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Crown Projection Area Models for Neem (Azadirachta Indica Linn) in Majia Fuelwood Reserve, Dange-Shuni, Sokoto State Nigeria

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ABSTRACT

This study was conducted in order to develop crown projection area models for Neem (Azadirachta indica) in Majia Fuelwood Reserve. Both linear and non-linear regression models were used. The highest adjusted coefficient of determination (R2adj) and the lowest Standard Error of Estimate (SEE) were considered appropriate criteria in selecting the best model. Model validation was achieved by dividing the data into two sets; (75%) of the data to calibrate the models and the other set (25%) to validate the models using paired sample T-test and R statistical package was used for analysis.All the candidate model parameters were found to be statistically significant at 5% with the exception of Model 10 (CPA = b0 + b1LnSLC) this indicates that at least one predictor variable (DBH or SLC) is significant in explaining the dependent variable. Equation 10 (CPA = 26.99861 + 0.101247SLC - 5.9087LnSLC) was identified as the most suitable for predicting the Crown Projection Area (CPA) of Azadirachta indica. The recommended model provides a practical tool for predicting canopy characteristics, aiding in informed decision-making for future forest management and timber production. The selected model is considered effective for predicting future growth values, which is essential for sustainable timber production planning

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INTRODUCTION

Estimation of forest canopy cover has recently become an important part of forest inventories (Hilbert et al., 2019). First, canopy cover has been shown to be a multipurpose ecological indicator, which is useful for distinguishing different plant and animal habitats, assessing forest floor microclimate and light conditions, and estimating functional variables like the Leaf Area Index (LAI) that quantifies the photosynthesizing leaf area per unit ground area. Secondly, many remote sensing applications involve estimation of either canopy cover or individual tree canopy area as an intermediate stage in distinguishing the signals reflected from forest canopy and forest floor (Mahdavi and Aziz, 2020) after which, for instance, estimation of timber volume becomes possible (Bolduc et al., 1999; Maltamo et al., 2004). Canopy cover is also an important ancillary variable in the estimation of LAI using empirical or physically based vegetation reflectance models (Korhonen, et al., 2006). The validation of canopy cover estimates obtained from remotely sensed data and development of new remote sensing techniques require field-based canopy cover measurements. Finally, the international definition of a forest is based on canopy cover: The United Nations Food and Agricultural Organization (FAO) has defined forest as land of at least 0.5 ha with potential canopy cover over 10% and potential tree height of at least five meters (FAO, 2000). To ensure compatibility of international forestry statistics, forest canopy cover needs to be included in national forest inventories. Measuring canopy cover accurately involves practical and theoretical difficulties. For interpreting the measurements, the difference between the concepts of canopy cover and canopy closure must be recognized. Canopy cover, defined here as the proportion of the forest floor covered by the vertical projection of the tree crowns, should be distinguished from canopy closure, which is defined as the proportion of sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al., 1999). The difference between these concepts is clear: if canopy is measured with instruments that have an angle of view (i.e. measure a larger area than just a vertical point), like cameras or spherical densiometers (Korhonen, et al., 2006) the results are estimates of canopy closure. In other words, canopy closure or "site factor" is just a percentage figure describing the fraction of non-visible sky within a certain angle, whereas canopy cover describes the fraction of ground area covered by crowns (Korhonen, et al., 2006)

Tree crown condition is one of the most first visible and viable indicators that physically describe the forest visibility and it have been widely and general used as indicators of forest health, forest tree health and vitality (Sharma et al., 2018). It was reported by Zarnoch et al. (2004) that the effects of natural and anthropogenic stress on a forest are firstly observed by the decline of the forest crown which convert the photosynthetic that the tree required for its growth which also have direct effect on the understory flora and fauna of the forest. Crown ratio is the portion of the tree height which supports live green foliage which is the distance end to end of the tree with branches, divided by the total tree height (Azuma et al., 2004). This crown ratio provides an approximation of the photosynthetic ability of the tree. Trees with larger live crown are generally refers to as healthy and fast-growing trees as asserted by (Zarnoch et al., 2004). The crown dimension plays a significant role in forest growth and yield models (Soares and Tome, 2001). Crown provides shade, temperature control, food, habitat for many organisms. Crown condition indicator are being used to observe noticeable changes in crown condition, relate crown condition to tree growth or stress such as insects and diseases, serve as an indicator of climate change and also helps in evaluating appropriateness of stand for wildlife and bird species (Mcgaughey, 1997). Crown ratio is also useful in determining the competition and survival potential of a tree (Oliver and Larson, 1996) as well as wind firmness (Navratil, 1997). Crown ratio is often used as predictor variables for tree growth and also indicates tree dynamism and vitality which is very useful in forest health assessment as reported by Popoola and Adesoye (2012). Canopy fire behavior and canopy fuel characteristic are crown features which are been influenced by crown ratio (Li et al., 2020). The size of the crown is an important measure of tree vigour which is widely used to predict growth and yield of trees and forests (Hasenauer and Monserud, 1996).

LITERATURE REVIEW

The crown of tree is the centre of physiological activity, particularly gas exchange, which drives growth and development. The crown contains the foliage, the photosynthetic structure that provides carbohydrates for the growth and development of the whole tree (Leites and Robinson, 2004). According to Dubravac et al. (2009) one of the most important elements of tree structure is the crown, where essential living processes like photosynthesis take place. The crown area also known as crown projection area, together with crown volume, also determines the amount of intercepted precipitation, and regulates the amount of precipitation that reaches the forest floor (Vrbek et al., 2008). Many ecological and economic problems in forestry are approached using crown dimensional measures (Grote, 2003). According to Bella (1971) individual tree competition indices are derived from crown area estimates. This is because crown dimension is a result of past competition as well as an indicator of the current growth potential (Iwasa, 1984). Conversely, assessment of crown dimensions remains one of the most difficult and tedious tasks in forestry. Crown area can be estimated from stem dimensions (Dubrasich, 1997). The difficult measurements and the sensitivity of crown dimension on management makes it desirable to develop estimation procedures based on variables that are easier to measure than crown extension itself. Thus, maximum crown diameters, which can be derived from stem diameter, has been used to estimate crown area (Goelz,1996). Measurement of crown dimension from either above the canopy or under the canopy are both subjected to a likely underestimation of crown width due to a limited visibility of crowns especially in a dense or mixed forest. The size of a tree crown is strongly correlated with the growth of the trees such as diameter at breast height, slenderness coefficient, tree height (Kazimierz et al., 2015). The crown displays the foliage for photosynthesis which is a key process in tree growth development. Thus, crown measurement is often done to help in the quantification of the growth of trees in the forest stand (Korhonen et al., 2006). Tree slenderness coefficient often serves as an index of tree stability, or resistances to wind throw (Navratil, 1996). A low slenderness coefficient value usually indicates a longer crown, lower centre of gravity, and a better developed root system. Most of forest stands in Nigeria suffer considerable losses due to action of abiotic factors, such as wind. This brings about damages in the forest structures. Tree slenderness coefficients which is defined as the ratio of total height to diameter at 1.3 m above ground, have been widely used as an index of the resistance of trees to wind throw. In earlier studies (Eguakun and Oyebade, 2015; Ola-Adams, 1999) slenderness was usually one of the factors analyzed or it was investigated in respect of trees of a single species or it concerned several species growing in different regions. However, the suitability and effect of slenderness coefficient in predicting CA in Tectona grandis in Omo Forest Reserve has rarely been investigated. This study was aimed at investigating the effect of slenderness coefficient in crown area.

METHODOLOGY

Study Area

Majiya is a Fuelwood Reserve located between the latitudes 120 52′53′′ and 12054′16′′N and longitudes 5018′19′′ and 5019′40′′E. The plantation covers an area of 252ha. The area falls within the Sudan savannah zone. It has about 70 - 125 days of rainy season (Ibrahim et al., 2018). Temperatures are variable during the dry and rainy seasons with minimum temperature between 10 and 23°C and the maximum between 33 and 45°C. The mean maximum ranges from 35 - 37°C. Relative humidity is between 52 - 56% (SERC 2014; Ibrahim et al., 2017). It is characterized by alternating rainy and dry seasons. The mean annual rainfall is 700 mm per annum. Rainfall is short and erratic, falling between the months of June and September with an altitude of 350 m above sea level (SERC 2014; Ibrahim et al., 2018). Sokoto has two main seasons; the dry season which lasts from October to May/June, and the rainy season that lasts from June to September/ October. The harmattan season stretches from November to March, which is dry and dust laden wind (SERC 2014; Ibrahim et al., 2018).

Sampling Design and Data Collection

Simple Random Sampling was employed in this research. Ten (10) sample plots (30mx30m) were marked and demarked at random covering both sides of the plantation, coordinates of every plot were also recorded. Plots were established 20m away from the boundary of the plantation avoiding edge effect. Information on standing trees and stump were also recorded.

Data Collection

The Data Obtained Include

i. Counting and recording of individual all trees within each plot
ii. Measuring the total height all selected plots using Haga Altimeter
iii. Diameter at the breast height (DBH) of all individual trees were measured at 1.3m, flexible measuring tape was used to determine the circumference of the boles.
iv. Diameter at three different points (Base, middle, Top) were determined with the aid of Spiegel Relascope.

Computations and Data Analysis

Both descriptive and inferential statistics were employed in this research. Linear and Nonlinear regression models were used in predicting Crown projection area (Dependent Variable) using Diameter at breast height and Slenderness coefficient (independent variables).

Basal Area Computation

The basal area for each sampled tree was determined using the formula suggested by Husch et al., (2003)

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

Where: BA = Basal area in m2; D = Diameter at breast height (m); π= Pi (3.142)

Basal area per plot were obtained by adding the basal area of all individual trees within the plot. Basal area per hectare for each age series was determined by first summing the basal areas of the 30 sample plots selected from the age series and finding their mean, then multiplying the mean basal area per plot by the number of sample plots per hectare which is 16.

Volume Estimation

The stem volume of each mean tree was estimated using the Newton's formula (Husch et al., 2003; Dantani et al., 2019). The formula is expressed as:

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

Where: V = Stem volume in (m3)
Db = Diameter (m) at the base of the tree
Dm = Diameter (m) at the middle of the tree
Dt = Diameter (m) at the top of the tree
H = Total height of the tree (m)

Tree Slenderness Coefficient Estimation

Tree Slenderness Coefficient was estimated for all trees using:

$$SC = \frac{Hi}{DBHi} \quad \ldots\ldots(3)$$

Where: Hi = total height of the ith tree; Dbhi = corresponding Dbh.

The measured trees were classified according to the SC as follows:

SC < 70: low slenderness coefficient; SC: 70 - 99: moderate slenderness coefficient; SC >99: high slenderness coefficient. The number of trees/ha and percentage of trees in each of the SC categories was computed for the area as adopted by Ige and Komolafe (2022)

Crown Diameter

This was measured for each tree using the formula as adopted by (Oyebade and Onyeoguzoro, 2017; Omijeh, 2022)

$$CD = \frac{\sum ri}{2} \quad \ldots\ldots(4)$$

Where, CD=crown diameter; ri= projected crown radii measured on four axes

Crown Projection Area Computation

The crown projection area for individual tree in the study area was estimated as:

$$CPA = \frac{(CD^2)}{4} \quad \ldots\ldots(5)$$

Where: CPA = crown projection area; CD = crown diameter

Crown Ratio Computation

Individual tree crown ratio was computed using:

$$CR = \frac{CLi}{Hi} \qquad (6)$$

Where: CLi = individual tree crown length; Hi = tree total height

Adopted by Adeyemi and Ugo-Mbonu, (2017)

Crown Projection Area Model Development

Both linear and non-linear regression models were employed in this research. The CPA is the dependent variable while DBH and Slenderness coefficient (the ratio of tree height to diameter) as the independent variable for the model

Table 1. Selected Candidate Modes

Function Code	Model Form
1	$CPA = b_0 + b_1*DBH$
2	$CPA = b_0 + b_1*DBH^2$
3	$CPA = b_0 + b_1*LnDBH$
4	$CPA = b_0 + b_1*DBH + b_2*DBH^2$
5	$CPA = b_0 + b_1*DBH + b_2*LnDBH$
6	$CPA = b_0 + b_1*SLC$
7	$CPA = b_0 + b_1*SLC^2$
8	$CPA = b_0 + b_1*LnSLC$
9	$CPA = b_0+ b_1*SLC + SLC^2$
10	$CPA = b_0+ b_1*SLC + b_2*LinSLC$
11	$CPA = b_0 + b_1*DBH + b_2*SLC$
12	$CPA = b_0 + b_1*DBH^2 +*SLC^2$
13	$CPA = b_0 + b_1*LnDBH + b_2*LnSLC$

CPA= Crown Projection Area, DBH=Diameter at Breast Height, SLC=Slenderness Coefficient, b_0 b_1 and b_2 = Parameter estimated

Model Selection and Validation

Different criteria for choosing the best model are available; for this study highest Adjusted coefficient of determination (R2adj) and the lowest Standard Error of Estimate (SEE) were considered appropriate criteria in selecting the best model. Model validation was achieved by dividing the data into two sets; (75%) of the data to calibrate the models and the other set (25%) to validate the models, testing for the significant differences in mean predicted and observed values of the dependent variables in all cases was achieved using paired sample T-test

Data Analysis

The data collected were organized and screened for analysis. Descriptive statistics was used to produce summary of the measured variables, basal area computation and volume estimation were achieved using excel. Model development and evaluation were achieved using R Statistical Package.

RESULTS AND DISCUSSION

Summary of Tree Growth Characteristics

Summary statistics providing a comprehensive overview of the variability and central tendencies of the tree growth characteristics in the dataset which is very important in understanding the distribution and range of each variable in the population of trees under consideration viz; Minimum, Maximum, Mean, standard error and standard deviation were obtained. Total Height (m) Ranges from 8.50- 46.00, mean 22.8683 with a standard error of 0.68213 and standard deviation of 7.56520. Diameter at Base (cm): Ranges from 24.76 to 61.11cm. The average diameter at the base is 41.4360cm, with an SE of 0.68746. The SD is 7.62429. Diameter at Breast Height (cm): Ranges from 20.05-52.04, mean=33.6451, SE= 0.62572. and SD=6.93953. Diameter at Middle (cm): Ranges from 15.00- 40.00, mean= 26.5650, SE= 0.43146 and SD=4.78512. Diameter at Top (cm): Ranges from 10.00-30.00, mean= 21.2967, SE=35342 and SD= 3.91962. Crown Diameter (m): Ranges from 3.30-10.45, mean=5.9512, SE=0.11965 and SD =1.32702. Crown Length (m) Ranges from 4.40-38.50, mean=15.2341 SE=0.60153, SD= 6.67130. Crown Ratio (m): Ranges from 0.34-0.84, mean= 0.6478 SE= 0.01013 and SD=0.11238. Crown Projection Area (m): Ranges from 2.72 to 27.30, mean= 9.2909, SE=0.40164, SD=4.45439. Slenderness Coefficients: Ranges from 23.74-125.30, mean=69.1483, SE=2.00544, SD =22.24142. Basal Area (m2) Ranges from 0.03-0.21, mean=0.0927 SE=0.00360 and SD= 0.03992. Stem Volume (m3): Ranges from 1.88-48.88, mean=13.7245, SE= 0.71118 and SD=7.88732.

Table 2. Summary of Tree Growth Characteristics

Tree Variables	**Min**	**Max**	**Mean** ± SE	**SD**
Total Height(m)	8.50	46.00	22.8683±0.68213	7.56520
Dimeter at Base (cm	24.76	61.11	41.4360±0.68746	7.62429
Diameter at Breast Height (cm)	20.05	52.04	33.6451±0.62572	6.93953
Diameter at Middle (cm)	15.00	40.00	26.5650±0.43146	4.78512
Diameter at Top (cm)	10.00	30.00	21.2967±0.35342	3.91962
Crown Diameter (m)	3.30	10.45	5.9512±0.11965	1.32702
Crown Length (m)	4.40	38.50	15.2341±0.60153	6.67130
Crown Ratio (m)	0.34	0.84	0.6478±0.01013	0.11238
Crown Projection (m)	2.72	27.30	9.2909±0.40164	4.45439
Slenderness Coefficients	23.74	125.30	69.1483±2.00544	22.24142
Basal Area(m^2)	0.03	0.21	0.0927±0.00360	0.03992
Stem Volume(m^3)	1.88	48.88	13.7245±0.71118	7.88732

Min=Minimum, Max=Maximum, *Mean ± Standard Error, SD=Standard Deviation

Correlation Coefficients

The correlation analysis reveals intricate relationships among tree growth characteristics. Total Height demonstrates positive correlations with various parameters, especially strong ones with Crown Length (CL), Basal Area (BA), and Stem Volume (SV). Diameter at Breast Height (DBH) exhibits moderate to strong positive correlations with multiple characteristics, notably strong ones with BA and SV. Crown Diameter and Crown Length show strong positive correlations with numerous variables, including BA and SV, while Crown Ratio (CR) displays moderate positive correlations. Crown Projection Area demonstrates strong positive correlations with several parameters, particularly with BA and SV, and negative correlations with Diameter at Middle (DM) and Diameter at Top (DT). Slenderness Coefficient exhibits a moderate negative correlation with multiple variables. Basal Area displays strong positive correlations with various characteristics, particularly SV, and Stem Volume shows strong positive correlations with several parameters. Overall, the correlation patterns provide insights into the interdependence of tree growth attributes.

The correlation between tree basal area and slenderness coefficient was negative. This implies that the proportion of trees prone to wind-throw or damage in the area decreases with increase in tree basal area. This agrees with the finding of Martin-Alcon et al. (2006) and Ezenwenyi and Chukwu (2017) that the proportion of wind-throw and damaged trees in a stand decreases strongly at higher stand basal area for a given slenderness ratio. Slenderness coefficient is negatively and significantly correlated with diameter variables and positively correlated with crown metrics (CD, CR, CPA) which is tin total disagreement with what was obtained by Ezenwenyi and Chukwu 2017, his variation may be as a result of difference in study areas, tree species, soil and environmental conditions on which tree grows. As the basal area of trees increases, the slenderness coefficient decreases, higher basal area indicates larger, more mature trees with a larger cross-sectional area, lower slenderness coefficient suggests that these trees are less slender or more robust in relation to their height, this implies that larger, more mature trees in the study area are less prone to wind-throw or damage compared to smaller, slender trees. The negative correlation aligns with the findings of Martin-Alcon et al. (2006) and Ezenwenyi and Chukwu (2017), who observed a decrease in the proportion of wind-throw and damaged trees with higher stand basal area.

Table 3. Correlation Matrix for Tree Growth Characteristics

	TH(cm)	DB(cm)	DBH (cm)	DM(cm)	DT(cm)	CD (m)	CL (m)	CR (m)	CPA(m)	SLC	BA(m^2)	SV(m^2)
TH(m)	1											
DB(cm)	0.329**	1										
DBH (cm)	0.331**	0.685**	1									
DM(cm)	0.038	0.183*	0.221*	1								
DT(cm)	0.010	0.388**	0.443**	0.568**	1							
CD(m)	0.354**	0.582**	0.525**	-0.014	0.048	1						
CL(m)	0.943**	0.306**	0.348**	0.002	-0.040	0.343**	1					
CR(m)	0.499**	0.059	0.152	-0.015	-0.095	0.073	0.734**	1				
CPA (m)	0.374**	0.569**	0.538**	-0.070	-0.023	0.984**	0.381**	0.111	1			
SLC	0.808**	-0.063	-0.259**	-0.087	-0.215*	0.029	0.723**	0.387**	0.026	1		
BA(m^2)	0.321**	0.667**	0.990**	0.153	0.373**	0.534**	0.350**	0.171	0.560**	-0.260**	1	
SV(m^3)	0.771**	0.783**	0.628**	0.037	0.112	0.621**	0.765**	0.382**	0.664**	0.380**	0.640**	1

TH=Total Height, DB=Diameter at Base, DBH=Diameter at Breast Height, Dm=Diameter at Middle, Dt=Diameter at Top, CD=Crown Diameter, CL=Crown Length, CR=Crown Ratio, CPA=Crown Projection Area, SLC=Slenderness Coefficient, BA=Basal Area, SV=Stem Volume. **. Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

Model Parameter Estimates

Fitting and evaluation is very important in model building, the fitted crown projection area models were based on the field data obtained. Thirteen (13) candidate models were developed for CPA prediction and fitted to the data with corresponding parameters. The fit and predicting parameters were presented in table 7 below, the candidate models were based on DBH and SLC as independent variables. Most model parameters were found to be statistically significant while others were not, this indicates that at least one predictor variable (DBH or SLC) is significant in explaining the dependent variable. Few models fitted well with the data while most of the models could not predict CPA.

Table 4. Developed Models and Their Parameters

F/C	Models	Parameters	SE	t-value	Prob. (t)
1	$CPA = b_0 + b_1DBH$	b_0 2.33876	1.68881	1.385	0.169
		b_1 0.34567	0.04917	7.030	0.0000
2	$CPA = b_0 + b_1DBH^2$	b_0 3.501070	0.8474957	4.131	0.0000
		b_1 0.004908	0.0006602	7.435	0.0000
3	$CPA = b_0 + b_1LnDBH$	b_0 -29.999	6.042	-4.965	0.0000
		b_0 11.240	1.726	6.514	0.0000
4	$CPA = b_0 + b_1DBH + b_2DBH^2$	b_0 12.371713	6.053322	2.044	0.0432
		b_1 0.501198	0.338682	1.480	0.1415
		b_2 0.011682	0.004625	2.526	0.0128
5	$CPA = b_0 + b_1DBH + b_2LnDBH$	b_0 57.1064	28.6559	1.993	0.04855
		b_1 1.0226	0.3294	3.105	0.00238
		b_2 -23.5219	11.3197	-2.078	0.03985
6	$CPA = b_0 + b_1SLC$	b_0 8.938305	1.321528	6.764	0.0000
		b_1 0.005107	0.018200	0.281	0.779
7	$CPA = b_0 + b_1SLC^2$	b_0 9.191	0.07609	12.079	0.0000
		b_1 0.0000191	0.000224	0.156	0.876
8	$CPA = b_0 + b_1LnSLC$	b_0 7.7603	4.9250	1.576	0.118
		b_1 0.3662	1.1740	0.312	0.756
9	$CPA = b_0 + b_1SLC + SLC^2$	b_0 7.1093450	3.2974354	2.156	0.0331
		b_1 0.0605188	0.0932838	0.64	0.5177
		b_2 0.0003799	0.0006271	-0.606	0.54589
10	$CPA = b_0 + b_1SLC + b_2LnSLC$	b_0 26.998614	6.006194	4.495	0.0000
		b_1 0.101247	0.008386	12.074	0.0000
		b_2 -5.908752	1.539595	-3.838	0.00019
11	$CPA = b_0 + b_1DBH + b_2SLC$	b_0 5.77955	2.24879	-2.570	0.0114
		b_1 0.37510	0.05006	7.494	0.0000
		b_2 0.03544	0.01562	2.269	0.0251
12	$CPA = b_0 + b_1DBH^2 + SLC^2$	b_0 1.8796783	1.1190324	1.680	0.0956
		b_1 0.0052785	0.0006721	7.853	0.0000
		b_2	0.0001032	2.175	0.0316

		0.0002246			
13	$CPA = b_0 + b_1LnDBH + b_2LnSLC$	b_0 -41.756	8.314	-5.022	0.0000
		b_1 12.106	1.756	6.893	0.0000
		b_2 2.088	1.029	2.030	0.0446

FC=Function Code, CPA=Crown Projection Area, DBH=Diameter at Breast Height, SLC= Slenderness Coefficient and SE=Standard Error

Model Selection and Evaluation

Thirteen equations were tested based on some statistics generated in the course of modelling. The selected candidate models were based on ranking with equation 10 ranked as No1. Model 10 has the highest R2adj value of 0.6397 and SEE of 4.504 which makes it the best model for predicting CPA in the study area. In contrast to the findings of Ezenwenyi and Chukwu (2017), the present study did not observe a significant enhancement in the model's performance with the inclusion of Diameter at Breast Height (DBH). Despite the widespread utilization of DBH in all models, previous research suggested its strong correlation with tree growth characteristics, including Crown Area (CA) (Shimano, 1997; Ezenwenyi and Chukwu, 2017). However, the current study did not yield a notable improvement upon incorporating DBH, possibly due to factors such as high stand density affecting both DBH and Crown Area Percentage (CAP) similarly, leading to growth reduction. Interestingly, the inclusion Slenderness Coefficient (SLC) in the models revealed a positive impact on predictive abilities. SLC, serving as a measure of tree stability and crown architecture, demonstrated a notable improvement in the models, as evidenced by the significant enhancements in R2adj and Standard Error of Estimate (SEE), this outcome deviates from the findings of Shimano (1997) regarding DBH and CA, reinforcing the unique influence of TSC in this study. The discrepancy between these results underscores the complexity of the relationships among these variables and highlights the need for further investigation into the nuanced factors affecting predictive modeling in tree growth studies.

Tables 5. Regression Equations of the Fitted Models

Models		Model Statistics						
F/C	Fitted Equation	R^2	R^2_{adj}	SEE	F-stat	Rank	P-value	Decision
10	CPA=26.99861 + 0.101247SLC - 5.9087LnSLC	0.6456	0.6397	4.504	110.2	1	0.0000 s	Accepted
12	CPA=1.8796783 + 0.0052785DBH² + 0.0002246SLC²	0.3396	0.3286	3.650	30.86	2	0.0000 s	Accepted
4	CPA = 12.371713 + 0.501198DBH + 0.011682DBH²	0.3259	0.3146	3.688	29.00	3	0.0000 s	Accepted
11	CPA = 5.77955 + 0.37510DBH + 0.03544SLC	0.3192	0.3079	3.706	30.86	4	0.0000 s	Accepted
2	CPA = 3.501070 + 0.004908DBH²	0.3136	0.3079	3.706	55.27	5	0.0000 s	Accepted
5	CPA = 57.1064 + 1.0226DBH - 23.5219LnDBH	0.3147	0.3033	3.718	27.55	6	0.0000 s	Accepted
1	CPA = 2.33876 + 0.34567DBH	0.2900	0.2841	3.769	41.43	7	0.0000 s	Accepted
13	CPA = -41.756 + 12.106Lin DBH + 2.088LnSLC	0.2842	0.2723	3.800	23.84	8	0.0000 s	Accepted
3	CPA = -29.999 + 11.240LnDBH	0.2596	0.2535	3.848	42.43	9	0.0000 s	Accepted
9	CPA = 7.1093450 + 0.0605188 SLC + 0.0003799SLC²	0.003696	-0.01291	4.483	0.2226	10	0.8008 ns	Rejected
6	CPA = 8.938305 + 0.0051075LC	0.00065	-0.0076	4.471	0.078	11	0.7795ns	Rejected
7	CPA = 9.191 + 0.00001915LC²	0.000202	-0.00806	4.472	0.04225	12	0.8760 ns	Rejected
8	CPA = 7.7603 + 0.3662LnSLC	0.0000803	-0.000074	4.471	0.0973	13	0.7556 ns	Rejected

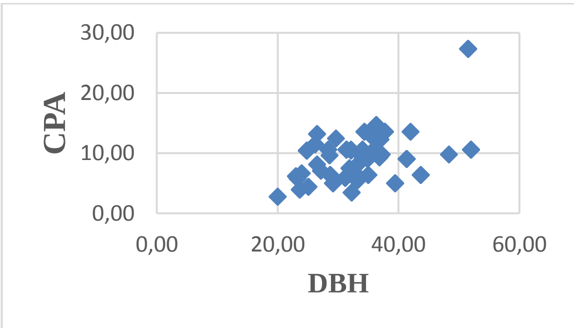

Figure 1. Relationship Between CPA & DBH

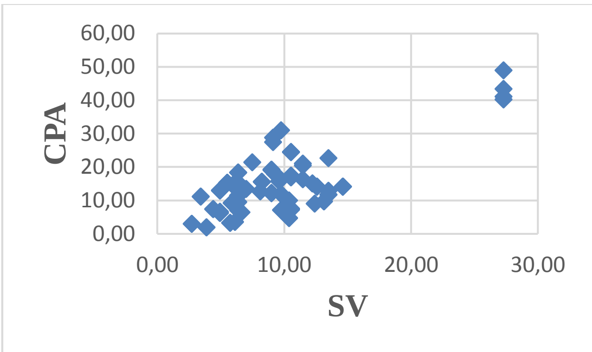

Figure 2. Relationship Between CPA & SV

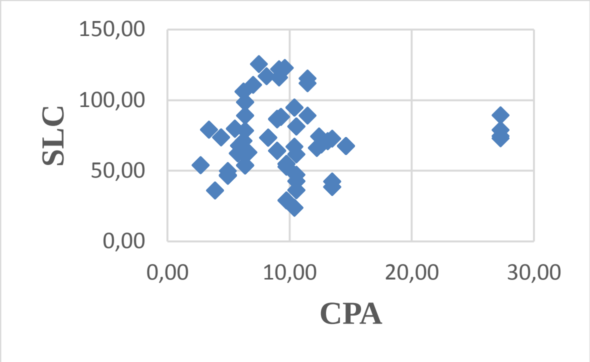

Figure 3. Relationship Between SLC & CPA

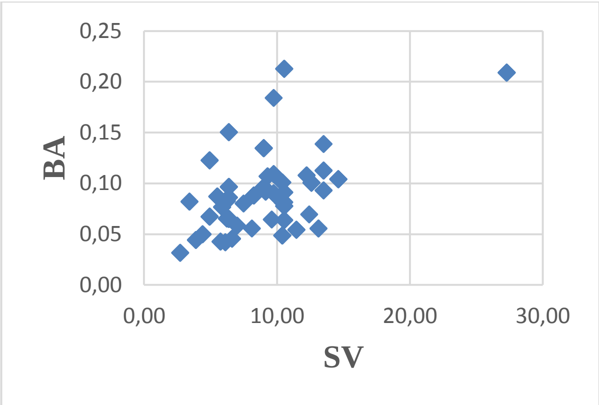

Figure 4. Relationship Between BA & SV

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this research successfully developed and validated a crown projection area (CPA) model for Neem (Azadirachta indica) in Majia Fuelwood Reserve. The rigorous evaluation of linear and non-linear regression models, considering criteria such as the adjusted coefficient of determination and the lowest Standard Error of Estimate, highlighted the superiority of Equation 10 (CPA = 26.99861 + 0.101247SLC - 5.9087LnSLC) in predicting the canopy characteristics. The statistical significance of model parameters, along with the model's simplicity and effectiveness in predicting future growth values, positions it as a valuable tool for informed decision-making in forest management and sustainable timber production planning.

The researchers recommend Equation 10 (CPA = 26.99861 + 0.101247SLC - 5.9087LnSLC) as the preferred model for predicting Crown Projection Area for Neem (Azadirachta indica) in Majia Fuelwood Reserve, offering a practical and effective tool for informed decision-making in future forest management and sustainable timber production planning. Establish a long-term monitoring program to regularly collect data on Neem trees, validating the effectiveness of the selected model over time. This ongoing validation process ensures the model's reliability and adaptability to changing environmental conditions.

FURTHER STUDY

This research still has related limitations so it is necessary to carry out further research on the topic of Crown Projection Area Models for Neem (Azadirachta Indica Linn) in order to improve this research and increase insight for readers.

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