilize the individual trees' location are termed distance dependent and those not using locations are referred to as distance independent.

Tectona grandis (teak) is a deciduous timber tree of the verbenaceae family. It is the world's most cultivated high grade tropical hardwood covering approximately 6 million hectares worldwide (Bhat, 2000; Diego, 2005). About 4.5% of the teak plantations are in tropical Africa (Diego, 2005). It is a durable timber used for varieties of products from general construction (including wall cladding) to wood joinery. Teak is mostly utilized in Nigeria as telegraphic poles and outdoor furniture. The wide acceptance of teak as timber material therefore serves as the necessary catalyst for further research on improvement of teak plantation.

This paper therefore investigated the competitive stress of individual trees using the spatial and non-spatial approaches and their potentials for modelling of tree growth characteristics using linear and nonlinear equations. The importance of this paper is entrenched by Wichmann (2002), who asserted that several spatially explicit competition indices exist; however, there is no general agreement on which index should be preferred for modeling.

MATERIALS AND METHOD

Study Site

The study sites are located within Oluwa Forest Reserve (OFR), between latitudes 06^0 52' and 7^0 20' N; and longitudes 3^0 45' and 4^0 32' E, in Odigbo Local Government Area of Ondo state, Nigeria (Figure 1). The study area is underlain by the basement complex rocks and the soils are of the ferruginous tropical type. The average altitude of the area is 100m above sea level and the topography is undulating with occasional steep slopes and hilly outcrops. The soils derived from the basement complex rocks are mostly well-drained, with a medium texture. The climate of the study area is of the Lowland Tropical Rain Forest type, with distinct wet and dry seasons. The annual total rainfall exceeds 2000 millimeters and the average monthly temperature is 27^0C. The natural vegetation is the tropical rain forest, composed of many varieties of hardwood timber species such as *Melicia excelsa*, *Antiaris africana*, *Terminalia superba*, *Lophira procera* and *Symphonia globulifera*.

METHOD OF DATA COLLECTION

Selection of teak stands of different ages (i.e. 16, 17, 19, 20 and 22 years) was based on the need to include different stand ages that are available within the study area. Five (5) teak stands of ages 16, 17, 19, 20 and 22 years within the study area were used for the study. Five (5) sample plots of size 20m × 20m (i.e. 0.04ha) were randomly established for the study in each stand age. Therefore a total of twenty-five (25) sample plots were involved.

In each of the sample plots, the stump diameters (i.e. at 0.3m above ground level) and diameter at breast height (over bark) of all trees within the plots were measured. Spiegel relaskop was used to measure tree total height (THT), merchantable height (MH), crown length, diameters at the top (Dt) and middle (Dm). Crown diameter estimation was obtained from the average of two (2) linear measurements of crown projection on the ground in North - South and East - West directions.

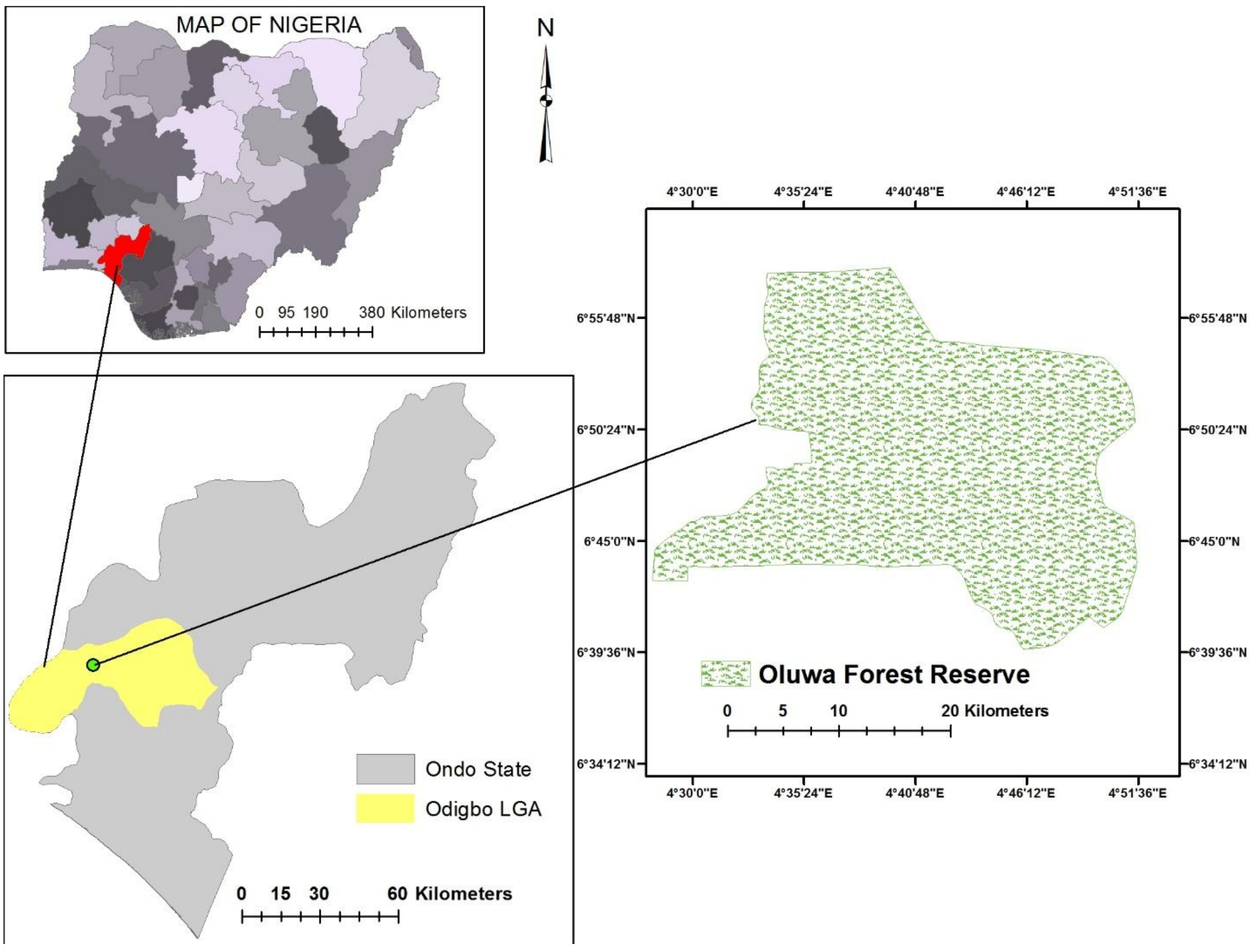

Figure 1: Map of Nigeria with Ondo State, Odigbo Local Government Area and Oluwa Forest Reserve Maps as Insets

Data Analysis

The basal area was computed using the formula**:**

Basal area (BA) = $\frac{\pi Dbh^2}{4}$

Where, Dbh = diameter at breast height (m)

Volume Computation

The merchantable volume of individual tree within each plot was computed using Newton's formula.

$$V = \left(\frac{A_b + 4A_m + A_t}{6}\right) * h \qquad (1)$$

Where A_b= cross sectional area at the base

A_m = cross sectional area at the middle

A_t= cross sectional area at the top.

h = merchantable height

Evaluation of Neighbourhood Competition Search Radius

For individual focal tree within the sample plots, a circumference of influence was calculated using the search radius estimator. Equation 2 was used to arrive at a search horizon (radius) for individual trees that were sampled:

$$SR = CD * k \quad (2)$$

Where SR – search radius

CD – crown diameter

k – Constant (1.75)

The constant (k) in equation 2 was adopted from the work of Lorimer (1983).The distances between individual subject tree and other competitor trees within the zone of influence as provided by the search radius was measured using a 20 meter measuring tape and recorded in meters, while the diameter at breast height (Dbh) of each competitor trees were recorded in centimeters.

Distance Dependent Estimators

The variants of competition indices were computed as follows:

(1) Hegyi (1974) competition index (CI)

$$CI = \sum_{i \neq j}^{n} \frac{D_j}{D_i(Dist_{ij} + 1)} \quad (3)$$

(2) Martins & Ek (1984) competition index

$$CI = \sum_{i \neq j}^{n} \frac{D_j}{D_i} e^{\left(\frac{-16Dist_{ij}}{D_i + D_j}\right)} \quad (4)$$

(3) Modified Hegyi (1974) competition index

$$CI = \sum [(D_j/D_i)/Dist_{ij}]/n \quad (5)$$

Distance Independent Estimator (DICI)

Modified Lorimer (1983):

$$CI = \Sigma (D_j/D_i)/n \quad (6)$$

Where Dj – Diameter at breast height of competitor tree

Di – Diameter at breast height of subject tree

$Dist$ – Distance between the subject tree and competitor tree

n – Number of competitor trees.

The values assumed by the competition indices can take any non-negative value from zero (0). A tree in the plantation can assume any value. The higher the value of the competition indices the greater the competitive effect on the tree. A tree with a competition index of zero (0) is assumed to be free from competition.

Regression Analysis

Regression models were used to assess the relationship between variants of competition measure (spatial and non-spatial) and some tree size attributes. Both the linear and nonlinear methods of regression analysis were employed**.** The general forms of the linear and nonlinear models used in this study are presented as follows:

$$\boldsymbol{TS = b_0 + b_1 CI_i} \; \ldots\ldots\ldots\ldots\,\mathbf{(7}$$

$$\boldsymbol{TS = 1 + e^{(b_0 + b_1 CI_i)}} \; \mathbf{\ldots\ldots.. (8)}$$

Where, TS = tree size variable (i.e. Dbh or volume), CI_i = variants of competition measure, b0 and b1 are regression parameters. The Akaike Information Criterion (AIC) and the Root Mean Square Error (RMSE) provided the basis for evaluating model fit. The smaller the values of AIC and RMSE, the better the model fit the sample data.

RESULTS

Table 1 shows the summary statistics of the tree size variables under each teak stand age assessed. The mean dbh values across the five stand ages ranged between 17.35 and 26.73 cm, with stand aged 20years recording the highest mean dbh. The average tree total height ranged between 15.31 and 22.47m across the stand ages studied. It can be observed that the oldest stand in this study, did not record highest tree size variables. Stand densities (in terms of number of stem per hectare also ranged between 460 and 600.

Table 1: Summary Statistics of Tree Growth Characteristics for the five stands of *Tectona grandis*

Tree Growth Characteristics	Stand Age (years)				
	16	17	19	20	22
Stand Density (stems/ha)	600	515	470	460	520
Dbh (cm)					
Minimum	4.92	4.02	8.4	7.8	6.27
Mean	17.35	17.71	22.35	26.73	19.65
Maximum	40.26	34.12	39.01	46.34	41.32
Total Height (m)					
Minimum	4.2	3.88	10.1	13.5	0.7
Mean	16.23	15.31	19.46	22.47	16.78
Maximum	22.4	21.05	25.4	30.1	25.1
Crown Diameter (cm)					
Minimum	1.6	0.8	1	1.2	1.94
Mean	3.22	3.42	3.26	4.2	4.16
Maximum	7.91	6.83	6.49	9.44	7.44
Crown Length (m)					
Minimum	0.8	1.05	3.2	2.5	2.8
Mean	6.28	5.97	6.55	6.32	5.58
Maximum	11.2	10.7	10.9	14.4	9.4

Linear and nonlinear regression models were assessed for their abilities to relate competition indices to the growth attributes of *Tectona grandis.* Results of the models developed were shown in Tables 2 and 3 for linear and nonlinear models respectively. The Turkey ladder of power was adopted to determine the appropriate transformation procedure in order to reduce the violation of normality assumptions. The observational data (dependent variable) were transformed using the natural logarithmic transformation. The observed pattern of relationship between the size attributes and the competition indices was non-positive as shown in Figure 2. A negative slope was the result of the regression models. The implication of the negative slope would be that an increase in inter-tree competition tend to be associated with decrease in the size attributes of forest trees.

Table 2: Results of linear regression analysis depicting tree size attributes of *Tectona grandis*.

Eqn no	Model	**Parameters**		**Fit statistics**			
		b_0	b_1	R^2 (%)	RMSE	AIC	Remark
1	$DBH=b_0 + b_1DICI$	3.411	-0.437	44.0	0.34	361.9	*
2	$DBH=b_0 + b_1HEG$	3.207	-0.189	14.9	0.42	576.7	*
3	$DBH=b_0 + b_1HEG_{mod}$	3.199	-1.097	30.2	0.38	427.5	*
4	$DBH=b_0 + b_1M\_EK$	2.986	-0.043	0.5	0.46	656.6	Ns
5	$Vol=b_0 + b_1DICI$	8.625	-0.945	38.1	0.84	1277.7	*
6	$Vol=b_0 + b_1HEG$	8.143	-0.381	11.2	1.01	1463.0	*
7	$Vol=b_0 + b_1HEG_{mod}$	8.159	-2.338	25.7	0.92	1371.6	*
8	$Vol=b_0 + b_1M\_EK$	7.629	-0.037	0.1	1.07	1523.4	Ns

Note: HEG = Hegyi spatial competition index: Vol = Merchantable Volume: DICI = Non-spatial competition measure: HEG_{mod} = Modified Hegyi spatial competition index: M_EK = Martins and Ek spatial competition index, * = significant relationship at α level of 0.05, $ns =$ Non-significant relationship at α level of 0.05

Table 3: Results of nonlinear regression analysis depicting tree size attributes of *Tectona grandis*.

		Parameters		Fit statistics			
Eqn no	Model	b_0	b_1	R^2	RMSE	AIC	Remark
1	$DBH=1 + \exp(b_0 + b_1DICI)$	1.251	-0.165	98.7	0.34	359.69	*
2	$DBH=1 + \exp(b_0 + b_1HEG)$	1.177	-0.071	98.0	0.42	574.24	*
3	$DBH=1 + \exp(b_0 + b_1HEG_{mod})$	1.213	-0.594	98.6	0.36	398.42	*
4	$DBH=1 + \exp(b_0 + b_1M\_EK)$	1.094	-0.014	97.6	0.46	656.88	ns
5	$V=1 + \exp(b_0 + b_1DICI)$	2.104	-0.054	98.2	1.00	1470.4	*
6	$V=1 + \exp(b_0 + b_1HEG)$	2.134	-0.050	98.7	0.88	1324.1	*
7	$V=1 + (b_0 + b_1HEG_{mod})$	2.134	-0.046	98.7	0.88	1324.1	*
8	$V=1 + \exp(b_0 + b_1M\_EK)$	2.032	-0.005	98.1	1.07	1523.5	ns

Note: HEG = Hegyi spatial competition index: V = Merchantable volume: DICI = Non-spatial competition measure: HEG_{mod} = Modified Hegyi spatial competition index, M_EK = Martins and Ek spatial competition index, * = significant relationship at α level of 0.05, ns = Non-significant relationship at α level of 0.05

Table 4 provides the summary statistics for the competition measures. Martins and Ek (1984) competition index had the least dispersion in terms of coefficient of variation. The scatter plot diagram in Figure 2 showed a non-linear association between the DBH and DICI, while Figure 3 depicts the distribution of non-spatial competition values. It can be seen that very few trees have competition index values between 0 – 0.5.

Table 4: Summary Statistics for the Competition Indices under different Approaches

Competition Index	Minimum	Mean	Maximum	Standard dev.	CV (%)	Standard Error
Martins & Ek (1984)*	0	1.44	4.61	0.77	55.5	0.03
Hegyi (1974)*	0	1.49	9.56	0.94	62.8	0.04
Modified Hegyi*	0	0.25	3.19	0.23	92.7	0.01
DICI**	0	1.11	4.76	0.64	62.7	0.03

Note, * = Distance dependent competition measures, ** = Distance independent competition measure

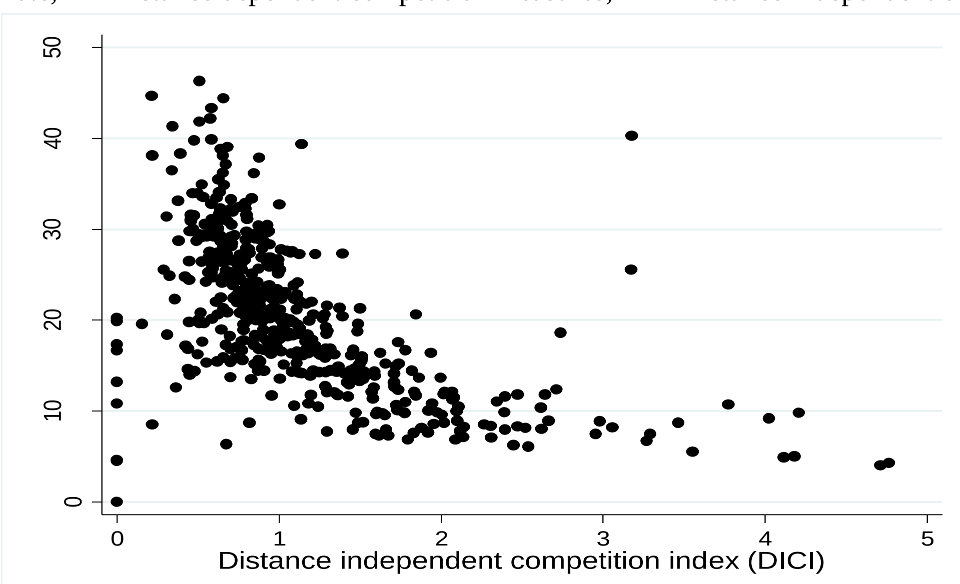

Figure 2: Scatter plot diagram relating Diameter at breast height and Non-spatial competition index.

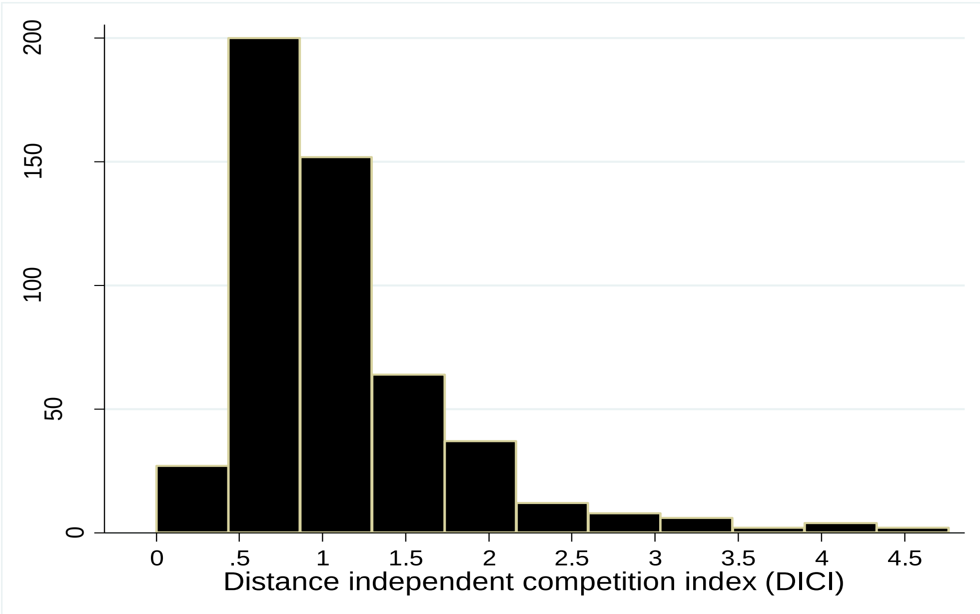

Figure 3: Histogram for the Non-spatial competition index

DISCUSSION

Spatial and non-spatial measures of competition involved varying degrees of complexities in their computation, with the spatial index being more difficult due to the inclusion of spatial measurement. It requires that metric distance between the subject tree and every other tree within the circle of influence is measured and included as input variable in the algorithm.

The non-spatial measure of competition related very well with tree size attributes and produced better fit statistics especially among the nonlinear models. It was apparent from the results obtained that competition measure exhibit a significant nonlinear relationship with the growth attributes of *Tectona grandis.* It can be seen from Table 2 that linear relationship between competition index and tree growth variables (especially dbh and volume) resulted in very low coefficient of determination (i.e. R^2 *ranged between* 0.07% *and* 44.00%). However, from Table 3, it is apparent that variations in growth attributes were best explained using nonlinear functions (R^2 *ranged between* 97.40% *and* 98.80%) The model is simple in that a single explanatory variable was used. This is similar to the findings of previous studies (e.g. Radtke *et al.* 2003, Brunner and Nigh 2000) that competition indices are commonly used as predictor variables in models that predict individual tree growth characteristics. The negativity of the regression slope as can be seen from Figure 2 and Table 3, indicates biological realism of the estimates of competition indices. This trend was also observed in the study of Shi and Zhang (2003)

The distribution of DICI was examined, as depicted in Figure 3, and it has a positively skewed distribution with sufficiently large numbers of trees appearing below the mean competition level. This could be attributed to the fact that relatively younger trees are more prone to the effects of inter-tree competition. The scatterplot as shown in Figure 2 re-affirmed the position that tree size, most especially Dbh, would decrease with any increase in competition.

Regression analysis between each of the tree size characteristics and the Martins and Ek (1984) competition index was not significant for both models investigated. The prediction performance of Martins and Ek (1984) competition measure was consistent with respect to producing lower R^2 and its attendant high standard error of estimate in the observed models so far.

The use of spatially explicit indices (i.e. distance dependent indices) of competition did not result in marked improvement in the models' ability to predict the tree size attribute. This could be attributed to relatively little variation in spacing among the trees. This finding is consistent with the findings of previous studies which indicated that the inclusion of inter-tree distances in the measure of competition does not necessarily improve model ability to account for the variation in tree growth characteristics (e.g. Lorimer, 1983; Granzlin and Lorimer, 1983; Martins and Ek, 1984; Biggins and Dobbertin, 1992).

This study shows that distance independent competition index (DICI) performed better than the spatial competition indices, judging from the values of the fit statistics. Competition measures based on spatial arrangement (i.e. relative distances) of potential competitors within the stand did not exhibit any superiority when compared with the non-spatial competition index in terms of their performance in the models developed. Furthermore, the non-performance of the Martins and Ek (1984) spatial index and the seemingly modest performance of other spatial indices may be attributed to the structure of the forest. This trend is contrary to the findings of Contreras *et al*. (2011) who found distance dependent competition to perform better than the distance independent measure. This could be attributed to the fact that their work was carried out in mixed stand. It can be proposed that suitability of a competition measure depend on the structure of the forest stand.

CONCLUSION AND RECOMMENDATION

The study examined the response of Dbh and stem volume to some inter tree competition measures under pure stand of *Tectona grandis*. The utility of the competition measures were examined based on their performance in accounting for the variability in the tree growth variables (i.e. Dbh and stem volume). This study showed that the inclusion of inter-tree distance in computing competition index showed no superiority over the non-spatial competition index in predicting tree Dbh and stem volume. The distance independent competition index (DICI) was consistent in its superiority in accounting for the tree growth characteristics studied. In general, the non-spatial index of competition measure was better related to selected tree size attributes than the more complex spatial indices of competition measure under a monoculture stand structure. In other to provide scientific benchmark for overview comparison, further research is encouraged, to explore other competition measures not investigated in this study, on similar varying stand conditions.

REFERENCES

Alexandra, W.and Peter, J. 2003. Indices of plant competition. *Journal of Ecology* **91:** 707–720.

Andrew, A. Bluhn., Sean M. Garber and David E. Hibbs., 2007. Taper Equation and Volume Tables for Plantation-grown Red Alder. U.S. Department of Agriculture Forest Service, pacific Northwest Research Station. General Technical Report October 2007.

Bhat, K.M. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. *Bois et Forêts des Tropiques* **263(1):** 6-15.

Biging, G.S, and Dobbertin, M. 1992. A comparison of distance dependent competition measures for height and basal area growth of individual conifer trees. *Forest Science* **3:**, 695-720.

Brunner, A. and Nigh, G. 2000. Light Absorption and Bole Volume Growth of Individual Douglas-fir trees. *Tree Physiology* **20:** 323 – 332.

Contreras, M. A., Afflek D. and Chung W. 2011. Evaluating Tree Competition Indices as Predictors of Basal Area Increment in Western Montana Forests. *Forest Ecology and Management* **262:**1939 – 1949.

De Luis, M., Raventos, J., Cortina, J., Moro, M. J. and Bellot, J. 1998. Assessing Components of a Competition Index to Predict Growth in an Even-Aged *Pinus nigra* Stand. *New Forests* **15:** 223 – 247.

Diego Perez. 2005. Stand Growth Scenarios for *Tectona grandis* Plantations in Costa Rica: Academic Dissertation Presented with the Permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public discussion in Lecture Hall B5 of the Department of Forest Ecology. http:// *metla.fi/**dissertation**es/df1.pdf*

Ganzlin, W. K. and Lorimer, C.G., 1983. Tests of Rapid Field Method for Evaluating Competition around Individual Trees. Research Note 253. Dept. of For., University of Wisconsin-Madison, 4p.

Hegyi, F. 1974. A simulation model for managing jack pine stands P. 74-90 in Growth models for tree and stand simulation, Fries, J. (ed.). Royal Coll. of For., Stockholm, Sweden.

Lorimer, C. J. 1983. Tests of age independent competition indices for individual trees in natural hardwood stands. *Forest Ecology and Management* **6:** 343-360.

Martin, G.L. and Ek, A.R., 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. *Forest Science* **30:** 731-743.

Munro, D. D. 1974. Forest growth models – A prognosis in Growth models for tree and stands simulation, *Fries, J*. (ed.). Royal Coll. Of For., Stockholm, Sweden. p. 7-21

Murphy, D. L. 1992. Database management: a forest inventory application. U.S. Department of Agriculture Forest Service, General Technical Report NC-67, '9 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Schreuder, H.T., and Williams, M.S. 1995. Assessing measures of tree competition using fixed-area, variable- radius, and horizontal-line plot sampling. *Canadian Journal of Forest Research*, **25:**1578{1582}.

Wichmann, L. 2002. Modeling the effects of competition between individual trees in forest stands. Ph.D thesis. Department of Economics and Natural Resources, The Royal Veterinary and Agricultural University, Copenhagen, Denmark 6th July 2002. 122p.

Woodall, C.W., Fiedler C.E., & Milner K.S. 2003. Stand density index in uneven-aged ponderosa pine stands. *Can. J. For. Res.* **33:** 96 – 100.