



## **Evaluation of Stem Biomass and Carbon Density of Four Deciduous Tree Species in Northern Plains of India Using Regression Modeling**

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### **Authors' contributions**

This work was carried out in collaboration between all authors. Author NAM designed the study, performed the statistical analysis and wrote the protocol, while the literature search and drafting of the manuscript was managed and done by authors PAS, GNP and TAR. All authors read and approved the final manuscript.

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### **ABSTRACT**

Assessment of carbon stock in trees is generally based on allometric equations relating either volume, or biomass, or carbon to DBH. The carbon density of different tree parts is not often measured directly, but generally assumed to be 50% of dry weight. In this study we try to analyze those assumptions and determined the effect different regression equations on carbon sequestration for *Tectona grandis*, *Vachellia nilotica*, *Madhuca indica*, *Dalbergia sissoo*. The present study aims to estimate the above-ground biomass (AGB) and carbon sequestration in 18 sampling plots of 30 × 30 m<sup>2</sup> size, at different sites in northern plains (Uttar Pradesh) India. Two regression

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models were used for each species; one using DBH only (Method 1) and the other using DBH and height (Method 2). The best fit models were chosen on the basis of highest  $R^2$ . The DBH, AGB and carbon density yielded a positive relationship for all the species. Apart from Model D1h, all  $R^2$  values for models developed with our data (both DBH and height) were above 99%. The  $R^2$  values for models developed with DBH only were below 90%, least for model M1 (77.6%) The co-efficient for DBH was not significant in Model D1h and M1h, but the co-efficient for DBH and height was significant at the 5% level of significance for all other coefficients in all other models. The estimated stem AGB was maximum for *Tectona grandis* with 376.2 and 355.63 t/tree with carbon sequestration of 621.25 and 587.50 kg/ha for the equation T1 and T2H respectively; whereas minimum AGB was recorded for *Dalbergia sisoo* with 221.55 and 211.58 t/ha and carbon sequestration of 362.93 and 349.65 kg/ha. The AGB and carbon sequestration estimation obtained in this study represents a more realistic picture of biomass of region.

**Keywords:** Regression equation; AGB; carbon sequestration; *Tectona grandis*; *Madhuca indica*; *Vachellia nilotica*.

## 1. INTRODUCTION

Forests play important role in CO<sub>2</sub> fixation. Carbon stored in terrestrial ecosystem is distributed in three compartments: biomass of living plants, plant detritus, and soil [1,2].

The rate of carbon storage increases in young stands, but then declines as the stand ages. An observation from a study on pine species planted on cropland in the southeastern U.S., the rate of carbon storage begins to decline at approximately age 20 and is close to zero by age 100 [3]. India is sequestering more than 116 million tons of CO<sub>2</sub> per year which is equal to 32 millions of carbon sequestration, this contributes to reduce atmospheric carbon of the globe [4]. Estimates of carbon stocks and stock changes in tree biomass (above and belowground) are necessary for reporting to the United Nations Framework Convention on Climate Change (UNFCCC) and will be required for Kyoto Protocol reporting [5].

According to [6], the amount of biomass in a forest determines the potential quantity of carbon. Carbon sequestration is a net elimination of CO<sub>2</sub> from atmosphere, which includes the uptake of carbon from atmosphere by all plants through photosynthesis. This carbon is stored as plant biomass in vegetation and organic matter in the soil [7]. Various terrestrial ecosystems such as forests and grasslands have different potential of carbon storage for instance; forest ecosystem contains more carbon per unit area than any other ecosystems [8]. In global carbon cycle, biomass is an important building block, especially carbon sequestration and is used to help quantify pools and changes of Green House Gases from

the terrestrial biosphere to the atmosphere associated with land use and land cover changes [9,10]. The rate of carbon sequestration differs with the species composition, region, climate, topography and management [11].

The increasing carbon emission is of major concerns for entire world as well addressed in Kyoto protocol [12,13]. Carbon sequestration in growing forests is known to be a cost-effective option for mitigation of global warming and global climatic change. In terms of atmospheric carbon reduction, trees in urban areas offer the double benefit of direct carbon storage and maintenance of climatic conditions by its bio-geochemical processes [12].

The present study focuses on estimation of Volume, biomass and carbon sequestration in deciduous forests of Uttar Pradesh. The biomass related studies have become significant due to growing awareness of carbon credit system world over [14]. According to Quirine et al. [15], the estimation of ABG is an essential aspect in study of carbon stock. Various methods are being employed for measuring biomass/carbon which include destructive, non-destructive and remote sensing methods [16].

Absolute measurements of biomass can take up only at the time of felling which is not possible because of green felling in India [17]. Therefore the non-destructive method using different regression models for estimation of ABG and carbon sequestration rate of four deciduous tree species in Viz. *Tectona grandis* (L.f.), *Vachellia nilotica* (L.), *Madhuca indica* (J.F. Gmelin. syn), *Dalbergia sissoo* (Roxb.) in northern plains (Uttar Pradesh) India.

## 2. EXPERIMENTAL METHODOLOGY

### 2.1 Study Area

Data was collected from 18 plantation plots (30x30 m) established in northern plains of India. Four tree species *Tectona grandis*, *Vachellia nilotica*, *Madhuca indica* and *Dalbergia sissoo* were found in scattered manner near the villages in Uttar Pradesh. In every 30x30 m<sup>2</sup> sampling plots five 10x10 m<sup>2</sup> quadrates were laid to record the independent variables (DBH, height and form factor), chosen randomly to reduce the sampling errors by employing the simple random sampling. The site is located at the latitude of 25.26° N and longitude 81.54° E with altitude 78 m above the mean sea level having tropical to subtropical climate with extremes of summer and winter. During winter months especially Dec-Jan temperature drops down to as low as 5°C while in summer temperature reaches above 45°C. Hot scorching winds (commonly known as loo) is regular feature during the summer where as there may be an occasional spell of frost during the winter. The annual rainfall is 1100 mm mostly during the monsoon autumn i.e. July-Sept with a few occasional showers during winter months.

### 2.2 Non-destructive Volume Estimation

The various methods used in the study are as follows:

- The height of the tree was calculated with the help of geometric method [18].
- DBH of the tree was measured by using the diameter tape.

The stem volume for each species was calculated by using the Von Betalanffys model adopted by Richard [19] and Chapman [20] termed as Chapman-Richard growth model was modified and used in this study

$$V = a + b \ln(DBH) \quad (1)$$

$$V = a + b \ln(DBH) + c \ln(H) \quad (2)$$

Where V = total stem volume, DBH = diameter at breast height (cm), H = total height (m), and a, b and c are species specific parameters. The regression model was developed by using the volume as endogenous variable and DBH and Height as exogenous variable. Two regression models for volume estimation were developed for each species by using DBH alone and DBH and

height. Each model was named with a code corresponding to the species (e.g., Model D1 was developed for *Dalbergia sissoo* using DBH data and Model D1h was developed using DBH and height data etc.).

### 2.3 Assessment of the Models

The volume models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used:

#### 2.3.1 Significance of regression (F-ratio)

This is to test the overall significance of the regression equations. The critical value of F (i.e., F-tabulated) at p<0.05 level of significance was compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) such equation is therefore significant and can be accepted for prediction.

#### 2.3.2 Coefficient of determination (R<sup>2</sup>)

This is the measure of the proportion of variation in the dependent variable that is explained by the behaviour of the independent variable [21]. For the model to be accepted, the R<sup>2</sup> value must be high (>50%).

The modeling was carried out by using Microsoft excel 2010. This was with the aim of minimizing the sum of squared deviations of the observed values for the dependent variable from those predicted by the models.

The above ground biomass for each species was calculated as follows:

$$\begin{aligned} AGB &= Volume \times Specificgravity \\ &= a \times D^b \times H^c \times Specificgravity \end{aligned}$$

The carbon storage for each species was computed by multiplying total biomass with constant factor 0.50 (IPCC, 2006) [22].

$$C = AGB \times 0.50$$

Where, C = Carbon (Mg ha<sup>-1</sup>) ABG = above ground Biomass (Mg ha<sup>-1</sup>).

Following [23], the following indicators of goodness of fit were calculated for each model:

1. R<sup>2</sup> of the simple regression.

2. Standard error: reported for the intercept and for partial regression coefficients of the independent variables.
3. Significance of t-value: reported for each independent variable.

### 3. RESULTS AND DISCUSSION

A good estimate of carbon sequestration is essential to any project of this particular type. Estimation of carbon sequestration is generally produced by measuring the total biomass of the population by different approaches. The first is to assess the volume of each tree using a volume equation, convert wood volume to mass using an estimate of wood density, and then convert volume to total AGB using a biomass expansion factor. The other approach is to apply a regression equation that directly converts external independent variables, such as DBH alone or DBH and height together. Individual AGB values produced using either approach are summed to produce the AGB of the entire population, which is then multiplied by a standard value of carbon concentration to produce an estimate of the carbon sequestration. The first approach to estimating carbon sequestration is useful where volume estimates already exist, the second approach requires fewer steps to estimate carbon sequestration once a regression has been prepared.

#### 3.1 Comparison of Models

In order to facilitate comparison to linear models in other papers [23], DBH, height and volume estimates given by all four models were ln-transformed, and linear regressions were fit to the ln-transformed data. Regressions of volume content on DBH and height, with ln-transformed data, do an excellent job of predicting the volume content of individual trees. Aside from Model D1h, all  $r^2$  values for models developed with our data (both DBH and height) were above 99%. The  $r^2$  values for models developed with DBH only were below 90%, least for model M1 (77.6%) (Table 1). The co-efficient for DBH was not significant in Model D1h and M1h, but the co-efficients for DBH and height was significant at the 5% level of significance for all other coefficients in all other models.

These models have the format  $V = C + \alpha \ln(\text{DBH}) + \beta \ln(H)$ , where V is volume per tree in  $\text{m}^3$  and DBH is diameter at breast height in meters and H is height of tree in meters. For

each species with only DBH in the model, the coefficient of the intercept (C) ranged from 0.041 to 0.378, and the coefficient of the independent variable ( $\alpha$ ) ranged from -7.822 to -0.969. The significance of the C coefficient is non-significant for each model ( $p > 0.05$ ) and the significance of  $\alpha$  coefficient is highly significant for each model ( $p < 0.01$ ). For models with both DBH and Height, the coefficient of the intercept (C) ranged from -0.001 to 0.004, coefficient of the independent variable ( $\alpha$ ) ranged from 0.961 to 1.163 and coefficient of the independent variable ( $\beta$ ) ranged from 0.630 to 0.697. The significance of the  $\beta$  coefficient is highly significant for each model ( $p < 0.01$ ). Among all these models the co-efficient of determination i.e.  $r^2$  is highest for model (M1h).

#### 3.2 Tree Size, AGB and Carbon Sequestration

The average height and DBH of *Madhuca indica* was maximum (17.80 m and 0.87 m respectively), where as the average height and DBH of *Vachellia nilotica* was minimum (10.83 m and 0.47 m respectively). The tree density per hectare was maximum (625) for *Tectona grandis* and minimum for *Madhuca indica* (325) (Table 2).

The estimated stem volume was maximum for *Madhuca indica* (1.551 and 1.440  $\text{m}^3$ ) while minimum was estimated for *Vachellia nilotica* (0.791 and 0.764  $\text{m}^3$ ) by using equation 2 and equation 1 respectively. The maximum AGB was recorded in *Tectona grandis* with 376.2 and 355.63t/tree with carbon sequestration of 621.25 and 587.50 kg/ha for the equation T1 and T2H respectively; whereas minimum AGB was recorded for *Dalbergia sisoo* with 221.55 and 211.58 t/ha and carbon sequestration of 362.93 and 349.65 kg/ha (Table 3).

Researchers generally estimate the carbon by assuming the carbon content of dry biomass to be a constant 50% by weight [24]. Volume, biomass and carbon sequestration is a function of height, diameter and tree density, at any particular site. These parameters contribute to the AGB, habitat, age, composition of forest, species variability and varying tree density etc. [25]. Terakunpisut et al. [26] suggested that variation in biomass at various sites can be attributed to some internal and external factors, viz. type of forest, site, disturbances, total annual rainfall and location of the forests. Our results

**Table 1. Regression models for estimation of above-ground biomass of *Dalbergia sissoo*, *Tectona grandis*, *Vachellia nilotica* and *Madhuca indica***

Model name	Regression model	Symbol	Value	Standard error	R <sup>2</sup>	Significance
<b><i>Dalbergia sissoo</i></b>						
D1	Ln(V) = C + α ln(DBH)	C	0.058	0.097	0.896	0.564
		α	-0.981	0.154		0.000
D2h	Ln(V) = C + α ln(DBH) +β ln(H)	C	-0.002	0.051	0.977	0.971
		α	1.006	0.373		0.025
		β	0.632	0.116		0.000
<b><i>Tectona grandis</i></b>						
T1	Ln(V) = C + α ln(DBH)	C	0.136	0.170	0.806	0.443
		α	-1.234	0.286		0.000
T2h	Ln(V) = C + α ln(DBH) +β ln(H)	C	-0.001	0.042	0.991	0.978
		α	1.085	0.194		0.000
		β	0.685	0.053		0.000
<b><i>Vachellianilotica</i></b>						
A1	Ln(V) = C + α ln(DBH)	C	0.041	0.093	0.912	0.669
		α	-0.969	0.145		0.000
A2h	Ln(V) = C + α ln(DBH) +β ln(H)	C	0.00007	0.034	0.999	0.998
		α	1.163	0.279		0.003
		β	0.697	0.090		0.000
<b><i>Madhuca indica</i></b>						
M1	Ln(V) = C + α ln(DBH)	C	0.378	0.235	0.776	0.139
		α	-7.822	2.009		0.000
M2h	Ln(V) = C + α ln(DBH) +β ln(H)	C	0.004	0.053	0.993	0.939
		α	0.961	0.689		0.197
		β	0.630	0.040		0.000

**Table 2. Summary of different growth parameters of *Dalbergia sissoo*, *Tectona grandis*, *Vachellia nilotica* and *Madhuca indica* used for estimation of biomass and carbon sequestration**

Species	Trees density / ha	Average height (m)	Average diameter (m)
<i>Dalbergia sissoo</i>	525	11.04	0.49
<i>Tectona grandis</i>	625	12.98	0.51
<i>Vachellia nilotica</i>	491	10.83	0.47
<i>Madhuca indica</i>	325	17.80	0.87

**Table 3. Summary of predicted volume, AGB, carbon density and carbon sequestration using two different regression models**

Species	Model	Volume /tree	AGB t/ha	Carbon density /ha	Carbon sequestration kg/ha
<i>Dalbergia sissoo</i>	D1	0.760	211.58	95.03	349.65
	D2h	0.796	221.55	99.75	365.93
<i>Tectona grandis</i>	T1	0.965	355.63	160.00	587.50
	T2h	1.028	376.25	169.38	621.25
<i>Vachellia nilotica</i>	A1	0.764	255.32	114.89	421.77
	A2h	0.791	264.16	118.82	436.50
<i>Madhuca indica</i>	M1	1.440	221.98	99.78	366.60
	M2h	1.551	239.20	107.58	395.20

clearly showed that AGB was less in *Dalbergia sissoo*, *Vachellia nilotica*, and *Madhuca indica*, but was very high in *Tectona grandis* due to its fast growth, irrespective of maximum DBH and height which was the maximum for *Madhuca indica* with 0.87 m and 17.80 m respectively due to big and old trees (Table 2). According to [27], over mature vegetation do not add up further biomass because most part of the primary productivity is either used up in respiration or returned back to the soil as organic matter. The two separate models for each species were used for volume estimation which depicted that the models with parameters DBH and Height showed maximum variation in dependent variable (volume, ABG and carbon Sequestration) due to two independent variables as shown by their  $R^2$  values. The model A2h for *Vachellia nilotica* has maximum ( $R^2=0.999$ ) followed by model D2h for *Dalbergia sissoo* with  $R^2=0.997$  (Table 1).

The DBH (1.37 m) and Height affects the final estimate of the tree's volume and AGB [23,28], they further added single stem sample at breast height (1.37 m) and height also affected the final estimate of the tree's weight by less than 4%. In our study the maximum AGB, carbon density and carbon sequestration was recorded for *Tectona grandis* with 376.25 t/ha, 169.38 and 621.25 kg/ha respectively for model T2h. whereas, the minimum biomass, carbon density and carbon sequestration with 211.58t/ha, 95.03 and 349.65 kg/ha was recorded for *Dalbergia sissoo* respectively for Model D1 (Table 3). Stem diameter explains nearly half of the variation between biomass and carbon concentrations for all the four species with different  $R^2$  values (Table 1) as has been previously reported by Losi et al. [28]. Although different Models were developed from different populations of trees, the estimations of carbon stock produced from these models only differ by small margin, when applied to the range of trees that both models were developed. Such an agreement between these two estimates are supported by the work of [29] that allometric regression models produced for the same species using the same range of tree sizes and similar methods did not vary much, even when trees are different ages and independent variables. These facts suggest that models developed with a little variation of diameters may be more precise in predicting carbon storage for a populace of trees in that range than a model developed from a wider variation of diameters classes. Some authors [28,30] include a catalogue of diameter

classes and biomass estimates for each harvested tree that can be used for this function.

#### 4. CONCLUSION

Carbon sequestration studies of forests is important to find out their role and prospective to mitigate global warming. Forests are substantial sink of carbon stored as biomass and in soil. Forest carbon storage is manipulated by different factors such as natural factors, environmental factors, edaphic factors and anthropogenic activates. In this study we try find the accuracy of the two different models for each species based on different variables and concluded that the models developed from a two are more variables (DBH, Height etc) are more accurate then the models developed from single variable for estimation/predicting volume, AGB and carbon sequestration of a single tree or population of trees. But at the same time estimation of AGB and carbon sequestration by using the model with multiple variables requires huge time as well as the error in obtaining height data in forests which make the process cumbersome. Therefore the models with single variable (DBH) is better to used for estimation of ABG and carbon sequestration in the forests.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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