Indian Journal of Agricultural Sciences **86** (11): 1477–81, November 2016/Article
https://doi.org/10.56093/ijas.v86i11.62935

Allometric equations for predicting biomass and carbon of *Simarouba glauca* plantations in dryland of Hyderabad, Telangana

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Received: 31 August 2015; Accepted: 17 June 2016

ABSTRACT

Estimating the carbon stocked in planted forests is important to assess the mitigation effect and to predict potential impact of mechanisms to reduce carbon emissions. This study was conducted in Central Research Institute for Dryland Agriculture, Hyderabad to develop the allometric equations for predicting the above and below ground biomass and total carbon in three different basal diameter classes (0-10 cm, 10-20 cm and 20-30 cm) of *Simarouba glauca DC*. Higher total biomass of 169.0 kg/tree in 20-30 diameter class followed by 10-20 cm (57.81 kg/tree) diameter class were recorded in *S. glauca*. From the findings, above ground biomass has a highly significant relationship with tree height, basal diameter, DBH, crown height, crown width. There was a significant linear relationship between below ground biomass and predictors, viz. tree height (0.803), basal diameter (0.820), DBH (0.810), crown height (0.985) and crown width (0.957). And also, strong non-linear relationship (0.985) exists between total biomass and crown height (0.985) followed by crown width (0.957). The allometric coefficients which were calculated from the allometric relations between the biomass of various tree components on total carbon for *S. glauca*. The highest and strong allometric coefficient registered between total carbon and crown height (0.992) followed by crown width (0.978). This finding may be first for *S. glauca* in India as no significant literature is available for estimation of biomass and carbon in different components of the species. So the result of this study will be helpful in predicting the amount of carbon credits earned by plantations on area basis, which are requisite under the Kyoto Protocol and REDD policy.

Key words: Allometric relationship, Biomass, *Simarouba glauca,* Total carbon

Allometry is the most common and essential approach of estimating growth and biomass of trees in plantations and forests. Equations are developed by relating biomass of tree components as dependent variables with easily measured variables, such as stem diameter, as independent variables (Ghezehei *et al.* 2009). This method is an accurate, easy to use and non-destructive for predicting tree growth and biomass. However, allometric equations are site specific and empirical. Equations developed here will be used for validating a two dimensional tree growth and biomass allocation model under various growing environments, without any destructive sampling. With the help of carbon content of tree biomass, which is assumed to be fixed proportion of the biomass (Montagnini and Porras 1998) or determined directly (Kraenzel *et al.* 2003), can be used to estimate carbon storage in trees and plantations (Losi *et al.* 2003) and their wood and foliage (Specht and West 2003). Allometric relationships can also be used for estimating carbon fluxes (Chambers *et al.* 2001) and implication of large scale deforestation and carbon sequestration on carbon cycle and carbon balance (Ketterings *et al.* 2001), monitoring growth and partitioning of above ground interactions when trees are used for agroforestry purposes.

A rainfed wasteland evergreen edible oil tree, *Simarouba glauca* DC, is commonly known as Laxmitaru or paradise tree belonging to family Simaroubaceae. *S. glauca* is indigenous to Southern Florida, the West Indies and Brazil. While exotic to India, Srilanka, Phillippines and Myanmar *S. glauca* occurs as an understorey shade tolerant tree. It is found to occur as associate with subtropical moist forest plants. The root system is shallow suitable for mountain soils. Stem is up to 9m height with 40-50 cm in diameter. The bark and leaf extract of *Simarouba* are well known for its different types of pharmacological properties such as haemostatic, antihelmenthic, antiparasitic, antidysentric, antipyretic and anticancerous (Patil Manasi and Gaikwad 2011).

Many studies have been conducted through non-destructive method to determine aboveground biomass of forest and agroforestry tree species (Lott *et al.* 2000,

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Claesson *et al.* 2001, Verwijst and Telenius 1999). Allometric scaling equations on the basis of total tree height (H) and basal diameter (D) have been developed for a range of Central American dry zone agroforestry species and *Azadirachta indica* in India (Kumar and Tewari 1999) and *Grevillia robusta* in Kenya (Lott *et al.* 2000). Present study was aimed at developing allometric equations for the estimation of total above and below ground biomass and total carbon in *S. glauca* plantation at dryland of Hyderabad, Telangana.

MATERIALS AND METHODS

This study was conducted in Hayathanagar Research Farm (HRF) of the Central Research Institute for Dryland Agriculture, Hyderabad. The study area is located at $17^{0}27'$N latitude, $78^{0}35'$ longitude with above mean sea level of 515 m. The mean annual temperature is 13.5°-38.6°C and the mean annual rainfall is 755 mm. The experimental soil represented Alfisol soil order (Typic Haplustalf), with pH slightly acidic to neutral (6.4) and EC 0.085 dS/m. The soils were low in available nitrogen (145 kg/ha), medium in available phosphorus (13.0 kg P/ha) and available potassium (175 kg/ha). The ten-year old S. *glauca* plantations were selected for allometry study with 6×6 m spacing.

The entire field was divided in to plots of equal size and within each plot, 25% of the trees were marked representing the population. Trees were harvested during the months of November, 2014 – February, 2015. Entire plantation was divided into three basal diameter classes, viz. 0-10 cm, 10-20 cm and 20-30cm for measuring the growth parameters. Destructive sampling of *S. glauca* trees were very laborious and time consuming. So, nine representative trees in the respective diameter class were selected for destructive sampling. Growth variables, viz. tree height, basal diameter, DBH, crown height and crown width were measured before felling of trees (Table 1). These measurements were recorded as per established procedure.

The trees were felled at ground level using a mechanical chain saw. After recording the total height and DBH of the felled trees, the above ground portions were separated into wood, branches and leaves. For below ground biomass estimation, pits were excavated and complete recovery of roots was done from tree base. Fresh weights of the entire above and below ground tree components were recorded immediately after felling using appropriate spring scales. A small sample (500 g) of wood, branches and leaves was immediately transferred to the laboratory in double sealed polythene bags. The collected samples were dried at 80 ^{o}C till constant weight was obtained. The oven dry weight of the whole sample was calculated using the formula given below (Gnana Mathuram 2009).

$$\text{Dry weight of the tree biomass} = \frac{\text{Oven dry weight of the sample}}{\text{Fresh weight of the sample}} \times \text{Fresh weight of the whole tree}$$

Allometry equation for estimation of biomass and carbon

A power function is generally used to predict a tree's biomass from the diameter (Ghezehei *et al.* 2009, Acthen *et al.* 2010). In order to assess the tree biomass the regression equations developed by Lodhiyal *et al*. (1992) have been used. Biomass and carbon was estimated using simple allometric equation in the form of,

$Y= aX^{b}$

where, Y is dry biomass and carbon of tree components, X is predictor variables (Tree ht, basal diameter, DBH, crown height, crown width, etc.), a is Y intercept, b is a regression coefficient.

The dry biomass may be replaced by tree dimensions such as tree height, basal diameter, DBH, crown height and crown width. Allometric equations were developed for both total above, total below and total (above + below) dry biomass.

Using logarithmic transformation on both sides.

$\log Y = b \log D + \log a$

where, Y is the dry biomass or carbon, b is the slope, log a is the intercept of the linear equation (log 10 yields a

Table 1 Descriptive statistics of *S. glauca*

Variable	Minimum	Maximum	Mean	SE (mean)	Std. deviation
Tree height (m)	3.40	4.60	3.95	0.141	0.424
Basal diameter (cm)	8.00	25.2	16.1	2.201	6.603
Number of branches	10.0	15.0	12.6	0.527	1.581
DBH (cm)	3.50	5.60	4.55	0.283	0.849
Crown height (m)	0.35	0.62	0.46	0.038	0.114
Crown width (m)	3.80	5.70	4.58	0.242	0.726
Leaves biomass (kg/plant)	2.00	8.80	4.45	0.985	2.955
Stem biomass (kg/plant)	4.50	21.0	10.9	2.229	6.688
Primary branch biomass (kg/plant)	7.28	36.0	18.6	4.010	12.03
Secondary branch biomass (kg/plant)	11.0	55.5	27.7	6.548	19.64
Above ground biomass (kg/plant)	27.9	118.	61.8	13.65	40.95
Below ground biomass (kg/plant)	48.4	10.3	24.5	5.696	17.09
Total biomass (above and below) (kg/plant)	38.2	167.2	86.4	19.34	58.02

Table 3 Allometric equation for estimating above ground biomass (kg/tree) of *S. glauca* tree

Independent variable (Predictor)	Predicted variable (Above Ground Biomass)						
	b	a	r	SSE	R^2	F cal	Corrected allometric equation
Tree height (m)	5.266	0.038	0.906	0.554	0.821	32.01*	AGB = 0.038(Tr Ht)$^{5.266}$
Basal diameter (cm)	1.275	1.649	0.897	0.601	0.805	28.95*	AGB = 1.649(BD)$^{1.275}$
DBH (cm)	3.017	0.557	0.916	0.496	0.839	36.60*	AGB = 0.557(DBH)$^{3.017}$
Crown height (m)	2.596	403.3	0.991	0.056	0.982	381.6*	AGB = 403.3(Cr Ht)$^{2.596}$
Crown width (m)	3.932	0.135	0.977	0.141	0.954	146.6*	AGB = 0.135(Cr Wd)$^{3.932}$

*Significant at 1% level

lower sum of squares than the natural logarithm ln), D is the predictor variable.

The allometric relationship was established using power model between dependent and independent variables (tree height, basal diameter, DBH, crown height, crown width and biomass of tree components).A total of all the allometric relationships were developed for predicting biomass and carbon were found significant at 1% based on F value.

The parameters of the linearized allometric equations (b and log a) were estimated by means of regression using SPSS (version IBM SPSS Statistics 20).The original parameter "a" was finally computed by taking antilog function. The significance and validity of the equations developed were evaluated with the R^2 value, the F-statistic, and a scatter plot of the residuals. Microsoft Excel was used to visualize graphs of the equations.

RESULTS AND DISCUSSION

Biomass production of S. glauca

Among the targeted species *S. glauca* recorded higher total biomass of 169.0 kg/tree in 20-30 diameter class followed by 10-20 cm (57.81 kg/tree) diameter class. The results on above and below ground biomass of *S. glauca* suggests that average total biomass (kg/tree) increased with a corresponding increase in diameter class (20-30 cm) (Table 2). The lowest total biomass was observed in 0-10 cm diameter class (39.94 kg/tree). The average total biomass of *S. glauca* was 88.91 kg/ tree. The maximum biomass recorded in leaf biomass (8.190 kg/tree), stem biomass (20.62 kg/ tree), primary branch biomass (35.75 kg/tree), secondary branch biomass (55.91 kg/tree) and root biomass (48.77 kg/ tree) under 20-30 cm diameter class during 2014-15. Among the fractionated plant parts, the average secondary branch biomass was maximum in *S. glauca* (27.96 kg/tree) followed by root biomass (24.66 kg/tree), primary branch biomass (20.73 kg/tree), stem biomass (11.2 kg/tree) and leaf biomass (4.34 kg/tree). The average above ground biomass was recorded as 64.25 kg/tree.

Table 2 Biomass of *S. glauca*

Basal dia. class	LB kg/tree	SB kg/tree	PBB kg/tree	SBB kg/tree	AGB kg/tree	BGB kg/tree	TB kg/tree
0-10	2.08	5.34	10.6	11.2	29.4	10.5	39.9
10-20	2.75	8.30	15.7	16.6	43.5	14.1	57.8
20-30	8.19	20.6	35.7	55.9	119.8	48.7	169
Mean	4.34	11.2	20.7	27.9	64.2	24.6	88.9

LB-Leaf biomass; SB - Stem biomass; PBB - Primary branch biomass; SBB - Secondary branch biomass; AGB - Above ground biomass; BGB - Below ground biomass; TB - Total biomass.

Allometric relationships between the variables in S. glauca

Generally the models developed in this study exhibited high coefficient of determination (R2 > 85%). The allometric regression was highly significant, with high and positive correlation coefficients.

Allometry equation for estimating Above Ground Biomass

At tree level, the allometric regression was highly significant, with high and positive correlation coefficients. Results of the regression relationship of above ground biomass with various growth variables of *S. glauca* are given in Table 3. The above ground biomass has a highly significant relationship with all the independent variables. The allometric relationship was established using power model among the fitted models; the model built using tree height (0.821), basal diameter (0.805), DBH (0.839), crown height (0.982) and crown width (0.954) shows highest strong relationship with the predicted variable of above ground biomass. Highest correlation (r = 0.982) was found with crown height followed by crown width (0.954).

Allometry equation for estimating Below Ground Biomass

The regression relationship of below ground biomass variable with various growth variables of *S. glauca* has been presented in Table 4. The above ground variables (tree height, basal diameter, DBH, crown height and crown had highly significant relationship with predicted variable of below ground biomass. There was a significant linear relationship between below ground biomass and predictors, viz. tree height (0.803), basal diameter (0.820), DBH (0.810), crown height (0.985) and crown width (0.957). A strong and high linear relationship exists between below ground biomass with crown height (0.985) followed by crown width (0.957). Crown height and crown width as predictor variables, exhibited very strong allometric relationship with

Table 4 Allometric equation for estimating Below Ground Biomass (kg/tree) of *S. glauca* tree

Independent variable (Predictor)	Predicted variable (Below Ground Biomass)						
	b	a	r	SSE	R^2	F cal	Corrected allometric equation
Tree height (m)	5.483	0.011	0.896	0.674	0.803	28.53*	BGB= $0.011(\text{Tr Ht})^{5.483}$
Basal diameter (cm)	1.354	0.520	0.905	0.617	0.820	31.79*	BGB= $0.520(\text{BD})^{1.354}$
DBH (cm)	3.119	0.186	0.900	0.650	0.810	29.85*	BGB= $0.186(\text{DBH})^{3.119}$
Crown height (m)	2.737	175.7	0.993	0.051	0.985	463.8*	BGB= $175.7(\text{Cr Ht})^{2.737}$
Crown width (m)	4.144	0.038	0.978	0.148	0.957	155.2*	BGB= $0.038(\text{Cr Wd})^{4.144}$

*Significant at 1% level

Table 5 Allometric equation for estimating Total Biomass (kg/tree) (Above ground + Below ground biomass) of *S. glauca* tree

Independent variable (Predictor)	Predicted variable (Total Biomass)						
	b	a	r	SSE	R^2	F cal	Corrected allometric equation
Tree height (m)	5.327	0.048	0.904	0.580	0.817	31.28*	TB= $0.048(\text{Tr Ht})^{5.327}$
Basal diameter (cm)	1.297	2.160	0.901	0.599	0.811	30.07*	TB= $2.160(\text{BD})^{1.297}$
DBH (cm)	3.046	0.741	0.913	0.531	0.833	34.83*	TB= $0.741(\text{DBH})^{3.046}$
Crown height (m)	2.635	578.5	0.992	0.048	0.985	451.6*	TB= $578.5(\text{Cr Ht})^{2.635}$
Crown width (m)	3.991	0.172	0.978	0.137	0.957	155.1*	TB= $0.172(\text{Cr Wd})^{3.991}$

*Significant at 1% level

below ground biomass in the present investigation. Similar findings were reported that by Shem Kuyah *et al.* (2012) in *Eucalyptus* species.

Allometry equation for estimating Total Biomass

There was significant linear relationship between dependent variable (total biomass) and independent variable (tree height, basal diameter, DBH, crown height, crown width, stem biomass and branch biomass) in the allometric equations. A strong linear relationship (0.985) exists between total biomass and crown height (0.985) followed by crown width (0.957). The significant relationship had shown between total biomass and independent variables, viz. tree height (0.817), basal diameter (0.811) and DBH (0.833) (Table 5). The significant non-linear relationship had shown between total biomass and independent variables, viz. tree height, basal diameter and DBH. A highly significant relationship was observed between total biomass and tree height, total biomass and basal diameter and total biomass and DBH. Strong linear relationship was registered between total biomass with crown height and crown width. The similar findings were supported that the above ground variables have highly significant relationship with tree height and basal diameter. This may be because of tree height as predictor variable has significant allometric relationship with biomass (Van *et al.* 2000 and Kumar and Tewari 1999). Similar findings were reported in *J. curcas* (Ghezehei *et al.* 2009) and *Pinus pinea* Correia *et al.* 2010.

Allometry equation for estimating total carbon

The allometric coefficients which were calculated from the allometric relations between the biomass of various tree components on total carbon for *S. glauca* have been presented in Table 6. The highest and strong allometric coefficient registered between total carbon and crown height (0.984) followed by crown width (0.956). The significant strong non-linear relationship has expressed between predicted variable and predictor, viz. tree height (0.816), basal diameter (0.809) and DBH (0.832). The allometric coefficients were calculated from the allometric relations between the biomass of various tree components

Table 6 Allometric equation for estimating Total Carbon content (kg/tree) of *S. glauca* tree

Independent variable (Predictor)	Predicted variable (Total Carbon content)						
	b	a	r	SSE	R^2	F cal	Corrected allometric equation
Tree height (m)	5.325	0.020	0.904	0.583	0.816	31.11*	TC= $0.020(\text{Tr Ht})^{5.325}$
Basal diameter (cm)	1.296	0.897	0.900	0.605	0.809	29.71	TC= $0.897(\text{BD})^{1.296}$
DBH (cm)	3.044	0.308	0.912	0.534	0.832	34.56*	TC= $0.308(\text{DBH})^{3.044}$
Crown height (m)	2.635	239.3	0.992	0.049	0.984	441.8*	TC= $239.3(\text{Cr Ht})^{2.635}$
Crown width (m)	3.989	0.071	0.978	0.140	0.956	152.1*	TC= $0.071(\text{Cr Wd})^{3.989}$

*Significant at 1% level

on total carbon for *S. glauca*. The significant strong non-linear relationship has expressed between predicted variable and predictor, viz. tree height, basal diameter, DBH, crown height and crown width. Generally, the models developed in this study exhibited high coefficient of determination. Diameter is the commonest predictor in most biomass allometric equations (Gower *et al*. 1999) although tree height is also used in some studies (Kenzo *et al*. 2009). There were relatively higher coefficients of determination for non-linear allometric equations that used diameter as a biomass predictor than those which used tree height as the predictor of *Simarouba* biomass (Patrick and Zakaria 2013).

Based on this investigation, the allometric equation suitable for estimating biomass and carbon stock of planted *S. glauca* forest is provided. The allometric relationship between the variables in *S. glauca* was highly significant with high and positive correlation. Crown height and crown width has showed strong linear relationship with above ground biomass variables. Total carbon had highest and strong allometric relations with crown height followed by crown width. It may be concluded from the study that could be used for further estimations of biomass and carbon stocks of other plantations of *S. glauca*.

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