Prediction models for above-ground wood of some fast growing trees of Nepal's eastern Terai

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Biomass study of *Acacia auriculiformis, Acacia catechu, Dalbergia sissoo, Eucalyptus camaldulensis* and *Eucalyptus tereticornis* was conducted on a five and half years old 'Fuelwood Species Trial under Short Rotation' through destructive sampling at Tarahara, Sunsari District of Nepal. The lowest Furnival Index (FI) was the main criteria for selecting a model. Among the six models tested, the transformed model Ln W= a + b Ln DBH from a power equation W = a DBH^b (W = weights of stem or branch or above-ground wood in kg, DBH= Diameter at breast height in cm) was selected. Selected prediction models of tree components and above-ground wood (green as well as oven dry), and their coefficient of determination (R^2) values, regression constant and coefficient, correction factor, precision and bias percent of five species are presented. With the exclusion of branchwood models, R^2 is higher in a range of 88.7% for oven dry stemwood of *Acacia catechu* to 99.3% for above-ground wood model of *Dalbergia sissoo.* However, R^2 is less than 80% in branchwood (green and oven dry) of *Acacia auriculiformis*, *Eucalyptus camaldulensis*, and *Eucalyptus tereticornis* showing moderate relationship between branchwood and DBH. In the case of *E. tereticornis*, precision is more than 49% which leads to low reliability in biomass estimation resulting in true biomass deviation in a range of about 49.51% to 56.74%, so biomass model's could not be used for estimation of tree components and above-ground wood. Despite it, generally, precision percent of the selected models has been found less than 15%. Bias percent was found quite large for allometric branchwood model comparatively to stemwood and above-ground wood models. *D. sissoo* had less than 10 % bias. Bias percent was the highest (23.11%) for green branchwood of *Acacia auriculiformis.* Others had in a range of 0.5% for green aboveground wood model of *D. sissoo* to 18.4% for green and oven dry branchwood models of *E. tereticornis.*

Keywords: Prediction models, wood biomass, fast growing trees, Terai, Nepal

Estimation of biomass yield is an important tool in the management of forests both for the large scale plantations and the small village woodlot. The established plantations always require appropriate estimates of growth and production so that forest managers and plantations owners can make decisions for further planning and management. Growth models and development of biomass (stem, branch, above-ground wood, leaf, root) tables based on these may help quantify and compare firewood production of various fast growing tree species of a particular locality. Moreover, keeping in view of increasing number of Forest User Groups (FUGs) in the Terai, there is an acute need to develop an above-ground wood (stem and brance) model for established community plantations to quantify the wood biomass for distribution and sale. This will ensure the productivity of the site for further management.

The exiting situation of plantations based on short rotations in the Terai region is still in infancy (Hawkins 1987). Although, the Forestry Research and Sagarnath Forestry Development Projects have identified some promising fast growing firewood species for plantations and smaller community woodlots under short rotations (White 1986) in the Central Terai/Bhabar region of Nepal. However, the results of this region may not be applicable without verification for the eastern Terai where no biomass models for the fast growing tree species have been developed yet. And, to achieve it A Fuelwood Species Trial under Short Rotation' was set up in July 1985 at Tarahara in the eastern Terai With the five fast growing fuelwood tree species *Acacia auriculiformis*, *Acacia catechu*, *Dalbergia sissoo*, *Eucalyptus camaldulensis* and *Eucalyptus tereticornis.* It is expected that the result of the present study will fill the gap, in quantifying established plantations.

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Methods

The reliability of green weight regressions is higher when trees are harvested during the winter months. The data (DBH, height, green weights of stem and branch) were collected in January 1991 from five and half years old trees planted at a spacing of 2.5 m x 2.5 m at Tarahara (for description of the study site see Thapa,1998). Twenty trees each of *Acacia auriculi formis* and *Dalbergia sissoo*, twenty two trees of *Acacia catechu*, twenty one trees of *Eucalyptus camaldulensis* and seventeen trees of *Eucalyptus tereticornis* were cut down for this purpose from the four replicates.

Percentage dry matter values of the samples were used to convert fresh to oven dry weights for the general data for the development of oven dry wood models. Green weights of tree components were kept outside for about one month to find out the conversion factor to change green weight to air dry weight figures.

Regression analysis of variance was performed on six models using MINITAB for green and oven dry weights of tree components and above-ground wood of five species to find out the values of regression constant a and coefficient b, coefficient of determination (R^2), F-value, residual mean squares. The regressor variables used were diameter at breast height (DBH), square of DBH, square of DBH and height (D^2H), Ln DBH, Ln DBH and Ln height; DBH and height independently to find out the best model. The relation was determined to select the best fitted prediction equation for green and oven- dry weights of tree components and above-ground wood. This method was based on the assumption that the two variables are connected by a straight line relationship (Mountford and Bunce 1973).

The following six models (linear and allometric) were chosen on the use of these for biomass study by many researchers:

Model I W=a+bX (i)
Model II W=a+bXj + cX_2 (ii)
Model III W=a+bX^2 (iii)
Model IV W = a+bX (iv)
Model V W=a+X^b

After logarithmic transformation,
LnW = a'+bLnX (v)
Model VI Ln W = a' + b Ln X, + c Ln X_2.... (vi)

Where:
W= Estimated green or oven dry weight of tree components (stem and branch) and above-ground wood (stem plus branch) in kg.
X = Diameter at breast height in cm (overbark)
X] = Diameter at breast height in cm (overbark)
X_2= Total height (m) to the tip of tree a' = Ln a

In model IV
X = square of diameter at breast height (cm^2) times height (m) i. e. D^2 H

The standard deviation and coefficient of determination are not suitable to compare weighted and transformed models having different dependent variables (Unnikrishnan and singh 1984). So comparisons of the above six models were made by an index developed by Furnival (1961).

Since the logarithmic transformation changes the distribution of residuals causing a slight underestimation in biomass prediction (Meyer 1941; Baskerville 1972; Mountford and Bunce (1973), Pukkala *et al.* (1990), and Sprugel (1983), a correction factor was added to the equation as follows:
0= exp (S^2/2) i. e. $e^{S\,S/2}$

Where S^2 = residual mean square of the regression equation
0 = Correction factor

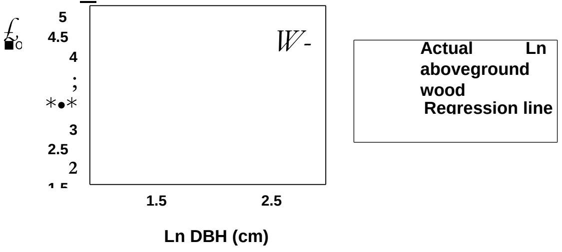
Bias (%) was calculated using the formula given by Brown (1976)

Uncorrected biomass (green and oven dry tree components and above-ground wood) was calculated using the model exp^a + b Ln DBH^ whereas corrected biomass was calculated using the model exp (a + b Ln DBH + c. f.) wjiere c> £ stands for correction factor (Annex 2).

Results

Close relationship were determined between the green and oven dry wood biomass of branches (including twigs without leaves), stemwood including bark and total above-ground wood respectively and the breast height diameter (logarithmic transformed) for all the five species.

Figure 1: Regression of Ln above-ground wood (green) 5 5 versus Ln DBH of *Acacia auriculiformis*



The transformed logarithmic model V, Ln W = a + b Ln DBH with DBH as independent variable was selected for biomass estimation of above-ground wood and tree components, since it has the lowest FI in most cases (Annex 1). The regression lines with observed values of green above-ground wood of *Acacia auriculiformis*, *A. catechu*, *D. sissoo* and *E. camaldulensis* are shown in figure 1 to 4. The actual green above-ground wood (AGW) weights of *A. auriculiformis* were found to be less than the predicted values in lower diameters (up to about 7.5 cm) indicating a slight bias. Actual green AGW weights of *A. catechu* were found more than the estimated values (13 out of 22 data i. e. 59% of the total sample data) in lower and higher diameters (Figure 2). Coefficient of determination (R^2) is higher in a range of 88.7% for oven dry stemwood of *A. catechu* to 99.3% for AGW of *D. sissoo* in selected regression equations. However, R^2 is less than 80% in branchwood (green and oven dry) of *A. auriculiformis*, *E. camaldulensis*, and *E. tereticornis* showing moderate relationship between branchwood and DBH (Annex 2).

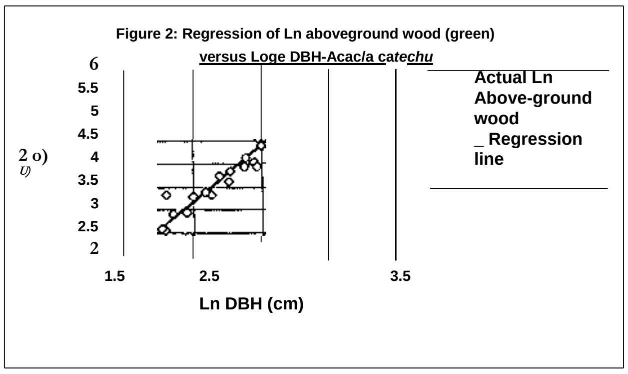
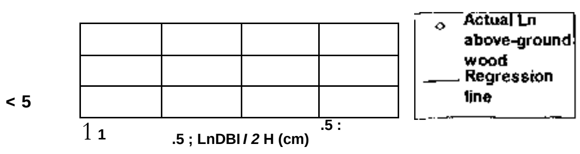


Figure 2: Regression of Ln aboveground wood (green) versus Loge DBH-Acacia catechu

The inclusion of height as an additional variable did not improve the precision as well as R^ and residual mean squares significantly, and similar case for exclusion of outliers. Bias percent was quite large for allometric branchwood model in comparison to stemwood and AGW models. *D. sissoo* had less than 10 % bias. Bias percent was the highest (23.11%) for green branchwood of *A. auriculiformis*. Others had in a range of 0.5% for green AGW model of *D. sissoo* to 18.4 for green and oven dry branchwood models of *E. tereticornis* (Annex 2).

figure 3: Regression of Ln above-ground wood (green) versus Ln DBH of *Dalbergia sissoo*



With the exclusion of *E. tereticornis*, precision percent ranged 11.28 for green stemwood of *Acacia catechu* to 16.24 for oven dry stemwood of *D. sissoo*, 14.20 for oven dry branchwood of *E. camaldulensis* to 19.62 for green branchwood of *D. sissoo*, 12.84 for green AGW of *A. catechu* to 16.81 for oven dry AGW of *D. sissoo*. Precision percent of branch wood models was found quite lower than the models of stemwood and AGW. Precision percent of selected models used for branch, stem wood and AGW (green and oven dry) of *E. tereticornis* was found more than 49 percent (Annex 2) resulting in an unreliable estimates of tree components and AGW.

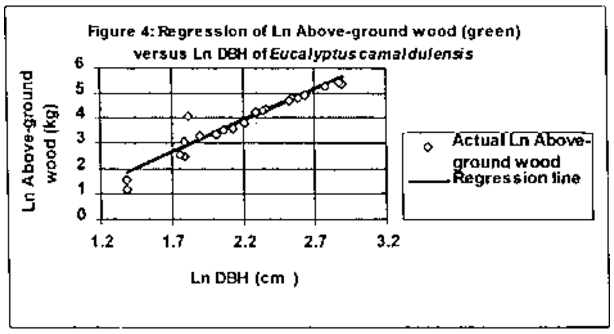


Figure 4: Regression of Ln Above-ground wood (green) versus Ln DBH of *Eucalyptus camaldulensis*

Discussions

Hawkins (1987) useing both DBH and height as predictor variables for biomass estimation of some species in the Central/Bhabar Terai of Nepal, he found that measurement of total height was time consuming and also created large errors. There was only a small increase in the precision of regressions with the inclusion of height, while the time increased three times due to height measurement in the field inventory. DBH is the preferred predictor variable of biomass per unit area for practical reasons and simplicity of measurement in the field (Applegate *et al.* 1988). An additional variable height is not necessary as a predictor variable from the cost point of view, if equally efficient prediction models are available with DBH alone (Tondon *et al.* 1988). Obviously, various researchers findings clarify the benefit of using predictor variable DBH alone.

So far the biomass equation (Ln W = a + b Ln DBH) could be used elsewhere for these species with conditions similar to Tarahara, but may not be appropriate to a wide geographical area. However, these equations need to be tested for validation by destructive sampling for each of these species but prediction error should be under 15 % (Hawkins 1987) of actual weights. If the prediction error is within 15 % of the actual weights, the models can be used safely in that place. Oven dry and green wood biomass models are produced for single tree species separately but not for mixed stands. No such mixed plantations in large scale have yet been established at the district level, however, such models may have importance in future. On the one hand, wood biomass models developed using the single predictor variable, DBH, which could be measured easily with less error than height, may increase the utility of these models to develop weight tables to the forestry sector as well as to the community and interested individuals. On the other hand, single tree biomass tables developed using DBH as the only variable have been found to be reliable for undamaged trees of a number of species in Nepal (Raeside 1986 quoted in Thompson 1990; Hawkins 1987). However, the benefit of DBH use lies in the fact that if the relationship (weight and DBH) is valid for a sufficiently large plantation area and if it does not change over a period of time, then the model can be used in subsequent inventories. Again this relationship breaks down if the tree has been lopped or pruned, in such situations, a new set of models for the development of biomass tables are essential for the pruning operation (Thompson 1990).

The above equetion is necessary to change the nonlinear power equation ($W = a\ \text{DBH}^{11}$) to a linear form. Moreover, in the above power equation, the relation between W and DBH is non-linear, the transformed variables Ln W and Ln DBH are connected by the straight line relationship (Mountford and Bunce 1973). For weighted and transformed models with different dependent variables, the standard deviation and coefficient of determination are not suitable to compare these models (Unnikrishnan *et al.* 1984). In such case, Furnival Index can be used for comparing and selecting the models with the lowest FI. It has the concept of maximum likelihood and reflects both the size of residuals and possible departures from linearity, normality and homoscadasticity (Mohd 1988).

The precision is lower in the equation of branchwood of *A. catechu* and *D. sissoo* except *E. tereticornis* as compared to the stemwood and AGW equation. It is subjected to large variation in the sample data from the mean (i.e. standard error of the mean being large). In the case of *E. tereticornis*, it is more than 49% which accounts for low reliability in biomass estimation resulting in true biomass deviation in a range of about 49.51% to 56.74% (Annex 2). The sample data of this species did not represent the 10-15 cm diameter class. Due to a big gap in the sample data and low precision of the selected models, biomass tables need to be developed only after validation. Biomass estimation in other species is reasonably accurate, since precisions are mostly under 15 % i.e. actual yields are within 15 % of the estimated wood biomass. Before using the air dry weight conversion factors for stem and branchwood of these five species, they may need to be verified for confirmation, if the duration of drying for green stem and branchwood of these species is less than or more than one month, or samples are dried, or are in large quantity, etc.

Most of the equations of tree components and AGW consists of a coefficient of determination greater than 90% indicating a strong relationship between tree DBH and component weights and AGW.

However, R^ in branchwood equation of *A. auriculiformis, E. camaldulensis* and *E. tereticornis* was found to be quite low, which indicates a reasonable relationship between branch weight and DBH. Furthermore, it indicates more variability in the form of trees. The general assumption of increasing branchwood with the increase in size of trees is not true here.

The predictive biomass equations developed in this paper are an early attempt to estimate the tree components of these species in the eastern Terai of Nepal. As suggested by Hawkins (1987) the models need to be revised and improved in due course when more data and new establishment methods and management techniques will be developed. However, these models have importance in providing reliable estimates of existing plantations of these species at present.

Conclusions and recommendations

Selected model Ln W = a + b Ln DBH (green as well as oven dry) would be valuable for forest managers, Forest User Groups and private growers to quantify the yield in their plantations managed on short rotations in the eastern Terai to make informed decisions for further management, distribution, and sale of products. But, it is necessary to validate these models before using them elsewhere. If the prediction error is within 15 % of the actual weights, the models can be used safely in that place. Due to low precision of the regression models of tree components and AGW (oven dry and green) of *£. tereticornis*, caution should be taken in the apply these models elsewhere. The models need to be tested and improved in due course time when new management methods and management techniques will be developed.

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Annex 1: Furnival indices for six models of oven dry weights of four species

Models are as follows:

Model I: $W = a + b D$
Model II: $W = a + bD + cH$
Model III: $W = a + b D^2$
Model IV : $W = a + b D^2H$
Model V: $\text{Ln } W = a + b \text{ Ln } DBH$
Model VI: $\text{Ln } W = a + b \text{ Ln } DBH + c \text{ Ln } H$

Where: W = tree component weights; DBH = diameter at breast height (cm); H = intercept; b = slope total height (m); a =

Species		Models					
		I	II	III	IV	V	VI
Acacia auriculiformis	Stem wood	6.02	5.79	6.28	4.25	3.34	2.18
	Branch wood	5.61	___	15.90	19.26	2.08	2.13
	Above-ground wood	5.30		3.99	4.13	3.41	2.46
Acacia catechu	Stem wood	5.96	6.11	4.47	4.20	4.15	4.49 ,
	Branch wood	6.52	5.83	4.45	5.26	1.74	1.75
	Above-ground wood	10.77	10.49	5.74	7.00	5.41	5.44
Dalbergia sissoo	Stem wood	3.59	3.69	1.82	1.45	1.44	0.73
	Branch wood	2.33	2.01	1.62	1.90	1.00	1.00
	Above-ground wood	5.12	5.13	1.73	1.97	1.37	0.93
Eucalyptus camaldulensis	Stem wood	6.78	6.89	5.10	5.10	4.90	4.85
	Branch wood	1.40	1.31	1.31	1.45	0.79	0.89
	Above-ground wood	6.85	6.83	4.79	5.20	4.60	4.70

Furnival indices for six models of green weights of five species

		I	II	III	IV	V	VI
Acacia auriculiformis	Stem wood	14.10	13.60	14.70	10.00	7.80	14.70
	Branch wood	13..08	12.05	11.71		4.85	4.92
	Above-ground wood	12.41	12.73	9.33	9.64	8.00	5.66
Acacia catechu	Stem wood	12.92	13.27	9.70	9.73	9.65	9.50
	Branch wood	14.93	13.35	10.20	12.04	3.94	3.92
	Above-ground wood	24.12	23.39	12.81	15.72	6.55	6.56
Dalbergia sissoo	Stem wood	11.70	11.70	4.00	4.47	3.13	2.12
	Branch wood	5.34	4.60	121	4.32	2.41	2.41
	Above-ground wood	8.16	8.40	4.13	2.75	2.60	1.58
Eucalyptus camaldulensis	Stem wood	16.24	16.43	12.23	12.23	5.50	13.75
	Branch wood	16.46	16.33	11.39	12.47	10.60	14.32
	Above-ground wood	3.60	3.38	3.40	3.73	2.06	2.09
Eucalyptus tereticornis	Stem wood	15.78	14.73	6.00	2.00	1.92	1.08
	Branch wood	5.43	4.73	3.05	1.97	1.05	0.06
	Above-ground wood	21.07	19.36	8.77	2.83	1.94	1.53

Single underline indicates the lowest Furnival Index followed by the second lowest by double underline.

Annex 2: Intercept, slope, R , precision (%), correction factor, bias (%) and conversion factor from green weight to air dry and oven dry weight

Regression model for green and oven dry weight for all species: Ln W = a + b Ln DBH,
where:
DBH = Diameter at breast height (cm)
W = Weights of tree components and above-ground wood

Species	**Green weight**			**Oven dry weight**		
Acacia auriculiformis	**Stem**	**Branch**	**Stem + Branch**	**Stem**	**Branch**	**Stem + Branch**
Intercept	-1.64	-3.97	-1.63	-2.49	-4.85	-2.48
Slope	2.28	2.75	2.40	2.28	2.76	2.41
R^2 (%)	92.5	77.7	95.9	92.4	77.6	95.9
Precision (%)	13.02	16.46	13.85	13.04	16.6	13.95
Correction Factor (s.e.^{2}/2)	0.041	0.211	0.024	0.041	0.213	0.024
Bias (%)	4.0	23.1	2.4	4.1	19.2	2.4

Conversion factor for green to oven dry weight		Conversion factor for green to air dry weight	
Stem	Branch	Stem	Branch
0.426	0.429	0.74	0.57

Species	**Green weight**			**Oven dry weight**		
Acacia catechu	**Stem**	**Branch**	**Stem + Branch**	**Stem**	**Branch**	**Stem + Branch**
Intercept	-4.300	-6.02	-1.517	-2.15	-6.91	-2.51
Slope	0.434	3.56	2.33	2.17	3.58	2.43
R^2 (%)	95.3	87.9	92.0	88.7	87.6	92.7
Precision (%)	12.3	19.51	14.50	11.35	19.55	15.10
Correction Factor (s.e.^{2}/2)	0.0405	0.118	0.0318	0.0405	0.1225	0.0314
Bias (%)	4.0	11.1	11.1	4.0	11.2	11.2

Conversion factor for green to oven dry weight		Conversion factor for green to air dry weight	
Stem	Branch	Stem	Branch
0.460	0.437	0.52	0.67

Species	**Green weight**			**Oven dry weight**		
Dalbergia sissoo	**Stem**	**Branch**	**Stem + Branch**	**Stem**	**Branch**	**Stem + Branch**
Intercept	-2.30	-5.12	-2.28	-3.15	-5.88	-3.13
Slope	2.58	3.25	2.69	2.59	3.22	2.70
R^2 (%)	98.7	93.0	99.3	98.7	93.7	99.3
Precision (%)	16.16	19.62	16.73	16.24	19.23	16.81
Correction Factor (s.e.^{2}/2)	0.0055	> 0.0895	0.0055	0.010	0.078	0.0055
Bias (%)	0.6	8.9	0.5	0.9	7.5	0.6

Conversion factor for green to oven dry weight		Conversion factor for green to air dry weight	
Stem	Branch	Stem	Branch
0.438	NA	0.79	0.68

Species	Green weight			Oven dry weight		
Eucalyptus camaldulensis	Stem	Branch	Stem + Branch	Stem	Branch	Stem + Branch
Intercept	-1.9353	-3.57	-1.739	-2.8094	-4.52	-2.6204
Slope	2.5799	2.25	2.539	2.5806	2.24	2.5397
R^2 (%)	91.1	79.5	92.0	91.1	79.5	92.1
Precision (%)	14.65	15.80	14.50	14.89	15.75	14.40
Correction Factor (s.e.^{2}/2)	0.0694	0.138	0.0595	0.0690	0.138	0.0588
Bias (%)	6.7	12.9	5.8	6.7	12.6	5.7

Conversion factor for green to oven dry weight		Conversion factor for green to air dry weight	
Stem	Branch	Stem	Branch
0.418	0.387	0.62	0.55

Species	Green weight			Oven dry weight		
Eucalyptus tereticornis	Stem	Branch	Stem + Branch	Stem	Branch	Stem + Branch
Intercept	-2.03	-4.53	-1.91	-3.02	-5.53	-2.90
Slope	2.47	2.75	2.49	2.47	2.75	2.49
R^2 (%)	98.2	80.5	98.7	98.2	80.5	98.7
Precision (%)	50.79	56.74	51.24	49.51	56.09	50.60
Correction I Factor (s.e.^{2}/2)	0.012	0.2035	0.0095	0.0125	0.2035	0.0095
Bias (%)	1.3	18.4	0.9	1.2	18.4	0.9

Conversion factor for green to oven dry weight		Conversion factor for green to air dry weight	
Stem	Branch	Stem	Branch
0.37	NA	0.61	0.58

NA - Not available