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Crown bole diameter linear equation for *Daniellia oliverii (Rolfe) Hutch* and *Daviz* and its application to stand density control in natural stands

Abstract

At present, no adequate information on the application of crown-bole diameter model to stand density and stock control for Daniellia oliveri (Rolfe) Hutch and Daviz open grown trees for sustainable forest management in the study area. The species numbers are threatened, because farmers and foresters do not actively plant this tree species. Livestock, fire, and anthropogenic activities are few factors that limit the success of natural regeneration of the species; and is facing regeneration problem. These have led to the species declining in the natural forest areas and the loss of biological values (genetic hereditary). A total of nine blocks as sample plots sizes 100x100 meters were randomly laid. Simple random sampling was used to collect data on tree diameter at breast height (dbh). Dbh was used to estimate crown diameter using a developed simple linear crown-bole diameter model. Based on this finding, dbh distribution was more (42 tree stands) concentrated at the lower diameter class (10 to 30cm) than at the upper diameter class distribution (31 and above). This could be that such tree stands might have been exploited as timber in the ecosystem. Nowadays, trees of smaller dimension are generally logged immediately they are discovered, especially the most economic and desirable species. The status of the tree species was a reversed "J" shaped distribution curve. The reverse 'J-shape' diameter distribution indicated healthy recruitment potentials; the lower class diameter tree stands could develop into mature trees and replace the old ones in the future if proper conservation efforts are sustained. Thus, this structure is typical of a natural forest. This finding estimated limiting stocking and stand density required for producing a complete canopy without effect of competition. D. oliverii with diameter 48.7cm would require a stocking of 168 trees per hectare in terms of total occupancy by tree crowns; stand density of 0.00001863m^2ha^{-1} would be needed. Also, tree stands of 80cm dbh would have 73 tree stands limiting stocking, covering a stand density of 0.00005027m^2/ha. Linear crown-bole diameter model could simply be used in forest inventory operations for determining the forest stock with less cost and time consuming. More research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes and ages.

Keywords: crown, diameter at breast height, density, growth space, open-grown, stem

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Introduction

Studies on growth spacing have consistently increases in breast height diameter (dbh) growth with decreasing stand density. Stands with wider spacing in time, have larger average diameters than similar stands with closer spacing. Inter-tree competition affects diameter growth at low stand densities, particularly in the case of fast-growing, shade-intolerant species; as a result, very low densities are required to produce maximum diameter growth throughout the life of an even-aged stand.[1,2] At any given age, there is a lower limit of stand density below which no further increase in diameter growth will result from continued density reduction. At density levels below this lower limit, the trees are growing free of inter-tree competition and usually referred to as open-grown-trees other vegetation present on the site may also affect diameter growth even though tree density is below this competition limit.[1]

Crown diameter and bole diameter at breast height are important tree characteristics where many of the forestry activities and processes were related with it. Any attempt that can improve the accuracy of measuring, predicting and analysing these variables should be taken into consideration.[3] The close relationship between crown diameter and bole diameter is very important to foresters; for predicting growth space, estimating and controlling stands density and limiting stocking in a forest plantation and reserves. Also, it is very relevant in the studies of growth and development of tree stands, and the 'packing' or density of trees in a stand.[1] The growth of a tree depends to a large extent on the tree crown characteristics. Tree crown size can determine tree growth and survival; tree height and crown dimension can determine length of its clear bole, which is important in merchandizing of the tree into various wood products.[2]

At present, there has been no adequate information on the application of crown-bole diameter model to stand density and stock control for *D. oliverii* open grown trees (natural stand) for sustainable forest management in the study area. The population of the species is threatened as natural resources are depleted and people will suffer from their poor economic situation; if urgent action (afforestation and reforestation) is not taken for the sustainable management of the tree species. Currently, farmers do not actively plant *D. oliverii* trees; therefore, regeneration only takes place by natural means. Livestock, fire, and humans are some factors that limit the success of natural regeneration.[2]

According to Adekunle et al.,[4] there is generally lack of emphasis on effective management of this important ecosystem today. This is as a result of the long rotation period for the indigenous species and the low productivity per hectare when compared with plantations. This neglect has led to the conversion of large tracts of the natural ecosystem to monoculture (Plantations of fast growing exotic and some indigenous species), relaxation of controls on legal and illegal logging and encroachment. Thus, the aim of this study is to predict crown diameter from bole diameter using crown-bole diameter simple linear model for *Daniellia oliverii* (*Rolfe) Hutch* and *Daviz;* and its application to stand density and stocking control in natural stands.

Materials and Methods

The study area

The study area lies between Longitude 8°21' and 9°E and Latitude 7°21' and 8°N in Benue State, southern guinea savanna ecological zone. The climate of the area is tropical sub-humid climate with high temperatures and high humidity. The area has average maximum and minimum daily temperature of 35°C and 21°C in wet season; as well as 37°C and 16°C in dry season. The climate is characterized by two distinct seasons: rainy and dry seasons. The mean annual rainfall value is between 1200mm to 1500mm. The vegetation of the area has been described as Southern guinea savanna. The major occupations of the people include; farming, civil service, trading and hunting; the major tribes are Tiv, Idoma and Igede.

Data collection

Daniellia oliverii (*Rolfe) Hutch* and *Daviz* tree was selected based on its economic values such as timber production. Data from *D. oliverii* tree stands were collected from temporary sample plots size 100mx100m each in the study area. Nine sample plots were randomly laid down. Purposive (selective) sampling design was used for complete enumeration of the tree species. *D. oliverii* trees ≥10cm-diameter at breast height (dbh) were assessed and the measurements of the variable of interest was taken. The data collected on *D. oliverii* trees were on diameter at breast height (dbh). Diameter of the sampled trees was determined with the use of diameter tape on winding the tape around the tree at point of measurement (1.3m) above the ground on the uphill side of the tree.

Data analyses

Basal area estimation: The diameter at breast height (dbh) was used to compute basal area using the formula:

$$BA = \frac{ðD^2}{4} \qquad \text{Equation (1)}$$

Where BA, Basal area (hectare); D, Diameter at breast height (m); π = 3.142

Crown-diameter: The data collected from the field on dbh were fitted into the crown-bole diameter model form for predicting crown diameter, developed and used within the study area. The developed model form showed the best ability to stabilize variance in the study area,[1] thus:

$$Cd = 1.743 + 0.143dbh \qquad \text{Equation (2)}$$

Where Cd, crown diameter; dbh, diameter at breast height

Limiting stock/carrying capacity

The carrying capacity was calculated using the predicted crown diameter and expressed in hectare basis (conversion of crown diameter in meters to area in hectares):

$$N = \frac{1}{A} \qquad \text{Equation (3)}$$

Where N, Limiting stock; A, growing space ($\pi Cd^2/4)/10{,}000$); π= 3.142; Cd, crown diameter

Stand density/ Basal area per hectare

$$SD = \frac{ðD^2}{40{,}000} \qquad \text{Equation (4)}$$

Where Stand density; π= 3.142; D, diameter

Results

Growth and yield characteristics on Daniellia oliverii (Rolfe) Hutch and Daviz

The result of this finding on *D. oliverii* bole diameter distribution is presented on Figure 1. The results showed the current status of the tree species in the study area. *D. oliverii* had bole diameters that ranged from 15.4–55.7cm. Thirty eight tree stands were found to have dbh size between 10 to 20cm, followed by 21 tree stands with dbh between 21 to 30cm and 12 trees were recorded under the dbh class of 30 to 40 cm while 8 trees had dbh of 40 to 50 cm and 3 tree stands had a dbh size >50cm and above.

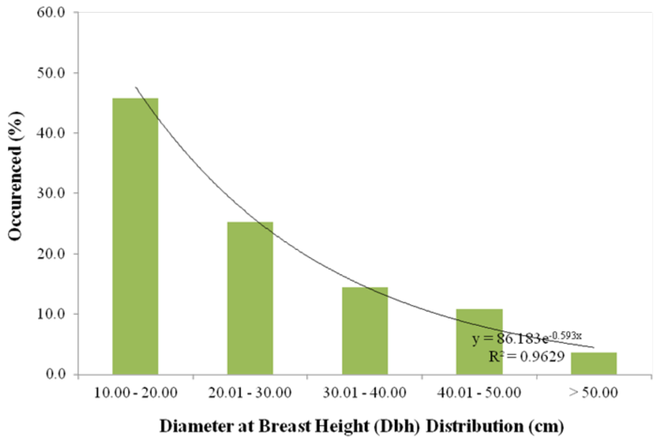

Figure 1 Bole-diameter Distributions on *Daniellia oliverii* (*Rolfe) Hutch* and *Daviz* Tree.

The crown diameter was predicted using the linear crown-diameter model developed by Dau et al.[1] Based on the result from the study area (Figure 2), *D. oliverii* trees had crown diameter distribution between 2.00 to 9.71m. Most of the trees (59) had crown diameter sizes between 2 to 6.04m, followed by 13 trees which had 6.1 to 8.04m crown diameter sizes while 7 and 3 tree stands had crown diameter distribution of 8 to 9.04m and 9.1m and above, respectively.

Growth variables on *D. oliverii* tree stands is presented in Table 1; it shows mean, standard deviation, co-efficient of variation, minimum and maximum of growth variables on *D. oliverii* trees in the study area. The mean diameter at breast height was obtained as 28.45cm, crown diameter 5.81m and a basal area of 0.0718m^3. The coefficient of variation for Dbh was 36.2%, crown diameter had 25.3% and B.A was 76.3%. The minimum and maximum dbh recorded in the study area were 15.40cm and 55.70cm, crown diameter had a minimum and maximum crown size of 3.95m and 9.71m, respectively while BA had 0.0219m^3 and 0.01868m^3 as the minimum and maximum, respectively.

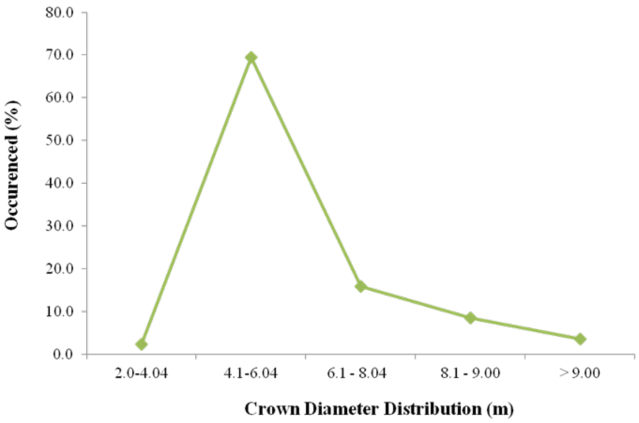

Figure 2 Crown-diameter Distribution on *Daniellia oliverii (Rolfe) Hutch* and *Daviz* Tree.

Crown-diameter and bole-diameter relationship on Daniellia oliverii (Rolfe) Hutch and Daviz

Simple linear equation developed by Dau et al.[1] was the best equation among the tested equations which was used to predict growth space for *Daniellia oliverii* (*Rolfe) Hutch* and *Daviz* in the study area. The equation was conformed to the assumptions of regression analysis with positive coefficients, couple with its superiority in previous research and ease of application.[5] The linear equation was fitted on data collected from the field. Height was not added to the equations because the studied was based on ease of application of equations on growth space. Also, it was thought to have little or less improvements to the growth space equation as observed.[2,6,7] Tree diameter can be measured easily and at little cost but total tree height, is more difficult and costly to measure due to time require to complete measurements, chance of observer error and visual obstruction.[8,9]

Crown-bole diameter equation and its application to stand density control in natural stands

The crown and bole diameter equation was used to predict crown diameter; crown area (A) and growth space were further estimated in hectare basis (Table 2). Limiting stocking per hectare (N ha^{-1}) was estimated; this was expressed as inverse of the growing space. The results are show on Table 2. This finding estimated limiting stocking required for producing a complete canopy (i.e. to fully occupy a site) without effect of competition over a period of time. Table 2 shows that open grown trees of *D. oliverii* with diameter 48.7cm would require a growing space of 0.0060ha without crown overlapping one another with stocking of 168 trees per hectare in terms of total occupancy by tree crowns; stand density of 0.00001863 (m^{2}ha^{-1}) would be needed. The tree species with 80 cm diameter at breast height will occupy a growth space of 0.0137 with 73 stands covering a stand density of 0.00005027m^2 per hectare.

Table 1 *Daviz* in Summary of Statistics on *D. oliverii* (*Rolfe) Hutch* and the Study Area

Variables	Mean	Standard Deviation	CV%	Minimum	Maximum
DBH (cm)	28.45	10.29	36.2	15.4	55.7
CD (m)	5.81	1.47	25.3	3.95	9.71
B.A (m^3)	0.0718	0.0548	76.3	0.0186	0.2437

DBH, Diameter at breast height (cm); CD, Crown diameter (m); BA, Basal area (m^2); CV, coefficient of variation

Table 2 Predicted crown diameter (cd), growing space (S), Stocking (N) and Stand density (D) on *Daniellia oliverii* (*Rolfe) Hutch* and *Daviz* Trees

Dbh (cm)	Cd (m)	Cd/dbh	Growing space (A)/hectare	Stocking/ha^{-1} (1/A)	Stand density (m^{2}ha^{-1})
18.7	3.79	0.203	0.0012	800	4.61E-05
25.1	5.16	0.206	0.0022	448	4.95E-06
30.8	6.46	0.21	0.003	337	7.45E-06
40.1	8.75	0.218	0.0044	228	1.26E-05
48.7	10.8	0.222	0.006	168	1.86E-05
55.2	10.95	0.198	0.0073	137	2.39E-05
70.3	11.56	0.164	0.0109	91	3.88E-05
76.6	11.95	0.156	0.0127	79	4.61E-05
80	12.3	0.154	0.0137	73	5.03E-05
84.3	12.6	0.149	0.015	67	5.58E-05

$Cd = 0.873 + 0.174 dbh$; Growing space (A) = $Cd^2 \pi / 40\,000$; stocking (N) = 1/ A; stand density= $D^2/4$.
Where dbh, diameter at breast height; Cd, crown diameter

The results on this finding showed that the crown diameter ratio diameter at breast height (Cd:dbh) was more elastic between 18.7 and 48.7cm; but gradually decreased as the diameter size increased (Table 2). The results on ratio showed that for 3.79m of crown diameter, 18.7cm of bole diameter was accumulated in *D. oliverii*; and for 10.8m of crown diameter, 0.222cm of bole diameter was added to *D. oliverii* tree stands, which was the highest efficient accumulated without serious crown interference or competition.

Discussion

The status of the tree species was a reversed "J" shaped distribution curve. According to Adekunle et al.,[4] the reverse 'J-shape' diameter distribution indicated healthy recruitment potentials; the lower class diameter tree stands could develop into mature trees and replace the old ones in the future if proper conservation efforts are sustained. Thus, this structure is typical of a natural forest.[10]

The results of this finding on dbh distribution (Figure 1) revealed that, there was more concentration of trees (42 trees) with stem diameter at the lower diameter class (10 to 30cm) than at the upper diameter class distribution (31 and above). This could be that such tree stands might have been exploited as timber in the ecosystem. Nowadays, trees of smaller dimension are generally logged immediately they are discovered, especially the most economic and desirable species.[4] Also the increased pressure on tree species for different uses has affected the growth and yield of forest trees; and structure of the forest ecosystem especially in the tropical areas. The rest, which are of smaller sizes, will provide an in growth into the merchantable class that will be ready for harvest in the future and they should be included in the working plan for conservation.

If relationships between crown diameter and bole diameter are known, basal area (BA), stand density and limiting stocking of tree species in the forest estates can be estimated from crown diameters derived from bole diameters.[1,2] Tree's dbh is often used as a substitute for tree's crown diameters, so also, a tree crown diameter can equally be used as the substitute for dbh.[11] The crown-bole diameter relationship is particularly useful for assessing crown competition factors, stand density, stocking relationships and tree growth.[12] Thus, crown-bole diameter model for *D. oliverii* was used to estimate and control stand density and stocking in the study area.

The crown-stem diameter ratio is a measure of the efficiency of a tree to accumulate diameter at breast height per unit of crown area. The higher the ratio, the more efficient a tree species is at accumulating dbh.[2] The highest bole diameter accumulated without serious competition was sizeable tree with a bole diameter size (20.40cm) which can only be used as fencing pole and utility pole but not sizeable enough to be used for timber and charcoal productions (Table 2). *D. oliverii* tree with dbh of 48.77cm and crown diameter of 9.36meters would face a serious competition if raised in a plantation. This implies that *D. oliverii* tree stands in the study accumulated bole diameter (wood fibre) at slower rate with increasing crown diameter, growing space and stand density while the limiting stocking was decreasing (Table 2). Thus, stand density and stocking of *D. oliverii* tree stands established in a plantation can be controlled when the bole diameter is above 48.7cm; if the plantation is for the purpose of timber production. This is to avoid serious competition, unhealthy crown and slow growth rate of the tree species.

At any given age, there is a lower limit of stand density below which no further increase in diameter growth will result from continued density reduction. At density levels below this lower limit, the trees are growing free of inter-tree competition and usually referred to as open-grown-trees. Other vegetation present on the site may also affect diameter growth even though tree density is below this competition limit. This finding is in line with Jerome et al.,[13] which reported that spacing experiments have consistently increases in breast height diameter (dbh) growth with decreasing stand density. Inter-tree competition affects diameter growth at low stand densities, particularly in the case of fast-growing, shade-intolerant species; as a result, very low densities are required to produce maximum diameter growth throughout the life of an even-aged stand.

Tree stands with optimum stocking in time, have larger average stem and crown diameter than similar stands with over stocking (closer spacing). Thus, *D. oliverii* tree would require optimum stocking for fast and healthy growth. This result is in agreement with the general belief that low densities are required to produce maximum bole diameter growth throughout the life of an even-age stand.[13] Thus, adequate spacing can significantly increase gross volume and growth yield while severe overcrowding of tree stands could greatly restrict root and crown development especially in the absence of thinning. The control of high density at stand establishment by silvicultural practices such as thinning is therefore an important aspect of forest management that can enhance fast growth, high production and yield for sustainable forest management. The rationale for optimum planting during the establishment and sustainable management of tree species (*D. oliverii)* should be generally based on fast growth, economic considerations, reduction of mortality and increased total production per unit area in a given period of time.

Conclusion

The study revealed that, stem diameter is the strongest variable as predictor of crown diameter for most tree species in Nigeria. *D. oliverii* would require low densities for optimum planting spacing, fast growth and high yield for the purpose of timber and high densities for non-timber forest products; because low densities are required to produce maximum diameter growth throughout the life of tree stands which is applicable to the studied tree species as shown by the results obtained from the area. Linear crown-bole diameter models could simply be used in forest inventory operations for determining the forest stock with less cost and time consuming. More research is needed with a greater variety of site and stand conditions in addition to a greater variety of tree sizes and ages. It should be noted that, the model used for this study were based on data collected from natural forest in Makurdi, Nigeria; thus, it should be used with caution outside this area.

Acknowledgments

None.

Conflicts of interest

Authors declare that there is no conflicts of interest.

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