TREE SLENDERNESS COEFFICIENT AND ITS RELATIONSHIP TO DIAMETER AT BREAST HEIGHT FOR *Azadirachta indica* STAND IN SANYINNA COMMUNITY PLANTATION, SOKOTO STATE, NIGERIA

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Abstract
The study was aimed at establishing relationship between tree slenderness coefficient (TSC) and diameter at breast height (Dbh) at Sanyinna Community Neem Plantation. Simple random sampling technique was adopted in selecting three (3) temporary plots from each hectare (15 plots in total) for measurement of tree heights, diameter at different positions of the tree (base, middle, breast height, and top). The TSC was computed using ratio of tree height to Dbh (both measured in meter). Trees were classified based on their TSC as high (TSC>80), moderate (TSC: 70-80) and low (TSC<70). Data were summarized using both frequency table and charts. Pearson correlation analysis was used to establish relationship between TSC and tree growth characteristics. Regression (linear and nonlinear) analysis was used to generate models for predicting TSC from Dbh. The functional models were evaluated with the least values of standard error of the estimates (SEE), Akaike information criterion (AIC), Bayesian information criterion (BIC) as well as the highest values of the coefficient of determination (R^2). The significance of the estimated parameters was verified with plot of residuals against predicted to ascertain the goodness of fit of the best models. The results of TSC classification showed that 52.2% of the measured trees in the area had low slenderness coefficient, 27.8% recorded high TSC and 20% shows moderate TSC, which implies low to moderate susceptibility to windthrow and damage. For the Neem stand, the relationship between TSC and Dbh was best predicted with Exponential model and is therefore recommended for predicting TSC of Neem stand.

Keywords: Trees slenderness coefficient; Dbh; Growth characteristics; *Azadirachta indica*

Introduction

Forests provide habitat for plants and animals, clean water, places for outdoor recreation, and many other benefits. Irrespective of these benefits, they are subjected to multiple threats which can jeopardize their health, ecology, biodiversity, and resources. Such threats can be natural or anthropogenic. Natural disturbances include wildfire, catastrophic wind events, drought, insect infestation, fungal/pathogen outbreaks, and invasive plants. Anthropogenic disturbances include pollution, forest fragmentation, and urbanization. The stability of a stand is mainly affected by biological and physical factors (Nivert, 2001). Neem tree (*Azardirachta indica*) is a tropical evergreen tree native to Indian sub-continent (Roxburgh, 1874). The tree grows naturally in areas where the rainfall is in the range of 450 to 1,200 mm. However, it has been introduced successfully even in areas where the rainfall is as low as 150 to 250 mm. Neem grows on altitudes up to 1,500 m (Jattan *et al.,* 1995; Chari, 1996). It can grow well in wide temperature range of 0 to 49°C (Hegde, 1995). It cannot withstand water-logged areas and poorly drained soils. The pH range for the growth of neem tree lies in between 4 to 10. Neem trees have the ability to neutralize acidic soils by a unique property of calcium mining (Hegde, 1995). It has been used in Ayurvedic medicine for more than 4,000 years due to its medicinal properties. Most of the plant parts such as fruits, seeds, leaves, bark and roots contain compounds with proven antiseptic, antiviral, antipyretic, anti-inflammatory, antiulcer and antifungal uses. It has great potential in the fields of pest management, environment protection and medicine. Neem is a natural source of eco-friendly insecticides, pesticides and agrochemicals (Brahmachari, 2004). Neem is considered to be a part of India's genetic diversity (Sateesh, 1998). It is the most researched tree in the world and is said to be the most promising tree of 21st century. The tree has adaptability to a wide range of climatic, topographic and edaphic factors. It thrives well in dry, stony shallow soils and even on soils having hard clay pan, at a shallow depth. Neem tree requires little water and plenty of sunlight (Sateesh, 1998).

Trees show considerably variation and flexibility in their shape and size of crowns, height and trunk diameters (Givnish, 2002). These are governed by an inherited developmental tendency, which may in turn be modified by the environment where the tree grows. The size of a tree canopy and its height above the ground is significant to a tree in that it determines the total amount of light that the tree intercepts for photosynthesis (Midgley, 2003). The physical factors are mainly related to the wind components, the topography, and the site properties while the biological factors include the species characteristics. Wind is a natural phenomenon in all forest landscapes and some amount of wind damage to forest stands is normal. Wind damage, sometimes referred to as blow down and is defined as the breaking or uprooting of live trees due to strong winds (Navratil, 1996). Vulnerability of individual trees and stands to wind is based on a combination of tree attributes (species, age, health, total height, crown size, rooting characteristics), stand conditions (species, density, and structure of surrounding stands), local topography, soils (texture, depth, soil moisture level), and predominant wind patterns (Ruel, 2000). The adaptive significance of tree height has been through a mathematical model that the higher a tree is, the more light it intercepts during the course of the day (Jahnke and Lawrence, 1965). The tree trunk size also has its own adaptive significance to a tree. It must be strong enough to withstand the forces that act on it and the force exerted on it by the wind. These forces are the weight of the tree and the drag exerted on it by the wind, as demonstrated by Fraser (1962). Experimentally, wind has been found to be much more important than weight in determining what thickness of trunk is necessary for a tree (Alexander, 1968).
The most promising approaches for determining tree and stand stability to wind throw are those which integrate tree stability characteristics (e.g., slenderness coefficient) with local stand (e.g., average tree height), site, topography, and windiness

features (Navratil *et al.*,1994*).* Wang *et al.* (1998) stated that susceptibility of a tree to wind damage is principally influenced by the slenderness coefficient or taper of the tree. Slenderness coefficient of a tree is defined as the ratio of total height (H) to diameter outside bark at 1.3 m above ground (DBH) when both H and DBH are measured in the same unit (Wang *et al.*, 1998*).* This coefficient is related to tree taper and is the inverse of the DBH/H ratio that is often used to measure tree taper over the entire main stem of the tree. A straight relationship exists between the slenderness coefficient of the stands and the risk of stem breakage or tree fall due to abiotic factors such as the wind. Due to tree slenderness coefficient importance for indexing tree resistance to wind throw, it is, therefore, important to get to know slenderness of trees, considered to be a measure of their stability as well as developing models that can predict these values.

In Silvicultural studies, the tree slenderness coefficient often serves as an index of tree stability, or the resistance to wind throws (Navratil 1995). The likelihood of wind throw of a tree may be influenced by many factors interacting with each other. These factors include tree attributes (e.g., tree height, taper or form, the size and shape of crown, and the size and shape of root system), site condition (e.g., soil characteristics), and local wind characteristics (e.g., average wind speed, frequency of wind gusts). A low slenderness coefficient value usually indicates a longer crown, lower centre of gravity, and a better developed root system. Therefore, trees with higher slenderness coefficient values (that is slender trees) are much more susceptible to wind damage. Actions improving the stability of trees and stands could considerably limit these damages. Tree slenderness coefficient has been variously described as a dimensionless value based on the ratio of tree diameter at breast height (Dbh) and total height and computed as the tree total height divided by the Dbh (Moravčík, 2007; Harja *et al.*, 2012; Magruder *et al.*, 2012; Budeanu and Sofletea, 2013). Greater values indicate taller and narrower trees, and trees with values over a threshold of 80 are prone to wind-throw as well as wind induced breakage (Rudnicki *et al.*, 2004). It has been observed that slenderness ratio of trees is an excellent indicator of their long-term exposure to wind before harvesting (e.g., Mattheck and Breloer, 1994; Harris *et al.*, 1999; Rudnicki *et al.*, 2001). A very tall, slender, plantation-grown tree would respond dynamically like a pole or chimney, which is the approximation used by Kerzenmacher and Gardiner (1998) when modelling tree behaviour with slenderness ratio of 75. James (2010) and Šebeň *et al.* (2013) noted that slenderness coefficients above 100 generally indicate low stability and the affected tree is likely to buckle under its own weight. For forest trees, slenderness coefficient below 80 indicates excellent stability (Smudla, 2004; Slodicak and Novak, 2006; Kontogianni *et al.*, 2011). For trees in urban areas, lower slenderness ratios of 50:1 have been proposed by Mattheck *et al.*, (2003). This study, therefore, intends to establish relationship between SC and tree characteristics (H and DBH) as well as to develop equations for predicting SC from tree DBH and H for Neem stand at Sanyinna Community Plantation.

METHODOLOGY

The Study Area

The research was conducted in Sanyinna Community Neem Plantation in Sokoto State, Nigeria. The area lies in the Northwestern region of Nigeria, and it is geographically geo-referenced on coordinates lines of 12.709^{o}N and 4.8572^{o}E. The plantation was established in the year 2016 by the British American Tobacco Nigeria Foundation and is being managed by the community. The plantation is about 5 ha with a spacing of 3 x 3 m. The vegetation of the area consists of very short grasses and shrubs with dominant plant species which include *Azadiractha indica* (Neem tree) and the annual rainfall ranges from 500 to 1,300 mm per annum.

Sampling and Data Collection

A total of 15 temporary sample plots (three plots/ha) of 25 x 25 m were randomly laid within the plantation. All trees within the selected plots were enumerated. Diameters at breast height (Dbh), bases (Db) middle (Dm) and top (Dt) were measured in centimeters. Db, Dbh, and Dm were measured using diameter tape, while Dt was obtained with the aid of Spiegel Relaskop. Total height, which is the height from the ground through the stem to the tip of the tree, was measured using Spiegel Relaskop in meters.

Data Analysis

The data collected were analyzed using descriptive statistics, correlation analysis, and regression analysis. Pearson's correlation was considered in order to establish relationship between TSC and other measured tree variables, while regression analysis was used in generating models that predict TSC (dependent variable) from Dbh (independent variable). Tree volume and TSC were computed using appropriate procedures as follows:

- Volume estimation

The volume of individual trees was estimated using Newton's equation developed for trees volume estimation (Husch *et al.*, 2003)

$$V = h\pi\left(\frac{D_b^2 + 4D_m^2 + D_t^2}{24}\right)$$

Where:
V = Tree volume (m^3)
H = Tree height (m)
D_b = Diameter at base (cm)
D_m = Diameter at middle (cm)
D_t = Diameter at top (cm)

- Slenderness coefficient (TSC)

$$TSC = \frac{THT}{Dbh}$$

Where:
TSC = Tree slenderness coefficient
THT = Total tree height (m)
Dbh = Diameter at breast height (m)

Model Fitting and Evaluation

Five different model forms (Table 1) were considered as candidate models for prediction of TSC for Neem tree stands at Sanyinna Community Plantation as adopted from Oladoye *et al.* (2020).

Table 1: Selected regression models to be fitted

Model No	Model type	Model expression
1	Simple linear	$TSC = a + bD$
2	Exponential	$TSC = ae^{bD}$
4	Logarithmic	$LnTSC = a + b\ln(D)$
5	Quadratic	$TSC = a + bD + cD^2$

RESULTS

Summary Statistics of the Field data

The statistical summary for the dataset collected and computed is presented in Table 2. The table shows the mean, the standard error, the standard deviation, minimum and maximum values of the tree variables obtained. Figure 1 presents the summary of the TSC classes as low, moderate, and high. The result reveals that more than 50% of the neem trees within the Sanyinna Community Plantation fall under low slenderness coefficient class, even though the average size of the tress is still small but have the potentials of growing bigger under sustained management practices.

Table 2: Summary Statistics

Variables	Dbh (cm)	THT(m)	BA (m^2)	Volume (m^3)	SLC
Mean	9.27	7.02	0.0069	0.0348	77.52
Minimum	6.78	6.00	0.0036	0.0170	51.64
Maximum	12.20	8.60	0.0117	0.0643	110.62
Standard Deviation	1.423	0.720	0.0021	0.0105	14.137
Standard Error	0.150	0.076	0.0002	0.0011	1.490

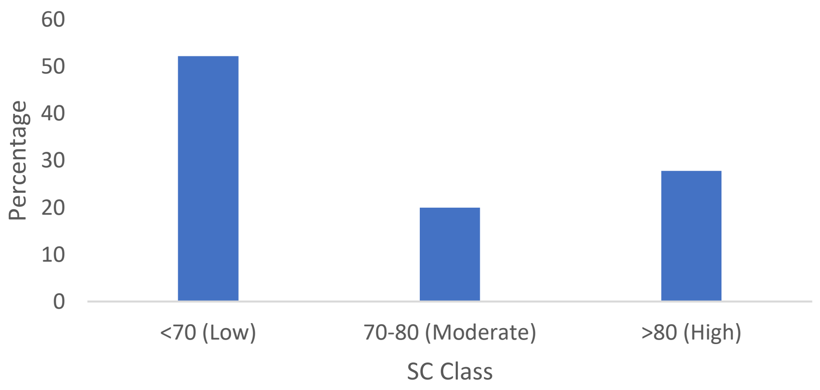

Figure 1: Distribution of Tree Slenderness Coefficient within the Plantation

Correlation Coefficients

Correlation analysis was used in order to investigate the relationship between tree slenderness coefficient and each measured and/or calculated tree variable (Table 3). The approximate correlation coefficients between TSC and all other variables (Db, Dm, Dbh, Dt, BA, Vol) were negative except the correlation between TSC and tree height. This result is an indication that the larger the tree the less slenderness and taller trees tend to have higher slenderness coefficient values (slender trees). It also, indicates that tree diameters are better predictors of TSC than tree height, hence the choice of Dbh for model calibration.

Table 3: Correlation Analysis between tree slenderness coefficient and tree variables

	Db	Dm	Dt	Dbh	THT	BA	Vol	TSC
Db	1							
Dm	0.35	1						
Dt	0.40	0.16	1					
Dbh	0.91	0.47	0.43	1				
THT	-0.18	0.30	-0.11	-0.07	1			
BA	0.92	0.45	0.43	0.99	-0.08	1		
Vol	0.50	0.93	0.23	0.61	0.50	0.59	1	
TSC	-0.81	-0.24	-0.38	-0.83	0.59	-0.83	-0.24	1

Db: diameter at the base, Dbh: diameter at breast height, Dm: diameter at the middle, Dt: diameter at the top, THT: total tree height, BA: basal area, Vol: tree volume, TSC: slenderness coefficient

Regression Models

Linear and nonlinear regression models (Table 1) were developed and tested in this study for tree slenderness coefficient (TSC) prediction using Dbh as independent variable and the results are presented in Table 4. The tree slenderness coefficient models are formulated to express slenderness coefficient as a function of tree growth characteristics. Model evaluation criteria adopted was based on the highest values of the coefficient of determination (R^2), the least values of the standard error of the estimate (SEE), the least values of Akaike information criterion (AIC), and least values of Bayesian information criterion (BIC). The four (4) fitted models were all significant ($p<0.05$) and based on the stated selection criteria, the Exponential model appeared to be the best model for estimating the TSC from Dbh.

Table 4: Developed models for predicting SC from Dbh

Model Name	Parameters			R^2	SEE	Sig.	AIC	BIC
	a	b_1	b_2					
Simple linear	146.48	-7.759		0.77	6.660	0.000	482.6	489.3
Logarithmic	236.54	-73.185		0.77	6.679	0.000	482.1	488.8
Quadratic	150.99	-8.724	0.050	0.77	6.697	0.000	483.6	490.3
Exponential	200.96	-0.109		0.80	0.087	0.000	482.3	488.9

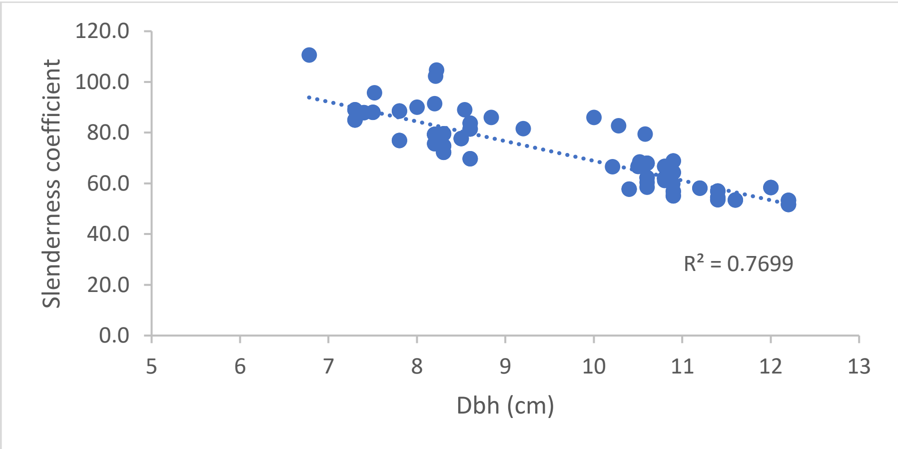

Fig 1: Relationship between SLC and Diameter at breast height

Discussion

The results of tree slenderness coefficient classification showed that over 50% of the measured trees in the area had low slenderness coefficient, 20% has moderate slenderness coefficient and about 28% of the trees fall under high slenderness coefficient class, which implies that the trees have low susceptibility to wind-throw and damage. The result is in agreement with Rudnicki *et al*. (2004) who reported that trees with values over a threshold of 80 are prone to wind-induced breakage. For forest trees, slenderness coefficient below 80 indicate excellent stability (Smudla, 2004; Slodicak and Novak, 2006; Kontogianni *et al*., 2011). The low occurrence of trees with high slenderness coefficients may be a result of plantation age and other climatic factors. Hence, it can be said that trees in the study area have been experiencing stress free growth, a situation pleasant to sustainable forestry. Trees with low slenderness coefficient are less susceptible to breakage than those with high slenderness coefficients which agrees with the findings of Eguakun and Oyebade (2015). Lower slenderness coefficient can be an indicator of larger crowns, lower centre of gravity and a better developed root system. The desirable height/dbh ratios for adequate wind resistance vary according to species and regions (Ige, 2017). In general, trees with a higher slenderness coefficient (low taper) are much more susceptible to damage than trees with low slenderness coefficient (high taper). Since smaller slenderness coefficient is usually indicating a higher resistance to wind throw, the relationships confirmed suggest that silvicultural treatments, such as producing long crowned trees, and maintaining appropriate stand density through spacing, thinning, or gradually harvesting overstory trees, can be helpful in reducing the risk of wind throw (Wang *et al*., 1998; Eguakun and Oyebade, 2015). As noted by Liu *et al*. (2003), when tree slenderness coefficient becomes very low, there is no possibility of exposure of such trees to bending stress, leading to reaction wood, which may affect wood properties as well as the ultimate usage to which the wood can be put. Negative correlation coefficient values were observed between TSC and all other tree variables except Tree Height, with Dbh, Db, and BA recording significantly ($p<0.05$) strong negative correlation, implying that the bigger the size of the trees the lower the TSC. This result indicates that the tree slenderness coefficient values tend to decrease for larger trees, and the largest slenderness coefficient values occur for the trees with small Dbh which is in accordance with the result of Onyekwelu (2001) and Onyekwelu *et al*. (2003).

Dbh and TSC data were first fitted in a scatter plot in order to have an idea of the kind of relationship that exist between the two variables for easy selection of candidate models. Based on the pattern of the relationship from the scatter chart, five (5) candidate models were selected to predict TSC (dependent variable) from Dbh as a major predictor due to the fact that it has the highest correlation coefficient and practically, Dbh is the easiest and commonest variable to measure in many forest inventories. All the models showed strong fit to the tree slenderness coefficient data. Hence, least values of AIC, BIC and SEE were used to select the best model that explains the relationship. Based on this criterion, Exponential model was adjudged the best among the candidate models. Hence, this model is therefore recommended for predicting slenderness coefficient in the stand.

CONCLUSION

It is concluded that the growth characteristics (Dbh, Height, BA, Volume) of the Neem stand at Sanyinna Community Plantation follows a regular growth pattern. Majority of the tee stands fall under low TSC which is an indicative of low vulnerability of trees to fell off due to windthrow. There was significant strong negative correlation between TSC and some tree characteristics (Db, Dbh, BA, Volume) which is an indication that the bigger the size of a tree the more the ability to withstand windthrow within the *Azardirachta indica* stand of Sanyinna Community Plantation, Nigeria. The study has projected that there is little possibility of occurrence of wind throw among this specie in Sanyinna plantation and advances the need for continuous silvicultural treatment and avoiding other environmental degradation within the plantations in Nigeria. Diameter at breast height (Dbh) was considered as the common useful independent variable used in all selected candidate models for the study. Both linear and nonlinear model forms were calibrated and evaluated for predicting TSC (dependent variable) from Dbh (independent variable) and based on the selection criteria adopted the Exponential Model was selected as the best model for predicting TSC. Based on the findings of the study it is recommended that there should continuous sustainable management of the plantation for healthy, productive, and stable stands with appropriate silvicultural treatment such as thinning and weeding to avoid competition.

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