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Biomass Accumulation and Carbon Sequestration in *Dalbergia sissoo* Roxb

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Abstract

Carbon management is a serious concern confronting the world today. The significance of role of biomass of tree species in carbon sequestration has long been recognized, but very little attempts have been made to estimate the biomass accumulation and their contribution for sequestration of carbon, especially in mined out areas. Carbon sequestration rates vary by tree species, soil type, regional climate, and topography and management practice. In the present paper, attempts were made to work out biomass accumulation and carbon sequestration by Dalbergia sissoo raised on coal mine overburden of Singrauli, M.P adopting non harvest technique. Over burden plantations of different years raised at different project sites of NCL Singrauli were taken for estimating the standing volumes and consequently biomass accumulation and carbon sequestration at different diameter and height of trees. The growth data was collected for 248 trees (above 4 cm DBH) covering the over burden plantations of Amlohri, Nigahi, Bina, Kakari and Khadia Open Cast Projects (OCP). The age of plantation varied from 2 to 19 years. The trees were selected in plantations of all available ages representing different diameters and height. The correlation between basal area vs volume, DBH vs volume and basal area vs total biomass was found to be significant. On the basis of results obtained, the Dalbergia sissoo proved as an efficient species pertaining to biomass and carbon accumulation, owing to high energy conversion efficiency.

Keywords: *Carbon sequestration, biomass accumulation, standing volume, energy conversion efficiency, coal mine spoil, overburden dumps, age series of plantations*

1. Introduction

Carbon management is a serious concern confronting the world today. A number of summits have been organized on this subject ranging from the Stockholm to Kyoto protocol. The current level of carbon in the atmosphere is about 375 ppm. It is estimated that if the carbon increases in the atmosphere at the present rate and no positive efforts are pursued, the level of carbon in the atmosphere would go up to 800–1000 ppm by the end of current century, which may create havoc for all living creatures on earth. Plants are the main source of the soil organic carbon, either from the decomposition of aerial plant parts or underground plant parts, e.g. roots in the form of root death, root exudates and root respiration. About 40% of the photosynthesis synthesized in the plant parts is lost through the root system into the rhizosphere within an hour and the rate of loss is influenced by several factors, e.g. plant age, different biotic and abiotic stresses, etc. The tree plantation plays an important role to removed CO_2 from the atmosphere and stored in and on the surface of the each assuming the given amount of CO_2 will remain stored in and on the same stable way as reserve of the oil, natural gas or coal beneath the ground for centuries to come (Brown, 2001). The phenomenon of CO_2 removal from the atmosphere and its storage in plant tissue or biomass is known as carbon sequestration. Selection of ideal species for revegetation of mined out areas is very important step for restoration of reduced ecosystem. The significance of role of biomass of tree species in carbon sequestration has long been recognized, but very little attempts have been made to estimate the biomass accumulation and their contribution for sequestration of carbon, especially in mined out areas. Carbon sequestration rates vary by tree species, soil type, regional climate, and topography and management practice. In the present paper, attempts were made to work out performance of biomass accumulation and carbon sequestration by *Dalbergia sissoo* Roxb. raised on coal mine overburden of Singrauli, M.P. The outcome of the present study is of vital importance to workout biomass accumulation and ecological function of *Dalbergia sissoo* Roxb. and for measuring its potential to serve as a carbon offset both above and below ground.

Dalbergia sissoo Roxb. belonging to family leguminosae is a multipurpose tree species found in many parts of India up to 900 m in the sub-Himalayan tract and occasionally ascending to 1500 m. It has been widely used for afforestation in most parts of the country except in the very hot, cold and wet tracts. According to Troup (1921), it is very likely that *D. sissoo* is an indigenous only to the sub-Himalayan and bhabar areas and has been introduced by man elsewhere. It is classical example of a pioneer species in the riverain succession of the Gangetic alluvium in India. The species occurs naturally on sandy and gravelly alluvial ground along the banks of rivers and streams, on the riverain islands and on freshly laid down alluvium. It tolerates a fair amount of salt concentration in the soil and offers a good possibility of being grown on saline or only mild sodic soils and also on mind out soils. There is remarkable variation in growth pattern and yield per unit area due to the wide adaptability of the tree in different ecological sites. The productivity of the tree is affected by different climatic, edaphic and biotic factors. Sapwood white to pale brownish white, heartwood golden brown to dark brown with deep brown streaks, soon becoming dull, working smooth with care, without characteristic odor or taste, moderately heavy to heavy, interlocked-grained in narrow straight lines, medium coarse-textured (Pearson and Brown, 1932).

2. Materials and Methods

Singrauli is the 50th district of Madhya Pradesh State of Union Republic India. The Singrauli coalfields (Lat 24^{o} 46’ 60’’- 24^{o} 78’ 33’’N and Long- 82^{o} 49’ 59’’- 82^{0} 83’ 30’’E) is spread over an area of 2200 sq km falling in Madhya Pradesh (eastern part of Sidhi district) and Uttar Pradesh (southern part of Sonebhadra district). The present paper deals with the biomass accumulation and carbon sequestration of *Dalbergia sissoo.* In Singrauli, *Dalbergia sissoo* has been raised in different years old plantations at different project sites. The growth data on diameter at breast height and afterwards at one meter interval up to the tip of the tree for minimizing the tapering effect and total height, was recorded for 248 trees (above 4 cm DBH) covering the over burden plantations of Amlohri, Nigahi, Bina, Kakari and Khadia Open Cast Projects (OCP). The age of plantation varied from 2 to 19 years. The trees were selected in plantations of all available ages representing different diameters and heights. The present paper deals with the estimation of standing biomass and carbon sequestration of *Dalbergia sissoo* adopting non harvest method, described as under:

2.1. Estimation of Volume Accumulation

Dalbergia sissoo was identified for estimation of volume accumulation and subsequently biomass accumulation and carbon sequestration. Trees of different diameter (above 4 cm

DBH) were selected for measurement from different years old overburden plantations raised at different project sites of Singrauli. For accuracy, more than 30 minimum required trees of different species were taken for volume estimation (FSI, 1996). The trees were selected randomly in plantations of all available ages representing different diameters and heights. The growth data was collected for total height, girth at breast height (GBH) and girth (over bark) at midpoint of each 1 meter interval after GBH till the top of the tree for minimizing the tapering effect. The girth was measured without felling trees with the help of climbers. Girth was converted to diameter by dividing π i.e. 3.14. Volume was calculated for different imaginary segments using cylindrical cross sectional areas, multiplied by height of each segment ($\pi r^2 h$). Total wood volume was calculated by using diameter over bark (DOB) at all intervals. Total volume of the bole was worked out by totaling the volumes of these imaginary segments. The DBH, total height and total volumes were fed in SPSS software using computer. On the basis of maximum correlation coefficient (R^2) and minimum standard error, the best fit modal was computed for each dominant species. Multiple regression equations were tried to work out the relationship between the DBH (diameter over bark at breast height) and height, and also between DBH and volume and subsequently, the best fit regression equation was determined using SPSS software to prepare volume growth tables. The general volume equations (GVEs) i.e. regression function in volume diameter and height, were selected for each species. The general volume equations were obtained from the actual data of standing trees by applying multiple regression methods. Following regression equations (FSI, 1996) were attempted:

(i) $VOB = a + b D^2H$

(ii) $VOB = a + bD + cD^2H$

(iii) $VOB = a + b D^2 + c (D^2H)^2$

(iv) $VOB = a + bD + c D^2H + d(D^2H)^2$

(v) $VOB = a + bD + c H + c D^2H$

(vi) $VOB = a + bD + cD^2 + d D^2H$

(vii) $Log_eVOB = a + b Log_eD + c Log_eH$

(viii) $VOB/D^2H = a + b D^2H$

(ix) $VOB/D^2H = a + b D^2H + c /D^2H$

Where,

VOB = Volume over bark (m^3)

D = Diameter at breast height (1.37m) over bark in cm

H = Height of tree in meter

and a, b, c are statistical constants.

After getting values of constants for best fit equation, the actual volumes as well as those predicted by the equation were tabulated an computed.

2.2 Estimation of Biomass Accumulation

Above ground biomass was worked out by multiplying volume with wood density of 0.75 tonnes/m^3 of *Dalbergia sissoo* (Reyes *et al*., 1992; Pearson and Brown, 1932). Below ground biomass was calculated by using simple default value of 25% (for hardwood species) of the above ground biomass as recommended by IPCC, 2006. Wood density information was presented in units of oven dry weight in gm/cm^3 (=tonnes/m^3) of green volume. Multiple regression equations were tried to establish the correlation between the biomass with DBH and / or bole biomass. The biomass tables for above ground and below ground biomass were prepared separately for different diameter and height classes for the targeted species, and by adding the values of above ground and below ground biomass, a table for total biomass was also prepared. The projected biomass tables for above ground, below ground and total biomass were also prepared using data of volumes estimated for tree of different DBH (2 cm interval) and heights (one m interval). The biomass was expressed in tonnes per tree.

2.3 Estimation of Carbon and CO_2 Tables

The amount of carbon sequestered was calculated by reducing the biomass yield to its 50% as per the guidelines of IPCC, 2006. Biomass value was converted to carbon stocks using 0.5 carbon fraction are default values (IPCC, 2006) and it was expressed in tonnes per tree. Carbon is multiplied by 44/12 the ratio in order to convert the carbon to CO_2. Finally, carbon tables for different species were prepared. These tables gave the content of carbon sequestered in trees of different diameter and height classes.

3. Results and Discussion

The DBH, total height, basal area, volume, biomass (above ground, below ground and total biomass) and carbon content of 248 *Dalbergia sissoo* trees were actually measured to prepare the volume table. The linear correlation between basal area vs volume, DBH vs volume and basal area vs total biomass among 248 trees taken for actual measurement was found to be significant with the values of R^2 0.912, 0.846 and 0.912 respectively as depicted in Figure 1, 2 and 3. The values of R^2 are closer to +1 which indicates that the better the line fits the data.

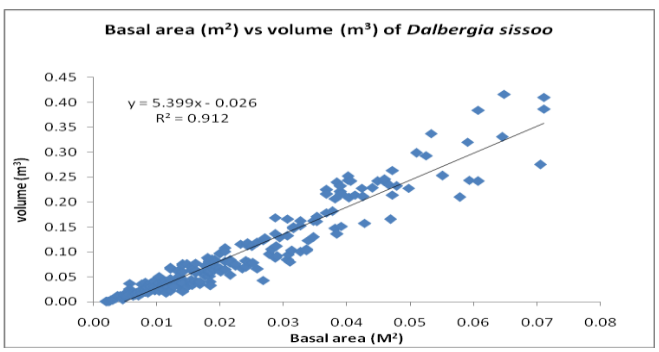

Figure 1. Basal Area (m^2) vs Volume (m^3) of *Dalbergia sissoo*

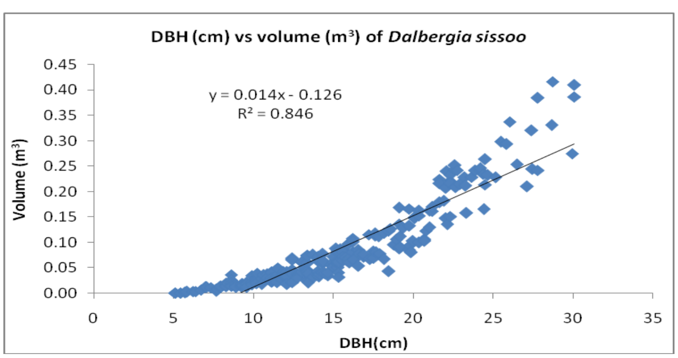

Figure 2. DBH (cm) vs Volume (m^3) of *Dalbergia sissoo*

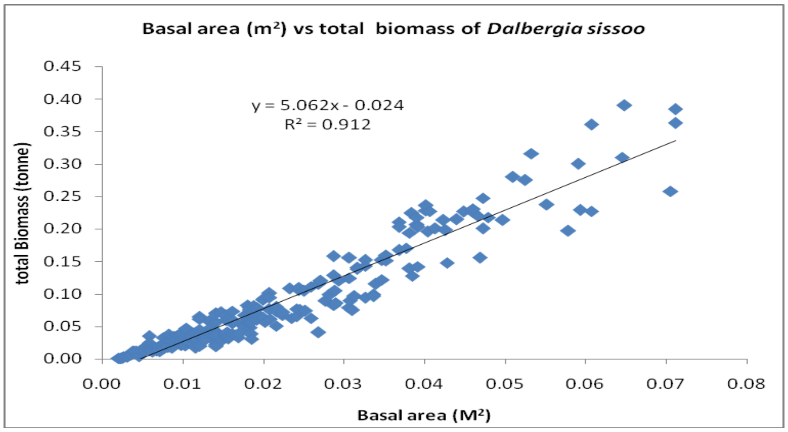

Figure 3. Basal Area (m^2) vs Total Biomass of *Dalbergia sissoo*

The actual data was used to prepare different tables of volume, biomass and carbon contents. Different multiple regression equations were set taking DBH and total tree height as independent variables and volume as dependent variable. On the basis of maximum correlation coefficient (R^2) and minimum standard error (SE), the best fit modal was computed. Multiple regression equations were tried to work out the relationship between the DBH (diameter over bark) at breast height and height and also between DBH and volume and the best fit equation was determined using SPSS software to prepare volume growth tables. Following regression equations were tried to find out best fit equation.

S.N.	Equations	R^2 (%)	SE
1	$VOB = 0.000 + 3.834 \times 10^{-5} D^2H$	0.968	0.0191808
2	$VOB = -0.023 + 0.002D + 3.361 \times 10^{-5}D^2H$	0.970	0.0186189
3	$VOB = -0.005 + 0.000 D^2 + 1.156 \times 10^{-9}(D^2H)^2$	0.965	0.0199936
4	$VOB = -0.033 + 0.004D + 2.365 \times 10^{-5}D^2H + 6.044 \times 10^{-10}(D^2H)^2$	0.971	0.0180987
5	$VOB = 0.008 + 0.002D - 0.003H + 3.709 \times 10^{-5} D^2H$	0.974	0.0172296
6	$VOB = 0.022 - 0.004 D + 0.000 D^2 + 2.546 \times 10^{-5} D^2H$	0.976	0.0165703
7	$Log_eVOB = -9.663 + 2.096 Log_eD + 0.671 Log_eH$	0.984	0.1258434
8	$VOB/D^2H = 4.084 \times 10^{-5} - 4.478 \times 10^{-10} D^2H$	0.041	0.00000593
9	$VOB/D^2H = 3.801 \times 10^{-5} - 2.370 \times 10^{-11} D^2H + 0.002 \times 1/D^2H$	0.264	0.00000520

On the basis of maximum correlation coefficient (R^2) and minimum standard error, the best model was computed to be

$$VOB = 0.008 + 0.002D - 0.003H + 3.709 \times 10^{-5} D^2H$$

Where, VOB = Volume over bark in cmt

D= Diameter at breast height in cm

H= Total tree height in m.

The general volume table was prepared by using the best fit regression equations on the actual growth data. The summary of statistical analysis of the best fit equation is given in

Table 1. Variables Entered/removed part of the table reveals that independent variables (D, H and D^2H) are part of the equation and V is the dependent variable. The model summary part of the output reveals that the multiple correlation coefficients R (0.987[a]) has significant correlation of volume with D, H and D^2H. The ANOVA part of the table tells us a statistically significant value (0.000[a]) portion of the variability in the dependent variable (V) from variability in the independent variables (D, H and D^2H). The Coefficients part of the output gives us the values that we need in order to write the regression equation. The regression equation will take the form: VOB = 0.008 + 0.002D - 0.003H + 3.709 x 10^{-5} D^2H, where 0.008 is the intercept, 0.002, -0.003 and 3.709 x 10^{-5} are the slope values.

Table 1. The Statistical Summary of the Data Based on Best Fit Equation

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	D^2H, H, D[a]	.	Enter

a. All requested variables entered.
b. Dependent Variable: V

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.987[a]	0.974	0.974	0.0172296

a. Predictors: (Constant), D^2H, H, D

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.721	3	0.907	3055.704	0.000[a]
	Residual	0.072	244	0.000		
	Total	2.794	247			

a. Predictors: (Constant), D^2H, H, D
b. Dependent Variable: V

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.008	0.007		1.071	0.285
	D	0.002	0.001	0.107	3.568	0.000
	H	-0.003	0.001	-0.096	-6.489	0.000
	D^2H	3.709 x 10^{-5}	0.000	0.952	28.952	0.000

a. Dependent Variable: V

The general volume table was prepared after getting values of constants for best fit equation; the actual volumes as well as those predicted by the equation were tabulated and computed (Table 2). It was found that in all cases, actual volume resembled closely with predicted volumes. Critical examination of the data (Table 2) reveals that the volume was found to be increasing with increase in the height and diameter at fast rate during the early growth (up to 5 meter height) and then become normal up to 10 meter height and again showed fast increasing trend thereafter.

Table 2. Volume Table of *Dalbergia sissoo*

Best fit equation: $VOB = 0.008 + 0.002D - 0.003H + 3.709 \times 10^{-5} D^2H$ $R^2 = 0.974$

Volume (m^3)	**Total Height (m)**																	
DBH (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**1**
4	0.011	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0.023	0.022	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	0.029	0.030	0.031	0.032	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.037	0.038	0.039	0.039	0.040	0.041	0.0
12	0.037	0.039	0.041	0.044	0.046	0.048	0.051	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.069	0.072	0.074	0.0
14	0.045	0.049	0.053	0.057	0.062	0.066	0.070	0.074	0.079	0.083	0.087	0.092	0.096	0.100	0.104	0.109	0.113	0.1
16	0.053	0.059	0.066	0.072	0.079	0.085	0.092	0.098	0.105	0.111	0.118	0.124	0.131	0.137	0.144	0.150	0.157	0.1
18	0.062	0.071	0.080	0.089	0.098	0.107	0.116	0.125	0.134	0.143	0.152	0.161	0.170	0.179	0.188	0.197	0.206	0.2
20	0.072	0.084	0.095	0.107	0.119	0.131	0.143	0.155	0.166	0.178	0.190	0.202	0.214	0.226	0.237	0.249	0.261	0.2
22	0.082	0.097	0.112	0.127	0.142	0.157	0.172	0.187	0.202	0.216	0.231	0.246	0.261	0.276	0.291	0.306	0.321	0.3
24	0.093	0.111	0.129	0.148	0.166	0.185	0.203	0.221	0.240	0.258	0.276	0.295	0.313	0.331	0.350	0.368	0.387	0.4
26	0.104	0.126	0.148	0.170	0.192	0.215	0.237	0.259	0.281	0.303	0.325	0.347	0.369	0.391	0.413	0.435	0.457	0.4
28	0.116	0.142	0.168	0.194	0.220	0.247	0.273	0.299	0.325	0.351	0.377	0.403	0.429	0.455	0.481	0.507	0.533	0.5
30	0.129	0.159	0.190	0.220	0.250	0.281	0.311	0.341	0.372	0.402	0.433	0.463	0.493	0.524	0.554	0.584	0.615	0.6
32	0.142	0.177	0.212	0.247	0.282	0.317	0.352	0.387	0.422	0.457	0.492	0.527	0.562	0.597	0.632	0.667	0.702	0.7
34	0.156	0.196	0.236	0.275	0.315	0.355	0.395	0.435	0.475	0.515	0.555	0.594	0.634	0.674	0.714	0.754	0.794	0.8
36	0.170	0.215	0.260	0.305	0.350	0.395	0.441	0.486	0.531	0.576	0.621	0.666	0.711	0.756	0.801	0.846	0.891	0.9
38	0.185	0.236	0.286	0.337	0.387	0.438	0.488	0.539	0.590	0.640	0.691	0.741	0.792	0.842	0.893	0.943	0.994	1.0
40	0.201	0.257	0.313	0.370	0.426	0.482	0.539	0.595	0.651	0.708	0.764	0.820	0.877	0.933	0.990	1.046	1.102	1.1
42	0.217	0.279	0.342	0.404	0.467	0.529	0.591	0.654	0.716	0.779	0.841	0.904	0.966	1.028	1.091	1.153	1.216	1.2
44	0.234	0.302	0.371	0.440	0.509	0.578	0.646	0.715	0.784	0.853	0.922	0.990	1.059	1.128	1.197	1.266	1.335	1.4
46	-	0.326	0.402	0.477	0.553	0.628	0.704	0.779	0.855	0.930	1.006	1.081	1.157	1.232	1.308	1.383	1.459	1.5
48	-	-	-	0.516	0.599	0.681	0.764	0.846	0.929	1.011	1.093	1.176	1.258	1.341	1.423	1.506	1.588	1.6
50	-	-	-	-	-	-	-	-	1.005	1.095	1.185	1.274	1.364	1.454	1.544	1.633	1.723	1.8

The correlation between actual volume and computed volume (detailed in table-2) for 248 measured trees, as determined by using SPSS software was found to be significantly positive at 0.01 levels (99% confidence level) as depicted below:

Correlations			
		Actual_Volume	Computed_Volume
Actual Volume	Pearson Correlation	1	.980**
	Sig. (2-tailed)		.000
	N	248	248
Computed Volume	Pearson Correlation	.980**	1
	Sig. (2-tailed)	.000	
	N	248	248
**. Correlation is significant at the 0.01 level (2-tailed).			

The general volume table was used for preparing the above ground biomass using the formula: wood density of *Dalbergia sissoo* (g/cm^3 = tonnes/m^3) x volume of tree (m^3). The above ground biomass table showed the increasing trend between biomass and growth (height and DBH) parameters. The minimum and maximum above ground biomass was found to be 0.008 tonnes (with 4 cm dbh and 2 m height) and 1.763 tonnes (with 50 cm dbh and 25 m height) respectively (Table - 3). The minimum and maximum below ground biomass was found to be 0.002 tonnes (with 4 cm dbh and 2 m height) and 0.440 tonnes (with 50 cm dbh and 25 m height) per tree respectively (Table-4). The total minimum and maximum biomass was found to be 0.010 tonnes (with 4 cm dbh and 2 m height) and 2.204 tonnes (with 50 cm dbh and 25 m height) per tree respectively (Table-5). The minimum and maximum values of carbon content were 0.005 tonnes (with 4 cm dbh and 2 m height) and 1.102 tonnes (with 50 cm dbh and 25 m height) per tree respectively (Table-6). The minimum and maximum values of CO_2 absorbed from the atmosphere were 0.019 tonnes (with 4 cm dbh and 2 m height) and 4.041 tonnes (with 50 cm dbh and 25 m height) per tree respectively (Table-7).

Table 3. Above ground Biomass (Wood Density =0.75*V) table of *Dalbergia*

Above ground biomass (tonnes)	Total Height (m)																	
DBH (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**1**
4	0.008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6	0.013	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
8	0.017	0.017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10	0.022	0.023	0.023	0.024	0.024	0.025	0.026	0.026	0.026	0.027	0.028	0.028	0.029	0.029	0.029	0.030	0.031	0.
12	0.028	0.029	0.031	0.033	0.035	0.036	0.038	0.040	0.041	0.044	0.045	0.047	0.049	0.050	0.052	0.054	0.056	0.
14	0.034	0.037	0.040	0.043	0.047	0.050	0.053	0.056	0.059	0.062	0.065	0.069	0.072	0.075	0.078	0.082	0.085	0.
16	0.040	0.044	0.050	0.054	0.059	0.064	0.069	0.074	0.079	0.083	0.089	0.093	0.098	0.103	0.108	0.113	0.118	0.
18	0.047	0.053	0.060	0.067	0.074	0.080	0.087	0.094	0.101	0.107	0.114	0.121	0.128	0.134	0.141	0.148	0.155	0.
20	0.054	0.063	0.071	0.080	0.089	0.098	0.107	0.116	0.125	0.134	0.143	0.152	0.161	0.170	0.178	0.187	0.196	0.
22	0.062	0.073	0.084	0.095	0.107	0.118	0.129	0.140	0.152	0.162	0.173	0.185	0.196	0.207	0.218	0.230	0.241	0.
24	0.070	0.083	0.097	0.111	0.125	0.139	0.152	0.166	0.180	0.194	0.207	0.221	0.235	0.248	0.263	0.276	0.290	0.
26	0.078	0.095	0.111	0.128	0.144	0.161	0.178	0.194	0.211	0.227	0.244	0.260	0.277	0.293	0.310	0.326	0.343	0.
28	0.087	0.107	0.126	0.146	0.165	0.185	0.205	0.224	0.244	0.263	0.283	0.302	0.322	0.341	0.361	0.380	0.400	0.
30	0.097	0.119	0.143	0.165	0.188	0.211	0.233	0.256	0.279	0.302	0.325	0.347	0.370	0.393	0.416	0.438	0.461	0.
32	0.107	0.133	0.159	0.185	0.212	0.238	0.264	0.290	0.317	0.343	0.369	0.395	0.422	0.448	0.474	0.500	0.527	0.
34	0.117	0.147	0.177	0.206	0.236	0.266	0.296	0.326	0.356	0.386	0.416	0.446	0.476	0.506	0.536	0.566	0.596	0.
36	0.128	0.161	0.195	0.229	0.263	0.296	0.331	0.365	0.398	0.432	0.466	0.500	0.533	0.567	0.601	0.635	0.668	0.
38	0.139	0.177	0.215	0.253	0.290	0.329	0.366	0.404	0.443	0.480	0.518	0.556	0.594	0.632	0.670	0.707	0.746	0.
40	0.151	0.193	0.235	0.278	0.320	0.362	0.404	0.446	0.488	0.531	0.573	0.615	0.658	0.700	0.743	0.785	0.827	0.
42	0.163	0.209	0.257	0.303	0.350	0.397	0.443	0.491	0.537	0.584	0.631	0.678	0.725	0.771	0.818	0.865	0.912	0.
44	0.176	0.227	0.278	0.330	0.382	0.434	0.485	0.536	0.588	0.640	0.692	0.743	0.794	0.846	0.898	0.950	1.001	1.
46	-	0.245	0.302	0.358	0.415	0.471	0.528	0.584	0.641	0.698	0.755	0.811	0.868	0.924	0.981	1.037	1.094	1.
48	-	-	-	0.387	0.449	0.511	0.573	0.635	0.697	0.758	0.820	0.882	0.944	1.006	1.067	1.130	1.191	1.
50	-	-	-	-	-	-	-	-	0.754	0.821	0.889	0.956	1.023	1.091	1.158	1.225	1.292	1.

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Table 4. Below ground Biomass (25% of the above ground biomass) table of *Dalbe*

Below ground Biomass (tonnes)	Total Height (m)																	
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
4	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6	0.003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
8	0.004	0.004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.008	0.
12	0.007	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.010	0.011	0.011	0.012	0.012	0.013	0.013	0.014	0.014	0.
14	0.008	0.009	0.010	0.011	0.012	0.012	0.013	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.020	0.020	0.021	0.
16	0.010	0.011	0.012	0.014	0.015	0.016	0.017	0.018	0.020	0.021	0.022	0.023	0.025	0.026	0.027	0.028	0.029	0.
18	0.012	0.013	0.015	0.017	0.018	0.020	0.022	0.023	0.025	0.027	0.029	0.030	0.032	0.034	0.035	0.037	0.039	0.
20	0.014	0.016	0.018	0.020	0.022	0.025	0.027	0.029	0.031	0.033	0.036	0.038	0.040	0.042	0.044	0.047	0.049	0.
22	0.015	0.018	0.021	0.024	0.027	0.029	0.032	0.035	0.038	0.041	0.043	0.046	0.049	0.052	0.055	0.057	0.060	0.
24	0.017	0.021	0.024	0.028	0.031	0.035	0.038	0.041	0.045	0.048	0.052	0.055	0.059	0.062	0.066	0.069	0.073	0.
26	0.020	0.024	0.028	0.032	0.036	0.040	0.044	0.049	0.053	0.057	0.061	0.065	0.069	0.073	0.077	0.082	0.086	0.
28	0.022	0.027	0.032	0.036	0.041	0.046	0.051	0.056	0.061	0.066	0.071	0.076	0.080	0.085	0.090	0.095	0.100	0.
30	0.024	0.030	0.036	0.041	0.047	0.053	0.058	0.064	0.070	0.075	0.081	0.087	0.092	0.098	0.104	0.110	0.115	0.
32	0.027	0.033	0.040	0.046	0.053	0.059	0.066	0.073	0.079	0.086	0.092	0.099	0.105	0.112	0.119	0.125	0.132	0.
34	0.029	0.037	0.044	0.052	0.059	0.067	0.074	0.082	0.089	0.097	0.104	0.111	0.119	0.126	0.134	0.141	0.149	0.
36	0.032	0.040	0.049	0.057	0.066	0.074	0.083	0.091	0.100	0.108	0.116	0.125	0.133	0.142	0.150	0.159	0.167	0.
38	0.035	0.044	0.054	0.063	0.073	0.082	0.092	0.101	0.111	0.120	0.130	0.139	0.149	0.158	0.167	0.177	0.186	0.
40	0.038	0.048	0.059	0.069	0.080	0.090	0.101	0.112	0.122	0.133	0.143	0.154	0.164	0.175	0.186	0.196	0.207	0.
42	0.041	0.052	0.064	0.076	0.088	0.099	0.111	0.123	0.134	0.146	0.158	0.170	0.181	0.193	0.205	0.216	0.228	0.
44	0.044	0.057	0.070	0.083	0.095	0.108	0.121	0.134	0.147	0.160	0.173	0.186	0.199	0.212	0.224	0.237	0.250	0.
46	-	0.061	0.075	0.089	0.104	0.118	0.132	0.146	0.160	0.174	0.189	0.203	0.217	0.231	0.245	0.259	0.274	0.
48	-	-	-	0.097	0.112	0.128	0.143	0.159	0.174	0.190	0.205	0.221	0.236	0.251	0.267	0.282	0.298	0.

Table 5. Total Biomass (Above ground + Below ground biomass) table of *Dalbe*

Total Biomass (tonnes)	Total Height (m)																	
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
4	0.010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6	0.016	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
8	0.022	0.021	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10	0.027	0.028	0.029	0.030	0.030	0.031	0.032	0.032	0.033	0.034	0.035	0.035	0.036	0.037	0.037	0.038	0.038	0.
12	0.035	0.037	0.038	0.041	0.043	0.045	0.048	0.050	0.052	0.054	0.056	0.058	0.061	0.063	0.065	0.068	0.069	0.
14	0.042	0.046	0.050	0.053	0.058	0.062	0.066	0.069	0.074	0.078	0.082	0.086	0.090	0.094	0.098	0.102	0.106	0.
16	0.050	0.055	0.062	0.068	0.074	0.080	0.086	0.092	0.098	0.104	0.111	0.116	0.123	0.128	0.135	0.141	0.147	0.
18	0.058	0.067	0.075	0.083	0.092	0.100	0.109	0.117	0.126	0.134	0.143	0.151	0.159	0.168	0.176	0.185	0.193	0.
20	0.068	0.079	0.089	0.100	0.112	0.123	0.134	0.145	0.156	0.167	0.178	0.189	0.201	0.212	0.222	0.233	0.245	0.
22	0.077	0.091	0.105	0.119	0.133	0.147	0.161	0.175	0.189	0.203	0.217	0.231	0.245	0.259	0.273	0.287	0.301	0.
24	0.087	0.104	0.121	0.139	0.156	0.173	0.190	0.207	0.225	0.242	0.259	0.277	0.293	0.310	0.328	0.345	0.363	0.
26	0.098	0.118	0.139	0.159	0.180	0.202	0.222	0.243	0.263	0.284	0.305	0.325	0.346	0.367	0.387	0.408	0.428	0.
28	0.109	0.133	0.158	0.182	0.206	0.232	0.256	0.280	0.305	0.329	0.353	0.378	0.402	0.427	0.451	0.475	0.500	0.
30	0.121	0.149	0.178	0.206	0.234	0.263	0.292	0.320	0.349	0.377	0.406	0.434	0.462	0.491	0.519	0.548	0.577	0.
32	0.133	0.166	0.199	0.232	0.264	0.297	0.330	0.363	0.396	0.428	0.461	0.494	0.527	0.560	0.593	0.625	0.658	0.
34	0.146	0.184	0.221	0.258	0.295	0.333	0.370	0.408	0.445	0.483	0.520	0.557	0.594	0.632	0.669	0.707	0.744	0.
36	0.159	0.202	0.244	0.286	0.328	0.370	0.413	0.456	0.498	0.540	0.582	0.624	0.667	0.709	0.751	0.793	0.835	0.
38	0.173	0.221	0.268	0.316	0.363	0.411	0.458	0.505	0.553	0.600	0.648	0.695	0.743	0.789	0.837	0.884	0.932	0.
40	0.188	0.241	0.293	0.347	0.399	0.452	0.505	0.558	0.610	0.664	0.716	0.769	0.822	0.875	0.928	0.981	1.033	1.
42	0.203	0.262	0.321	0.379	0.438	0.496	0.554	0.613	0.671	0.730	0.788	0.848	0.906	0.964	1.023	1.081	1.140	1.
44	0.219	0.283	0.348	0.413	0.477	0.542	0.606	0.670	0.735	0.800	0.864	0.928	0.993	1.058	1.122	1.187	1.252	1.
46	-	0.306	0.377	0.447	0.518	0.589	0.660	0.730	0.802	0.872	0.943	1.013	1.085	1.155	1.226	1.297	1.368	1.
48	-	-	-	0.484	0.562	0.638	0.716	0.793	0.871	0.948	1.025	1.103	1.179	1.257	1.334	1.412	1.489	1.
50	-	-	-	-	-	-	-	-	0.942	1.027	1.111	1.194	1.279	1.363	1.448	1.531	1.615	1.

Table 6. Wood carbon (Total Biomass*0.5) table of *Dalbergia sissoo*

Wood Carbon (tonnes)	Total Height (m)																
DBH (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
4	0.005	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	0.008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	0.011	0.010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	0.014	0.014	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.017	0.017	0.017	0.018	0.018	0.018	0.019	0.019
12	0.017	0.018	0.019	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.034	0.035
14	0.021	0.023	0.025	0.027	0.029	0.031	0.033	0.035	0.037	0.039	0.041	0.043	0.045	0.047	0.049	0.051	0.053
16	0.025	0.028	0.031	0.034	0.037	0.040	0.043	0.046	0.049	0.052	0.055	0.058	0.061	0.064	0.068	0.070	0.074
18	0.029	0.033	0.038	0.042	0.046	0.050	0.054	0.059	0.063	0.067	0.071	0.075	0.080	0.084	0.088	0.092	0.097
20	0.034	0.039	0.045	0.050	0.056	0.061	0.067	0.073	0.078	0.083	0.089	0.095	0.100	0.106	0.111	0.117	0.122
22	0.038	0.045	0.053	0.060	0.067	0.074	0.081	0.088	0.095	0.101	0.108	0.115	0.122	0.129	0.136	0.143	0.150
24	0.044	0.052	0.060	0.069	0.078	0.087	0.095	0.104	0.113	0.121	0.129	0.138	0.147	0.155	0.164	0.173	0.181
26	0.049	0.059	0.069	0.080	0.090	0.101	0.111	0.121	0.132	0.142	0.152	0.163	0.173	0.183	0.194	0.204	0.214
28	0.054	0.067	0.079	0.091	0.103	0.116	0.128	0.140	0.152	0.165	0.177	0.189	0.201	0.213	0.225	0.238	0.250
30	0.060	0.075	0.089	0.103	0.117	0.132	0.146	0.160	0.174	0.188	0.203	0.217	0.231	0.246	0.260	0.274	0.288
32	0.067	0.083	0.099	0.116	0.132	0.149	0.165	0.181	0.198	0.214	0.231	0.247	0.263	0.280	0.296	0.313	0.329
34	0.073	0.092	0.111	0.129	0.148	0.166	0.185	0.204	0.223	0.241	0.260	0.278	0.297	0.316	0.335	0.353	0.372
36	0.080	0.101	0.122	0.143	0.164	0.185	0.207	0.228	0.249	0.270	0.291	0.312	0.333	0.354	0.375	0.397	0.418
38	0.087	0.111	0.134	0.158	0.181	0.205	0.229	0.253	0.277	0.300	0.324	0.347	0.371	0.395	0.419	0.442	0.466
40	0.094	0.120	0.147	0.173	0.200	0.226	0.253	0.279	0.305	0.332	0.358	0.384	0.411	0.437	0.464	0.490	0.517
42	0.102	0.131	0.160	0.189	0.219	0.248	0.277	0.307	0.336	0.365	0.394	0.424	0.453	0.482	0.511	0.540	0.570
44	0.110	0.142	0.174	0.206	0.239	0.271	0.303	0.335	0.368	0.400	0.432	0.464	0.496	0.529	0.561	0.593	0.626
46	-	0.153	0.188	0.224	0.259	0.294	0.330	0.365	0.401	0.436	0.472	0.507	0.542	0.578	0.613	0.648	0.684
48	-	-	-	0.242	0.281	0.319	0.358	0.397	0.435	0.474	0.512	0.551	0.590	0.629	0.667	0.706	0.744
50	-	-	-	-	-	-	-	-	0.471	0.513	0.555	0.597	0.639	0.682	0.724	0.765	0.808

Table 7. CO_2 (Total carbon *44/12) table of *Dalbergia sissoo*

CO_2 in tonnes	Total Height (m)																	
DBH (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**1**
4	0.019	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6	0.029	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
8	0.040	0.038	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10	0.050	0.052	0.053	0.055	0.055	0.057	0.058	0.058	0.060	0.062	0.064	0.064	0.065	0.067	0.067	0.069	0.070	0.0
12	0.064	0.067	0.070	0.076	0.079	0.083	0.088	0.091	0.095	0.100	0.103	0.107	0.112	0.115	0.119	0.124	0.127	0.1
14	0.077	0.084	0.091	0.098	0.107	0.113	0.120	0.127	0.136	0.143	0.150	0.158	0.165	0.172	0.179	0.187	0.194	0.2
16	0.091	0.101	0.113	0.124	0.136	0.146	0.158	0.168	0.180	0.191	0.203	0.213	0.225	0.235	0.248	0.258	0.270	0.2
18	0.107	0.122	0.138	0.153	0.168	0.184	0.199	0.215	0.230	0.246	0.261	0.277	0.292	0.308	0.323	0.339	0.354	0.3
20	0.124	0.144	0.163	0.184	0.205	0.225	0.246	0.266	0.285	0.306	0.327	0.347	0.368	0.388	0.407	0.428	0.449	0.4
22	0.141	0.167	0.193	0.218	0.244	0.270	0.296	0.321	0.347	0.371	0.397	0.423	0.449	0.474	0.500	0.526	0.552	0.5
24	0.160	0.191	0.222	0.254	0.285	0.318	0.349	0.380	0.413	0.443	0.474	0.507	0.538	0.569	0.602	0.633	0.665	0.6
26	0.179	0.217	0.254	0.292	0.330	0.370	0.407	0.445	0.483	0.521	0.559	0.596	0.634	0.672	0.710	0.748	0.785	0.8
28	0.199	0.244	0.289	0.333	0.378	0.425	0.469	0.514	0.559	0.603	0.648	0.693	0.737	0.782	0.827	0.871	0.916	0.9
30	0.222	0.273	0.327	0.378	0.430	0.483	0.535	0.586	0.639	0.691	0.744	0.796	0.847	0.901	0.952	1.004	1.057	1.1
32	0.244	0.304	0.364	0.425	0.485	0.545	0.605	0.665	0.725	0.785	0.846	0.906	0.966	1.026	1.086	1.146	1.207	1.2
34	0.268	0.337	0.406	0.473	0.541	0.610	0.679	0.748	0.816	0.885	0.954	1.021	1.090	1.158	1.227	1.296	1.365	1.4
36	0.292	0.370	0.447	0.524	0.602	0.679	0.758	0.835	0.913	0.990	1.067	1.145	1.222	1.299	1.377	1.454	1.531	1.6
38	0.318	0.406	0.492	0.579	0.665	0.753	0.839	0.926	1.014	1.100	1.188	1.274	1.361	1.447	1.535	1.621	1.708	1.7
40	0.345	0.442	0.538	0.636	0.732	0.828	0.926	1.023	1.119	1.217	1.313	1.409	1.507	1.604	1.702	1.798	1.894	1.9
42	0.373	0.480	0.588	0.694	0.803	0.909	1.016	1.124	1.231	1.339	1.445	1.554	1.660	1.767	1.875	1.982	2.090	2.1
44	0.402	0.519	0.638	0.756	0.875	0.993	1.110	1.229	1.348	1.466	1.585	1.702	1.820	1.939	2.057	2.176	2.295	2.4
46	-	0.560	0.691	0.820	0.950	1.079	1.210	1.339	1.470	1.598	1.729	1.858	1.989	2.118	2.248	2.377	2.508	2.6
48	-	-	-	0.887	1.030	1.170	1.313	1.454	1.597	1.738	1.879	2.021	2.162	2.305	2.446	2.588	2.729	2.8
50	-	-	-	-	-	-	-	-	1.727	1.882	2.037	2.190	2.344	2.499	2.654	2.807	2.961	3.1

The *Dalbergia sissoo* proved as an efficient species pertaining to biomass and carbon accumulation. The maximum biomass accumulation in *Dalbergia sissoo* may be due to high energy conversion efficiency as compared to other species. The energy conversion efficiency may be defined as the ratio of amount of photosynthetically active radiation (PAR) that falls on the plant canopy to the amount of energy fixed by the plant. The results are in agreement with the findings of Kok (1973), and Kok *et al* (1976). The efficiency of utilization of solar energy at celluler level in quite high being 30 percent. However, this must be treated as theoretical and can never be attained in nature, because much of the energy is lost as photorespiration, considerable part of fixed energy is utilized for growth and development; the theoretical maximum energy conversion efficiency (ECE) at cellular level is of the order of 12 percent. Kimothi (1984) has worked out tbe solar energy conversion efficiency of five fast growing forest plants at different periods of growth upto 36 months of age under energy plantation practices. The values for solar energy conversion efficiency at 36 months age for *Dalbergia sissoo*, *Cassia siamea*, *Acacia nilotica*, *Eucalyptus* and *Albizia lebbeck* were 2.09%, 1.58%, 1.44%, 1.26% and 1.19% respectively. Kimothi *et al.*, (1983) have carried out extensive studies on biomass production by seven different species grown under energy plantation practices under semi-arid non-irrigated conditions. They reported that *Dalbergia sissoo* produced a maximum total biomass of 114 dt/ha at the age of three years as compared to other species. The higher number of nodules formation in the roots of *Dalbergia sissoo* may also add more biomass accumulation as compared to other species. The wood of *Dalbergia sissoo* is also heavy as compared to other species (Pearson and Brown, 1932). The photosynthetic rate of *Dalbergia sissoo* was also reported to be maximum as compared to *Acacia auriculiformis* and *Albizia lebbek* (Srivastava and Ram, 2009). The nature of biomass accumulation may vary in the same species under different locality factors such as accumulation of nutrient in the soil, management practices and availability of light and other environmental factors. Perusal of data on biomass accumulation (above ground, below ground and total biomass) showed increasing trend with DBH and height classes.

4. Conclusion

Looking to the serious concern of carbon management, the role of *Dalbergia sissoo* Roxb. to estimate the biomass accumulation and their contribution for sequestration of carbon in mined out areas, the following conclusions were derived:

1. The DBH, total height, basal area, volume, biomass (above ground, below ground and total biomass) and carbon content of 248 *Dalbergia sissoo* trees were actually measured to prepare the volume table, estimation of biomass accumulation and carbon content in open cast coal mind out areas. In all cases, actual volume resembled closely with predicted volumes and showed significantly increasing trend with the increase in the height and diameter of trees.
2. The minimum and maximum biomass (above ground + below ground) was found to be 0.010 tonnes (with 4 cm dbh and 2 m height) and 2.204 tonnes (with 50 cm dbh and 25 m height) per tree respectively. The minimum and maximum values of carbon contents were 0.005 tonnes (with 4 cm dbh and 2 m height) and 1.102 tonnes (with 50 cm dbh and 25 m height) per tree respectively. The minimum and maximum values of CO_2 absorbed from the atmosphere were 0.019 tonnes (with 4 cm dbh and 2 m height) and 4.041 tonnes (with 50 cm dbh and 25 m height) per tree respectively. Based on literature review, *Dalbergia sissoo* has proved as more efficient with respect to solar energy conversion efficiency than *Cassia siamea*, *Acacia nilotica*, *Eucalyptus* and *Albizia lebbeck.*

Keeping above in view, *Dalbergia sissoo* is recommended as an efficient species pertaining to biomass and carbon accumulation for restoration of reduced ecosystem and for measuring its potential to serve as an efficient carbon offset.

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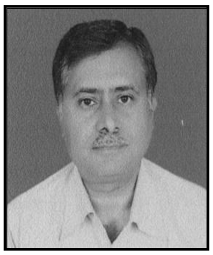

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