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PREDICTIVE MODELS OF FOREST LOGGING RESIDUES OF *TRIPLOCHITON SCLEROXYLON* IN ONDO TROPICAL RAINFOREST, NIGERIA

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ABSTRACT

In this study, biomass yield residue was quantified and equations developed for Triplochiton scleroxylon, in secondary forests, Ondo State, Nigeria. Plotless sampling technique was used for the study. A total of 31 Triplochiton scleroxylon were randomly selected. Tree identification and detailed growing stock of outside bark diameters at breast height (dbh), base, middle, top and total height were measured for selected trees. Each tree was felled as close to the ground as possible. The logging residues were categorized into stump, stem, branch and foliage. Fresh weights of representative samples from the various logging residues components were obtained and dry-weights to fresh-weights ratio of the various biomass components were calculated. The results showed that the mean biomass of the residues for Triplochiton scleroxylon was 66.40 kg, 312.98 kg, and 19.56 kg for stem, branches and foliage respectively which indicated that the branch components generated more logging residue than other components. The proportion of residues generated for Triplochiton scleroxylon ranged from 12.00% to 49.02%. The biomass models for logging residue were fitted using dbh predictor. The model developed indicated that logarithmic functions performed better than other form of equation. The findings of this study revealed that there is significant logging residues left to waste in the forest after timber harvest and quantifying this logging residue in terms of biomass model can serve as management tools in ensuring useful planning for economic utilization of the residues.

Key words: Logging residue, biomass yield, biomass model, *Triplochiton scleroxylon*

INTRODUCTION

Logging residues is any portion of a tree lying on the ground as a direct result of logging operations and trees severely damaged during logging operations but could be used in manufacturing and for other purposes. (Kantola, 1966; Thomas, 2001). These logging residues could contribute to increasing the share of renewable energy and prominent source of bioenergy (Karjalainen *et al*, 2004). But they are more or less left on the forest floor in most cases. Such residue often becomes waste unless action to develop use for it is taken (FAO, 1985).

In the southwest geo-political zone of Nigeria, the current rate of forest deforestation was put at 1.36 % per annum (Salami, 2006) and in Nigeria, the rate of deforestation was reported to be about 18.56% (about 2.06 million ha) between 2000 and 2010 (FRA, 2010; FAO, 2011). These forests deforestation can be attributed mainly due to unregulated and uncontrolled logging activities. In addition, the dominant logging method in developing countries is conventional logging, which does not ensure sustainable timber yields because it damages a disproportionately high percentage of future crop trees and emerging regeneration. Conventional logging is characterized by inadequate planning of logging roads, landings and skid trails, insufficient care for the residual stand, poor felling techniques and use of inappropriate and often outdated equipment (Tropical Forest Foundation (TTF), 2006). This unregulated logging method has resulted into massive generation of residues in most cases. This massive logging waste would have been utilized to meet the gap in the increasing demand for wood in timber resource market.

Against the background of increasing demand for industrial wood and the serious reduction of the forest resource base in Nigeria if the report of FRA (2010) is considered, then there is need to quantified logging residues for productive venture. Hence, this study was conducted to model the logging residue and estimate the biomass yield of *Triplochiton scleroxylon* in Southwest region of Nigeria. It is hoped that the results of this study will provide a basis for optimizing logging residue and expected to provide information which will be of use to policy-makers, industry, forest managers, planners, and researchers.

METHODOLOGY

Study Area

The study was conducted in Ondo tropical rainforest which lies between latitude 5^0 45′ and 8^0 15′ N and longitude 4^0 45′ and 6^0 E. The area has a mean annual rainfall ranges between 1500 mm and 2000 mm, most of which occurs during the wet season and mean monthly temperature ranges from 27 to 30°C while mean annual relative humidity is over 75%. The topography is partly undulating and generally gentle. Average altitude above sea level is between 309 m and 332 m. The soils are predominantly ferruginous tropical soil (Ola-Adam, 1992) and have a characteristic of the variety normally found in the intensively weathered areas of the basement complex formations in the tropical rainforest zone of south-western Nigeria (Onyekwelu, 2001). The top soils are mostly sandy loam and few areas are clayey loam as top soils. It is highly weathered and well drained.

Data collection

Thirty one (31) trees of *Triplochiton scleroxylon* were randomly selected using a plotless sampling technique in the natural forest which also depends on their availability and the time of harvesting by timber contractors. Diameter at breast height (dbh) and height were measured for all the selected trees. Over bark diameter at the base, middle and top were also measured for all the trees with spiegel relascope before felling took place. Trees were felled as closely to the ground as possible.

The logging residues were grouped into stump, stem, branch and foliage. Representative samples from the various logging residues such as branches, stump, leaves and twigs and stem off-cuts were taken and their fresh weights were obtained. The fresh samples of the various components were transported to the laboratory and oven dried to a constant weight at 110^0C while branch and foliage samples were oven dried to a constant weight at 70^0C. The oven dry weights of the various samples were determined after constant weights were attained. The dry to fresh weight ratios for the residue samples were thereafter computed. The process of computation was in line with the standard procedures earlier adopted for similar works by Van *et al.* (2000), Fuwape *et al.* (2001), Onyekwelu (2006) and Akindele *et al.* (2010).

Data analysis

Biomass estimation

The dry-weights to fresh-weights ratio of the various biomass components were calculated using the method adopted by Irvin *et al.,* (2008) to obtain dry weights biomasses

$$DW_f = FW_f \times \frac{DW_S}{FW_S}$$

Where DW_f= Dry weight of the sample

FW_f= Fresh weight of sample

DW_s= Dry weight of subsample

FW_s= Fresh weight of subsample

The biomasses of the various residue components (stem, branch and foliage) from each tree were thereafter summed up to obtain the total logging residue (TAGB) of each of the tree species. The biomass of the sample trees formed the basis of the database for fitting the residue biomass models.

Fitting of data for regression equations

Series of regression equations were fitted to biomass data and compared. The equations that produced unbiased estimates as well as residual plots that show conformity with the assumption of independence of errors were considered. All the regression statistics were computed using SPSS 17.0 Software package.

Some of the models tried were:

$$Y = b_0 + b_1 dbh \text{ ....Equation 1}$$

$$Y = b_0 + b_1 Ht \text{ ....Equation 2}$$

$$Y = b_0 + b_1 dbh + b_2 Ht \text{ ....Equation 3}$$

$$Y = b_0 + b_1 dbhHt \text{ ....Equation 4}$$

$$\log Y = b_0 + b_1 \log dbh \text{ ....Equation 5}$$

$$\log Y = b_0 + b_1 \log Ht \text{ ....Equation 6}$$

$$\log Y = \log b_0 + b_1 \log dbh + b_2 \log Ht \text{ ....Equation 7}$$

$$\log Y = b_0 + b_1 \log dbhHt \text{ ....Equation 8}$$

Where Y = Dependent variable (m^3); dbh = Diameter at breast height (cm); Ht = height (m); and $b_0, b_1, and\ b_2$ = regression coefficients.

The dependent variables were total above ground residues (TAGB), stem residues (SB), branch residues (BB) and foliage residues (FB). The best adjudged models were based coefficient of determination (R^2), Root Mean Square Error (RMSE) and F-ratio from the regression analysis. The values of the predicted models were compared with the observed values using student t-test for paired means to check if there is significant difference between two data sets for validation purpose. For functions with logarithmic transformed dependent variable, the computation of Correction Factor (CF) was necessary to correct the bias in biomass estimation due to logarithmic transformation (Onyekwelu, 2006). CF was calculated as given by Whitesell *et al*, (1988):

$$CF = \exp[(SEE^2)/2] \text{ or } \exp[(\text{variance})/2] \qquad \text{Equation 9}$$

Where CF = Correction Factor, SEE = Standard Error of Estimate, Variance = square of the root mean square error (in logarithmic form).

RESULTS AND DISCUSSION

Biomass yield of residues

The average residue biomass values of the selected species are presented in Table 1. The mean biomass of the residues for *Triplochiton scleroxylon* was 66.40 kg, 312.98 kg, and 19.56 kg for stem, branches and foliage respectively (Table 1). The total biomass yield of *Triplochiton scleroxylon* is shown in Table 2. Biomass yield of the residues was more in the branch, followed by that of stem while the least was from the leaves which almost in all cases in the south western region are left to waste away in the forests. This result was corroborated with the report of Eshun (2000) for tropical high forest in Ghana that, of the major sources of logging residues, branch wood contributed the highest average proportion of 42 percent followed by crown-end offcuts (26 percent), butt-end offfcuts (19 percent) and stump wood (13 percent). Auke and Jaap (1997) also reported that out of the 40% logging waste generated in Asia, the 40% consists of 12% stemwood (above first branch), 13.4% branch wood, 9.4% natural defects, 1.8% stemwood below first branching, 1.3% felling damage, 1.6% stump wood and 0.5% other losses. One of the reasons branch component amount to more logging waste than stem component is because more utilizable logs are derived from the bole.

The result as shown in Table 2 indicates that *Triplochiton scleroxylon* has a total residue yield of 8,521.49 kg (31 tree species). This value could defer from species to species and from site to site. The yield residues of timber species could also depend on felling operation, utilizable portion of tree and wood properties. Kiljunen (2002) reported that the amount of logging residues from a tree varies significantly independently of the basic tree variables usually measured. In comparison of yield total residue of other results with result of this study, Mate *et al*, (2014) reported biomasses of 1016 kg for 15 Jambire species of mean dbh, 33.8 ± 12.4 cm; 864 kg for Chanfuta species of mean dbh, 34.8 ± 8.2 cm and 334 kg for 19 Umbila species 334 kg of mean dbh, 27.0 ± 9.5 cm in Sofala and Inhambare Provinces of Mozambique. Logging residue may be attributed to a several causes. Especially when a large proportion of total harvested tree is left on forest floor. FAO (1982) reported that about 60% of the total harvested tree is left in the forest and practices such as slicing and squaring logs in the forest, rather than at the sawmill, wastes an additional 8–10% and 30–50%, respectively.

Table 1: Mean yield of *Triplochiton scleroxylon*

Species	No of tree	Mean dbh(cm)	Mean tree volume (m^3)	Mean stem biomass (kg)	Mean branch biomass (kg)	Mean foliage biomass (kg)	Mean Total Residue biomass (kg)
Triplochiton scleroxylon	31	68.84	5.13	66.40	312.98	19.56	398.94

Table 2. Residue Biomass yield

Tree species	Biomass component	Residue yield (kg)	% of Total residue
Triplochiton scleroxylon	Stem residues	2,058.44	24.16
	Branch residues	5,717	67.09
	Foliage residues	746.05	8.75
	Total residues	8,521.49	100

* *Table 2 shows the total biomass yield of the trees which are 31 in number each from the study area*

Variation in the proportion of residues generated in *Triplochiton scleroxylon*

The variation in the proportion of yield of the residues of *Triplochiton scleroxylon* species was assessed and the results presented in Table 3, which showed the extent of the residues generated by the species in percentage. A comparison of the volume of the trees and the harvested logs show that the proportion of residues for *Triplochiton scleroxylon* ranged from 12.00% to 49.02% with a mean of 26.38%. The proportion of logging residue estimated for this present study is less than the report of Nketiah (1992) and Ofori *et al*. (1993) who estimated logging residue generation in Ghana to be 50 percent and 52 percent of the above-ground total tree volume, respectively. However, the residues generated from this species in the study area are significant (Table 3). The implication of this is that the loggers in the study area are more interested in harvesting mostly the available economic trees in order to get maximum profits. Imail *et al* (2012) opined that when logging is uncontrolled, it often damages more than 50% of the original forest biomass through soil disturbances by heavy machinery. The resultant effects therefore are more pronounced in residue generation, degradation of forest ecosystem which eventually becomes a major social and environmental concern. Tools for harvesting trees are a major factor in residue generation. Esun (2000) reported that an estimated proportion of an average 20 percent as residues were generated in Ghanaian forests when hand tools were used but with the introduction of chain saws, this logging residue was reduced to about 10 to 15 percent.

Table 3: Variation in the proportion of residues generated in *Triplochiton scleroxylon*

Total Volume (m^3)	Volume of logs removed (m^3)	Proportion of residues (%)
7.31	5.36	26.68
6.08	4.63	23.78
6.07	4.75	21.75
5.27	4.47	15.17
6.31	5.48	13.23
5.43	4.23	22.10
9.7	5.51	43.17
8.96	5.64	37.07
6.67	4.53	32.08
3.62	2.84	21.68
6.34	5.11	19.37
9.61	7.48	22.16
8.23	5.78	29.77
7.92	4.66	41.16
4.95	3.35	32.32
3.6	2.77	23.00
8.28	6.66	19.62
5.27	4.64	12.00
5.36	4.04	24.70
2.62	2.09	20.05
3.73	2.56	31.37
6.63	4.10	38.16
2.52	1.93	23.26
3.57	1.82	49.02
4.32	3.41	20.97
2.74	1.85	32.48
6.32	4.51	28.64
4.55	3.93	13.65
5.18	3.78	27.03
2.36	1.62	31.36
3.57	2.81	21.17

Biomass Models for *Triplochiton scleroxylon*

Several models were tried to predict stem biomass residue (SB), branch biomass residue (BB), foliage biomass residue (FB) and total above ground biomass residue (TAGB). Table 4 shows the best adjudged model for the components biomass. The best adjudged models for stem biomass showed relatively low values of coefficient of determination ($R^{2)}$ which was 20%. The reason for low R^2 for SB is because residue generation does not follow apriori expectation as in the case of total residue biomass production. Stem component with very big diameter may produce small quantities of residues while Stem component of lower diameter range could produce much more residues depending on the interests of the loggers. However, the R^2 values for the biomass of residue of the branches, foliage and total component indicate a better model fit.

The equations selected as the final predictive equations for the logging residue biomass were those with the lowest Standard Error of Estimate (SEE), highest coefficient of determination (R^2), highest significant F-ratio and unbiased estimates as well as with residual plots that show conformity with the assumption of independence of errors. The model developed indicated that logarithmic functions performed better than other form of equation and dbh is a good predictor of forest biomass of logging residue. Some researchers have also used dbh as a good predictor in the estimation of biomass of some tree species. For example, Cleemput *et al* (2004), Onyekwelu (2003, 2006), have all used dbh as an independent variable to model biomass of tree species. Onyekwelu (2003) reported that dbh are simple, practical and easy to use. They also provide a more rapid and less costly biomass estimates with low data requirements.

Table 4: Model values for *Triplochiton scleroxylon*

Biomass Component	Model	R^2	RMSE	F	Sig
Stem Residues	(1) $\ln \text{SB} = -0.891+0.362\ln \text{dbH}^2 + 0.637\ln \text{H}$	0.20	0.28	1.040	0.05
	(2) $\ln \text{SB} = -0.891+0.724 \ln \text{dbh} + 0.637 \ln \text{H}$	0.20	0.28	1.040	0.05
Branch Residues	(1) $\ln \text{BB} = 1.135 + 0.056\ \text{dbh}$	0.98	0.15	1.012	0.000
	(2) $\ln \text{BB} = 3.059 + 0.000\text{dbh}^2$	0.96	0.22	1.025	0.000
Foliage Residues	(1) $\ln \text{FB} = 0.090 + 0.032\ \text{dbh}$	0.96	0.09	1.004	0.000
	(2) $\ln \text{FB} = -0.78 + 1.05 \ln \text{dbh}^2$	0.95	0.09	1.004	0.000
Total Above Ground Residues	(1) $\ln \text{TAGBR} = 2.753 + 0.040\text{dbh}$	0.97	0.13	1.009	0.000
	(2) $\ln \text{TAGBR} = 4.110 + 0.000\ \text{dbh}^2$	0.95	0.16	1.013	0.000

Validation of Models

Comparison was carried out between observed and predicted mean for the various biomass components, the t-test analysis (Table 5) showed that the observed values were not significantly different from the predicted values at $p < 0.05$. This implies that the variables are good predictors of residue biomass and that the models specified are valid and biologically plausible. Figures 1- 4 also indicate the relationship between the observed mean and predicted mean.

Table 5: Validation results for best-fit models of residues of *Triplochiton scleroxylon*

Estimate	Observed Mean	Predicted Mean	% Bias	Pearson Correlation	t-Statistic	*Sig
Stem residues	66.40	70.00	5.42	0.313	-1.012	ns
Branch residues	184.49	201.92	9.44	0.952	-1.448	ns
Foliage residues	24.07	24.51	1.82	0.957	-0.783	ns
Total above residues	274.96	289.89	5.42	0.952	-1.56	ns

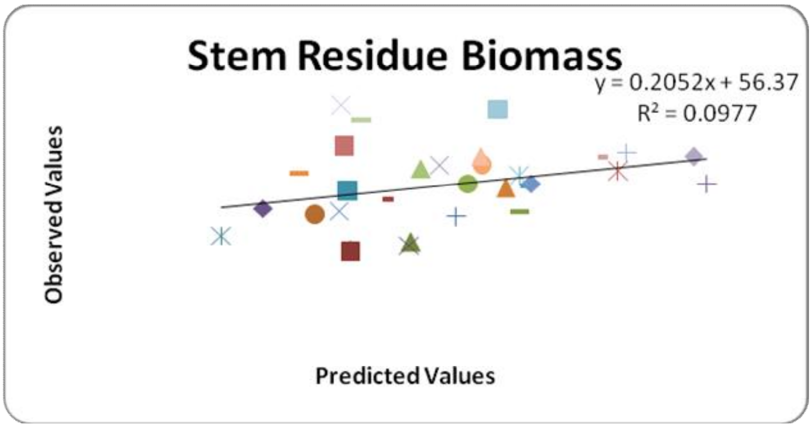

Figure 1. Observed and predicted values of stem residues of *Triplochiton scleroxylon*

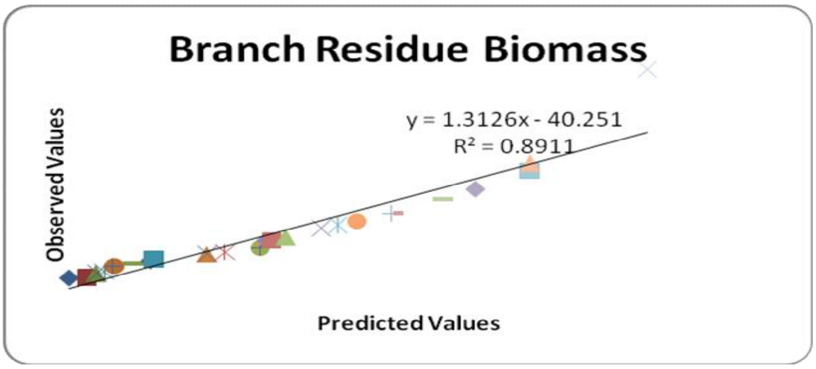

Figure 2. Observed and predicted values for branch residues of *Triplochiton scleroxylon*

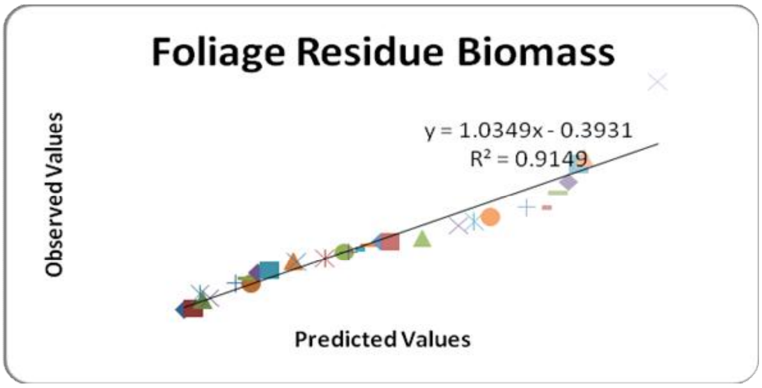

Figure 3. Observed and predicted values of foliage residues of *Triplochiton scleroxylon*

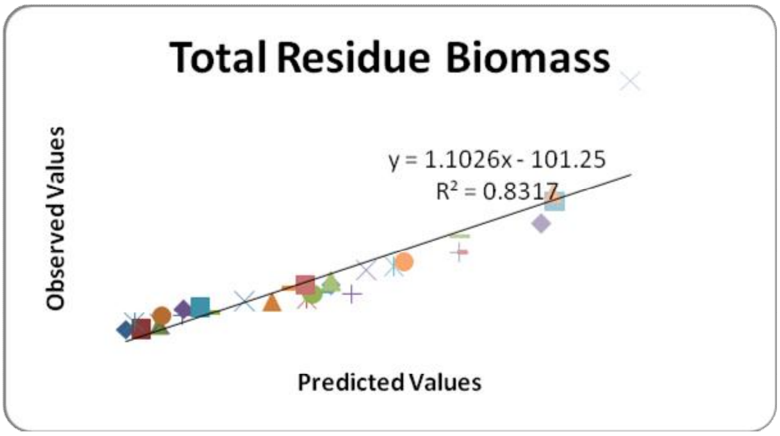

Figure 4. Observed and predicted values of total residues of *Triplochiton scleroxylon*

CONCLUSION

Logging residue may be attributed to several causes but this study has revealed that logging residue is mainly generated by the branch components of trees due to the fact that it is unutilized for timber purposes. Biomass yield of the residues of *Triplochiton scleroxylon* was more in the branch, followed by that of stem while the least was from the leaves. These logging waste are in most cases left to waste away in the forests of Ondo state in south western region of Nigeria. A comparison of the volume of the trees and the harvested logs shows that an average proportion of 26.38 % of residues for *Triplochiton scleroxylon* was left on the forest floor to waste away. To reduce this logging residue, it is necessary to seek alternatives to re-using the wood residues, reducing its generation and exploring management strategies to maximize the potentials of the residues for efficient results instead of allowing it to waste in the forest.

The study has also shown that biomass yield of logging residue can be estimated for *Triplochiton scleroxylon* from dbh with reasonable precision and that log-transformed data was more efficient for estimation of biomass logging residue. The model developed in this study can be very useful in planning and exploring management strategies to maximizing the potentials of the residues for efficient use.

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