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Quadratic Functions for Estimating Biomass in *Eucalyptus camaldulensis* Energy Plantations in the Semi-Arid Region of Northeastern Nigeria

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Abstract: Quadratic functions for estimating biomass yield were developed for 25-year-old *Eucalyptus camaldulensis* energy plantations, in a semi-arid region of northeastern Nigeria. Data obtained using the mean tree method were subjected to stepwise multiple regression analysis. Forty-eight (48) mean trees were clear-felled, separated into components and weighed fresh. Replicate wood discs and foliage samples were extracted fresh from tree components and dried in the oven until constant weight was attained. The fresh:dry weight ratio of the samples were used to estimate the dry biomass of the mean trees. The total aboveground biomass (TAGB) production per hectare was 256,245.08 kg. Mean TAGB per tree was 289.87 kg, biomass of the bole, branches, twigs and the foliage were 153.08, 85.52, 29.81 and 21.46 kg, respectively. Mean contribution of components to total above ground biomass were 52.82, 29.5, 10.28 and 7.4%, by the bole, branches, twigs and foliage respectively. Increases in dbh of the trees resulted in a corresponding increase in TAGB, total woody biomass, bole and biomass of the branches, but increases in twigs and foliage biomasses was less responsive to dbh. Dbh as the only measured independent variable explained a lot of the variation observed in yield. The combination of Dbh and Dbh^2 within the same models gave better estimations of biomass yield, than the use of Dbh only. The addition of a third variable Dbh^2H made only a slight improvement in a few of the models. For foliage biomass, dbh alone gave a good estimate, but the addition of another variable; number of large branches (NTBr) made an improvement. Results of residual analysis showed that the models satisfied all the assumptions of regression analysis.

Key words: Models % Biomass estimation % Arid % Energy plantation % Fuelwood

INTRODUCTION

It is widely opined that of all energy sources accessible by man, the most exploited is wood and by implication, the most disturbed sites are forests. Fuwape [1] showed that the progress of humanity from primitive times until now has been associated with dependence on wood and that its utilization is invariably indispensable, in both the history and the near future of humanity. An overriding concern of the nations of the world is that the small but crucial supplies of commercial energy as well as the noncommercial energy required for food production and domestic processes must be supplied [2]. This obvious need has instigated extensive deforestation in many parts of Nigeria, especially the arid regions in the Northeastern parts, which are characterised by marginal areas with low biological primary production. Many authors [3-5, 1] have asserted that there is no feasible alternative to sustainably managed forests as an energy source in areas as such, where the rate of consumption could sometimes be many times the rate of regeneration.

Planning for sustainability in energy plantations, requires careful assessment of possible biomass productivity, availability of adequate land and comparative costs/benefits in relation to competition with other land uses and the potential of the growing stock in providing efficient biofuels. It is pertinent that planners and managers concerned with energy plantations, make the most out of using management tools, such as mathematical models, especially in fragile and marginal ecosystems where less destructive inventory methods could be vital. In developing

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economies such as Nigeria's, the acquisition of efficient management tools is of high importance, since sustainable management of both existing and proposed forest plantations is largely dependent on reliable quantitative and qualitative assessments.

The most common procedure for estimating tree biomass in extensive land areas is by regression [6]. The efficacy of allometric equations in estimating and predicting the biomass of various species including *E. camaldulensis* have already been established by several authors [6, 7-18]. Allometry, which is the measure and study of growth or size of a part in relation to an entire organism [19] and multivariate allometry, which is the application of allometry to multiple components at once [10], could be very vital in the management of energy plantations, since most components of trees could be burned as fuel.

Energy plantations that are in most parts of the arid regions of Northeastern Nigeria are extensively stocked with *E. camaldulensis* [20]. This attests to the fact that *Eucalyptus,* a genus in the family *Myrtaceae* (native to Australia), has been successfully grown in most parts of the planet [21], mainly due to its great diversity and its ability to adapt to various environmental conditions. However, the sustainable management of these plantations in its ideal form is presently nonexistent in the study area, especially where it concerns the availability of management plans that are based on accurate estimator functions and predictive tools.

MATERIALS AND METHODS

Study Site: The assessment took place within *Eucalyptus camaldulensis* energy plantations located in Northeastern Nigeria: situated between latitudes 7° and 11° N of the equator and longitudes 11° and 14°E of the Greenwich meridian. Sunshine hours range from 2500-3000 hrs/annum, relative humidity range from 27 to 79, temperature range from 18.1°C to 39.6°C and mean annual rainfall is 910 mm [22]. The soil is predominantly vertisol; of ferruginous origin, derived from the basement complex in most places and in other places, from sandstones, shale and alluviums, which show a marked differentiation of horizons and an abundance of free iron oxides, usually deposited as red or yellow mottles or concretions [23]. Due to indiscriminate logging observed at some parts, the plantation was stratified into three: heavily disturbed, disturbed and undisturbed. Using a sampling intensity of 30%, twelve sample plots (0.0625 ha each) were randomly selected for assessment within the undisturbed area (8.67 ha). The stand used for this study was 25 years old.

Data Collection

Estimation of Dry Biomass: Using a uniform class interval, four basal area (BA) classes were established. All the trees in each BA class were normally distributed to locate the mean tree. In this way, four mean trees were assessed for each sample plot, resulting in 48 mean trees. Each mean tree was clear-felled and separated into components: bole, branches, twigs and foliage, weighed fresh. All twigs with diameter less than 1.0 cm were considered part of the foliage. Wood discs, 2.5 cm in diameter were extracted in three replicates from the base, middle and top of the bole and from the top and bottom of branches. Samples (15 cm long) were taken from five randomly selected twigs. Three 2.0 kg replicate samples were taken from the foliage of every tree. All samples were individually enclosed in polythene bags for laboratory analysis. All wood samples were dried in an electric oven at 103±2°C until constant weight obtained, while all foliage samples were dried at 65°C until constant weight was obtained. The fresh: dry weight ratios of the samples were used to convert the fresh biomasses of the trees and their components, into dry biomass estimates (anhydrous).

Regression Equations: A data set (variables in their original and transformed forms), referred to as the calibration set, was subjected to stepwise regression analysis and used to develop the equations. Afterwards, an independent set (validation set) was used to test the equations. Several models: simple linear, quadratic, semi-log and double log forms were fitted as appropriate making estimates for the whole tree and the various components. Dependent variables were: total aboveground biomass, woody biomass, branch biomass, twig biomass and foliage biomass. The independent variables that were tried (both in the original and in various transformed forms) while developing the models were; diameter at breast height (DBH), basal area (BA), merchantable height (MHt), total height (THt) and the number of large branches (NTBr).

The best prediction models were selected based on their Coefficients of Determination (R^2), Root Mean Square Error (RMSE), F-ratio from the regression Analysis of Variance (ANOVA) and the outcome of Residual Analysis. To validate the equations, the predicted values were compared with the observed values (validation set), by using the student t-test for paired means, to check for significant difference between the two sets. The differences (residuals) between predicted and observed values were expressed as percentages of the observed values, to give the percentage bias. Models that were

Table 1: Biomass and Charcoal yield of 25 year old *Eucalyptus camaldulensis* at Namtari Forest Reserve, Nigeria

Parameters	Woody Biomass Yield (kg)	% of TAGB
Mean Tree Components (kg treeG^{1})		
Bole	153.08±7.77	52.81
Branches	85.52±3.63	29.51
Twigs	29.81±1.36	10.28
Foliage	21.46±0.98	7.4
Total Aboveground Yield		
Woody components (kg treeG^{1})	268.41±12.29	
Aboveground (kg treeG^{1})	289.87±13.07	
Aboveground (kg plotG^{1})	18,841.55±355.88	
Aboveground (kg haG^{1})	256,245.08±1,393.86	

based on data sets that exhibited no significant difference (" = 0.05) were accepted as valid.

RESULTS

Aboveground Biomass Yield: The mean biomass yield of *E. camaldulensis* trees and tree components in the study area is presented in Table 1. Mean total above ground biomass (TAGB) was 289.87 kg (range: 176.66 to 409.48 kg. The highest accumulation of biomass was found to be in the bole, 153.08 kg (range: 86.15 to 270.13 kg), mean accumulation in branches was 85.52 kg (range: 48.11 to 152.42 kg), mean accumulation in twigs was 29.81 kg (range: 12.58 to 45.66 kg) while the least accumulation of biomass was in the foliage, 21.46 kg (range: 11.35 to 38.29 kg). Accumulation in foliage accounted for between 5.3 and 10.2% of the TAGB (average; 7.4%), bole biomass accounted for between 46.1 and 62.5% (average; 52.81%) of TAGB, branches accounted for between 19.2 and 38.2% (average; 29.51%), while the mean accumulation in twigs accounted for between 6.1 and 15.8% (average; 10.28%).

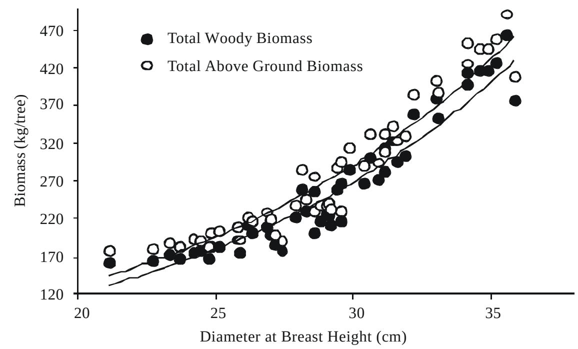

Fig. 1: Relationship between diameter at breast height (Dbh), total aboveground biomass and total woody biomass in Eucalyptus camaldulensis

A combination of the bole, branches and twigs resulted to mean total woody biomass of 268.41 kg, which was 92.3% of the TAGB (range: 161.19 to 376.67 kg). Table 1 also shows the proportion of TAGB stored in the various tree components: foliage, twigs, branches and bole. Generally, as the dbh of the trees increased, TAGB and total woody biomass also increased (Fig. 1). Figure 2 depicts the allometric relationships between diameter at breast height (dbh) and biomass accumulation in various components o f *Eucalyptus camaldulensis*. The trend was similar for the increases observed in the bole and in the branches (Fig. 2). For example, at the dbh of 21.1, 28.6 and 35.2 cm, bole biomass accounted for 48.77, 53.36 and 58.82% of TAGB, respectively. However, increases in the dbh of the trees resulted in slight corresponding increases in twigs and foliage biomasses (Fig. 2). The total aboveground biomass production per plot was 18,841.55 kg (size of plot = 0.0625 ha, spacing = 2.5 X 3.0 m and mean number of trees per plot = 65). The total aboveground biomass production per hectare was 256,245.08 kg (mean number of trees per hectare = 884).

Table 2: Allometric Models for Estimating Biomass Yield of *Eucalyptus camaldulensis*

Equation	Regression Summary Adj. R^2	RMSE	F-Ratio	Pr>| t |
Total Biomass = 982.8172 + 1.6828 Dbh^2 - 73.6403 Dbh	0.97	4.02	36.79	0.0001
Woody Biomass = 958.7776 + 1.6305 Dbh^2 - 72.0308 Dbh	0.97	4.37	55.68	0.0001
Bole Biomass = 629.0816 + 1.0661 Dbh^2 - 47.9262 Dbh	0.95	17.10	517.28	0.0001
Branch Biomass = 296.6772 + 0.4788 Dbh^2 - 21.4260 Dbh	0.91	15.85	535.39	0.0001
Twig Biomass = 32.2487 + 0.0851 Dbh^2 - 2.6308 Dbh	0.77	11.49	390.57	0.0001
Foliage Biomass = 3.7042 + 0.0023 $(Dbh^2)H$ - $0.3329e^{NTBr}$	0.66	7.65	183.00	0.0001
Foliage Biomass = 2.1086 + 0.0019 $(Dbh^2)H$	0.60	4.59	63.77	0.0001

Table 3: Validation results for best-Fit models for estimating biomass of tree components

Estimate	Observed Mean	Predicted Mean	% Bias	Pearson Correlation	t Statistic	# Sig.
Total Aboveground Biomass	304.27	323.61	5.98	0.969	-1.655	NS
Total Woody Biomass	282.10	299.32	5.75	0.971	-1.516	NS
Bole Biomass	164.82	172.58	4.50	0.981	-1.658	NS
Branch Biomass	85.76	94.66	9.40	0.646	-1.069	NS
Twig Biomass	31.65	32.30	2.01	0.844	-0.350	NS
Foliage Biomass	22.16	25.53	13.20	0.819	-1.990	NS
Foliage Biomass (one variable)	22.16	23.48	5.62	0.860	-0.892	NS

t- critical (two tail) = 2.365, * NS = Not Significant (p<0.01)

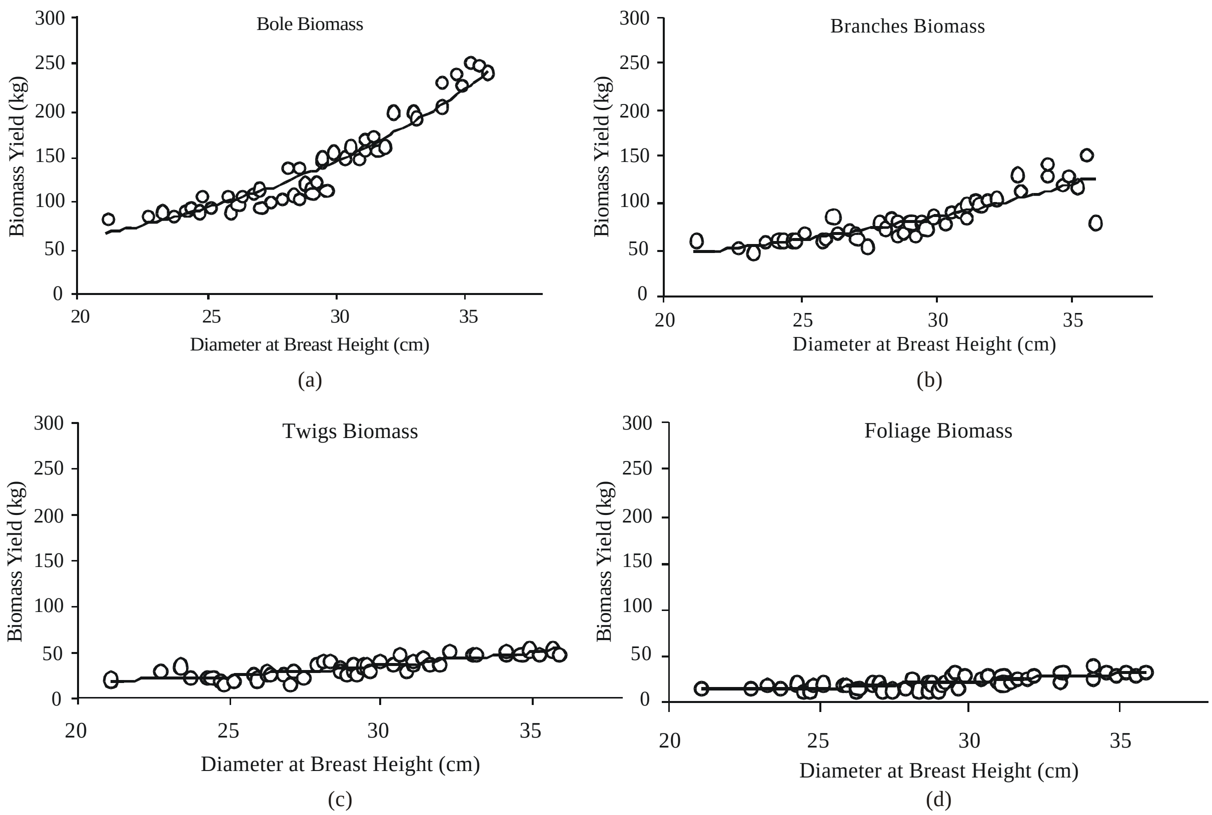

Fig. 2: Relationship between diameter at breast height (Dbh) and biomass of *Eucalyptus camaldulensis* tree components: bole (a), branches (b), twigs (c) and foliage (d)

The best models found for biomass estimation are shown in Table 2. All the models were significant at P<0.0001. Diameter at breast height (Dbh) gave better estimates when combined with its quadratic form (Dbh^2) in the same equation. The adjusted R^2 ranged from 0.97 to 0.60, the regression mean square error ranged between 4.02 to 17.10, while the F-ratio ranged from 36.79 to 535.39 (Table 2). For foliage biomass, a model that incorporated the number of large branches (defined as any branch whose diameter at 20 cm from insertion point is equal to or greater than half the bole diameter at breast height), gave a better estimate than the one that used only the product of Dbh^2 and height as the independent variable (Table 2). The result of the validation test is summarized in Table 3. For the total aboveground biomass, the mean of the observed values was 304.27 kg while the mean of the predicted values was 323.61 kg. This gave a bias of 5.98% and a correlation coefficient of 0.969. The calculated bias of predicted values from observed values, for biomasses of the bole, branches, twigs and foliage were 4.5, 9.4, 2.01 and 5.62%, respectively. The Pearson correlation coefficients obtained ranged from 0.65 to 0.98

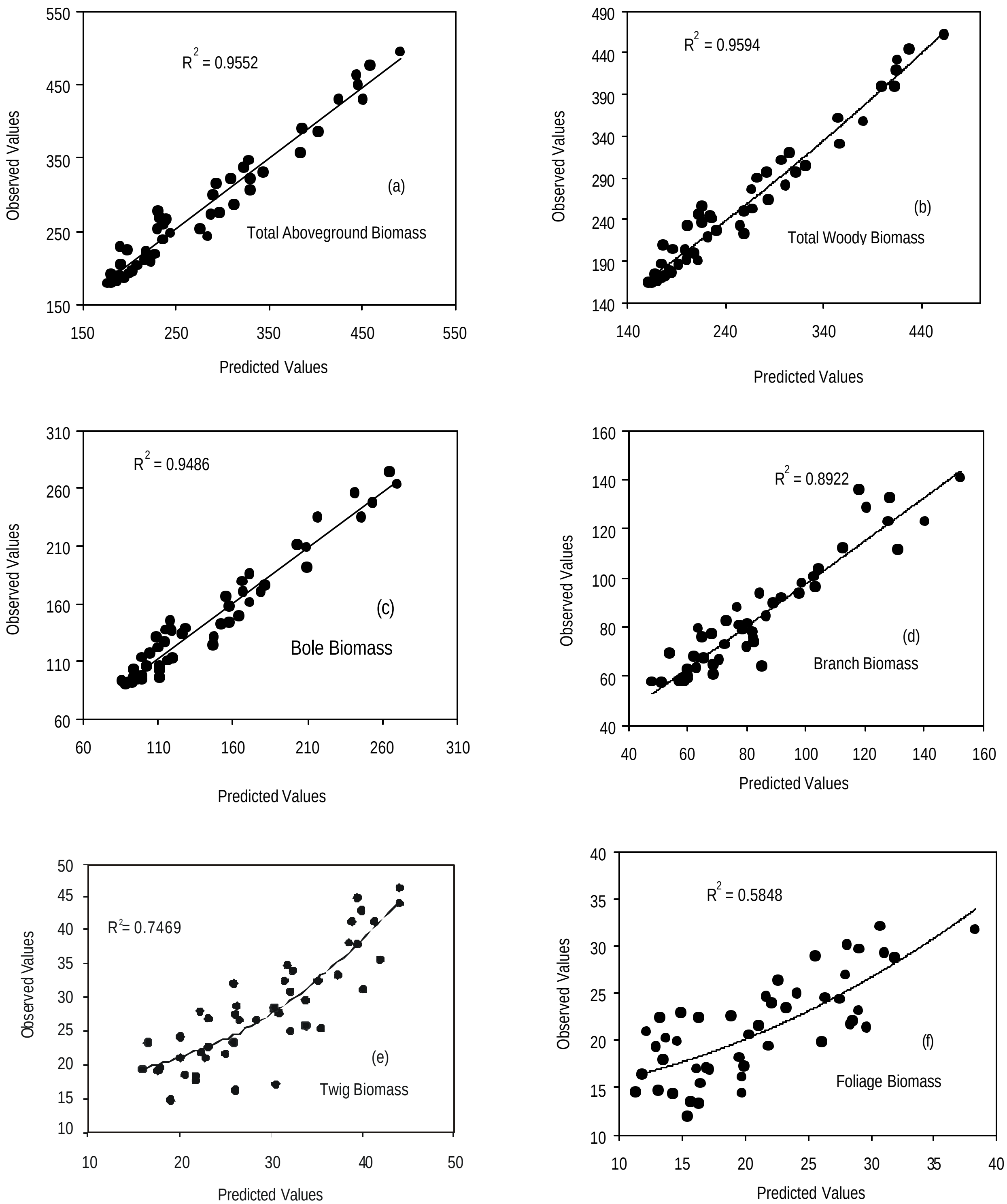

Fig. 3: Observed values vs Predicted Values: (a) Total Aboveground Biomass, (b) Total Woody Biomass, (c) Bole Biomass, (d) Branch Biomass, (e) Twig Biomass, and (f) Foliage Biomass

(Table 3). The t statistic showed that pair of observed and predicted values for all the models were not significantly different at P<0.01.

DISCUSSION

Biomass Yield: The major objective of establishing the *Eucalyptus camaldulensis* plantations in the study area was for the production of poles and energy. The results of this study indicate that the species is good for the management objective, because the dry biomass production per hectare is high: mean total aboveground biomass (TAGB) was 256.25 t ha^{-1} (Table 1). This value is high when compared with the value reported by Harmand *et al.* [24], 43.15 t ha^{-1} for a 10 year old *E. camaldulensis* stand. Mean accumulation per tree was also high, 289.87 kg (Table 1), when compared proportionally with the mean TAGB accumulation of 89.95 kg tree^{-1} reported by Deans *et al.* [15] for 10-year old stand and the 43.15 t ha^{-1} reported by Harmand *et al.* [24] for 7-year old stand in Cameroon. TAGB yield of *E. camaldulensis* in the study area also compared well with accumulation in other species of similar age: TAGB of 264.76 t ha^{-1} and 88.29 t ha^{-1} reported by Fuwape *et al.* [12] for *Gmelina arborea* and *Nauclea diderrichii* stands in South Western Nigeria. It was however less than the 394.9 t ha^{-1} TAGB yield reported by Onyekwelu [17] for 21-year-old *Gmelina arborea* plantations, also in South Western Nigeria.

The total woody biomass (a combination of the bole, branches and twigs) resulted to 92.3% of the TAGB. This large proportion of TAGB stored in the woody tree components of this species is of great potential for wood and energy production. The obvious implication being that, over 90% of each standing tree could readily be converted to fuel. The finding of this study agrees with the report of Fuwape *et al.* [12] for two other species, which showed that for both *Gmelina arborea* and *Nauclea diderrichii*, over 90% of the TAGB could be burned as fuel. Another possible implication is that where the boles are extracted for use as poles or timber, there would still be quite a lot of woody biomass to be burned for energy.

Most assimilates in *E. camaldulensis* in the study area were partitioned to the bole (52.81%). This was however less than the trend observed for two other species: *Gmelina arborea* and *Nauclea diderrichii*, where the stem contributed over 75% to the TAGB [12]. This difference is due to the presence of many large branches in *E. camaldulensis* trees. Most of the trees had up to three branches, each of which had diameter greater than half the bole diameter. The results of this study suggests that for this species, large branches constitute a major portion of the total aboveground biomass yield for individual trees (29.5%) and by implication, could affect stand estimation. Similar findings were reported by Brown and Lugo [25]; Flint and Richards [26]; lverson *et al.* [8], who have suggested that the presence or absence of trees with large diameter trees and branches influences the computation of total aboveground biomass yield, from forest inventories. Similar pattern between TAGB and proportion of TAGB due to large trees and large branches have also been observed for forests in Nigeria [26], in the Brazilian Amazon [25] and in Bangladesh [8]. The trend observed for the contributions of tree components to total biomass (Fig. 2) is similar with those obtained by Swamy *et al.* [16] (stem, 55.3-56.3%; branches, 18.3-19.8%; and foliage 6.6-7.0%); Onyekwelu [17] (stem, 84%; branch wood, 13% and foliage, 3%) and Harmand *et al.* [24] (stem 29.69 t ha^{-1}, twigs 5.07 t ha^{-1} , foliage, 3.06 t ha^{-1}).

Regression Equations: The amount of fuel obtainable from the plantation is expected to significantly differ for diameter groups, because of the highest influence of diameter at breast height observed in this study (clearly exemplified in the models developed). This finding corroborates the results of some earlier studies, such as Whitesell *et al.* [28], which indicated the pre-eminence of two equation forms (both double log) that used dbh and dbh plus height over others in predicting biomass yield of *Eucalyptus saligna.* Allometric functions developed by Harmand *et al.* [24] for estimating both aboveground and belowground biomass yield of *Eucalyptus camaldulensis* in Cameroon emphasized the import of dbh as an independent variable, while Tewari *et al.* [29], which presented growth and yield functions for plantations of *E. camaldulensis* in India, which used dbh along with height and age in exponential models.

Most of the models developed in this study used dbh doubly in the quadratic form within functions that were originally linear and those that were linearised by logarithimic transformation. In the multiple usage of dbh, the models were similar to those parametirised for *Eucalyptus camaldulensis* plantations in Brazil by Almeida *et al.* [30] and the second order and third degree polynomial equations developed by Sah *et al.* [18] for estimating aboveground biomass of broadleaved woody plants in the understory of Florida Keys pine forests.

In estimating the biomass yield of many other species, the use of dbh as a reliable estimator variable as found in this study has been shown by many authors: Newton and Jolliffe [31] (*Picea mariana*); Fuwape and Akindele [9] (*Gliricidia sepium*, *Leucaena leucocephala* and *Gmelina arborea*); Labrecque *et al.* [32] (*Salix viminalis*); Johansson [11] (*Alnus glutinosa*); Onyekwelu [17] (*Gmelina arborea*) and Fuwape *et al.* [12] (*Gmelina arborea* and *Nauclea diderrichii*).

Overall, an examination of all the models selected (Table 2 and Fig. 3) show well defined randomness and normality. This indicates that reliable estimates and predictions could be expected from them [33, 17] over the entire range of diameter classes observed in this study. The models developed corroborate the successful use of allometric models in many parts of the world [34, 31, 9, 35, 12, 17]. The adjusted coefficient of determination (R^2), the root mean square error (RMSE) and the F-ratio of allometric regression equations developed for estimating biomass yield (Table 2) and the depiction of the residuals (Fig. 3) show that the models are reliable. The addition of a third variable Dbh^2H which has been used successfully in many studies involving *Eucalyptus camaldulensis* [18, 36, 29, 37] made only a slight improvement in a few of the models.

CONCLUSIONS

The results of this study have shown that in both quantitative and qualitative terms, *Eucalyptus camaldulensis* trees in the study area are highly desirable for energy production. A large proportion of TAGB was stored in the woody tree components and thus is of great potential for wood and energy production using this species. The implication is that over 90% of each standing tree could readily be converted to fuel. The results of this study also suggests that for species such as *E. camaldulensis*, large branches constitute a major portion of the total aboveground biomass yield for individual trees and by implication, could affect stand estimation. The contribution of the branches and twigs to total biomass yield was very high, indicating that for this species, the branchwood and twigs should not be ignored when managing plantations for energy production.

Diameter at breast height (Dbh) as an independent variable, especially combined in its basic form and its quadratic form (Dbh^2) proved to be a very good estimator of biomass yield. Dbh as the only measured independent variable explained a lot of the variation observed in yield. The best-fit models found for biomass estimation were the quadratic models. Biomass accumulation responded well to increase in diameter, both for the whole tree and the components. Other independent variables (total height, merchantable height, number of large branches and basal area) were tried in various combinations: in original forms and when transformed, but none of them seemed to explain a significant portion of the variation observed in biomass yield, as much as dbh did. The low influence of height observed in *E. camaldulensis* in this study is probably because the trees used in the other studies were much younger (three to ten years), when height growth is more emphasized than diameter growth. For the trees used in this study (25 years), diameter is expected to be more closely related to biomass than in younger years. For foliage biomass, dbh alone would give good estimates, but where greater accuracy is required, the addition of another variable; number of large branches (NTBr) would make a significant improvement.

REFERENCES

1. Fuwape, J.A., 2001. Wood utilization from cradle to grave. Inaugural Lecture series, Federal University of Tech., Akure, Nigeria, pp: 32.
2. Hall, D.O. and J.I. Scrase, 1998. Will biomass be the environmentally friendly fuel of the future? Biomass and Bioenergy, 15(4/5): 357-367.
3. Fuwape, J.A. and J.C. Onyekwelu, 1995. The effect of uncontrolled fuelwood on the environment. UNESCO-MAB Regional training Workshop, Akure, Nigeria, pp: 239-244.
4. Food and Agricultural Organization (FAO), 1997. Forest Products Outlook. United Nations Food and Agricultural Organisation (FAO). Rome.
5. Tella, I.O. and J.A. Fuwape, 1998. Performance of a solar-heated kiln in Southern Nigeria. J. Appl. Trop. Sci., 3(8): 1-8.
6. Parresol, B.R., 1999. Assessing tree and stand biomass: A review with examples and critical comparisons. Forest Sci., 45(4): 573-593.
7. Brown, S., A.J.R. Gillespie and A.E. Lugo, 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia, 17(1): 8-18.
8. Iverson, L.R., S. Brown, Prasad H. Mitasova, A.J.R. Gillespie and A.E. Lugo, 1992. Use of GIS for Estimating Potential and Actual Forest Biomass for Continental South and Southeast Asia. In: Effects of Land Use Change on Atmospheric Carbon Dioxide Concentrations: Southeast Asia as a case study. V.H. Dale (Ed.). Springer-Verlag, New York.

9. Fuwape, J.A. and S.O. Akindele, 1997. Biomass yield and energy value of some fast growing multipurpose trees in Nigeria. Biomass and Bioenergy, 12(2): 101-106.
10. Broad, L.R., 1998. Allometry and growth. Forest Sci., 44(3): 40-46.
11. Johansson, T., 2000. Biomass equations for determining fractions of common and grey alders growing on abandoned farmland and some practical implications. Biomass and Bioenergy, 18: 147-159.
12. Fuwape, J.A., J.C. Onyekwelu and V.A.J. Adekunle, 2001. Biomass equations and estimation for *Gmelina arborea* and *Nauclea diderrichii* stands in Akure forest reserve. Biomass and Bioenergy, 21: 401-405.
13. Guo, L.B., R.E.H. Sims and D.J. Horne, 2002. Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand I: Biomass and nutrient accumulation. Bioresource Technol., 85: 273-283.
14. Klasnja, B., S. Kopitovic and S. Orlovic, 2002. Wood and bark of some poplar and willow clones as fuelwood. Biomass and Bioenergy, 23: 427-432.
15. Deans, J.D., J. Morgan and J. Grace, 1996. Biomass relationships for tree species in regenerating semi-deciduous tropical moist forest in Cameroon. For. Ecol. Manage., 88: 215-225.
16. Swamy, S.L., S.K. Kushwaha and S. Puri, 2004. Tree growth, biomass, allometry and nutrient distribution in *Gmelina arborea* stands grown in red lateritic soils of central India. Biomass and Bioenergy, 26: 305-317.
17. Onyekwelu, J.C., 2004. Above-ground biomass production and biomass equations for even-aged *Gmelina arborea* (ROXB) plantations in south western Nigeria. Biomass and Bioenergy, 26: 39-46.
18. Sah, J.P., M.S. Ross, S. Koptur and J.R. Snyder, 2004. Estimating aboveground biomass of broadleaved woody plants in the understory of Florida Keys pine forests. For. Ecol. Manage., (In Press).
19. West, G.B., J.H. Brown and B.J. Enouist, 1997. A general model for the origin of allometric scaling laws in biology. Science, 276: 122-126.
20. Akosim, C.I., I.O. Tella and D.F. Jatau, 1999. Vegetation and Forest Resources. In: Adamawa State in Maps. Adebayo A. A. and A. L Tukur (Eds.). Paraclete Publishers, Yola, pp: 112.
21. Fulkerson, D., 1996. Diversity and Distribution of *Eucalyptus*. In Australian Vegetation, 2nd Edn. R. H. Groves (Ed.) Cambridge: Cambridge.
22. Adebayo, A.A., 1999. Climate I: Sunshine, Temperature, Evaporation and Relative Humidity. In: Adamawa State in Maps. Adebayo A.A. and A.L. Tukur (Eds.). Paraclete Publishers, Yola, pp: 112.
23. Ray, H., 1999. Soils and erosion. In: Adamawa State in Maps. Adebayo, A.A. and A.L. Tukur (Eds.). Paraclete Publishers, Yola, pp: 112.
24. Harmand, J., C.F. Njiti, F. Bernhard-Reversat and H. Puig, 2004. Aboveground and belowground biomass, productivity and Nutrient accumulation in tree Improved fallows in the Dry tropics of Cameroon. For. Ecol. Manage., 188: 249-265.
25. Brown, S. and A.E. Lugo, 1992. The storage and production of organic matter in tropical forest and their roles in the global carbon cycle. Biotropioca, 14: 161-187.
26. Flint, E.B. and J.F. Richards, 1992. A Century of the Land Use Change in South and Southeast, Asia. In: Effects of the land use change in atmospheric carbon dioxide, concentrations: Southeast Asia as the Case Study. V.H. Dale (Ed.), Springer-Verlag, New York.
27. Akindele, S.O., 1990. Site quality assessment and yield equations for teak plantations in the dry forest area of Nigeria. Ph.D. Thesis, University of Ibadan, Ibadan, pp: 180.
28. Whitesell, C.D., S.C. Miyasaka, R.F. Strand, T.H. Schubert and K.E. McDuffle, 1988. Equations for predicting biomass in 2 to 6 year old *Eucalyptus saligna* in Hawaii. USA Dept. of Agric. Research Notes, pp: 1-5.
29. Tewari, V.P., A. Verma and V.S. Kishan-Kumar, 2002. Growth and yield functions for irrigated plantations of *Eucalyptus camaldulensis* in the hot desert of India. Bioresource Technology, 85: 137-146.
30. Almeida, A.C., J.J. Landsberg and P.J. Sands, 2004. Parameterisation of 3-PG model for fast-growing *Eucalyptus camaldulensis* plantations. For. Ecol. Manage., 193: 179-195.
31. Newton, P.F. and P.A. Jolliffe, 1993. Above-ground dry matter partitioning, size variation and competitive processes within second growth black spruce stands. Canadian J. Forest. Res., 23: 1917-1929.
32. Labrecque, M., T.I. Teodorescu and S. Daigle, 1997. Biomass productivity and wood energy of *Salix* species after 2 years growth in SCIR fertilized with wastewater sludge. Biomass and Bioenergy, 12(6): 409-417.
33. Vann, D.R., P.A. Palmiotto and G.R. Strimbeck, 1998. Allometric equations for two South American conifers test of a Non-destructive method. For. Ecol. Manage., 106: 55-71.

34. Kadeba, O., 1991. Above-ground biomass production and nutrient accumulation in an age sequence of *Pinus caribaea* stands. For. Ecol. Manage., 41: 237-248.
35. Claesson, S., K. Sahlen and T. Lundmark, 2001. Functions for biomass estimation of young *Pinus sylvestris*, *Picea abies* and *Betula* sp from stands in Northern Sweden with high sand densities. Scandinavian J. Forest Res., 16: 138-146.
36. Bhati, M. and G. Singh, 2003. Growth and mineral accumulation in *Eucalyptus camaldulensis* seedlings irrigated with mixed industrial effluents. Bioresource Technology, 88: 221-228.
37. Hunter, I., 2001. Aboveground biomass and nutrient uptake of three tree species (*Eucalyptus camaldulensis, Eucalyptus grandis* and *Dlabergia sissoo*) as affected by irrigation and fertilizer, at 3 years of age, in southern India. For. Ecol. Manage., 144: 189-199.