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Allometric Modelling of Tectona grandis for Diameter at Breast Height and Crown Collar Diameter Estimations in the Dry Semi-Deciduous Forest Zone of Ghana

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Abstract
The increased rate of deforestation and forest degradation in developing tropical countries like Ghana, necessitated massive afforestation and reforestation as the approach for mitigating this menace with mostly short rotational tree crops like *Tectona grandis* (teak). Teak poles have been noted worldwide for their durability especially for electrification projects. However, its usage for electrification projects in Ghana has attracted immense attention and concern in Ghana primarily because of massive demand but frequent rejection of the poles due to unsuitable crown collar diameter and length of the tree required for electric poles. Currently, the relationship between the diameters at breast height, collar diameter and height - parameters that can be adopted for easy determination of crown collar diameter on field has not been well established in Ghana. This study was carried out to determine the relationships between and among diameter at breast height, height and crown collar diameter and diameter at breast height, height and crown collar diameter of teak in the dry semi-deciduous forest zone of Ghana to ease the determination of crown collar diameter to avoid its waste due to rejection. The study was carried out in compartment 5 of Chirimfa Forest Reserve. Diameter at breast height, total height and crown collar diameter variables were measured on hundred (100) felled trees. Regression analysis performed at a confidence level of 95% revealed no significant relationship ($R^2 = 0.00$, $p > 0.05$) between diameter at breast height and total height. However, significant relationship ($R^2 = 73.40$, $p < 0.05$) was found between crown collar diameter and diameter at breast height. The significant relationship ($R^2 = 76.60$, $p < 0.05$) among crown collar diameter, diameter at breast height and height as indicated by the model $CD_{(cm)} = 0.6625DBH_{(cm)} - 0.563H_{(m)} + 3.83$, indicates that the appropriate determination of crown collar diameter of teak is a function of height and DBH growth. However, relationship between DBH and collar diameter was the strongest and suggest the DBH as the most important determining parameter for correlating Collar diameter of teak trees in the dry semi-deciduous forest zone of Ghana The study has thus provided a baseline equation that could be used to predict and determine teak trees crown collar diameters with diameter at breast heights in Ghana and also for further exploration for better predictions.
Keywords: Deforestation, degradation, reforestation, electrification, diameter, collar

1.0 Introduction

The degree of deforestation and forest degradation is more swift and vast in developing tropical countries (FAO, 2005) and these loss of the natural forests have been counteracted by the rapid increase in degraded forestland allocated to plantation establishment (FAO, 2007). In Ghana, the approach for mitigating the ever increasing deforestation has been massive afforestation and reforestation by Government and the private sector with mostly short rotational trees like *Tectona grandis* (teak). This has led to the establishment of large plantation areas both in Forest reserves and off-reserves with teak trees.

Presently, teak is the most important plantation species in Ghana in terms of the areas planted and the value of its wood products. In 2010, almost 50,000m^3 of teak wood was exported in the form of air and kiln-dried lumber, poles and billet (Ghana Forestry Commission, 2011). An increase in teak plantations occurred following a five-year Rural Afforestation Programme in 1989 under the erstwhile Ghana Forestry Department, which saw a boost in teak planting through the establishment of new plantations and small-scale community woodlots in Northern Ghana. Apart from electric and telephone transmission poles, teak is also valued by small-scale farmers and local communities particularly in Northern Ghana as poles for construction, fencing, rafters, fuelwood, stakes and wind breaks.

Teak wood has been noted worldwide for its durability and suitability to be used as electric and telephone poles but unfortunately, this usage for electrification poles is faced with wanton economic and ecological waste here in Ghana. This is due to the frequent rejection of the wood due to smaller collar diameter and length of the wood. This has subsequently led to the waste of large quantities of teak which are primarily deemed for transmission poles. Currently, no relationship between the diameters at breast height, collar diameter and height of teak has been established in the dry semi-deciduous forest zone and in Ghana as a whole.

Based on the above problem, there is the need to devise a mechanism to determine with minimal errors, the allometric equation between diameter at breast height (DBH) and crown collar diameter (CD) to facilitate easy determination of suitable teak trees for electrification projects.

The development of effective and accurate models to predict forest growth and products during the forest rotation is essential for forest managers and planners. Growth and yield models, which rely on functions to measurement data from a sample of the forest population of interest are the tools that have mainly been used to provide decision-support information that meets basic operational needs for evaluating various forest management scenarios (Mohren and Burkhart, 1994). Need for specific information for forest managers and planners are one of the reasons for the increase of the demand for forest models.

The specific objectives of the study were to determine the (i) DBH – height relationship of the teak in the dry semi-deciduous forest zone; (ii) DBH – crown collar diameter relationship of the teak in the dry semi-deciduous forest zone and (iii) DBH, height and crown collar diameter relationship of *Tectona grandis* in the dry semi-deciduous forest zone.

2.0 Materials and Methods

2.1 Description of Study Area

The study was carried out in compartment 5 of Chirimfa Forest Reserve at the Mampong Forest District in the Ashanti Region. The area falls within the dry semi-deciduous forest zone of Ghana (Hall and Swaine, 1981) and it is characterized by bimodal rainfall pattern with an average annual rainfall of 1270 mm (major rainy season starts from March to mid-August and minor season starts from mid-August to November. The dry season starts from December to March and it is usually warm and dusty). The reserve covers a total land area of 114 km^2 and was gazetted in the year 1932. It is located within latitudes 7 ^{0}10'35''N and 7 ^{0}1'20'' N and longitudes 1^{0}22'20'' W and 1^{0}13'05'' W. The relief is generally low-lying and gradually rising through rolling hills with the highest point being 2400m whilst the lowest is 135m above mean sea level. The reserve is fairly drained by the Chirimfa River and underlain by Pre-Cambrian rocks of the Birimaian formation. The area is characterized by a mean annual temperature of 27^{o}C with variations in mean monthly temperature ranging between 22^{o}C and 30^{o}C throughout the year. The soil type is sandy loam (Soil Research Institute of Ghana, 1994).

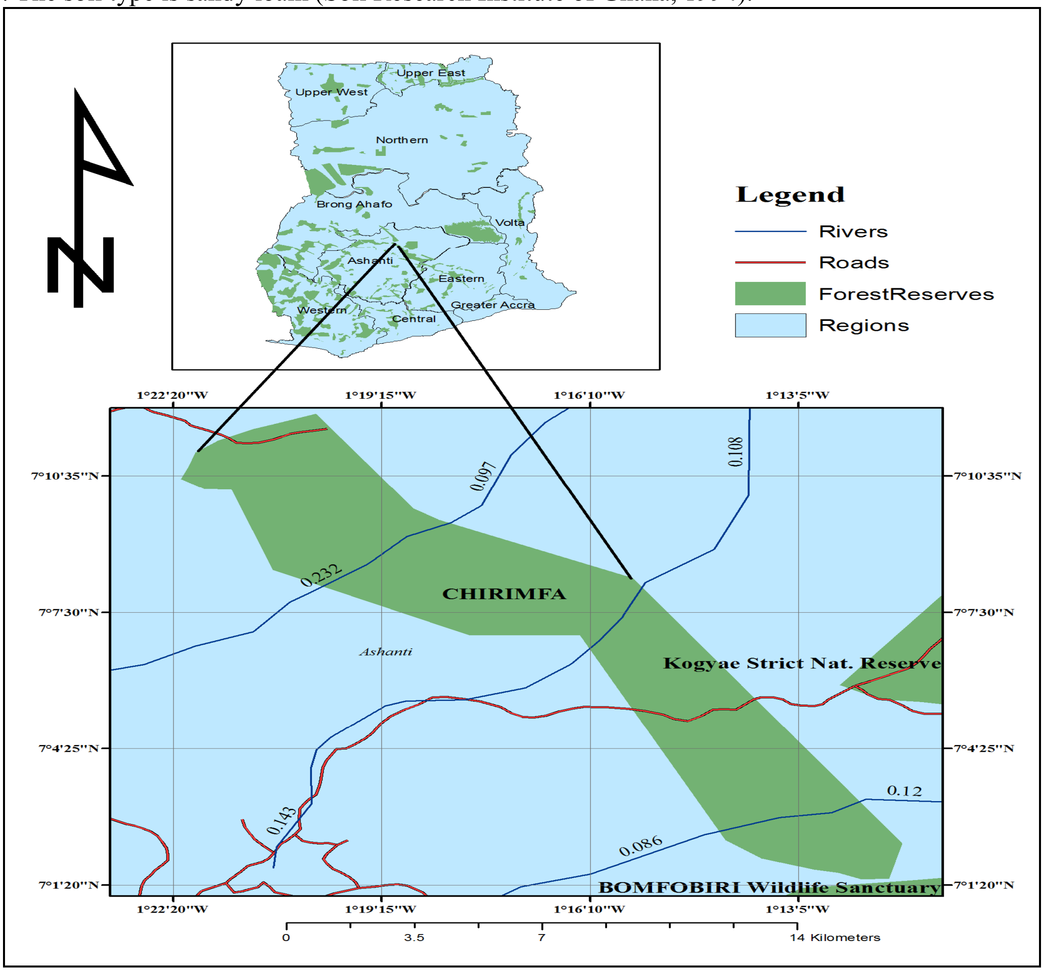

Figure 1: Forest Map of Ghana showing the study site (Chirimfa Forest Reserve)

2.2 Methods of Data collection
Hundred (100) harvested teak trees were used for the study. Variables such as diameter at breast height (DBH), crown/collar diameter and height were measured on each teak tree.
2.2.1 Diameter at breast height (DBH) – height relationship
The total heights (TH) of the teak trees were measured using a 50-meter measuring tape from the butt-end to the last merchantable height of the teak tree. The initial DBHs (DBH_1) were measured at 1.3m from the butt-end of the tree using a diameter tape. The corresponding heights (H) to DBH_1 was then computed as: $H_1 \Longrightarrow (TH - 1.3)$m for every teak tree.
2.2.2 Diameter at breast height and crown collar diameter relationship
The initial DBH_1 was measured at 1.3m from the but-end of the tree. The corresponding collar diameters (Cd) thus, (Cd_1, Cd_2, Cd_3…….. Cd_n) at every 1m interval from the initial collar diameter (Cd_1) were measured on the same tree using a diameter tape. Thus, Thus, $DBH_1 \Longrightarrow Cd_1$, $DBH_1 \Longrightarrow Cd_2$, $DBH_1 \Longrightarrow Cd_3$. This implies $DBH_1 \Longrightarrow Cd_n$. Collar diameters less than 5cm were rejected. The initial collar diameter was taken on the tree bole at the exact point where the tree begun tapering.
2.2.3 Diameter at breast height – crown collar diameter – height relationship
The initial height (H_1) was measured from DBH_1 to Cd_1. Other height measurements (H_2, H_3… H_n) was taken from Dbh_1 to the corresponding Cd readings (Cd_2, Cd_3… Cd_n). Thus, $DBH_1 \Longrightarrow Cd_1 \Longrightarrow H_1$; $DBH_1 \Longrightarrow Cd_2 \Longrightarrow H_2$; $DBH_1 \Longrightarrow Cd_n \Longrightarrow Cd_n$
The data obtained were correlated using the following relationships as proposed by (Niklas *et al.*, 2003; Rio *et al.*, 2001; Temesgen and Gadow, 2004).
DBH = β (H-1.3) ……………………….equation (1)
And DBH = β (CD)…………………….equation (2)
Where:
DBH is diameter at breast height
H is the total height of the teak tree
CD is the collar or crown diameter (taken at exact tapering of the tree bole)
β is the constant of proportionality

2.3 Data Analysis
The data were subjected to regression analysis using GENSTAT RELEASE 10.3DE at a confidence level of 95%. The results are presented in tables and graphs. The regression power analysis (R-power) was done at two sided 0.05 probability level to determine the variables' significance to the regression model.

3.0 Results
The results focus on establishing models on the allometric relationships between collar diameters (CD), diameter at breast height (DBH) and height (H) growth of *Tectona grandis* (Teak) in the dry semi-deciduous forest zone (DSFZ) of Ghana.
3.1 Relationship between DBH and height of teak
No significant relationship was found between the DBH and height variables ($R^2 = 0.00\%$, $p > 0.05$) of teak **(Figure 2)**. A two-sided test done at a significance level of 0.05 showed that much of the variations in the height growth of teak cannot be explained by significant changes in the DBH variable (R-power = 0.04) as indicated in

Table 1. Power of the Regression analysis/ model (Two-sided)

Variable/ Parameters	Estimates	Standard error (S.e.)	R-power
Constant	8.565	0.9135	1.000
DBH (cm)	-0.0075	0.0353	0.040

** *Higher R-power value indicates significant contribution to the regression model at 0.05 probability level.*

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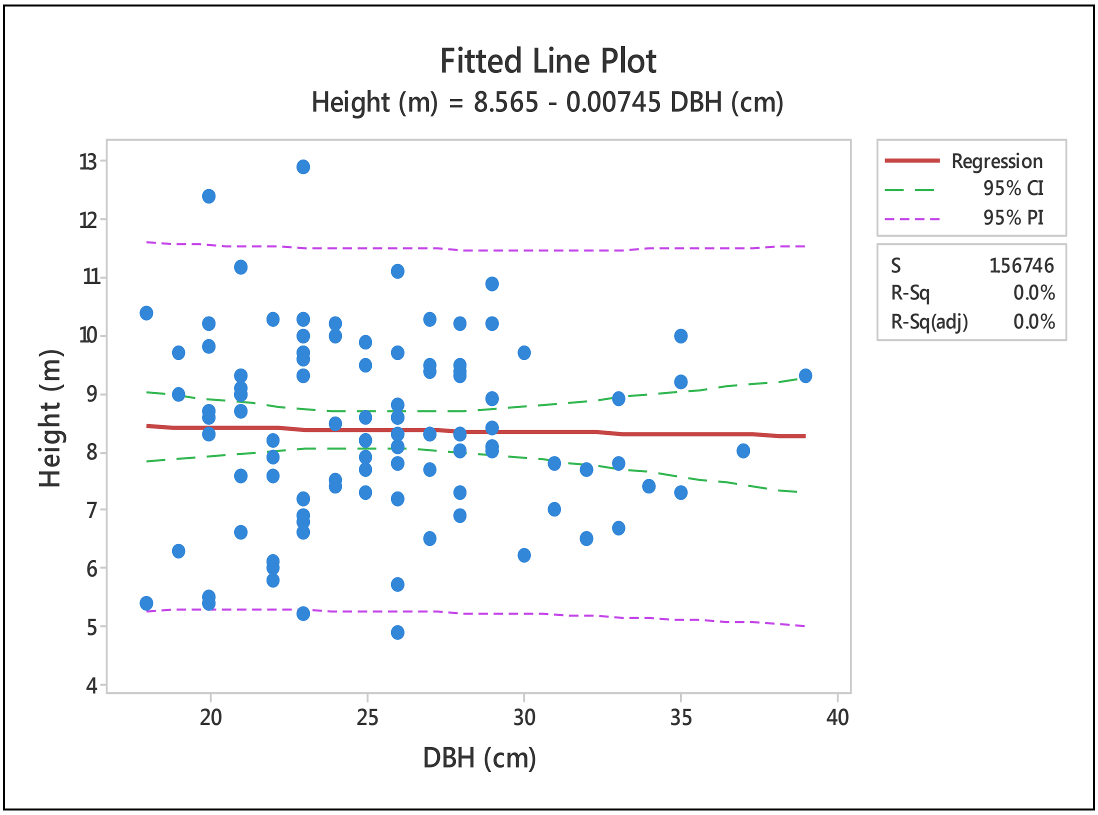

Figure 2: Allometric relationship between DBH and Height growth of teak in the DSFZ.

3.2 Relationship between DBH and Crown Collar Diameter

The study showed strong significant relationship between the DBH and crown collar diameter (CD) variables (R^2 = 73.40%, p <0.05) of teak **(Figure 3).** The results showed that 27.6% of changes in CD cannot be explained by variations in DBH.

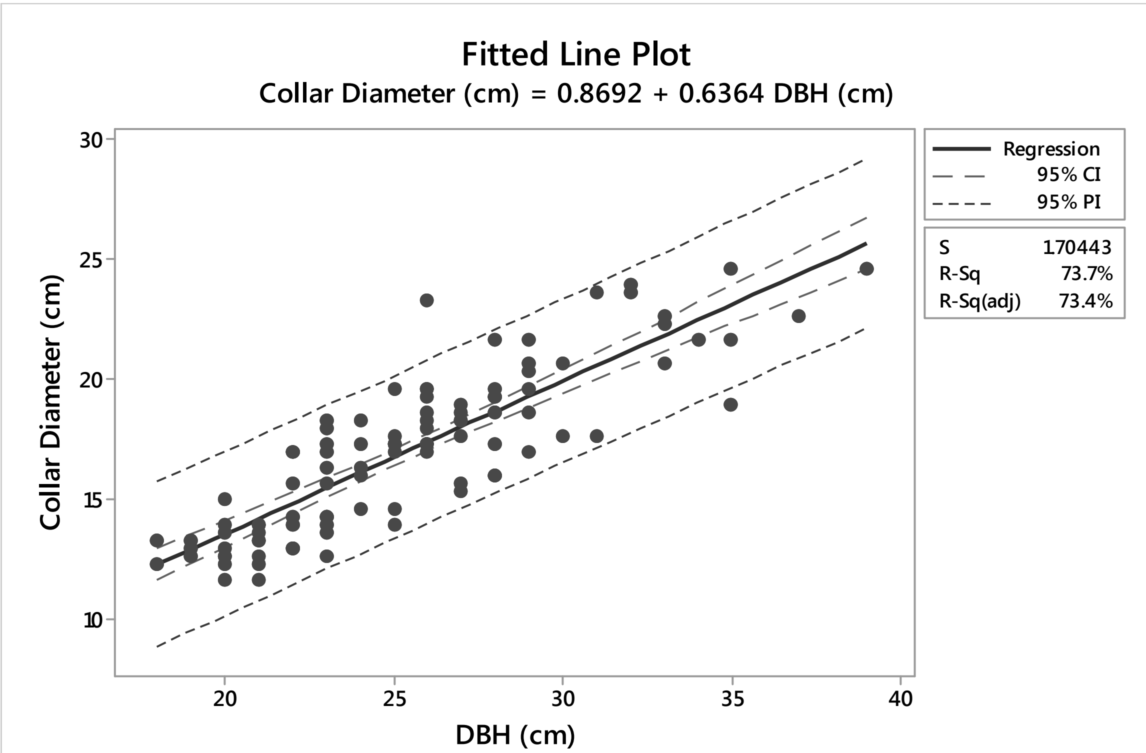

Figure 3. Allometric relationship between DBH and Collar diameter of teak in the DSFZ.

3.3 Relationship between Crown Collar Diameter and Height

No significant relationship was found between the crown collar diameter and height variables ($R^2 = 0.00\%$, $p > 0.05$) of teak **(Figure 4)**.

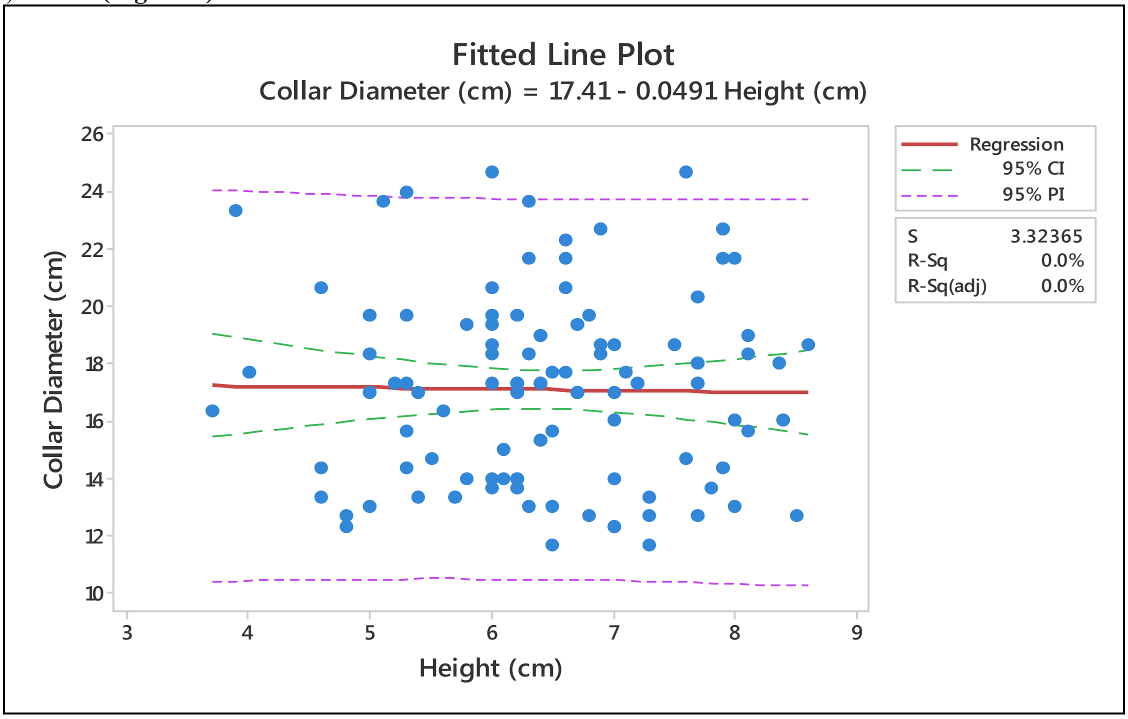

Figure 4. Allometric relationship between height and Crown Collar diameter of teak in the DSFZ

3.4 Relationship among Height, DBH and Crown Collar Diameter

The results indicated a strong correlation among DBH, height and crown collar diameter ($R^2 = 76.6\%$, $p < 0.05$) of teak **(Figure 5)**. An increase in DBH results in an increase in collar diameter whilst the height has a negative correlation with the collar diameter of teak in the dry semi-deciduous forest zone of Ghana. A two-sided power of the regression analysis showed that much of the variations in collar diameter of teak could be explained by significant changes in the DHB (R-power = 1.00) as indicated in **Table 2**.

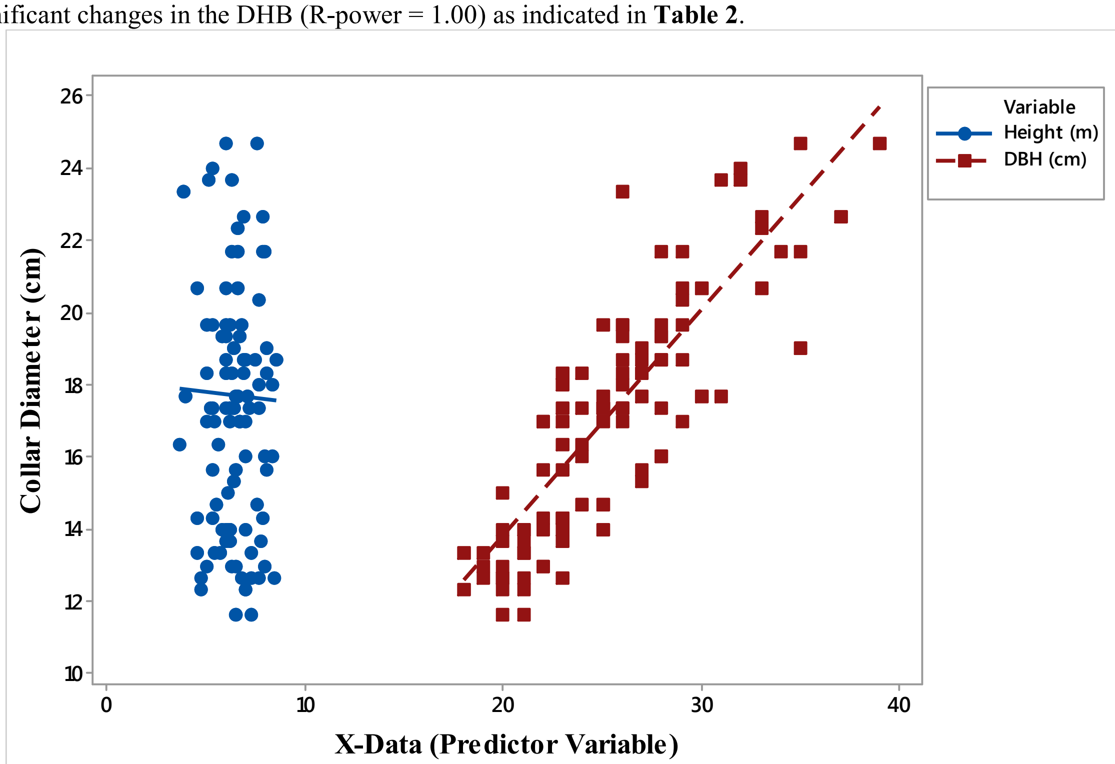

Figure 5. Relationship among DBH, height and crown collar diameter of teak in the DSFZ.

Table 2. Power of the Regression analysis/ model (Two-sided)

Variable/ Parameters	Estimates	Standard error (S.e.)	R-power
Constant	3.828	1.2217	0.873
DBH (cm)	0.663	0.0367	1.000
Height (m)	-0.563	0.1502	0.960

** *Higher R-power value indicates significant contribution to the regression model at 0.05 probability level.*

4.0 Discussion

4.1 Crown collar diameter, height and diameter at breast height relationships of teak

The lack of significant ($p>0.05$, $R^2 = 0.00\%$) relationship between DBH-height **(Figure 2)** could imply that variations in DBH of Teak may not have any significant effect on height growth. This, DBH cannot predict height growth of teak. A negative correlation between DBH and height confirms the assertion by Gregoire *et al.* (1995) who reported that, the diameter of a tree bole decreases with increasing height aboveground.

Regression power analysis further revealed that the constant/x-factor (8.565 ± 0.9135) could have influenced the height growth of teak. This x-factor/ constant could be due to soil and or environmental conditions and insect damage (White, 1991; Kaosa-ard, 1998). The findings supports the assertion by Usoltsev and Vanclay (1995) who reported that growth of teak trees are primarily due to resources potentially available. Viquez and Perez (2005) reported that, total height growth of teak cannot be predicted by DBH but by silvicultural practices such as pruning.

Moreover, some of the variability in diameter-height growth within and among species groups can be explained by the stand and tree variables contained within this model, much of the variability is due to other factors such as the spatial variation of weather, and micro-site conditions (Jamalludin, 2005)

Although the results showed a straight line through the origin, the findings were inconsistent with studies by Sharma *et al*. (2002), who found a significant linear model between DBH and Height of an even-aged teak plantation.

On the other hand, a significant ($p < 0.05$, $R^2 = 73.4\%$) correlation between the crown collar diameter (CD) and DBH **(Figure 3)** of Teak suggests that much (73.4%) of the variations in the crown collar diameter of teak could be attributed to changes in the DBH. Hence, the DBH if properly determined could be used to predict crown collar diameter of Teak.

With respect to the three parameters measured, significant ($p < 0.05$, $R^2=76.6\%$) relationship was found among DBH, height (H) and crown collar diameter (CD) of Teak **(Figure 5)**. The results could probably indicate that the proper determination of crown collar diameter of teak is a function of height and DBH growth. Consequently, an increase in DBH results in an increase in crown collar diameter whilst the height has a negative correlation with the crown collar diameter of teak.

5.0 Conclusion

5.1 Conclusion

The study has shown how the prediction of growth variables (height, crown collar diameter, and diameter at breast height) of a teak plantation could be done using a standardized equation in the dry semi-deciduous forest zone of Ghana.

The study revealed no significant relationship between DBH and Height (H) as shown by the model: $\mathbf{H_{(m)} = 8.565 - 0.00745\,DBH_{(cm)}}$. However, significant relationship was found between crown collar diameter (CD) and DBH - $\mathbf{CD_{(cm)} = 0.8692 + 0.6364DBH_{(cm)}}$. Similarly, the relationship among all the three measured parameters (CD, DBH and H) was significant as shown by the model: $\mathbf{CD_{(cm)} = 0.6625DBH_{(cm)} - 0.563H_{(m)} + 3.83}$.

Forest biometry plays a significant role in providing critical information to forest resources management and policy decision making. Therefore, these baseline growth models could be explored further for making clearly desirable and necessary future long-term decisions based on quantitative estimates and projections.

5.2 Acknowledgements

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