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ASSESSMENT OF STAND GROWTH AND SLENDERNESS COEFFICIENT OF *NAUCLEA DIDERRICHII* A. CHEV AND *TERMINALIA IVORENSIS DE WILD AND THUR* IN FORESTRY RESEARCH INSTITUTE OF NIGERIA, (FRIN) ARBORETUM, OYO STATE, NIGERIA

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ABSTRACT

The contribution of trees to human well-being cannot be overemphasized. The study assessed the growth characteristics and Slenderness Coefficient (SLC) of Nauclea diderrichii and Terminalia ivorensis two tree species in Forestry Research Institute of Nigeria (FRIN) Arboretum. A complete sampling of all trees encountered in each plantation were counted and their Diameter at breast height (Dbh) and total height (Ht) were measured using Haga altimeter and girthing tape respectively. Basal area (BA) and Volume (Vol) were computed using allometric formulae. The mean Dbh, Ht, BA and Vol of Nauclea diderrichii (5.870.27; 7.65± 0.87; 0.004±0.00; 0.016 ±0.0011); Terminalia ivorensis (26.18±1.00; 12.4±0.338; 0.06 ±0.004; 0.38 ±0.029), implying that Terminalia ivorensis had more substantial growth and larger size. More trees (97.43%) of the total trees encountered in both plantation were in the low SLC > 70 category while the remaining were in the medium to high SLC Class. The correlation matrix shows negative correlation between DBH, BA, Vol and SLC which implies more stable trees in the arboretum. The study recommends selecting logging of the trees in the high SLC class as they are vulnerable to wind throw.

Keywords: Basal area, Growth variable, Plantation, Stand growth, Vulnerable

INTRODUCTION

Forests provide a wide range of renewable resources essential for human well-being. The diversity of forest resources and their inherent capacity for renewal present humanity with significant opportunities for sustainable exploitation (Etigale et al., 2014). This necessitates a healthy forest management strategy to ensure the continuity of these resources and their benefits, meeting both immediate and long-term agroforestry needs.

The sustainable management of forest resources is vital for environmental conservation, economic development, and climate regulation. Understanding the growth dynamics of tree species is crucial for optimizing forest management practices and ensuring the long-term sustainability of forest ecosystems (Adekunle et al., 2013). Implementing sound forest management strategies, based on reliable data, is crucial for the sustainability of these resources.

Nauclea diderrichii, known for its durable and water-resistant timber, thrives in moist evergreen and transitional-to-moist semi-deciduous forests. Recent studies have highlighted its growth performance and potential for sustainable timber production in Nigeria's diverse ecological zones (Sidiq et al., 2018; Ige & Adedapo, 2021; Olaniyi et al., 2022).

Terminalia ivorensis, recognized for its fast growth and high-quality wood, is extensively used in reforestation and agroforestry systems (Ibe et al 2015). Recent research has focused on its growth rate and stand density, emphasizing its role in sustainable forest management and reforestation efforts (Adekunle et al., 2013; Owusu et al., 2024).

The Forestry Research Institute of Nigeria (FRIN) has established an arboretum dedicated to studying various tree species, including *Nauclea diderrichii* and *Terminalia ivorensis.* This arboretum provides a controlled environment where researchers can monitor the growth, health, and adaptability of these species under different conditions. However, since its establishment, there is a dearth of comprehensive information on the growth characteristics and slenderness coefficients of these species within FRIN arboretum. Such information is critical for effective forest management and informed decision-making concerning conservation efforts for the species.

Consequently, this study was aimed at assessing the stand growth and tree slenderness coefficient of *Nauclea diderrichii* and *Terminalia ivorensis* in the FRIN arboretum. By analyzing assess the growth characteristics of *Terminalia ivorensis* and *Nauclea diderrichii* in the FRIN arboretum, determine the slenderness coefficient of both species and evaluate the correlation between various growth variables for these species, this study provides valuable insights into the growth dynamics of these species. The findings of the study provides reliable data from forest inventories that are crucial for sustainable management of the arboretum and environmental conservation in Nigeria and beyond. Information on growth parameters can help in developing management guidelines and making silvicultural decisions.

MATERIALS AND METHODS

Study Area

The study took place in the arboretum of the Forestry Research Institute of Nigeria, situated between Longitude 3°51'20" and 3°51'45" E, and latitudes 7°23'18" and 7°55'43" N (Nurudeen et al., 2014). This region experiences a bimodal rainfall pattern, with peaks in June and July, September and October, averaging approximately 1548.20mm annually (Salami et al., 2020). Located within Nigeria's tropical rainforest zone, the area features mean maximum and minimum temperatures ranging from 39°C to 24.9°C. Relative humidity averages around 82% from June to September and about 60% from December to February (Ugwu and Ojo, 2015). The topography is undulating, underlain by ferruginous sandy loamy soil on crystalline rock of undifferentiated Pre-Cambrian basement complex (Salami et al., 2020).

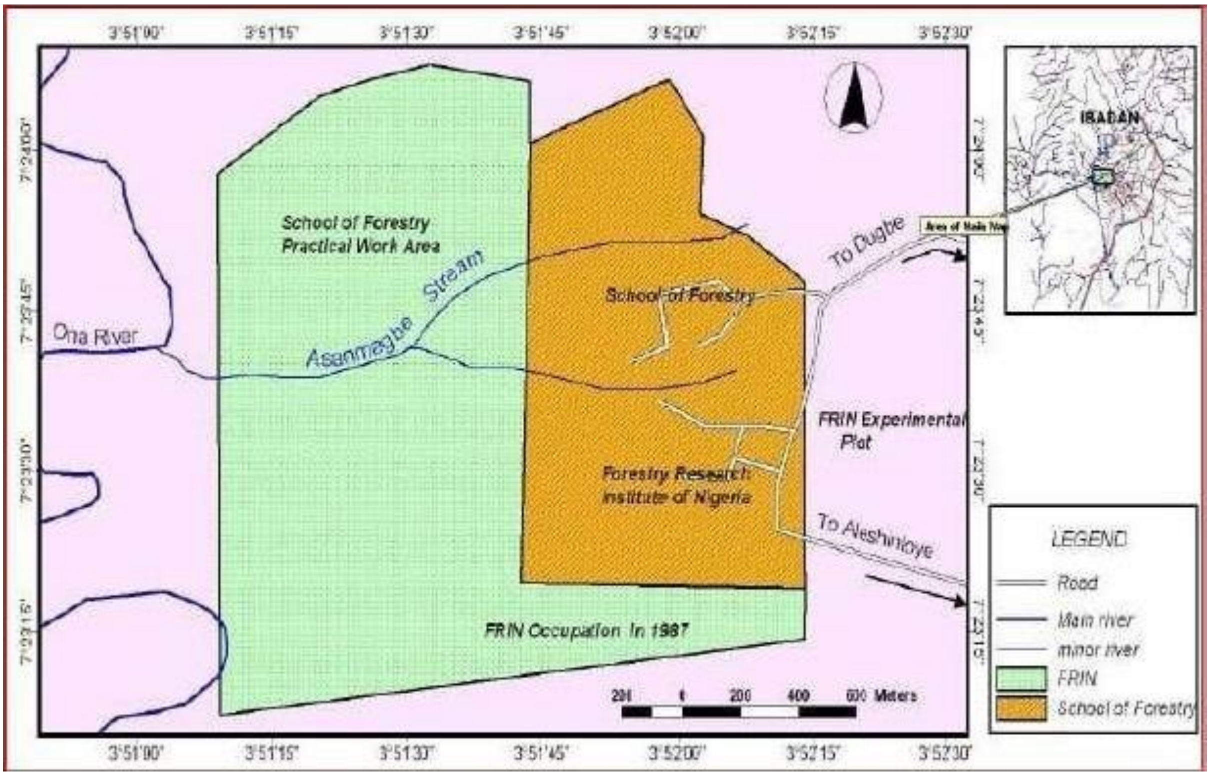

Figure 1: Map showing Forestry Research Institute of Nigeria (Adopted after Ariwaodo et al. 2012)

Sampling technique and Data collection

The study used one age series of *Nauclea diderrichii* and *Terminalia ivorensis* plantation planted in 2010 with a spacing of 5m x 5m. The *Nauclea diderichii* stands cover an area of 0.99 hectares, while the *Terminalia ivorensis* stands occupy approximately 0.35 hectares.

Data collection utilized a total enumeration method due to the plot sizes being ≤ 1 hectare, to make for a thorough assessment. Tree growth variables measured included Dbh (diameter at breast height) and total height. The Dbh (cm) was measured at 1.3 m a from the ground level using a girthing tape while the total height (m) was measure using Haga altimeter at 20 cm from the base of the tree for easy access to the tree crown. Information on all living tree in each plantation were recorded.

Data computation

Basal Area

The basal area of individual trees within each stand was estimated using the formula provided by Husch et al. (2003). The equation for basal area is as follows:

$$BA = \frac{\pi D^2}{4} \quad (1)$$

Where BA = Basal Area (m^2); π = 3.142 (constant); D = diameter at breast height (m).

To obtain the total basal area of the stand for each tree species, the basal areas of individual trees was summed up.

Tree Volume

This was estimated using the formular adopted by Salami et al (2020) which is given as:

$$V = BA \times H \quad (2)$$

Where BA = Basal Area (m^2) and H = Height of tree

The slenderness coefficient (SLC)

The slenderness coefficient is the ratio of the total height (H) of a tree to its diameter at breast height (Dbh) measured at 1.3 meters above the ground. The formula for calculating the SLC is:

$$SLC = \frac{H}{Dbh} \quad (3)$$

Where H = Height of tree and Dbh = Diameter at breast height

The slenderness coefficient is often used as an index of tree stability or resistance to wind-throw. SLC values were categorized using Ige et al (2019) classification. Therefore, there were three categories:

SLC values > 99 …………… High slenderness coefficient
70 < SLC values > 99 Moderate slenderness coefficient
SLC values < 70 ……………. Low slenderness coefficient

Data Analysis

All data analyses for this study were conducted using Microsoft Excel 2010 and the Statistical Package for Social Science (SPSS).

RESULTS AND DISCUSSION

Tree growth variables for *Terminalia ivorensis* and *Nauclea diderrichii* in Forestry Research Institute of Nigeria arboretum

The results of the study as presented in table1 indicates that the mean diameter at breast height (Dbh) for *Terminalia ivorensis* was 26.18 ± 1.000 cm, while for *Nauclea diderrichii*, was 5.87 ± 0.27 cm. *Terminalia ivorensis* has a minimum Dbh of 5.8 cm and a maximum Dbh of 51.5 cm, whereas *Nauclea diderrichii* has a minimum Dbh of 1 cm and a maximum Dbh of 14.3 cm. The total volume of *Terminalia ivorensis* was 31.02 m³, compared to 2.266 m³ for *Nauclea diderrichii*.

Table 1: Tree growth variables for *Terminalia ivorensis* and *Nauclea diderrichii* in Forestry Research Institute of Nigeria arboretum

Variables	*Terminalia ivorensis*	*Nauclea diderrichii*
Mean Dbh (cm)	26.18 ± 1.000	5.87 ± 0.27
Mean Ht (m)	12.45 ± 0.338	7.65± 0.87
Mean BA (m^2)	0.060 ± 0.004	0.004 ± 0.000
Mean Vol. (m^3)	0.38 ± 0.029	0.016 ± 0.001
Min Dbh (cm)	5.8	1
Max Dbh (cm)	51.5	14.3
Total BA (m^2)	4.80	0.516
Total Vol. (m^3)	31.02	2.266
No. of trees	80	146

Note: Dbh- Diameter at breast height; Ht – tree height; BA- Basal Area, Vol.- Volume

The result shows that *Terminalia ivorensis* has a considerably higher mean Dbh and height compared to *Nauclea diderrichii*, indicating that the species has more substantial growth and was larger in size. Onilude & Osundun (2019) observed similar trends where T*erminalia ivorensis* exhibited higher mean diameter at breast height (Dbh) and greater height compared to *Nauclea diderrichii*. The mean basal area and volume per tree for *Terminalia ivorensis* were also significantly larger, reflecting its potential for timber production. With a total basal area of 4.80 m^2 and a total volume of 31.02 m^3 across 80 trees, *Terminalia ivorensis* demonstrates a higher capacity for biomass accumulation and carbon sequestration.

Nauclea diderrichii has a much smaller mean DBH and height, suggesting it is less robust in growth compared to *Terminalia ivorensis.* The mean basal area and volume per tree was also lower, indicating a lower yield of timber per tree (Ogunlade et al. 2018). Despite having a greater number of trees (146), Nauclea diderrichii exhibited lower total basal area (0.516 m^2) and total volume (2.266 m^3) compared to Terminalia ivorensis, which indicates substantial disparities in growth metrics between the two species. Guuroh (2021) similarly emphasize the growth advantages of Terminalia ivorensis over Nauclea diderrichii in tropical forest ecosystems

Akindele and LeMay (2006) study on the growth dynamics of tropical tree species in Nigeria indicates that *Terminalia ivorensis* typically exhibits superior growth performance in terms of Dbh, height, and volume compared to many other indigenous species, including *Nauclea diderrichii.* This aligns with the findings of study, where *Terminalia ivorensis* shows greater growth metrics. Similarly, a study by Adekunle et al. (2013) study on the comparative growth of various tree species in Nigerian forests reports that *Terminalia ivorensis* has higher timber yield and better growth rates, making it a preferred species for plantation forestry and reforestation projects.

Limited tropical rainforest tree species have been observed to grow above 80 cm in DBH (Aderounmu et al., 2017). This observation is not supported by the results of this study, as all trees measured fall below 80 cm Dbh probably due to the age of the plantation (13 years as of the time of the study). Tropical natural forest ecosystems are typically characterized by high population densities of plants, complex plant diversity, and competition for nutrients, soil water, space, and solar insolation, resulting in lower Dbh and taller trees (Adekunle et al., 2013; Aderounmu et al., 2017).

Tree Slenderness Coefficient Assessment

Figures 2 and 3 shows the slenderness coefficients (SLC) between Nauclea diderrichii and Terminalia ivorensis trees

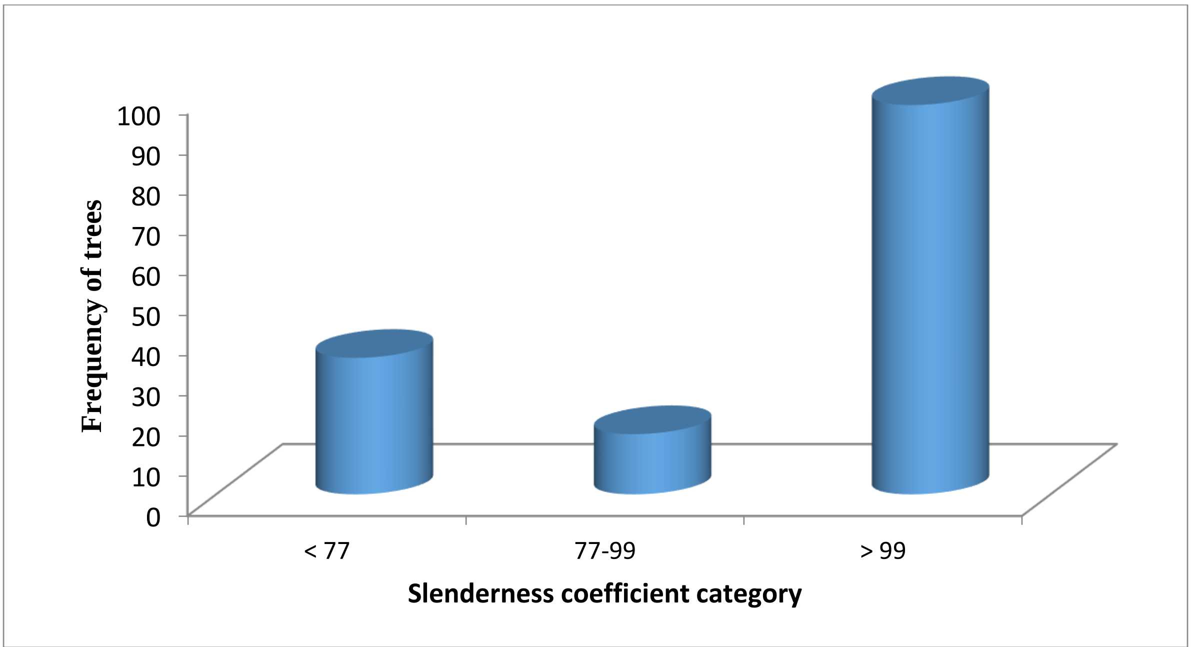

Figure 2: Slenderness Coefficient category for *Nauclea diderrichii* trees

Figure 2 shows that 13.7% of the *Nauclea diderrichii* trees have low SLC (< 70) which indicates these trees are stable and less susceptible to wind damage. Chave et al., (2019), found that tropical trees with lower SLC are less prone to wind induced damage; while 19.90% with moderate SLC (70 < SLC < 99) indicate some resistance to wind, but they are still vulnerable to damage under adverse weather conditions. 66.4% with high SLC (> 99) indicate a high risk of wind-throw and damage, indicating significant challenges for maintaining stability and preventing erosion in the arboretum.

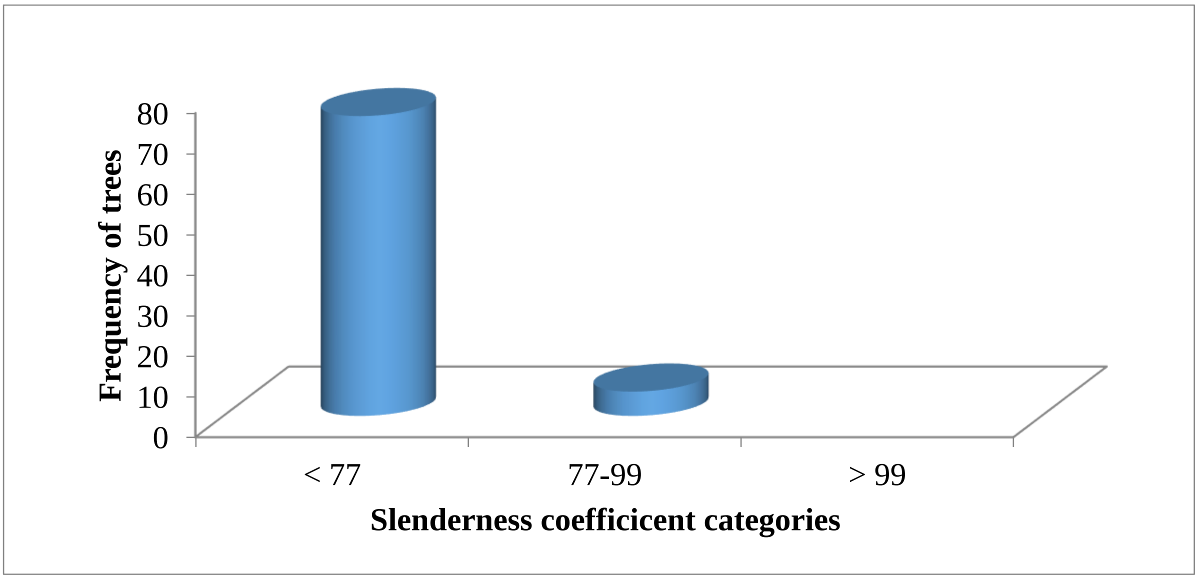

Figure 3: Slenderness coefficient category for *Terminalia ivorensis* tree

Figure 3 indicates that 83.75% of Terminalia ivorensis trees are characterized with low SLC (< 70), indicating they can withstand high-velocity winds effectively without significant damage. This stability suggests they are crucial for maintaining soil integrity and preventing erosion in the arboretum. 16.25% with moderate SLC (70 < SLC < 99) offer moderate resistance to wind, they may still be susceptible to damage under severe wind conditions.

Ige (2017) posit that trees with higher SLC are susceptible to wind damage compared to trees with low SLC. A large percentage (97.43%) of the trees in the arboretum has low SLC, which translate to stability. This finding aligns with Adeyemi & Ugo-Mbonu (2017); Adeyemi & Moshood (2019) and Moshood et al. (2022). However, the percentage of trees in this category is higher than the 95.8% observed by Adeyemi & Ugo-Mbonu (2017) in Nnamdi Azikwe University in Awka, Cross River State.

Correlation Matrix for Tree Growth variables

The correlation matrix provides insights into the relationships between various tree growth variables: Diameter at Breast Height (Dbh), Height (H), Basal Area (BA), Volume (Vol), and Slenderness Coefficient (SLC).

Table 2: Correlation Matrix Analysis for growth variables of *Nauclea diderrichii* stands

	Dbh	Ht	BA (m^2)	Vol (m^3)	SLC
Dbh	1				
Ht	0.135212	1			
BA	0.962826	0.10992	1		
Vol	0.697251	0.645916	0.74508	1	
SLC	-0.29677	0.779464	-0.25306	-0.234554	1

Note: Dbh- Diameter at breast height; Ht- Tree height, BA- Basal Area, Vol- Volume, SLC- Slenderness Coefficient

Table 2 shows that there is a strong positive correlation between Dbh and basal area (0.962826) and between Dbh and volume (0.697251), indicating that as Dbh increases, both basal area and tree volume increase significantly. This suggests that larger Dbh is associated with higher tree volume. Chen et al. (2007) conducted in Brazilian tropical forests who observed a strong positive correlation between Dbh and both basal area and volume. However, there is only a weak positive correlation between Dbh and height, indicating a slight relationship between DBH and tree height, this is in line with study Sumida et al. (2013) also reported a weak positive correlation between Dbh and tree height. A moderate negative correlation between Dbh and the SLC (-0.29677) suggests that trees with larger Dbh tend to have a lower slenderness coefficient, implying better stability. Oladoye et al. (2020) observed negative correlation between Dbh and slenderness coefficient in temperate and subtropical forests. This implies that trees with larger Dbh tend to have lower slenderness coefficients, indicating greater stability against wind and other mechanical stresses.

Additionally, there is a strong positive correlation between height and volume (0.645916), indicating that taller trees generally have a larger volume. Xu et al. (2019) in tropical rainforests observed a strong positive correlation between tree height and volume, consistent with the findings of this study. The correlation between SLC and height (0.779464) is also strongly positive, meaning that taller trees tend to have higher slenderness coefficients, indicating less stability. Oladoye et al. (2020) investigated the relationship between slenderness coefficient and tree height in diverse forest ecosystems. They reported a strong positive correlation similar to your statement, indicating that taller trees tend to have higher slenderness coefficients.

The strong positive correlation between basal area and volume (0.74508) suggests that trees with a larger basal area also have a higher volume. Lastly, a weak negative correlation between volume and SLC (-0.25306) indicates that trees with larger basal areas tend to have slightly lower slenderness coefficients, implying better stability. This supports the assertion of Ige and Akinyemi (2016) who reported that slenderness coefficient values tend to decrease for larger trees.

Understanding these correlations is crucial for forest management practices. For instance, focusing on promoting trees with larger Dbh can enhance carbon sequestration potential due to their higher volume and biomass accumulation capabilities (Chen et al., 2007), while comprehending the weaker correlation with height suggests that forest structure and competitive interactions may influence vertical tree growth patterns differently than the horizontal growth (Forrester, 2019).

Table 3: Correlation Matrix for growth variables of *Terminalia ivorensis* stands

	Dbh (cm)	Ht	BA (m^2)	Vol (m^3)	SLC
Dbh	1				
HT	0.360272	1			
BA	0.975073	0.239704	1		
Vol	0.949379	0.458193	0.950215	1	
SLC	-0.7053	0.319144	-0.71115	-0.57098	1

Note: Dbh- Diameter at breast height; Ht- Tree height, BA- Basal Area, Vol- Volume, SLC- Slenderness Coefficient

There is a very strong positive correlation between Dbh and basal area (0.975073), indicating that as the diameter of the tree increases, the basal area increases significantly. This relationship is intuitive since the basal area is calculated based on the tree's diameter. Recent studies confirm that Dbh is a crucial predictor of BA, essential for estimating forest biomass and carbon storage (Pretzsch, 2010). The strong positive correlation between Dbh and volume (0.949379) suggests that trees with larger diameters tend to have greater volumes. This is consistent with studies that use Dbh as a primary variable for predicting tree volume, highlighting its importance in forest management and timber production assessments (Chave et al., 2014).

The weak positive correlation between Dbh and tree height (0.360272) indicates only a slight relationship. This suggests that while larger diameters can be associated with taller trees, height is influenced by other factors such as species, site conditions, and tree age, similar experience were reported by Xu et al. (2019) who have shown moderate to strong positive correlations between tree height and volume. Studies indicate that height-diameter relationships can vary widely among species and environments (Zhang et al. 2016). In addition, a moderate positive correlation between height and volume (0.458193) suggests that taller trees generally have larger volumes, but height alone is not as strong a predictor of volume as Dbh. This is consistent with forest growth models that use both height and Dbh to estimate volume more accurately. The strong positive correlation between basal area and volume (0.950215) underscores the importance of BA as a reliable indicator of tree volume. Mäkinen et al. (2022) found strong positive correlation between basal area and volume across various forest types. Thus, basal area often serves as a reliable indicator of tree volume due to its direct relationship with stem cross-sectional area and biomass, highlighting its utility in forest inventory and carbon storage assessments in most research (Mäkinen et al., 2022).

A moderate positive correlation between height and volume (0.458193) suggests that taller trees generally have larger volumes, but height alone is not as strong a predictor of volume as Dbh. Xu et al. (2019) conducted in tropical forests of West Africa found similar moderate positive correlations between tree height and volume. Ariyo et al. (2021) highlighted that while height contributes to estimating tree volume, Dbh remains a stronger predictor. This is consistent with forest growth models that use both height and Dbh to estimate volume more accurately. This approach aligns with global best practices in forest inventory and management, ensuring robust assessments of forest resources and carbon dynamics (FAO, 2020)

The moderate negative correlation between Dbh and the slenderness coefficient SLC (-0.7053) implies that trees with larger diameters tend to have lower slenderness coefficients, indicating better stability. Trees with lower SLC are generally more stable and less prone to wind damage, as supported by Adeyemi & Moshood (2019), who found that trees with a high slenderness ratio are more vulnerable to bending and breaking. The weak positive correlation between height and SLC (0.319144) indicates that taller trees tend to have higher slenderness coefficients, meaning they are relatively less stable. This relationship is important for understanding tree architecture and stability, especially in the context of forest dynamics and wind throw risk (Moore et al., 2018).

The moderate negative correlation between volume and SLC (-0.57098) suggests that trees with larger volumes tend to have lower slenderness coefficients, 8hich implies better stability. This finding aligns with research showing that larger, more massive trees are generally more stable due to their lower slenderness ratios. This result is in line with the result reported by Onilude and Adesoye (2007) in their study of relationship between tree slenderness coefficient and tree growth characteristics of *Triplochiton scleroxylon* stands in Ibadan metropolis.

CONCLUSION

The study reveals that of the two species assessed, *Terminalia ivorensis* had more substantial growth and were larger in size than *Nauclea diderrichii.* Also, most of the trees of the assessed species were stable as they have low Slenderness Coefficient. The study recommends regular measuring of tree growth parameters to create a comprehensive growth data bank and the selective logging of the few trees with high Slenderness Coefficient as they are susceptible to wind throw and could cause damage to lives and properties.

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