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Development and validation of generalized biomass models for estimation of carbon stock in important agroforestry species

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ABSTRACT: Estimation of biomass/wood production from timber species like *Acacia nilotica*, *Dalbergia sissoo* and *Tectona grandis* is required for research and merchant purposes. Accurate estimation of biomass can be done through destructive sampling, but that is cumbersome exercise. Alternatively, one can develop regression equations using easily measurable parameter like diameter at breast height (DBH). Usually biomass models are developed with the help of tree data for a particular location/area. Therefore, these models may not suitably be applied to other locations, as growth behavior of trees on other locations are not accounted for. In present study, generalized models for *A. nilotica*, *D. sissoo* and *T. grandis* have been developed and validated using available biomass equations, secondary data and primary data. The developed regression models were also validated on an independent dataset and found statistically good fit. In case of *A. nilotica*, model $B = 0.360\ D^{1.598}$ ($R^2 = 0.926$), for *D. sissoo*, exponential model $B = 3.084\ e^{0.172D}$ ($R^2 = 0.924$) and for *T. grandis*, parabolic model $B = -22.262 + 2.845\ D + 0.115\ D^2$ ($R^2 = 0.951$) were found good fit; where, B- biomass (kg tree^{-1}) and D- DBH (cm). On validation, these models gave an error of 0.536, 2.419 and 3.896 kg tree^{-1}, respectively in prediction of biomass. Hence, these models may be used for estimating biomass of *A. nilotica*, *D. sissoo* and *T. grandis* plantations in different regions.

Key words: *Acacia nilotica*, *Dalbergia sissoo* and *Tectona grandis.*

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1. INTRODUCTION

Acacia nilotica, a nitrogen fixing legume tree, is widely spread in Africa and Asia. It is complex species with nine sub-species, of which six are native to the African tropics and other three are native to the Indian subcontinent. It is considered as a very important economic plant species since early time as a source of tannins, gums, timber, fuel, fodder and medicines. The main advantage of this genus is its fast biological nitrogen fixation, ability to establish on nitrogen-deficient and drought prone soils and suitability for agroforestry systems. *Dalbergia sissoo*, a multipurpose tree species produces nitrogen-rich fodder and green manures, high quality fuelwood, strong durable poles and beautiful dark brown wood for furniture and paneling (Sharma *et al.*, 2007). It is also used in agroforestry system to protect soil, improve crop production (due to nitrogen fixation) and provide long-term financial security. These characteristics make *D. sissoo* a popular species for afforestation, industrial plantations and agroforestry planting (Karki *et al.*, 1994). *Tectona grandis* is an important timber species which has multiple end uses like furniture, construction, decorative veneer, railway sleepers etc. (Bhat, 2000). Today teak ranks among the top five tropical hardwood species in terms of plantation area worldwide (Krishnapillay, 2000).

Singh and Tokey (1995) developed allometric equations, which were used for estimation of biomass and net primary productivity of *A. nilotica* trees planted in energy plantations in arid region of Hisar district in Haryana. Tewari and Singh (2006) developed provisional equations for total and merchantable wood volume of *A. nilotica* trees in Gujarat state. Rizvi *et al.* (2014) developed non-linear models for branch, stem and total wood biomass of *A. nilotica* for semi-arid region. Rizvi *et al.* (2008) constructed linear and non-linear models for stem and aboveground wood biomass of *D. sissoo* using D and D^2H as predictor variables and found Logistic and linear models as best fit. But models fitted using 'D^2H' were better than those fitted using 'D'. Goel and Singh (2008) and Tyagi *et al.* (2009) also developed biomass models for *D. sissoo* for Uttar Pradesh. Buvaneswaran *et al.* (2006) developed and validated biomass models for *T. grandis* for western and southern zones of Tamil Nadu, which were used for estimating biomass in different components (foliage, branch and stem). All these developed models are either location specific or region specific, but no such models for any tree species are available which can be used for different regions. Keeping this in view, an attempt was made to develop generalized biomass models for *A. nilotica*, *D. sissoo* and *T. grandis*. These models were statistically validated on independent dataset to make them useful for different regions.

2. MATERIALS AND METHODS

Biomass equations for *A. nilotica*, *D. sissoo* and *T. grandis* available in the literature were searched. A total of six equations on wood biomass of *A. nilotica* were found in the literature, two each for Haryana, Uttar Pradesh and Karnataka. These equations pertain to Hisar in Haryana and Jhansi in Uttar Pradesh (Table 1). Total four equations each for stem/bole biomass and stem volume for *D. sissoo* were found in the literature. Out of four, three equations were for Uttar Pradesh and one for Rajasthan (Table 2). Only two equations were found in literature on bole biomass of *T. grandis*, one for Madhya Pradesh and other for Tamil Nadu (Table 3).

In all these equations, diameter at breast height (DBH) was used as independent variable for predicting bole or aboveground biomass of three species. From the available equations, simulated dataset on DBH and biomass were generated. This simulated data together with available primary data was used for developing generalized models. Non-linear type of equations *viz*., $B = a. D^b$, $B = a. e^{bD}$, $B = a + bD^2$ and $B = a + b_1D + b_2D^2$ were fitted using SYSTAT 15.0 software. These developed models were compared on the basis of adjusted R^2 and root mean square error (RMSE). For validation of these models, an independent dataset for Jhansi, Hisar and Pantnagar available with the authors was used. Mean prediction error (MPE) was calculated, model which gave least MPE was finally selected out of fitted models. For calculation of carbon stock in biomass, carbon content for *A. nilotica* (48%), *D. sissoo* (48%) and *T. grandis* (47%) was taken from Negi *et al.* (2003).

3. RESULTS AND DISCUSSION

Generalized models for wood biomass of *A. nilotica*

DBH range for equations of Karnataka was 6.45-10.77 cm, with the simulated data set of DBH and biomass, an equation of type $B = a. D^b$ was fitted. The model $B = 0.0109\ D^{3.2408}$ was found good fit with R^2

Table 1. Biomass equations for *Acacia nilotica* found in literature

Equation (s)	DBH range (cm)	Reference/Region
$B = 3.3092\ D - 18.553$	6.45 - 10.77	Raizada *et al.* (2007)/Karnataka
$B = 6.9319\ D - 43.731$	6.45 - 10.77	
$B = 1.879\ D - 6.459$ (4-yr old)	3.70 - 9.90	Singh and Tokey (1995)/Hisar, Haryana
$B = 2.325\ D - 9.071$ (8-yr old)	4.00 – 18.30	
$B = -0.519 - 0.065\ D + 0.557\ D2$	1.20 – 9.30	Rizvi *et al.* (2014)/Jhansi, U.P.
$B = 72.428\ (1 - e^{-.202D})^{3.648}$	1.20 – 9.30	

B- Wood biomass (kg tree^{-1}); D- Diameter at breast height (cm)

Table 2. Biomass equations for *Dalbergia sissoo* found in literature

Parameter/ DBH range	Biomass equation	Reference/ Region
Bole/ Stem [8.40 – 17.50 cm]	$B = 4.608 \exp (0.599\ e^{0.085D})$	Rizvi *et al.* (2008)/Uttar Pradesh
Aboveground biomass	$B = 6.442\ e^{0.156D}$	
Bole/ Stem [2.5-12.1 cm]	$B = -0.247 + 18.40\ D^2$	Goel and Singh (2008)/Rajasthan
Bole/ Stem [1.21-12.52 cm]	$\text{Log}\ B = 1.184 + 3.071\ \text{Log}\ D$	Tyagi *et al.* (2009)/Uttar Pradesh
Above ground biomass	$\text{Log}\ B = 1.536 + 2.929\ \text{Log}\ D$	

Table 3. Biomass equations for *Tectona grandis* available in literature

Parameter/ DBH range	Biomass equation	Reference/Region
Bole biomass	$Y = 0.025\ X^{2.817}$	Buvaneswaran *et al.* (2006)/
	$Y = 0.0581\ X^{2.523}$	Tamil Nadu
	X – DBH	
Aboveground	$Y = 0.025\ X^{2.817}$	
	$Y = 0.0581\ X^{2.523}$	
Bole biomass	$\text{Log}\ Y = -2.85 + 2.655 \log X$	Kale *et al.* (2004)/
	X- circumference at breast height	Madhya Pradesh

value of 0.715. Therefore, this fitted model may be used for estimating biomass of *A. nilotica* trees in Karnataka. Similarly, simulated data set for Haryana was used for fitting generalized biomass model of *A. nilotica*. The fitted model $B = 0.2372\ D^{1.7248}$ was found good fit with R^2 value of 0.987 for estimating biomass of *A. nilotica* trees for DBH range of 3.70-9.90 cm. Similarly, simulated data set for Uttar Pradesh was used for fitting generalized biomass model of *A. nilotica*. The fitted model $B = 0.7646\ D^{1.7913}$ was found good fit with R^2 value of 0.994 for estimating biomass of *A. nilotica* trees for DBH range of 1.20-9.30 cm.

Three datasets simulated from state level equations were pooled to get a single dataset on DBH and timber biomass. This dataset was used for developing country level generalized models for wood biomass of *A. nilotica*. High correlation coefficient between DBH and timber biomass (0.909) indicated that DBH would be good predictor of biomass. Three types of models were fitted (Table 4) but the model $B = 0.3601\ D^{1.598}$ was found good fit ($R^2 = 0.926$, RMSE= 3.939). The developed model was validated on an independent data set for predicting biomass (Figure 1). Mean prediction error was found to be 0.54 showing that this model will give an error of 0.54 kg in prediction of biomass. Thus, this model may be used for predicting wood biomass of standing *A. nilotica* trees for the DBH range of 1.20-9.90 cm.

Generalized models for stem biomass of *D. sissoo*

From available equations, dataset on DBH, stem biomass and stem volume were simulated. DBH has strong correlations with both stem biomass (0.923) and stem volume (0.921). The DBH ranged from 2.5 to 17.5 cm and stem biomass ranged from 0.90 to 65.30 kg. Three types of non-linear equations were fitted for stem biomass and found that exponential equation $B = 3.084\ e^{0.172D}$ has lowest RMSE (4.375) and highest value of adjusted R^2 (Table 4). Fitted equation was also validated on an independent dataset and MPE was calculated. Exponential equation has the lowest MPE of 2.419 i.e. there will be an error of about 2.42 kg in prediction of stem biomass (Figure 2). Thus, this model may be used for estimating stem wood biomass of standing *D. sissoo* tree on the basis of DBH for range of 2.5-17.5 cm.

From simulated dataset on DBH and stem volume, three non-linear models have been fitted. Parabolic equation found to be the best in terms of mean square error (0.0001) and adjusted R^2 (0.949). Therefore, the developed model $V = 0.024 - 0.005\ D + 0.001\ D^2$ may be used for prediction of wood volume of *D. sissoo*. But this model needs to be validated on an independent dataset for evaluating its prediction error.

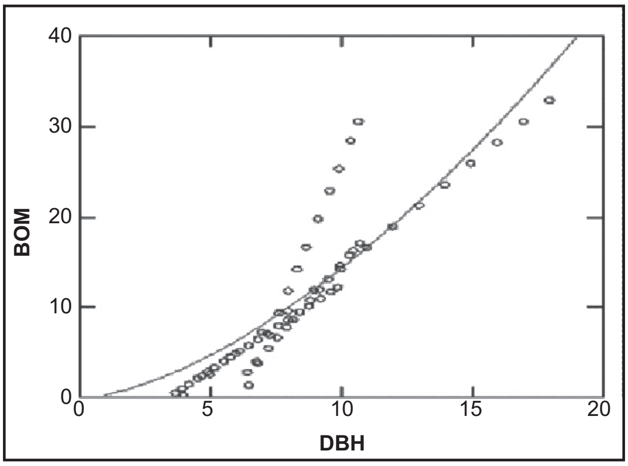

Fig. 1. Fitted generalized model for wood biomass of *Acacia nilotica*

Table 4. Fitted statistics for generalized biomass models for *A. nilotica, D. sissoo* and *T. grandis*

S. No.	Fitted equation	Adjusted R^2	RMSE	MPE
Acacia nilotica				
1.	$B = 0.360\ D^{1.598}$	0.926	3.939	0.536
2.	$B = 3.313\ e^{0.137\ D}$	0.894	4.702	0.614
3.	$B = -13.851 + 3.382\ D - 0.043\ D^2$	0.921	4.311	0.578
Dalbergia sissoo				
1.	$B = 0.105\ D^{2.209}$	0.917	4.588	2.591
2.	$B = 3.084\ e^{0.172D}$	0.924	4.375	2.419
3.	$B = 4.892 - 1.226\ D + 0.245\ D^2$	0.917	4.619	2.617
Tectona grandis				
1.	$B = -4.244 + 0.222\ D^2$	0.947	4.061	4.108
2.	$B = -22.262 + 2.845\ D + 0.115\ D^2$	0.951	3.932	3.896
3.	$B = 0.121\ D^{2.1861}$	0.943	4.225	4.438

RMSE- Root mean square error; MPE- Mean prediction error

Generalized models for stem biomass of *T. grandis*

Three types of non-linear equations were fitted for bole/stem biomass of *T. grandis* (Table 4). Out of three, parabolic model B = -22.2616 + 2.8447 D + 0.1152 D^2; where B- biomass (kg $tree^{-1}$) and D - DBH; was found best fit because it has highest value of R^2 (0.951) and lowest value of RMSE (3.932). These models were validated on an independent dataset and MPE was computed. The parabolic model gave smallest MPE of 3.896 among three, indicating that there will be an error of 3.896 kg in prediction of stem biomass. Thus, developed generalized model may be used for estimation of stem biomass of *T. grandis* for any region.

Estimation of carbon stock in *A. nilotica* trees

With the help of generalized models for wood biomass, the carbon stock under *A. nilotica* trees were estimated using the following approaches: i) aboveground biomass was calculated by taking stem biomass as 45% of aboveground biomass (Raizada *et al*., 2007), ii) both stem and aboveground biomass were converted into dry biomass by multiplying with 0.6 (considering 40% moisture loss), and iii) carbon stock in stem and aboveground biomass was calculated by formula C = 0.48 B, where C– carbon stock (kg $tree^{-1}$) and B- biomass (kg $tree^{-1}$).

Carbon stock in stem and aboveground biomass was estimated to be 2.83 and 4.01 kg $tree^{-1}$, respectively for 5-10 cm DBH. This carbon stock has increased up to 5.32 and 7.41 kg $tree^{-1}$, respectively for 10-15 cm DBH. For 50 trees ha^{-1} and DBH range of 10-15 cm, carbon stock in stem and aboveground was estimated to be 0.316 and 0.371 t ha^{-1}, respectively. This carbon stock in stem and aboveground will increase up to 0.474 and 0.556 t ha^{-1}, respectively for 75 trees ha^{-1}. Carbon stock in total biomass of *A. nilotica* for 10-15 cm DBH comes out to be 0.412 and 0.617 t ha^{-1} for 50 and 75 trees ha^{-1}, respectively.

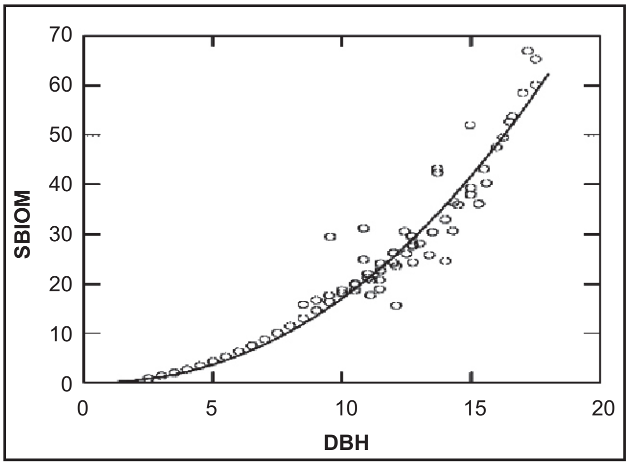

Fig. 2. Fitted generalized model for wood biomass of *Dalbergia sissoo*

Estimation of carbon stock in *D. sissoo* trees

Using the generalized model, stem and aboveground biomass were estimated; aboveground biomass was taken as 40% of stem biomass (Rizvi *et al*., 2008). This biomass was converted into dry biomass by considering 40% moisture loss. Carbon stock in stem and aboveground biomass was calculated by formula C = 0.48 B; where C– carbon stock (kg $tree^{-1}$), B- biomass (kg $tree^{-1}$). Average carbon stock in stem biomass was estimated to be 8.13 kg $tree^{-1}$ for 10-15 cm DBH and 14.64 kg $tree^{-1}$ for 15-20 cm DBH. From this carbon stock in stem, the carbon stock in aboveground biomass was computed, which comes out to be 20.16 kg $tree^{-1}$ for 10-15 kg $tree^{-1}$ and 36.30 kg $tree^{-1}$ for 15-20 cm DBH class. Carbon stock in stem as well as aboveground were estimated considering different tree densities (50, 100 and 200 trees ha^{-1}) of *D. sissoo* and different DBH classes (Figure 3). For 100 trees ha^{-1} and 10-15 cm DBH class, carbon stock in stem and aboveground biomass were estimated to be 0.81 and 2.02 t ha^{-1}, respectively. This carbon stock increased to 1.46 and 3.63 t ha^{-1} for 15-20 cm DBH range with same tree density.

Estimation of carbon stock in *T. grandis* trees

From developed generalized model, stem and aboveground biomass were estimated. From literature, it is found that stem biomass is about 67% of aboveground biomass (Buvaneswaran *et al*., 2006). Then dry stem and dry aboveground biomass were calculated by taking 60% of fresh biomass. From dry biomass, carbon stock in stem and aboveground biomass was worked out by formula C = 0.47*B; where C- carbon stock (kg $tree^{-1}$) and B– biomass (kg $tree^{-1}$).

Carbon stock per tree was multiplied with tree densities (100, 200, 400 trees ha^{-1}) to get carbon stock per ha for different DBH classes (Figure 4). Carbon stock in aboveground and total biomass for 200 trees ha^{-1} was estimated to be 5.448 and 8.004 t ha^{-1} for 15-20 cm DBH class, which increased to 8.607 and 12.644 t ha^{-1} for 20-25 cm DBH class, respectively. This shows that *T. grandis* has good potential of carbon storage in its biomass.

Rizvi *et al.* (2014) estimated total wood biomass production of *A. nilotica* that varied from 12.13 t ha^{-1} at four years and 35.64 t ha^{-1} in seven years old plantations in semi-arid region of Central India. Tyagi *et al.* (2009) found bole and aboveground biomass of 10.30 and 16.28 t ha^{-1}, respectively in six years old *D. sissoo* plantations in sodic soils. This biomass production rose to 23.59 and 38.31 t ha^{-1}, respectively

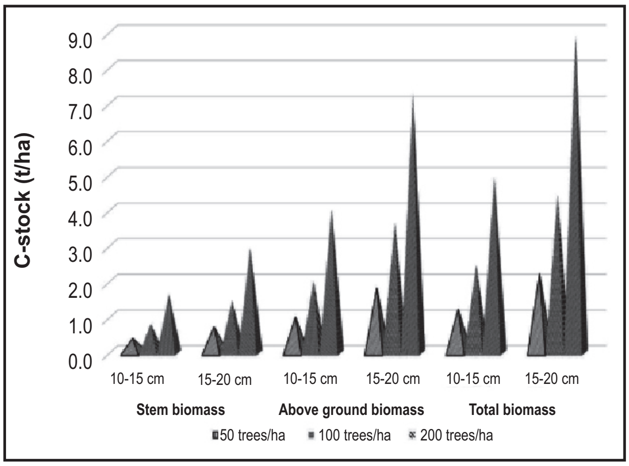

Fig. 3. Estimated carbon stock in stem and aboveground biomass of *Dalbergia sissooo*

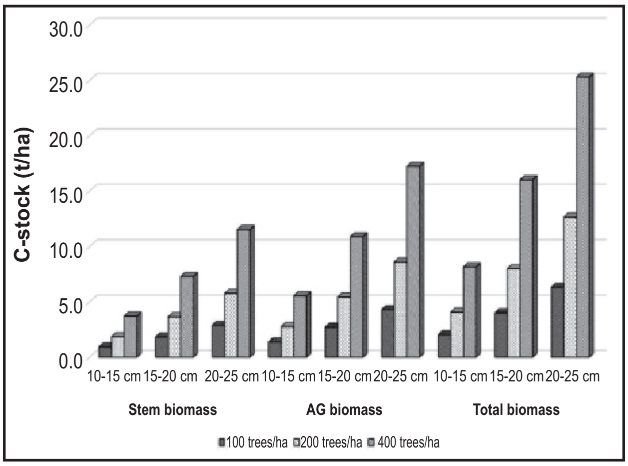

Fig. 4. Estimated carbon stock in aboveground and total biomass of *Tectona grandis*

in six years old plantations. Giri *et al.* (2014) estimated total biomass in *T. grandis* plantation in Dehradun using volumetric equations. The total biomass was estimated to be 147.50 t ha^{-1} with aboveground biomass 121.88 t ha^{-1} and belowground biomass 25.62 t ha^{-1}. Total biomass of *T. grandis* ranged from 0.004 to 0.153 t tree^{-1} and carbon sequestration varied from 0.0021 to 0.076 t tree^{-1} for trees with DBH range of 5.09-18.77 cm (Bohre *et al.*, 2013).

4. CONCLUSION

Most of the biomass models for *A. nilotica*, *D. sissoo* and *T. grandis* are either location or area specific; hence, these can be applied for biomass estimation of trees grown in that location/area. In the present study, generalized models have been developed taking into account growth behavior of these species in different regions. Thus, with the help of developed generalized models, one can estimate biomass production of *A. nilotica*, *D. sissoo* and *T. grandis* plantations. Hence, generalized models may be used for assessment of carbon stock under these species in different regions of India.

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