ISSN (Online): 2349-1183; ISSN (Print): 2349-9265
TROPICAL PLANT RESEARCH
The Journal of the Society for Tropical Plant Research

9(1): 37–43, 2022
DOI: 10.22271/tpr.2022.v9.i1.006

Research article

Relationships between tree slenderness coefficients and stand characteristics for major plantation-grown species in North-western Nigeria

S. B. Shamaki

Department of Forestry and Environment, Faculty of Agriculture,
Usmanu Danfodiyo University, Sokoto, Nigeria

Corresponding Author: sanusi.shamaki@udusok.edu.ng

[Accepted: 27 March 2022]

Abstract: This study established relationships between tree slenderness coefficient (used as an index of resistance of trees to windthrow) and some stand characteristics of three major tree species used for plantation establishment in some part of North-western Nigeria. Tree measurements for diameter at breast height (DBH) and total tree height were conducted on 60 randomly selected temporary sample plots (TSP) of 20 × 20 m, while tree slenderness coefficient (TSC), basal area (BA), and tree volume were computed from the field data. Pearson correlation was used to establish a relationship between TSC and other tree variables, while nonlinear regression analysis was used in developing models for predicting TSC from DBH and tree height. Results from descriptive statistics indicate that there were low slenderness coefficient values across the three species under study. TSC was found to be negatively correlated with tree DBH, BA, and volume but positively correlated with tree height. Five candidate models were selected as base models to predict TSC from DBH alone and result from the nonlinear regression analysis revealed that the exponential function produced better fit statistics and it was further modified to include an additional tree variable (height). Results of the regression model that includes additional tree variables have better fit statistics compared to those models (base models) without additional tree variables. An exponential function model is recommended for estimating TSC from DBH and tree height for the three major plantation-grown species in North-western Nigeria.

Keywords: Eucalyptus - Gmelina - Teak - Modelling.

[Cite as: Shamaki SB (2022) Relationships between tree slenderness coefficients and stand characteristics for major plantation-grown species in North-western Nigeria. *Tropical Plant Research* 9(1): 37–43]

INTRODUCTION

The tree slenderness coefficient is defined as the ratio of total height (H) to the diameter at breast height (DBH) when both H and DBH are measured in the same units. The coefficient is related to tree taper and is the inverse of the DBH/H ratio that is often used to ensure tree taper over the entire main stem of the tree (Wang *et al*. 1998). In silvicultural studies, the tree slenderness coefficient often serves as an index of tree stability, or the resistance to windthrow (Navratil 1995). The likelihood of the windthrow of a tree may be influenced by many factors interacting with each other. These factors include tree attributes (e.g., tree height, taper/form, the size and shape of the 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). The most promising approaches for determining tree and stand stability to windthrow 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).

However, besides basic structural variables such as the basal area, tree slenderness is also a measure recognized as a good indicator of the windthrow stability of trees. Proper and adequate silvicultural treatments at the early stage of plant development have the ability of influencing tree form and other physiological characteristics. It indicates the shape of trees and together with tree vitality provides insight into the general

Received: 20 December 2021
Published: 30 April 2022
https://doi.org/10.22271/tpr.2022.v9.i1.006

stability of planted forests (Dodan & Perić 2019). Tree slenderness coefficient (TSC) often serves as an index of tree stability, or the resistances to wind throw (Navratil 1996, Onilude & Adesoye 2007). A low slenderness coefficient value typically indicates a longer crown, a lower centre of gravity, and a better-developed root system. Therefore, trees with higher slenderness coefficient values (slender trees) are much more susceptible to wind damage. Actions improving the stability of trees and stands could considerably limit these damages. Because of the tree slenderness coefficient's importance for indexing tree resistance to windthrow, it is therefore crucial to understand the slenderness of trees, considered to be a measure of their stability, especially for most of the planted tree species in the Sudan savannah region of Nigeria, where the majority of the indigenous species are disappearing and there is an urgent need for restocking the degraded lands with fast-growing, drought, and wind resistant species.

Climate change and environmental degradation are part of the major drawbacks of forestry development in northern Nigeria. The region is characterized by vast land that is devoid of tree vegetation and even where trees are established, they are often sparsely distributed which makes the area open and vulnerable to excessive windstorms and other natural catastrophic conditions. However, sustainable forest management can be ensured through reliable data gathering on growth and yield of forest stands, which can as well be useful in updating forest inventory records for current and future use. A good management of the planted forest reserves in North-western Nigeria must have on the table, current, accurate and up-to-date information on the growing tree species, to help them possibly plan for the future growth potentials of the trees. This study intends to estimate the slenderness coefficient for the major plantation-grown tree species in North-western Nigeria as well as to develop models that will predict TSC from other trees and/or stand characteristics that can be used for better wind-throw hazard management.

MATERIALS AND METHODS

The study area

The study was conducted in two locations where these three important species (Eucalyptus, Gmelina, and Teak) are planted in large hectares. The two sites are Afaka Plantation (for Eucalypts) and Nimbia Plantation (for Gmelina and Teak) both in Kaduna state.

Afaka plantation is situated in the Northern Guinea Savannah ecological zone, located at about 15 km from Kaduna city between latitudes 10° 35´ and 10° 38´ N and longitudes 7° 15´ and 7° 20´ E with an elevation of 610 m above sea level with an almost imperceptible slope towards the south or undulated layers in many subsoils. The mean annual rainfall is 1300 mm, but yearly totals show a wide range of variation, particularly for April and May. Relative humidity from January to March is very low (10%) during which temperatures may rise to over 37.7°C (Adegbehin 2002). The introduction of exotic species started in 1958 and emphasis was given to the trial of eucalyptus and pines species within the reserve area. More intensive management was later introduced, and critical examination of fertilizer requirements, spacing and thinning regimes were also introduced to enhance the growth performance of the species (Shamaki & Akindele 2014).

Nimbia Plantation is a multipurpose plantation located in Jema'a Local Government of the southern part of Kaduna State, Nigeria belonging to the Northern Guinea Savanna zone of Nigeria, 70 km southeast of Jos, along Jos-Kafanchan Road It lies between latitudes 8° 20´ and 9° 32´ N and longitudes 8° 27´ and 8° 36´ E with an elevation of 594 m above mean sea level. The climate is determined by altitude and its location in relation to the seasonal migration of the inter-tropical convergence zone. The position of Nimbia with respect to altitude (about 600 m above sea level) induces orographic rain and has an annual rainfall of between 1500–2000 mm spread over a period of seven months (April–October) while the dry months are five months (November–March). Minimum temperatures range between 17–22°C (December–March) and the maximum ranges from 28–35°C (August–March). Relative humidity is between 30–36% in the dry season and 95% in the rainy season.

Data collection

Data were obtained from Temporary Sampling Plots (TSP) established for this study at both Afaka and Nimbia Forest Plantations. Permanent Sample Plot data are rarely available in most tropical rainforests and plantations of Nigeria due to the complex nature of the tropical rainforest as well as funding and other logistic challenges. The two study sites are both multispecies plantations with each species separated by compartments. Within each compartment, 20 × 20 m plots were established, and 20 plots were randomly selected for each species, thereby making a total of 60 temporary plots for the three species. All live trees with a DBH greater than 5 cm were marked and measured.

Tree volume, Basal Area (BA) and Tree Slenderness Coefficient (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)

- Basal Area (BA)

$$BA = \frac{\pi D^2}{4}$$

Where:
BA = Basal Area (m^2)
D = Tree diameter (cm)

- Slenderness coefficient (TSC)

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

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

Correlation and graphical analysis

Before model calibration, the computed TSC was plotted against DBH and, against tree height to check for a possible relationship that exists between TSC and tree characteristics (DBH and height) and to also check for possible measurement error.

Correlation analysis was used to determine the relationship between tree slenderness coefficient values and tree characteristic values measured or computed from the data obtained.

Model development

A two-stage modelling approach was adopted in developing models for predicting TSC from other tree characteristics. In the first stage, a base model that relates TSC to DBH was developed. In the second stage, tree height was incorporated into the base model to improve the predictive ability.

Based on the scatter plots of TSC against DBH values by species, five candidate models (nonlinear) were selected as base models (Table 1). The entire field data were split into estimation (70%) and validation (30%) sets. A nonlinear regression procedure in SPSS version 23.0 was used in fitting both base models and the models that incorporate tree height. Model validation statistics (R^2, SEE, F-value) were produced in the process of model development.

For effective model validation of the developed models, each model was used to predict the slenderness coefficient using measured DBH values in the validation data set. The estimated TSC values from the developed models were then compared with the actual TSC computed using the goodness-of-fit test. Residual analysis was further adopted for model evaluation.

Table 1. Selected candidate base regression models.

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

RESULTS AND DISCUSSION

Data description

Summary statistics for both measured variables and computed parameters are presented in table 2. As described earlier, data for this study emanate from the temporary sampling plots due to the difficulties of establishing PSPs in parts of Nigeria's forest plantations. Therefore, growth characteristics may vary from plot to plot depending on the site conditions of the plots at the time of measurement.

Table 2. Summary statistics.

Species	Statistic	TSC	DBH (cm)	H (m)	BA (m^2)	Volume (m^3)
Eucalyptus	Mean	43.8	14.6	6.0	0.0202	0.1253
	Min	10.9	6.7	3.0	0.0035	0.0075
	Max	89.1	42.3	17.5	0.1408	1.9241
	SD	12.7	6.6	2.1	0.0237	0.2191
Gmelina						
	Mean	43.5	16.3	6.8	0.0227	0.1130
	Min	18.5	8.3	2.8	0.0054	0.0156
	Max	86.2	40.4	12.5	0.1284	0.6790
	SD	9.9	4.7	1.5	0.0144	0.0852
Teak						
	Mean	43.4	15.0	6.8	0.0187	0.0964
	Min	22.0	8.6	3.4	0.0058	0.0178
	Max	87.3	31.8	12.5	0.0796	0.6968
	SD	8.8	3.6	1.2	0.0099	0.0653

Slenderness coefficient versus tree variables

The correlation coefficient values estimated between TSC, and four tree characteristics are presented in table 3. All three tree species produced a similar pattern of relationship showing negative coefficient values for all the variables except for height which gave positive correlation in all three species.

Table 3. Correlation coefficients between TSC and tree variables.

Species	DBH	H	BA	Volume
Eucalyptus	-0.458	0.360	-0.426	-0.218
Gmelina	-0.573	0.325	-0.551	-0.346
Teak	-0.610	0.531	-0.582	-0.347

Figures 1 to 3 depict the pattern of the relationship between TSC and DBH, and between TSC and tree height for all three species. The essence of using graphical illustration of this relationship pattern is to have an idea of the possible regression model functions to be selected for model calibration/training.

Regression models for predicting slenderness coefficient values

The model fitting procedure was a two-stage method which produced two sets of models for predicting TSC. The first set termed as base models predicted the TSC from DBH alone, while the second set uses both DBH and tree height in predicting the TSC (Tables 4 and 5).

DISCUSSION

Based on the descriptive statistics result obtained the data set appeared quite suitable for the intended study as the standard deviation for all the variables is relatively low indicating low variability in the data sets. The mean TSC for all the species is about 44 indicating low slenderness coefficient across the plantation-grown

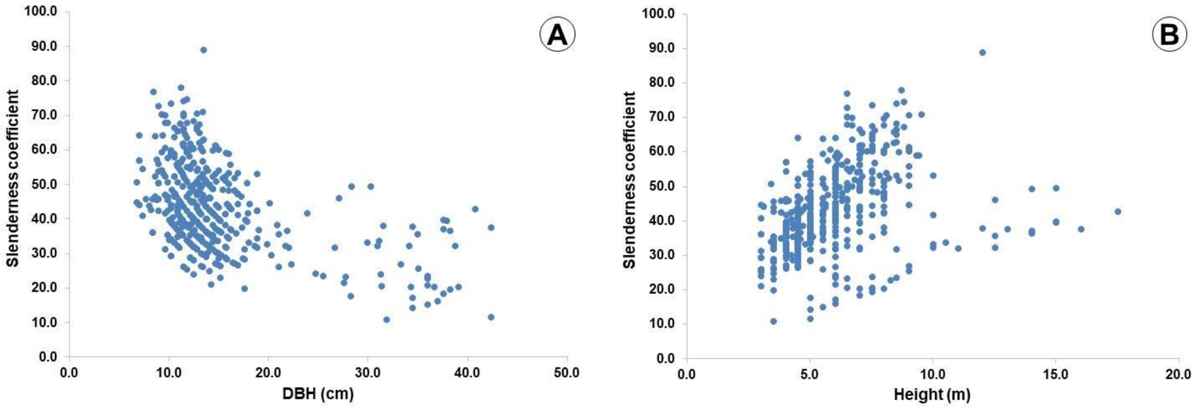

Figure 1. Relationship of TSC with DBH and Height for Eucalyptus stand.

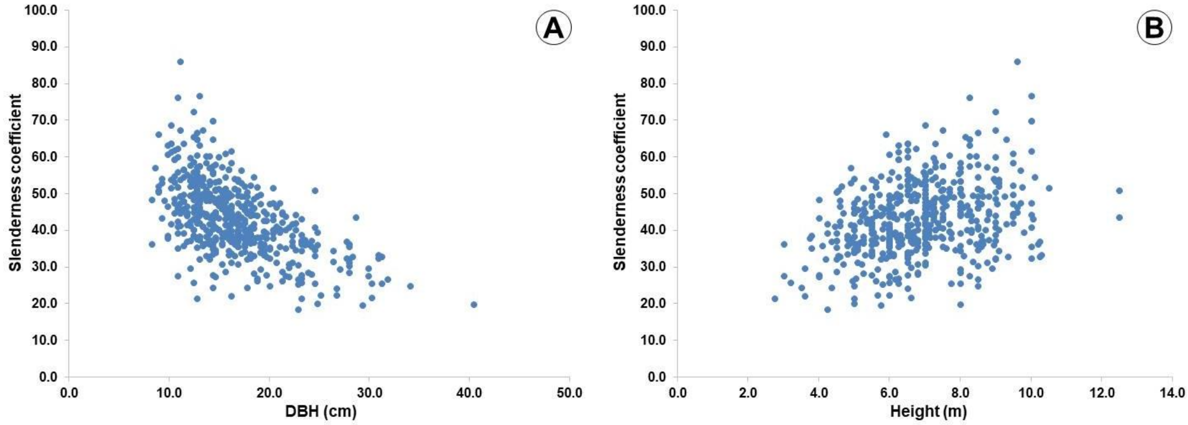

Figure 2. Relationship of TSC with DBH and Height for Gmelina stand.

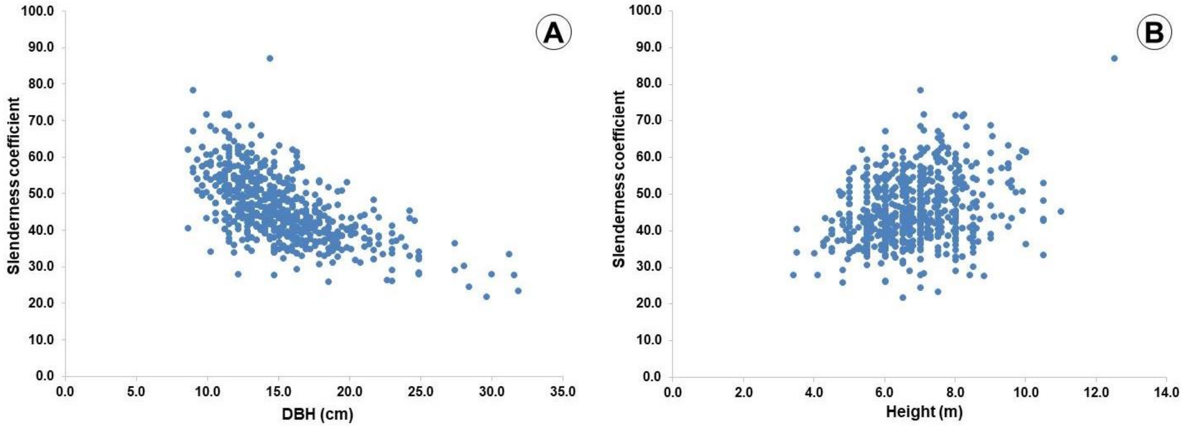

Figure 3. Relationship of TSC with DBH and Height for Teak.

Table 4. Developed base models for predicting TSC from DBH alone.

Species	Model type	Coefficients				R^2	SEE	Sig.
		a	b_1	b_2	b_3			
Eucalyptus								
	Linear	56.59	-0.877			0.21	11.26	0.000
	Logarithmic	88.65	-17.179			0.22	11.18	0.000
	Quadratic	67.30	-2.082	0.027		0.23	11.17	0.000
	Cubic	63.51	-1.426	-0.007	0.001	0.23	11.18	0.000
	Exponential	60.12	-0.025			0.28	0.26	0.000
Gmelina								
	Linear	63.35	-1.215			0.33	8.14	0.000
	Logarithmic	101.97	-21.217			0.33	8.15	0.000
	Quadratic	69.23	-1.884	0.017		0.33	8.13	0.000
	Cubic	66.87	-1.496	-0.002	0.000	0.33	8.14	0.000
	Exponential	69.29	-0.030			0.36	0.19	0.000
Teak								
	Linear	68.65	-1.483			0.37	6.96	0.000
	Logarithmic	111.00	-24.085			0.38	6.89	0.000
	Quadratic	79.58	-2.832	0.039		0.38	6.90	0.000
	Cubic	91.80	-5.034	0.164	-0.002	0.38	6.90	0.000
	Exponential	75.62	-0.034			0.41	0.15	0.000

Table 5. Estimated coefficients and fitting statistics for the model predicting TSC from DBH and height.

Species	Coefficients			R^2	SEE	Sig.
	a	b_1	b_2			
Eucalyptus	37.90	-2.01	5.85	0.83	5.16	0.000
Gmelina	40.23	-2.26	5.88	0.90	3.05	0.000
Teak	43.37	-2.71	6.46	0.92	2.46	0.000

species. Gmelina stand produced relatively bigger size trees compared to the other species under study. This could be attributed to the fact that Gmelina stand were less disturbed (trespassed) than Teak and Eucalyptus as seen in the field during data collection. Wang *et al.* (1998) reported that smaller TSC is usually indicating higher resistance to windthrow; those 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 windthrow.

The negative correlation coefficient values obtained between TSC and DBH implies that size instead of height is responsible for low tree slenderness for plantation grown species. The bigger a tree is the more stable it becomes and the taller a tree is the more susceptible to windthrow it becomes. Similarly, the approximate correlation coefficients between TSC and DBH were consistently higher than those correlation coefficient values between TSC and all other tree characteristics, implying that tree DBH is a better predictor of tree slenderness than other tree characteristics. The positive correlation coefficients observed between height and TSC is also an indication of high competition among the tree stands, especially within the Gmelina and Teak stands because of the density which compelled the trees to compete for sunlight and other limited resources within the plantations. Wang *et al.* (1998) reported a similar pattern of relationships among the major species in boreal mixed-wood forests to expect with the height where they reported negative correlation coefficient values for the five species they worked on.

The slenderness coefficient values decreased with the increasing average size for the three plantation-grown species, but the decrease in TSC values is more with Gmelina and Teak species and low with Eucalyptus stands. The low correlation coefficient value observed between TSC and Eucalyptus diameter is as a result of low stocking density per hectare, as Eucalyptus stands are managed in Northern Nigeria mostly to produce poles and fencing posts. For optimum utilization, these products obtained from Eucalyptus are more of a tree height dependent than the size of the stem. Oladoye *et al.* (2020) reported a similar pattern of decreasing TSC values with an increasing tree size for tree species in Omo Biosphere Reserve, with other tree characteristics (crown length, volume, height) showing low correlation with tree slenderness coefficient. Adeyemi & Adesoye (2016) also, reported similar results while working on some tree species in a tropical rainforest of Nigeria. Both TSC vs DBH and TSC vs H produced a nonlinear kind of scatter plots, suggesting the adoption of nonlinear regression modelling for developing models that will predict TSC from tree characteristics (DBH and H). Furthermore, the relationship pattern based on the charts validate the correlation coefficient values obtained between TSC and DBH (positive correlation), and between TSC and H (positive correlation).

Based on the fit statistics of the base models, the whole five selected base models showed significant predictive coefficients, but low coefficient of determination (R^2) for all the three tree species considered for this study. The Exponential model produced better fit statistics with low standard error of the estimate compared to the other four models across the species and similar results were reported by Wang *et al*. (1998) and Oladoye *et al.* (2020). From the estimated R^2 values, 21 to 41% of the total variation in observed tree slenderness coefficient values was explained by the fitted base models. Even though the statistics produced from the validation dataset using the candidate base models provided some indication of the accuracy of prediction, but the low percent R^2 as a determinant of a better fit necessitate the need for using an additional stand or tree variable to improve the predictive capacity of the base models.

The exponential model is a better fit model (based on fitting statistics) was further assessed by estimating the TSC using the validation data set and the result of the validation shows better estimates of the TSC with low standard error of the estimates. To improve the performance of the selected base model, another independent variable (height) was included to form a new model (Table 5) for all three species. The model was estimated using a nonlinear modelling approach, and each estimated coefficient as tested for significance at 5% probability level and all the coefficients for all three species produced significant coefficients. Immediately the height variable was included in the model, there was remarkable improvement in the fit statistics producing a strong R^2 values and low standard error of the estimates for all the species. The R^2 increases from 0.28 to 0.83, 0.36 to 0.90, and 0.41 to 0.92 for Eucalyptus, Gmelina, and Teak, respectively. There was also a reduction in SEE values ranging from 11.26 to 2.46 (Tables 4 and 5). This improvement recorded by using additional tree variables is an indication that using DBH alone for predicting TSC may not produce the best models but additional stand and/or tree variables could improve the prediction.

CONCLUSION

Based on the findings of this study it can be concluded that tree size is a strong factor for tree stability as the tree slenderness coefficient values decrease with an increasing tree diameter. Even though tree DBH is a good predictor of TSC, predicting TSC by using tree DBH and additional stand and/or tree variables could improve the accuracy of prediction. The Exponential function model was found to be the best for predicting the TSC from DBH, and tree height for the three species. Since slenderness coefficient values have been widely used for determining tree stability in many parts of the world, its application should be extended to many indigenous tree species in the drier region of the Northern Nigeria in order to guide policy makers in choosing the most likely wind resistant species for afforestation and reforestation projects.

ACKNOWLEDGEMENTS

The author wish to thank the management of Kaduna State Forestry Project for granting permission to conduct this study at both Afaka and Nimbia Plantations.

REFERENCES

Adegbehin JO (2002) Growth and yield of *Tectona grandis* (Linn. f) in the Guinea and Derived savanna of Nothern Nigeria. *International Forestry Review* 4(1): 66–76.

Adeyemi AA & Adesoye PO (2016) Tree slenderness coefficient and percent canopy cover in Oban Group Forest, Nigeria. *Journal of Natural Sciences Research* 6(4): 9–17.

Dodan M & Perić S (2019) Windthrow resistance of Norway spruce (*Picea abies* (L.) Karst.) forest cultures preliminary results. *South-east European Forestry* 10(1):77–88.

Husch B, Charles IM & Thomas WB (2003) *Forest Mensuration*. The Ronald Press Company, New York, U.S.A., pp. 120–123.

Navratil S (1995) *Minimizing wind damage in alternative silviculture systems in boreal mixedwoods*. Publ. No. Fo42-91/124/1995E. Canadian Forest Service and Alberta Land and Forest Service, Edmonton Alta.

Navratil S (1996) Silvicultural systems for managing deciduous and mixed wood stands with White spruce understory. *In*: Comeau PG & Thomas KD (eds) *Silvicultural of Temperate and Boreal Broadleaf-conifer Mixture*. B.C. Ministry of Forests, Victoria, pp 35–46.

Navratil S, Brace LG, Sauder, EA & Lux S (1994) *Silvicultural and harvesting options to favor immature white spruce and aspen regeneration in boreal mixedwoods*. Canadian Forest Service, North Forest Centre In. Rep. No. NOR-X-337.

Oladoye AO, Ige PO, Baurwa N, Onilude QA & Animashaun ZT (2020) Slenderness coefficient models for tree species in Omo Biosphere Reserve, South-western Nigeria. *Tropical Plant Research* 7(3): 609–618.

Onilude QA & Adesoye PO (2007) Relationship between tree slenderness coefficient and tree growth characteristics of *Triplochiton scleroxylon* K. Schum in Nigeria. *Academia Journal of Scientific Research* 3(11): 178–183.

Shamaki SB & Akindele SO (2014) Modelling diameter distribution for a seven year *Eucalyptus camaldulensis* stand in Afaka Forest Reserve-Nigeria using Weibull function. *Journal of Agriculture and Environment* 10(1&2): 45–53.

Wang Y, Titus SJ & LeMay VM (1998) Relationship between tree slenderness coefficients and tree or stand characteristics for major species in Boreal mixed forest. *Canadian Journal of Forest Research* 28: 1171–1183.