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Production of wood biomass by high density *Acacia nilotica* plantation in semi-arid region of central India

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Abstract

Acacia nilotica (Babool) is one of the most common and important tree species found in dry areas of the Indian sub-continent and Africa. It is one of the most prominent tree species for agro-forestry systems in the dry land areas of India. A total of 75 trees (30 trees each at age of 4.5 and 5.5 years and 15 trees at 6.5 years) were harvested. Out of six non-linear functions fitted, parabolic models *viz*., $W_b = -1.931 + 0.816\ D + 0.164\ D^2$ (R^2=0.899), $Wt = -0.519 - 0.065\ D + 0.557\ D^2$ (R^2=0.929) were found best in case of branch wood (W_b) and total wood biomass (W_t) whereas, Chapman-Richard model, $W_s = 109.474\ (1 - e^{-0.09\ D})^{2.685}$ (R^2=0.935) was found best in case of stem wood biomass (W_s). These models were validated and compared on the basis of mean bias, mean absolute error and Root mean square error (RMSE). Prediction errors of only 0.897, 0.706 and 0.742 kg in branch wood, stem wood and total wood biomass, respectively was found. Total wood biomass production varied from 12.13 t ha^{-1} at 4 years age to 35.64 t ha^{-1} at 7 years age. Total wood volume was estimated to be 0.011 m^3/ tree at the age of 4 years, which increased upto 0.033 m^3/ tree at the age of 7 years.

Keywords: *Acacia nilotica*, Biomass, Fodder, Model, MPTS, Non-linear, Production, Semi-arid

Abbreviations: DBH: Diameter at breast height; **MAE:** Mean absolute error; **MPSE:** Mean percent standard error; **MSE:** Mean square error; **RMSE:** Root mean square error

Introduction

Acacia nilotica is one of the most common and important tree species found in dry areas of the Indian sub-continent and Africa. It is an indigenous species widely planted for fuelwood throughout India, having faster growth than other Indian arid and semi-arid species (Bisht and Toky, 1993). The species seldom occurs above 500 m or in areas with more than annual 1,500 mm of rain, except on gravelly porous soils on river beds. Under irrigation, it grows in low rainfall conditions of even 100 mm (Gupta, 1993). *A. nilotica* is found on a variety of soils, compact sandy loam, shallow stony, riverine alluvial, black cotton, alluvial loam, saline, mild alkaline, ravines and soils containing calcareous concretions. The absolute maximum shade temperature ranges from 40-48^{0}C and minimum from 1^0 to 15^{0}C (Troup, 1983).

Although it forms natural stands in some localities, it is usually a tree of cultivated fields, villages grazing grounds and other types of wasteland where it regenerates readily and withstands excessive environmental stress (Singh, 1982). Leaves and pods are relished by cattle, goats and sheep and are a nourishing fodder. It is strongly light demanding drought resistant, frost tender and sometimes produces root suckers. It is susceptible to fire damage, browsed by goats and camels and freely lopped for thorny fences and fodder (Troup, 1983).

In the present study, an attempt has been made to develop non-linear models for wood biomass of *Acacia nilotica* in semi-arid region of central India. Using developed models, the production of wood biomass for high density *A. nilotica* plantation at different ages was also estimated.

Material and Methods

A trial of *A. nilotica* was established on experimental farm of National Research Centre for Agroforestry, Jhansi under rainfed condition at spacing of 3 x 3 m in the year 2005 consisting of 15 families. From each family, two trees at an age of 4.5 and 5.5 years and one tree at 6.5 years were harvested randomly. In this way, total number of seventy five trees were harvested and data on tree height, diameter at breast height (DBH) was recorded for each tree. Immediately after harvesting, branches were cut from the main stem and fresh branch wood and fresh stem wood of the trees was weighed. Total wood biomass was obtained by adding branch wood and stem wood biomass. Data of 60 trees was used for construction of models and data of 15 trees was used for validation of models as suggested by Snee (1977), the splitting of data set.

Six non-linear functions were fitted for branch, stem and total wood biomass using SYSTAT 11.0 using non-linear regression method (Table 1). All the functions were fitted using DBH as independent variables except function 6. The fitted functions were compared for goodness of fit on the basis of statistical criteria *i.e*. adjusted R^2 and mean square error (MSE). Low value of MSE and high value of adjusted R^2 indicates the goodness of fit (Reynolds *et al*., 1988).

The selected models were subjected to validation on an independent data set and their prediction errors were compared using mean bias, mean absolute error (MAE), root mean square error (RMSE), Mean Percent Standard Error (MPSE). The developed models were used for estimating the wood biomass of *A. nilotica* trees at different ages. This wood biomass was converted into wood volume by dividing with wood density *i.e*., 978 kg/m^3 as estimated by Kumar *et al*. (2009). Therefore, wood volume was estimated by relationship: V = W / 978; where, Vï wood volume (m^3) and Wï wood biomass (kg).

Results and Discussion

Growth and biomass data: Tree height and DBH varied from 1.80-9.12 m and 1.20-9.30 cm, respectively for construction data and from 3.65-7.42 m and 3.10-7.25 cm, respectively for validation data. Mean branch, stem and total wood biomass for harvested trees were 4.21, 5.25 and 9.46 kg/tree, respectively for construction data and 5.50, 8.08 and 13.56 kg/tree, respectively for validation data (Table 2). SW p-value showed that all the variables are normally distributed in construction data set but not in validation data set.

Pearson correlation coefficients between independent variables (height and diameter at breast height) and dependent variables (branch, stem and total wood biomass) indicated that both height and DBH are highly correlated with branch, stem and total wood biomass. The correlation coefficients were higher for DBH (0.934, 0.948. 0.948) than tree height; hence selected as independent variable.

Biomass models: Out of six non-linear functions fitted, adjusted R^2 was highest for function 5 but the value of MSE was lowest for function 4 (Table 3). Therefore, these two functions fitted for branch, stem and total biomass of *A. nilotica*, were selected for final validation. The validation of functions 4 and 5 was done on an independent data set and branch, stem and total wood biomass were predicted. Mean bias, MAE, RMSE and mean percent standard error (MPSE) in predictions was computed and compared (Table 4). Predictions for branch and total wood biomass were on higher side and for stem wood biomass on lower side as indicated by mean bias. On the basis of these criteria, parabolic functions were found best in case of branch and total wood biomass (Fig. 1a,b) whereas, Chapman-Richard function was found best in case of stem biomass. Plot of residuals showed that residuals are normally distributed. Mean absolute error indicated that these models would yield an error of only 0.897, 0.706 and 0.742 kg in prediction of branch wood, stem wood and total wood biomass.

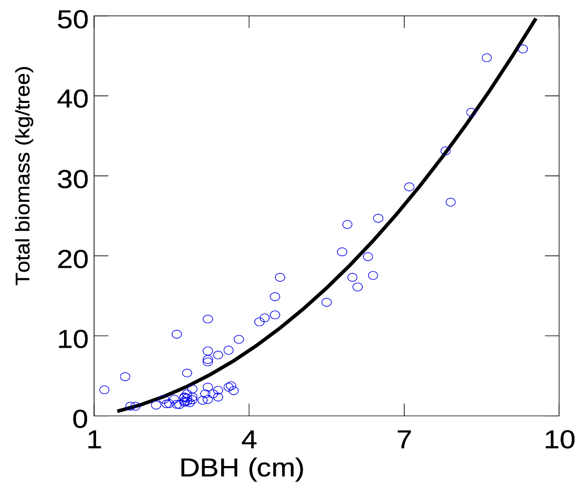

Fig. 1(a) Fitted parabolic model for total biomass of *Acacia nilotica*

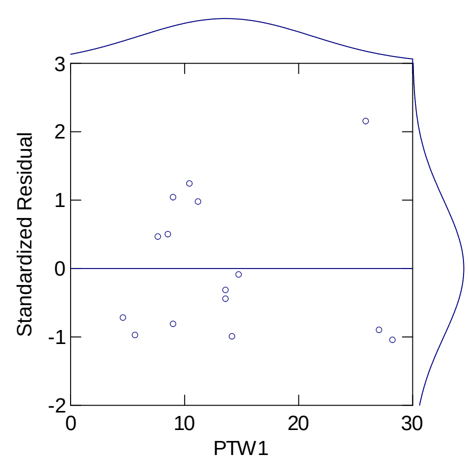

Fig.1(b) Plot of standardized residuals for total wood biomass of *Acacia nilotica*

Table 1. Non-linear functions fitted for branch, stem and total wood biomass of *A. nilotica*

F. No.	Function from	References
1.	Exponential: $W = a.\ e^{bD}$	Harding and Grigal (1985)
2.	Gompertz: $W = a.\ \exp(-b.e^{-cD})$	Causton and Venus (1981)
3.	Logistic: $W = a.\ (1 + \exp.(b \text{ ï } c\ D))^{-1}$	Hutchinson (1978)
4.	Chapman-Richards: $W = a\ (1 \text{ ï } e^{-bD})^{c}$	Richards (1959)
5.	Parabolic: $W = a + b_1 D + b_2 D^2$	Tewari and Kumar (2001)
6.	$W = a + b_1 D + b_2 DH + b_3 D^2H$	Tewari and Singh (2006)

D- diameter at breast height, H- height of tree, W- weight or biomass

Table 2. Branch, stem wood and total wood biomass of harvested *A. nilotica* trees

Statistics	Height (m)	DBH (cm)	Branch wood biomass (kg)	Stem wood biomass (kg)	Total wood biomass (kg)
Construction data (n=60)					
Mean	4.06	3.94	4.21	5.25	9.46
S.D.	1.60	1.85	4.48	5.63	10.06
SW statistics	0.896	0.863	0.803	0.767	0.789
SW p-value	0.000	0.000	0.000	0.000	0.000
Validation data (n=15)					
Mean	5.59	4.94	5.50	8.08	13.56
S.D.	1.24	1.28	2.68	4.54	7.17
SW statistics	0.951	0.907	0.880	0.838	0.847
SW p-value	0.537	0.121	0.048	0.012	0.016

DBH- diameter at breast height

Table 3. Fitting statistics of the functions used for branch, stem and total wood

F. No.	Branch wood		Stem wood		Total wood	
	Adj. R^2	MSE	Adj. R^2	MSE	Adj. R^2	MSE
1.	0.809	4.067	0.898	3.426	0.867	14.283
2.	0.895	2.186	0.935	2.162	0.922	8.214
3.	0.889	2.323	0.933	2.193	0.917	8.695
4.	0.896	2.177	0.935	2.146	0.922	8.164
5.	0.899	2.572	0.944	2.211	0.929	8.516
6.	0.893	2.757	0.934	2.486	0.922	10.011

Table 4. Validation of two selected models for branch, stem and total wood biomass

Parameter	Fitted models	Mean bias	MAE	RMSE	MPSE
Branch wood biomass(kg/tree)	$W = -1.931 + 0.816\ D + 0.164\ D^2$	-0.845	0.897	1.156	-14.469
	$W = 18.411\ (1 \text{ ï } e^{-0.384\ D})^{6.276}$	-1.037	1.038	1.317	-17.391
Stem wood biomass(kg/tree)	$W = 1.411 - 0.881\ D + 0.393\ D^2$	0.836	0.836	0.983	11.147
	$W = 109.474\ (1 \text{ ï } e^{-0.09\ D})^{2.685}$	0.704	0.706	0.943	8.356
Total wood biomass(kg/tree)	$W = -0.519 - 0.065\ D + 0.557\ D^2$	-0.033	0.742	0.889	0.667
	$W = 72.428\ (1 \text{ ï } e^{-0.202\ D})^{3.648}$	-0.360	0.803	0.924	-2.124

Table 5. Estimated branch, stem and total wood biomass at different ages

Age (years)	Branch biomass (kg/tree)	Stem biomass (kg/tree)	Total wood biomass (kg/tree)	Stem volume (m^3/tree)	Total wood volume (m^3/ tree)
2.5	1.89	2.42	4.45	0.002	0.006
4	4.93	5.88	10.92	0.006	0.011
5	7.58	8.96	16.82	0.009	0.017
6	11.86	14.02	27.28	0.014	0.028
7	13.79	16.21	32.08	0.017	0.033

Thus, the fitted models *viz*., $W_b = -1.931 + 0.816\ D + 0.164\ D^2$; $W_s = 109.474\ (1 \text{ ï } e^{-0.09\ D})^{2.685}$ and $W_t = -0.519 - 0.065\ D + 0.557\ D^2$ may be used for estimating branch wood, stem wood and total wood biomass of *A. nilotica* trees in semi-arid region of central India. Raizada *et al*. (2007) developed prediction models for bole, utilizable and above ground biomass of *A. nilotica* planted in salt affected soils and found linear models to be best fit.

Wood biomass and wood volume: Using the developed biomass models and available growth data of *A. nilotica* trees; branch wood, stem wood and total wood biomass was estimated at different ages. Mean branch, stem and total wood biomass was estimated to be 1.89, 2.42 and 4.45 kg/ tree at the age of 2.5 years, respectively. Estimated branch, stem and total wood biomass increased upto 7.58, 8.96 and 16.82 kg/ tree at the age 5 years, and further upto 13.79, 16.21 and 32.08 kg/ tree at the age 5 years, respectively (Table 5). The stem biomass production of *A. nilotica* plantation varied from 6.54 to 18.00 t ha^{-1} at the age of 4 to 7- years. Total wood biomass production of *A. nilotica* plantation varied from 12.13 to 35.64 t ha^{-1} at the age of 4 to 7 years (Fig. 2). Contribution of branch biomass in total wood biomass production ranged between 42 to 45 per cent.

Fig 2. Standing wood biomass of high density *A. nilotica* plantation at different ages

The stem wood volume was estimated to be 0.006 m^3/ tree at the age of 4-years (Table 5), which became almost three times at the age of 7-years (0.017 m^3/ tree). Similarly, the total wood volume comes out to be 0.011 m^3/ tree at the age of 4 years, which increased upto 0.033 m^3/ tree at the age of 7 years. It was found that stem wood volume was almost 50 per cent of total wood volume.

Acacia nilotica, an important tree species of arid and semi-arid region of India, is most prominent tree species for agroforestry. Because of its fast growth, it produces good biomass in its stem and branches which are mainly used as timber wood and firewood. The estimation of its wood biomass needs some model development; therefore the models were fitted and their validation was also done. The proposed models for branch, stem and total wood were judged and selected on the basis of various statistical criteria. Hence these models may be used for estimating biomass of *Acacia nilotica* trees in semi-arid region of Central India.

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