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EQUATIONS FOR ESTIMATING BARK THICKNESS OF *Gmelina arborea* (ROXB) TREES IN OMO FOREST RESERVE, NIGERIA

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ABSTRACT

The measurement of bark thickness is an important factor for computing inside bark volume of a standing tree or log. Bark thickness at breast height can easily be measured. However, when bark thickness at relative height of a standing tree is required, the application of equations becomes imperative. In this study, equations were developed for estimating bark thickness at relative height and at breast height. Stratified random sampling was used to establish 50 sample plots of 0.04 ha size across 10 age series in the *Gmelina arborea* plantation in Omo Forest Reserve, Nigeria. Eight equations for estimating bark thickness as function of diameter inside bark (*dib*) and Relative Bark Thickness (*RBT*) were developed. Equation was also developed for predicting absolute bark thickness at breast height. The equations were assess based on Root Mean Square Error (RMSE), Mean Absolute Bias (MAB), Akaike Information Criterion (AIC) and Shapiro-Wilk test of normality. The results showed that six out of the nine equations performed relatively well in estimating bark thickness. The best equation for estimating bark thickness as function of *dib* had RMSE, MAB and AIC values of 0.065, 0.049 and -125.989, respectively. The best equation for *RBT* had 0.109, 0.079 and -75.577, respectively. The equation for absolute bark thickness at breast height had 0.204, 0.152 and -12.697. The equations did not violate the assumption of normality as revealed by normality test ($p > 0.05$). With these equations, any analytic volume equation can be used to compute the inside bark volume of the standing trees. The relative back thickness and diameter inside back functions developed in this study were found to be satisfactory based on the various criteria used for their assessment. Thus, they are recommended for use in estimating the back thickness and diameter inside bark of *Gmelina arborea* stands in similar ecosystem.

Keywords: Bark thickness; Equations; Gmelina

INTRODUCTION

Tree bark is defined as the combination of secondary phloem, cortex and periderm (Williams *et al*. 2007). The periderm formed protective bark tissue. The outer bark is known as the rhytidome; a collective layer of dead cortex tissues (Borger, 1973 cited in Williams *et al*. 2007). The inner bark of a tree is the main assimilating tissue situated outward of the xylem and inward of the periderm (Junikka, 1994). The importance of tree bark cannot be overemphasized. It has a protective function which helps to reduce mortality from fire. It can also be used as fuelwood or as specific product such as mulch or medicine. More importantly, it is a major determinant of merchandising decisions as logs are often sold based on inside bark volume (Li and Weiskittel, 2011).

Tree bark thickness increases with age. It also varies with species, site, tree size, position, buttress and so on (Smith 1979; Cunningham 2001). Bark thickness of standing tree is usually measure with Swedish bark gauge. However, it has been reported that there are errors associated with the use of the instrument (Johnson and Wood, 1987). For example, Laar and Akça (2007) stated that the use of the instrument is based on assumption that the instrument will not be driven into the sapwood. This might be somehow difficult for tree species with relatively hard barks. A penetration of the sapwood, overestimates the bark thickness. The diameter inside bark can be determine by the removal of tree bark and then measured. Actual inside bark diameter along the tree stem can be measured after the tree has been felled. Debarking a standing tree often predisposed the stem to insect attack thereby affecting the wood quality, in consequence, reduce the product value. To avert such problem, models have been developed to predict tree bark thickness so that volume inside bark can be estimated with some level of precision.

Previously, bark thickness was predicted from diameter at breast height (Dolph, 1989). In recent times, other variables such as tree height, age, tree forms have been incorporated for modelling bark thickness. This is because bark thickness varies from the base to the top of the tree (Li and Weiskittel, 2011). In view of this, some studies have predicted bark taper along tree stems (e.g. Laasasenaho *et al.* 2005, Brooks and Jiang, 2009). Bark thickness model can either be in absolute (predicting bark thickness directly from other variables) or relative bark thickness (*RBT*) (ratio of bark thickness at a given height along the tree stem to bark thickness at breast height). Alternatively, diameter inside bark (*dib*) at given point on the bole can be modelled as function of diameter outside (*dob*) at the same point; the difference will give the bark thickness (Li and Weiskittel, 2011). Several literatures exist on bark thickness models including Monserud (1979), Johnson and Wood (1987), Dolph (1989), Cunningham (2001), Laasasenaho *et al.* (2005), Williams et al. (2007), Brooks and Jiang (2009), Li and Weiskittel (2011), and Stängle *et al*. (2016).

Despite the period over which the concept of modelling bark thickness has evolved, there is little or no information on tree bark thickness model for both native and exotic species in Nigeria to the best of our knowledge. This is evident as there is no exiting literature on bark thickness model in the country. This can be attributed to the difficulty in obtaining data on bark thickness. Most of the volume equations developed were based on outside bark volume (e.g. Akindele 2002; Aigbe *et al.* 2012; Shamaki and Akindele, 2013).

The *Gmelina arborea* Roxb plantation in Omo Forest Reserve, Nigeria is one of the most studied (e.g. Adetogun and Omole, 2007; Alo *et al*., 2012; Ogana *et al.*, 2017) and exploited forest plantations in the country. The species has a smooth bark that is greyish in colour (Keay, 1989). Thus, developing bark thickness model for this species will provide a reliable estimate of the growing stock (volume) inside bark. In consequence, monetary value can be placed on the forest plantation. Therefore, the main objective of this study is to develop functions for estimating the bark thickness of *Gmelina arborea* Roxb plantation in Omo Forest Reserve, Nigeria.

MATERIALS AND METHODS

The Study Area

The data for this study were collected from the *Gmelina arborea* plantation in Omo forest reserve, Ogun State, Nigeria. The reserve is located between latitudes 6.625°N and 7.000°N and Longitudes 4.250°E and 4.500°E and the average elevation is 291.47 m above sea level (Alo, 2016). It covers an area of 130,500 ha (Chima *et al*. 2009, Ogana *et al*. 2017). The climate is completely tropical, with dry season spanning from November to March and wet season spanning from April to October. The mean annual temperature and average relative humidity are 26.5^0C and 80%, respectively while the annual rainfall ranges from 1250 to 2200 mm. Soil parent materials were formed from sedimentary rocks, which is mainly crystalline rocks of the undifferentiated basement complex of the pre-cambrian series.

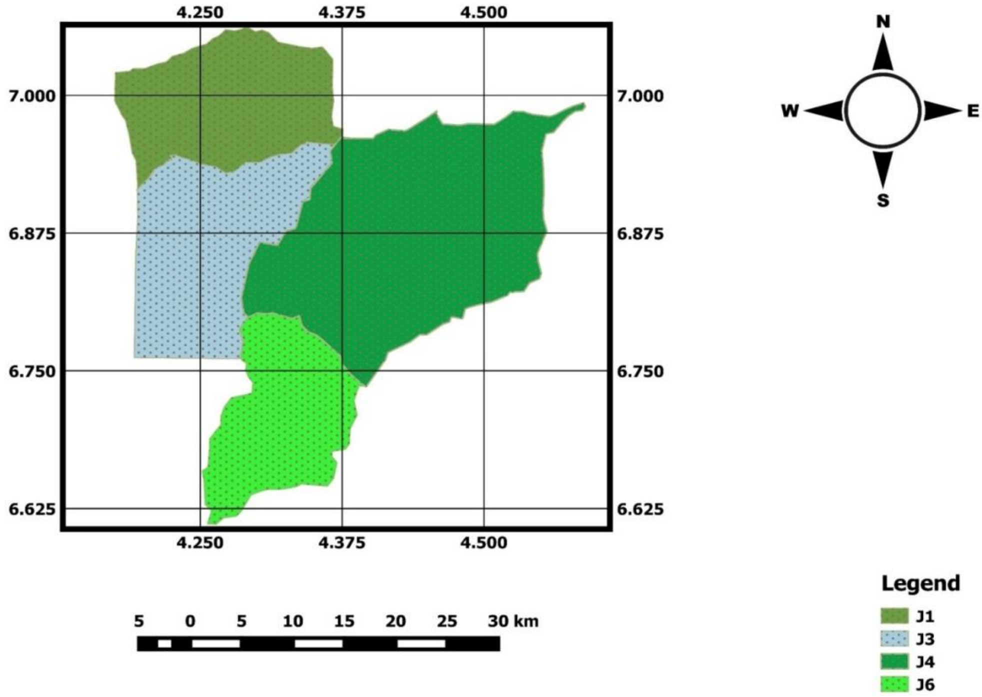

Figure 1: Omo Forest Reserve, Ogun State, Nigeria
Source: Adapted from Alo, (2016)

Sampling and Data Collection

Reconnaissance survey was carried out prior to the stand inventory to assess the condition with the view to selecting only stands with no proof of past felling. Since there were no permanent sample plots in the study area, temporary sample plots were adopted as proposed by Clutter *et al*. (1983) and adopted by Akindele, (2005), Akindele and LeMay, (2006), Adekunle *et al*. (2011), Alo *et al*. (2011), Alo *et al*. (2014). A stratified random sampling technique was used in demarcating 50 sample plots across 10 age series (13, 15, 16, 20, 21, 22, 24, 25 and 26 years) in the *Gmelina arborea* plantation. The diameter at breast outside bark (DBHOB) and total height of all standing trees were measured. The data were classified by DBH classes across the age series.

Two trees from each class were randomly selected and fell at 0.6 m above the ground. The trees were cut into sections at 1 m interval. The diameter outside bark (*dob*) and inside bark (*dib*) at these sections and the relative height (h) were measured. Inside bark diameter was taken after the debarking. Bark thickness was obtained as the difference between *dob* and *dib*. Diameter inside bark at breast height (DBHIB) was also measured. Other variables that were computed include relative bark thickness (*RBT*), relative diameter (*RD*) and bark thickness at breast height (BTBH). The descriptive statistics of the data set are presented in Table 1.

Table 1: Descriptive statistics of the data set

Variables	Descriptive statistics			
	Mean	Max	Min	Standard deviation
Age (years)	20.10	26.00	13.00	4.20
DBHOB (cm)	33.50	62.30	10.60	13.55
DBHIB (cm)	31.80	60.10	9.60	13.33
BTBH (cm)	0.84	1.90	0.40	0.28
dob (cm)	8.80	10.00	6.00	0.99
dib (cm)	8.50	9.70	5.80	0.98
H (m)	25.80	40.60	9.90	7.62
h (m)	20.60	31.30	6.70	6.76
RD	0.31	0.64	0.15	0.14
RBT	0.39	0.75	0.16	0.14

Model specification

Different model specification for bark thickness was used in this study. Bark thickness were modelled along tree stem indirectly from diameter inside bark (*dib*) and relative bark thickness (*RBT*) as well as model for absolute bark thickness at breast height. Thus, three categories of models were developed for the *Gmelina arborea* plantation in Omo forest reserve. Most of the models used in this study were adopted from Li and Weiskittel (2011).

Bark thickness from dib

The bark thickness at any given height (h) along the tree stem can be computed by first predicting the diameter inside bark (dib) at that point as a function of other measured tree variables. And then subtract the resulting dib value from the diameter outside bark (dob) at that point.

$$dib = dob\left[a + b\left(\frac{h}{H}\right) + c\left(\frac{h}{H}\right)^2 + dH\right] \qquad (1)$$

$$dib = dob\left[a + b\left(\frac{h}{H}\right) + c\left(\frac{h}{H}\right)^2 + dH + e\left(\frac{DBHIB}{DBHOB}\right)\right] \qquad (2)$$

$$dib = b.dob \tag{3}$$

$$dib = adob^b \tag{4}$$

Where *a, b, c, d* and *e* are regression coefficient; h = height (in m) at any given point on the tree stem; H = tree total height (in m), *DBHOB* = diameter at breast outside bark (in cm); *DBHIH* = diameter at breast inside bark (in cm); dob = diameter outside bark at h (in cm) and dib = diameter inside bark at h (in cm).

Relative Bark thickness (RBT)

The relative bark thickness is the ratio of bark thickness at a given height (h) along the tree stem to bark thickness at breast height. This was modelled as a function of relative diameter (RD; ratio of diameter over bark (dob) at a given height to diameter at breast height over bark (*DBHOB*).

$$RBT = a + bRD \tag{5}$$

$$RBT = a + bRD^2 \tag{6}$$

$$RBT = \frac{(a-1)}{(a-RD^b)} \tag{7}$$

$$RBT = \frac{(a-1)}{(a-RD)} \tag{8}$$

Equations 5 to 8 were adopted from Johnson and Wood (1987).

Absolute Bark thickness at Breast Height (BTBHt)

A stepwise linear regression technique was used to model tree bark thickness at breast height as function of diameter at breast outside bark (*DBHOB*), tree age, height etc. However, only DBHOB was selected as the best predictor variable for bark thickness at breast height.

$$BTBHt = a + bDBHOB \tag{9}$$

All parameters are previously defined.

The models were assessed based on root mean square error (RMSE), mean absolute bias (MAB) and Akaike information criterion (AIC). The smaller the fit indices are, the better the model. Residual analysis was also used to check if the equations violate the assumption of homoscedasticity i.e. constant variance. Normality test of the residual was carried out using Shapiro-Wilk at 5% level. We assessed the equations based on the different categories. All statistical analyses including model fitting, residual analysis and normality test were carried out in R statistical software (R Core Team, 2017).

RESULTS AND DISCUSSION

The models for predicting tree bark thickness for the *Gmelina arborea* plantation in Omo Forest Reserve have been developed. The parameter estimates, their standard errors, the fit indices and the Shapiro-Wilk test of normality of the equations are presented in Table 2. To avoid negative prediction of dib, equation 3 was constrained to pass through the origin (intercept was removed from the equation). All equations within the different categories of computing bark thickness performed relatively well. The parameters in the models had Student's *t* value that were significant at 5% and had small standard errors. The best equations for predicting *dib* at a given height along the tree stem were equations 1 and

2. The equations had the same RMSE and MAB values of 0.065 and 0.049, respectively. There was slight variation in their AIC values (equation 1 had -125.989 and equation 2 had -125.139). Nevertheless, we still regard the equations to be the same, because as a rule of thumb, two equations are indistinguishable if the difference in their AICs (ΔAIC) is ≤ 2. The difference between Equation 1 and 2 is the inclusion of additional variable (*DBHIB*/*DBHOB*) in equation 2; as such, additional effort is required to compute diameter inside bark at breast height for the equation. Similar observation was reported by Li and Weiskittel, (2011), although equation 2 had the best performance for six out of the seven species considered in their study. The inclusion of relative height (*h*/*H*) to Equation 1 and 2 enhanced their fitting performance and make prediction of diameter inside back at any point along the tree stem possible. Equations 3 and 4 performed relatively well and their results are comparable with equation 1 and 2 based on the fit indices.

In the case of the equations predicting relative bark thickness (RBT), the result showed that equation 5 (the simple linear model) had the smallest RMSE, MAB and AIC values of 0.109, 0.079 and -75.577, respectively; as such rank best. Equation 7 also performed well in predicting RBT. Equation 5 was slightly better than equation 7 with marginal differences of 0.001 and 1.016 in RMSE and AIC, respectively. Both equations had the same MAB of 0.079. This study is in line with Johnson and Wood (1987), who also did not observe any statistical different between equation 5 and 7 in their study on predicting the bark thickness *Pinus radiata* D. Don. Equations 6 and 8 had relatively larger values for the fit indices. Köhl *et al*. (2006) asserted that the proportion of bark thickness varies with site, species, stem size, buttressing, tree age and position on the stem. However, these equations are independent of age, site and even forest location. Johnson and Wood (1987) reported that the inclusion of site index, species location (a dummy variable) in the simple linear equation did not improve the model - their parameters were not significant at 5% level. These models can be used to predict the relative bark thickness and hence the bark thickness at point along the tree stem with respect to bark thickness at breast height for the *Gmelina arborea*.

A simple linear equation for predicting absolute bark thickness at breast height (*BTBH*t) was developed for the *Gmelina arborea* trees. Different exogeneous variables were used including tree age, height and diameter at breast height over bark (*DBHOB*). The result of the stepwise regression showed that larger proportion of the variation in *BTBHt* was accounted for by only *DBHOB*. Tree age and tree total height were excluded from the final model (equation 9). The equation had RMSE, MAB and AIC values of 0.204, 0.152 and -12.697, respectively. Borger (1973) cited in Williams et al. (2007) attributed this linear relationship between bark thickness and stem diameter to the resistance of tree bark to weathering and the persistent nature of the rhytidome (outer bark).

Table 2. Equation parameters, stand errors of estimate (SEE), fit indices and Shapiro-Wilk (S-W) test

Categories	Equation	Parameters	Estimates	SE	RMSE	MAB	AIC	S-W test
from dib	1	a	0.97621	0.04527	0.065	0.049	-125.989	0.871
		b	-0.00104	0.12246				
		c	-0.02108	0.08024				
		d	0.00016	0.00015				
	2	a	0.92335	0.06868	0.065	0.049	-125.139	0.696
		b	0.00600	0.12259				
		c	-0.02669	0.08038				
		d	0.00004	0.00019				
		e	0.05708	0.05578				
	3	a	0.96604	0.00110	0.069	0.051	-122.718	0.228
	4	a	0.93366	0.02233	0.068	0.047	-122.802	0.026*
		b	1.01558	0.01091				
RBT	5	a	0.21100	0.03760	0.109	0.079	-75.577	0.061
		b	0.60000	0.10900				
	6	a	0.31177	0.02402	0.114	0.083	-71.544	0.046*
		b	0.73951	0.15090				
	7	a	1.11124	0.21330	0.110	0.079	74.561	0.077
		b	0.15948	0.33699				
	8	a	1.44523	0.03026	0.114	0.083	-72.363	0.031*
BTBHt	9	a	0.56160	0.09610	0.204	0.152	-12.697	0.603
		b	0.00838	0.00267				

Note: the values on the last column are p-values of the Shapiro-Wilk test of normality; * = significant at 5%

To conclude on the model performance, residual analysis was carried out. First, Shapiro-Wilk test of normality was carried out on each model to check if the assumption of normality for error was violated (see Table 1). The result showed that equations 1, 2 and 3 for predicting *dib* did not violate the assumption of normality of error as the test gave nonsignificant difference ($p > 0.05$). Similarly, only equations 5 and 7 gave nonsignificant difference among the equations developed for predicting relative bark thickness. Also, the linear equation for predicting bark thickness at breast height (*BTBHt*) did not violate the assumption of normality of error.

Finally, to assess the trend in residual, the residuals were plotted against predicted values in 9 classes for equations that did not violate the assumption of normality. This was used to check whether the assumption of homoscedasticity (constant variance was violated). Thin and thick lines were added to the class-specific means (Fig 1 to 6). The thin and thick lines correspond to the class-specific standard deviations and standard errors, respectively, of mean at 95% confidence intervals (CIs) based on the assumption of normality (Mehtatalo, 2017). The graphs showed that the equations for *dib* had all 95% CIs for means i.e., thick lines intersect the x-axis except for the third class (Fig 1 to 3). While all 95% CIs for mean intersect the x-axis for equations predicting *RBT* and *BTBHt* (Fig 4 to

6). This implies that the equations (1, 2, 3, 5, 7 and 9) fit the data relatively well. Furthermore, the specific-class standard deviations, i.e., the thin lines, did not show increasing variance as a function of prediction. This means that the assumption of homoscedastic (constant variance was not violated).

The equations for predicting diameter inside bark (*dib*) and relative bark thickness (*RBT*) can be used to estimate the bark thickness at any point along the stem of the *Gmelina arborea* in Omo forest reserve. For example, the bark thickness can be computed by subtracting the predicted dib from the diameter out bark (*dob*) at any given point *h* on the stem of the standing tree. In the case of estimating bark thickness from *RBT*, the actual bark thickness at breast height must be known, so that the predicted *RBT* can be used to multiply the bark thickness at breast height. For this reason, equation 9 was developed. With known bark thickness at breast height, anyone of the equations predicting *RBT* can be used depending on the variable(s) available.

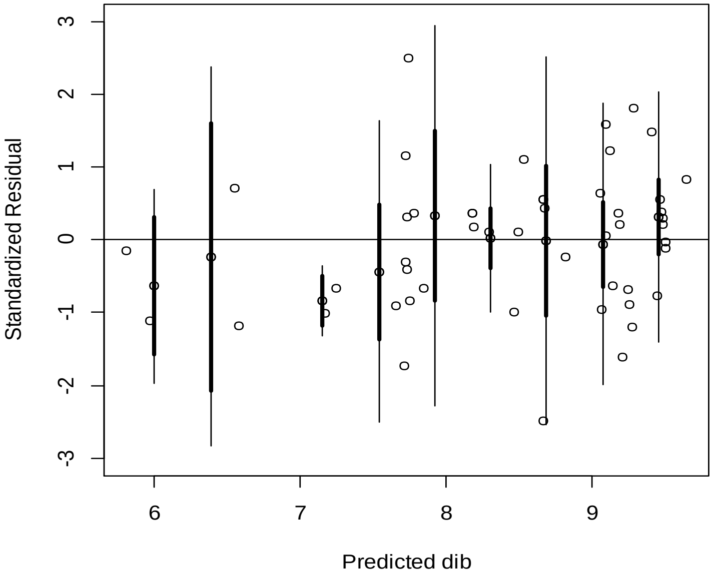

Fig. 1: Residual analysis for equation 1

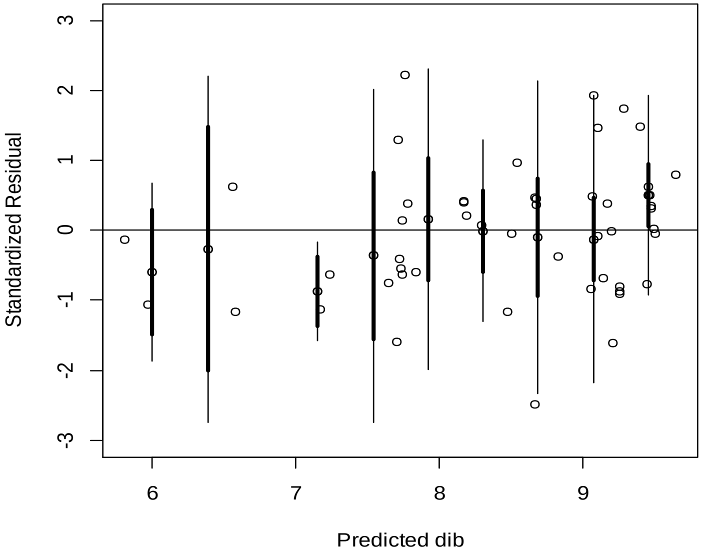

Fig. 2: Residual analysis for equation 2

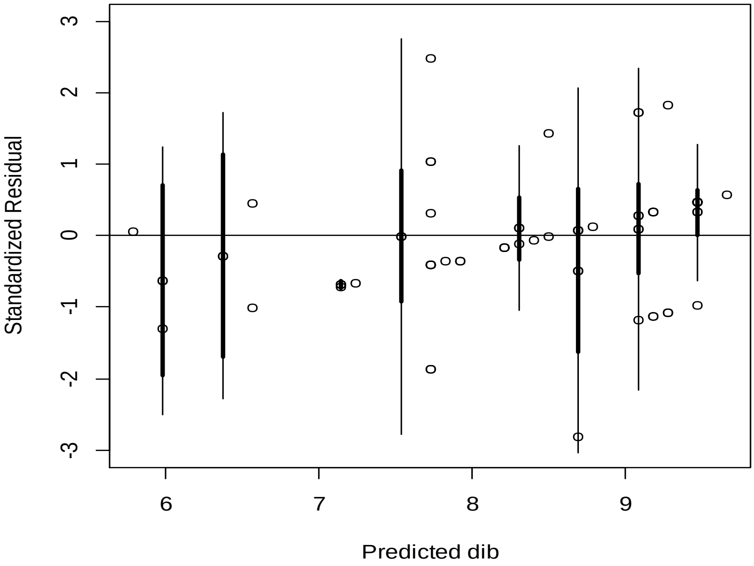

Fig. 3: Residual analysis for equation 3

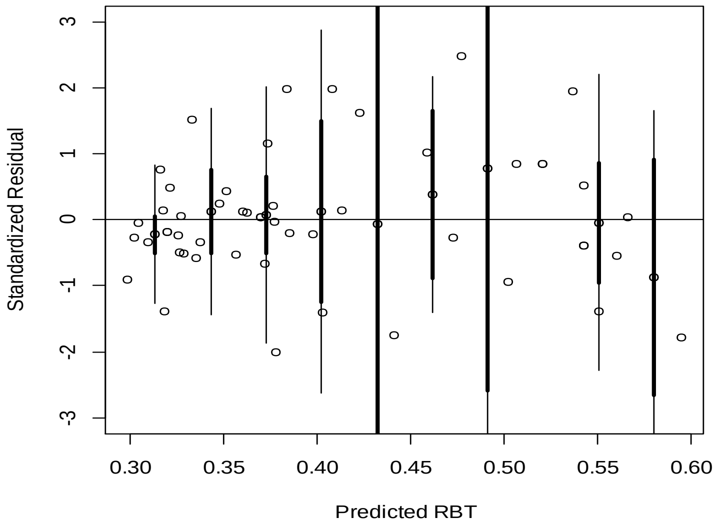

Fig. 4: Residual analysis for equation 5

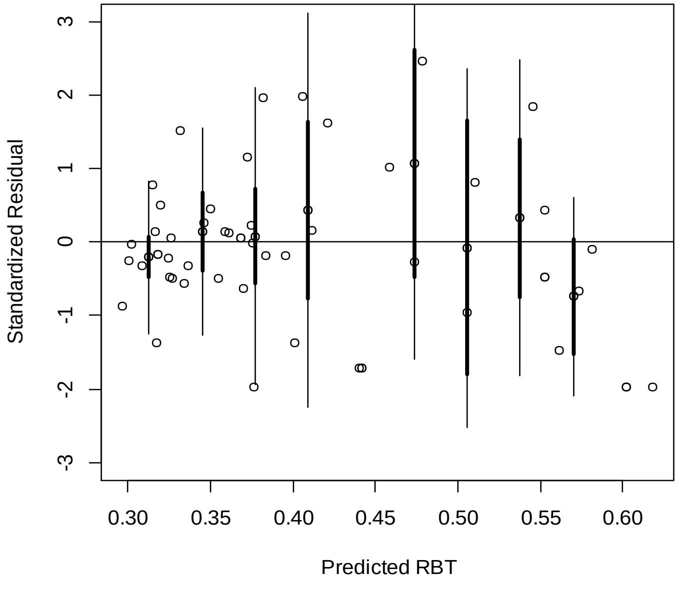

Fig. 5: Residual analysis for equation 7

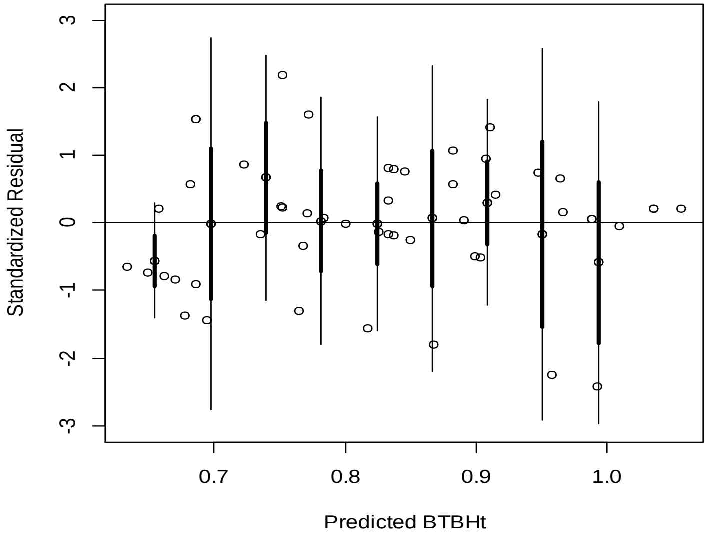

Fig. 6: Residual analysis for equation 8

CONCLUSION

This study has developed equation for estimating bark thickness at any height as a function of diameter inside bark and relative bark thickness. The equations are consistent and the parameters are biological and realistic. With these equations, inside bark volume of the standing trees and the entire forest stand can be computed by applying appropriate analytical volume formula such as Huber's, Smalian's or Newton formula.

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