Biomass Accumulation and Carbon Sequestration in *Tectona grandis* Linn. f. and *Gmelina arborea* Roxb.

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Abstract

The significance of role of biomass of tree species in carbon sequestration had 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. Selection of ideal species for carbon sequestration is very important step for restoration of reduced ecosystem. Tectona grandis and Gmelina arborea belonging to family Verbenaceae, are most widely distributed and economically important timber species in India. In the present paper, attempts were made to work out biomass accumulation and carbon sequestration of these species raised in age series of plantations on coal mine overburden of Singrauli, M.P, India, adopting non harvest technique using following steps: volume over bark (vob), standing biomass, carbon of standing tree, biomass accumulation and carbon sequestration and finally, preparation of biomass and carbon tables. On the basis of maximum correlation coefficient and minimum standard error, the best fit equations were computed to be VOB = -0.017 + 0.003D + 0.0014H + 1.899 x 10^{-5} D^2H (R^2 =0.986, SE = 0.0049702113); and VOB = -0.009 + 0.003D + 0.000D^2 + 4.889x10^{-5} D^2H (R^2= 0.979, SE = 0.0070497) for Gmelina arborea and Tectona grandis, respectively and Where, VOB = volume over bark in CMT; D= diameter at breast height in cm; H= total tree height in meter. The growth data was collected for 49 trees of Gmelina arborea and 72 trees of Tectona grandis (above 5 cm diameter at breast height) covering the over burden plantations of Northern Coal Field Limited, Singrauli (M.P.), India. The best fit equation was then applied to determine the accumulation of total biomass (above- and below- ground) and carbon content adopting IPCC guidelines. The trees were selected in plantations of all available ages representing different diameters and heights. The linear correlation between basal area vs volume, DBH vs volume and basal area vs total biomass was found to be significant in both the species. The values of R^2 were closer to +1 which indicated the better line fits of the data.

Keywords: *Overburden plantations, biomass accumulation, carbon sequestration, non harvest technique*

1. Introduction

Carbon management is a serious concern confronting the world today. Since the beginning of the industrial revolution, carbon dioxide concentration in the atmosphere has been rising alarmingly, *i.e.*, from 270 ppm prior to the industrial revolution to about 394ppm in December 2012 (Manua Loa observatory, 2013). In spite of increasing interest of ecologists in the production of organic matter in different ecosystems, work of this nature in forests of tropical region is scanty due to great biological richness and diversity of species. Many workers study biomass production of tropical forests and different species by actual harvest at a predetermined age and allometric equations relating biomass with one or more tree dimensions (Odum and Pigeon, 1970; Jordan, 1971; Whitemore, 1975; Edwards and Grubbs, 1977; Enright, 1979; Tanner, 1980; Negi *et al.*, 1984; Prasad and Mishra, 1984; Prasad *et al.*, 1984; Rai, 1984; Sharma and Srivastava, 1984; Jain and Ansari, 2012). The results may be quite different, if the age of assessments is changed. In the scenario of climate change, it is necessary to assess the biomass production and carbon sequestration using non harvest techniques through developing multiple regression equations. Both *Gmelina arborea* and *Tectona grandis* belonging to family Verbenaceae, are commercially important and growing throughout the greater part of the country. The present paper deals with the biomass accumulation and carbon sequestration of *Tectona grandis* and *Gmelina arborea* in age series of plantations raised on different project sites of Northern Coal Field Limited, Singrauli (M.P.).

2. Materials and Methods

Singrauli (24^o 46' 60''- 24^o 78' 33''N, 82^o 49' 59''- 82^0 83' 30''E, 275 -500m AMSL) is the 50^{th} district of Madhya Pradesh. Considering the geological and technical feasibility of mining, and environmental conditions, the opencast mining is prevailing in the entire area. Vegetation during pre-mining period was very dense and covered with Northern tropical dry sal forests (5 B/C) and Northern tropical dry mixed deciduous forests (5 B/ C 2). Due to mining, the large forest areas were clear felled and laid barren. The present study covered artificial plantations raised in the mined out NCL area. For the estimation of biomass non harvest technique was adopted using following steps:

1. Volume over bark (VOB).
2. Standing biomass.
3. Carbon in standing tree.
4. Biomass accumulation and carbon sequestration in *Gmelina arborea* and *Tectona grandis*.
5. Biomass and carbon Tables.

2.1. Volume over Bark

The growth data was collected for total height and girth at breast height (GBH) at overbark. Besides, the length of tree after GBH had been divided into different segments of one meter each upto the tip of the tree. The girth at over bark of each segment was measured at the center of the segments throughout the height 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 each imaginary segment using cylindrical cross sectional areas, multiplied by height of each segment ($\pi r^2 h$). Total volume of the bole was worked out by adding the volumes of different imaginary segments starting from GBH to top of a height and the volume of the base segment (*i.e.*, below GBH). The DBH, total height and total volumes were fed in SPSS software using computer. On the basis of the maximum coefficient of determination (R^2) and the minimum standard error, the best fit model was computed for both the species. Multiple regression equations were tried to establish the correlation between the DBH and height between DBH and volume and the biomass and DBH.

2.2. Standing tree biomass

The stem wood biomass was worked out by multiplying volume with wood density (Reyes *et al*., 1992; Pearson and Brown, 1932) of *Tectona grandis* and *Gmelina arborea*. The stem wood biomass was then "expanded" to total above ground biomass of tree including leaves, twigs, branches, bole and bark using biomass expansion factor (BEF).

Total above ground biomass = Stem wood volume X Wood density X BEF

The mean BEF value of 1.5 was used for this study as prescribed by Brown and Luge (1992). The below ground biomass was calculated by using simple default value of 25% (for hardwood species) of the total above ground biomass as recommended by IPCC (2006). Wood density information was presented in units of oven dry weight in gm^{-3} (i.e. tonne m^{-3}) of green volume. Multiple regression equations were tried to establish the correlation between the biomass and DBH and / or bole biomass.

2.3. Standing Tree Carbon

The amount of carbon in a standing tree was calculated by dividing its biomass by 2 as per the guidelines of IPCC (2006), and was expressed in tonne $tree^{-1}$ and tonne ha^{-1}. Carbon content was then multiplied by 44/12 to estimate CO_2.

2.4. Biomass Accumulation and Carbon Sequestration

Nursery raised seedlings were used for this purpose**.** Fifteen randomly selected seedlings of each species were harvested for measuring their height and dry weight (dried at 104°C till the constant weight obtained). The average height and DBH of each species according to age were taken to estimate volume. The best fit equation was then applied to determine the accumulation of total biomass (above- and below- ground) and carbon content. The initial value of biomass and carbon in a seedling of a species was then subtracted from its corresponding estimates to obtain realistic amount of biomass accumulation and carbon sequestration by a tree. The per tree accumulation of biomass was multiplied by the actual number of seedlings usually planted per hectare (*i.e.*, 3333) to express the values in tonne ha^{-1}.

2.5. Biomass and Carbon Tables

The biomass and carbon tables were prepared after making volume growth tables. 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 following nine regression equations, as used by Forest Survey of India (FSI, 1996), were attempted to determine the best equation for estimating volume over bark (VOB) for this species:

(i)	VOB	=	$a + b\,D^2H$
(ii)	VOB	=	$a + b\,D + cD^2H$
(iii)	VOB	=	$a + b\,D^2 + c\,(D^2H)^2$
(iv)	VOB	=	$a + b\,D + c\,D^2H + d(D^2H)^2$
(v)	VOB	=	$a + b\,D + c\,H + c\,D^2H$
(vi)	VOB	=	$a + b\,D + cD^2 + d\,D^2H$
(vii)	Log_eVOB	=	$a + b\,Log_eD + c\,Log_eH$
(viii)	VOB	=	$(a + b\,D^2H)\,D^2H$

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

Where,

VOB = Volume over bark (m^3)

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

H = Height of tree (m)

a, b, c are the statistical constants of the equations.

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

The biomass tables for above - and below- ground biomass were prepared separately for different diameter and height classes for *Tectona grandis* and *Gmelina arborea*. The table for the total biomass of a tree was obtained by adding its values of above and below ground biomass. The projected biomass tables for above- and below- ground and total biomass were also prepared using data of volumes estimated for tree of different DBH (2 cm interval) and height (1 m interval) class. The biomass was expressed in tonne tree^{-1}. Finally, carbon tables for these species were prepared according to different diameter and height classes.

3. Results

3.1. Tectona Grandis

3.1.1. Biomass and carbon in standing trees of *Tectona grandis*: Seventy two trees (each having ≥ 5 cm DBH) were randomly selected from total trees to quantify their biomass and carbon. The diameter and girth at breast height varied widely from 5.09 to 18.77 cm and 16 to 59 cm, mainly due to variation in the age of tree in different plantations. Total height ranged from 3.5 to 14 m. The height varied significantly within a GBH or DBH class, denoting that vertical growth of trees varied among different sites due to variation in growth factors. For example, the height of trees with DBH of 6.36 cm varied from 4.91 to 7.90 m. Such variations were observed in all age classes. The volume of teak trees varied positively and linearly in response to variation in its basal area (Figure 1, r=0.959, r^2=0.92). The variation in basal area could explain nearly 92% of the variation in volume. Therefore, basal area can be a good predictor of volume in teak trees. The total biomass of trees varied positively and linearly with variation in its basal area (Figure 1, r=0.959, r^2=0.92). Basal area explained a higher proportion (*i.e.*, 92%) of variation recorded in total biomass. Though, diameter at breast height was used to estimate basal area, it could explain relatively lower amount of variation in volume (Figure 1 r=0.934, r^2=0.873). DBH could hardly explain 87% of variation recoded in volume of teak trees.

The minimum and maximum stem wood volume values of trees were found as 0.0044 m^3 and 0.1638 m^3, minimum and maximum total biomass values of trees ranged between 0.0042 tonne and 0.1531 tonne tree^{-1} and the value of carbon sequestered varied from 0.0021 tonne tree^{-1} (minimum) and 0.0766 tonne tree^{-1} (maximum), respectively. The linear correlation between basal area and volume, DBH and volume, and basal area and total biomass among 72 trees taken for actual measurement was found to be significant with the values of R^2 being 0.92, 0.873 and 0.92, respectively as depicted in Figure 1. The values of R^2 are closer to 1, which indicates that the better the line fits the data.

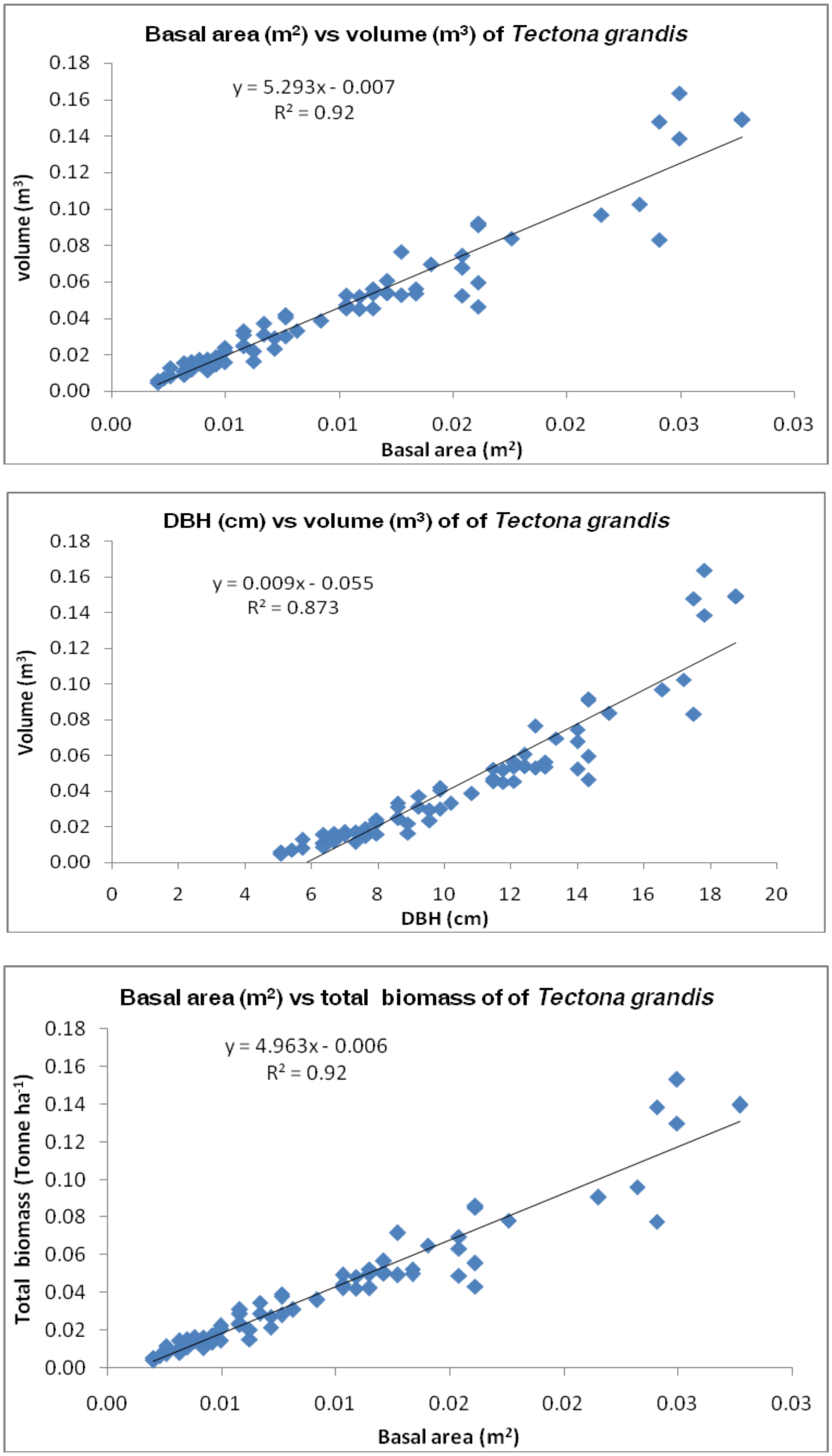

Figure 1. Relationship Among Different Growth Parameters in Tectona Grandis

3.1.2. Net accumulation of biomass and carbon during growth of *Tectona grandis* (teak) in plantation forests: The trees for estimation of biomass accumulation and carbon sequestration were taken from 2, 8, 9, 10 and 19 years old plantations at different OCP sites. The seedlings used for plantations had the average height of 0.59 m. The average DBH in different year plantations showed increasing trend with the advancement of age. In different aged plantations of 2, 8, 9, 10 and 19 years, the average DBH were 3.8 cm, 7.6 cm, 10.8 cm, 12.4 cm and 17.8 cm, and average height were 2.41 m, 5.10 m, 7.25 m, 8.15 m and 11.70 m, respectively. The values of above and below ground biomass, total biomass, carbon content and CO_2 sequestered were computed using best fit equation used for individual trees of different DBH and height (Table 1).

On critical examination of the data, the biomass accumulation from the seedling stage to tree stage in plantations of 2, 8, 9, 10 and 19 years was found to be 12.97, 88.84, 202.87, 279.89 and 706.37 tonne ha^{-1}, respectively, showing the increasing trend of biomass accumulation (Table 2). The values of mean annual increments in terms of total biomass were 6.48, 11.10, 22.54, 27.99 and 37.18 tonne ha^{-1} yr^{-1} and for carbon content were 3.22, 5.55, 11.27, 13.99 and 18.59 tonne ha^{-1} yr^{-1} in 2, 8, 9, 10 and 19 years old plantations, respectively (Table 3).

Table 1. Biomass and Carbon Content in *Tectona Grandis* (Teak) according to Age of the Plantations (values are mean ± standard deviation)

S. No.	Plantation year/ site	Age (year)	Av. DBH (cm)	Av. Height (m)	Above ground Biomass (Tonne ha^{-1})	Below ground Biomass (Tonne ha^{-1})	Total Biomass (Tonne ha^{-1})	Carbon content (Tonne ha^{-1})	CO_2 (Tonne ha^{-1})
Seedling used for planting		1/2 (6 month)	-	0.59	0.070	0.030	0.100	0.050	0.183
1	2007-08 (Nigahi)	2	3.8 ±0.82	2.41 ±0.54	10.43 ±3.55	2.61 ±0.88	13.04 ±4.48	6.52 ±2.21	23.90 ±8.14
2	2001-02 (Dudhichua)	8	7.6 ±0.59	5.10 ±1.95	71.13 ±3.24	17.78 ± 0.81	88.91 ±4.05	44.45 ±2.02	162.99 ±7.40
3	2000-01 (Jhingurdah)	9	10.8 ±2.19	7.25 ±1.00	162.35 ±36.13	40.59 ±9.03	202.94 ±45.17	101.47 ±22.58	372.05 ±82.81
4	1999-00 (Nigahi)	10	12.4 ±2.42	8.15 ±1.95	223.97 ±67.72	56.00 ±16.93	279.96 ±84.65	139.98 ±42.32	513.26 ±155.19
5	1990-91 (Jhingurdah)	19	17.8 ±3.35	11.70 ±3.10	565.16 ±148.82	141.29 ±37.20	706.44 ±186.03	353.22 ±93.01	1295.14 ±341.05

Table 2. Net Accumulation of Biomass and Carbon during Growth of *Tectona Grandis* (Teak) in Plantation Forests

S. No.	Plantation year/ site	Age (years)	Biomass and carbon content accumulation after planting (Biomass accumulation - Biomass of seedling)				
			Above ground Biomass (Tonne ha^{-1})	Below ground Biomass (Tonne ha^{-1})	Total Biomass (Tonne ha^{-1})	Carbon content (Tonne ha^{-1})	CO_2 (Tonne ha^{-1})
1	2007-08 (Nigahi)	2	10.36	2.54	12.97	6.45	23.83
2	2001-02 (Dudhichua)	8	71.06	17.71	88.84	44.38	162.92
3	2000-01 (Jhingurdah)	9	162.28	40.52	202.87	101.40	371.98
4	1999-00 (Nigahi)	10	223.90	55.93	279.89	139.91	513.19
5	1990-91 (Jhingurdah)	19	565.09	141.22	706.37	353.15	1295.07

Table 3. Rate of Accumulation of Biomass and Carbon by *Tectona grandis* (Teak) in Plantation Forests

S. No.	Plantation year/ site	Age (years)	Mean annual accumulation of biomass and carbon content after planting (Biomass accumulation by subtracting seedling biomass / Age of plantation)				
			Above ground Biomass (Tonne $ha^{-1}y^{-1}$)	Below ground Biomass (Tonne $ha^{-1}y^{-1}$)	Total Biomass (Tonne $ha^{-1}y^{-1}$)	Carbon content (Tonne $ha^{-1}y^{-1}$)	CO_2 (Tonne $ha^{-1}y^{-1}$)
1	2007-08 (Nigahi)	2	5.18	1.27	6.48	3.22	11.91
2	2001-02 (Dudhichua)	8	8.88	2.21	11.10	5.55	20.37
3	2000-01 (Jhingurdah)	9	18.03	4.50	22.54	11.27	41.33
4	1999-00 (Nigahi)	10	22.39	5.59	27.99	13.99	51.32
5	1990-91 (Jhingurdah)	19	29.74	7.43	37.18	18.59	68.16

3.1.3. Preparation of biomass and carbon tables of teak: On the basis of maximum correlation coefficient (R^2) and minimum standard error (SE), the best fit model was computed. Multiple regression equations were tried to work out the relationship between the DBH (diameter over bark) and height and also between DBH and volume. The best fit equation was determined using SPSS software to prepare volume growth tables. Multiple regression equations were tried to find out best fit equation (Table 4).

Table 4. Multiple Regression Equations to Work out best Fit Equation for Volume Growth Tables

S.N.	Equations	R^2	SE
1	$VOB = 0.003 + 4.393 \times 10^{-5} D^2H$	0.974	0.0077167
2	$VOB = -0.003 + 0.001D + 3.901 \times 10^{-5}D^2H$	0.977	0.0073601
3	$VOB = 0.000 + 0.000 D^2 + 3.223 \times 10^{-9}(D^2H)^2$	0.958	0.0099550
4	$VOB = 0.002 + 0.000D + 5.431 \times 10^{-5}D^2H - 2.338 \times 10^{-9} (D^2H)^2$	0.978	0.0071566
5	$VOB = -0.006 + 0.000D + 0.001H + 3.887 \times 10^{-5} D^2H$	0.979	0.0071356
6	$VOB = -0.009 + 0.003 D + 0.000 D^2 + 4.889 \times 10^{-5} D^2H$	0.979	0.0070497
7	$Log_eVOB = -9.584 + 1.768 Log_eD + 1.103 Log_eH$	0.995	0.1177404
8	$VOB/D^2H = 5.669 \times 10^{-5} - 4.078 \times 10^{-9} D^2H$	0.301	0.0000067
9	$VOB/D^2H = 5.285 \times 10^{-5} - 2.402 \times 10^{-9} D^2H + 0.000 \times 1/D^2H$	0.519	0.0000056

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

$$VOB = -0.009 + 0.003 D + 0.000 D^2 + 4.889 \times 10^{-5} D^2H$$

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 based on data of 72 trees. These trees were used for testing the dependability of the table. The summary of statistical analysis of the best fit equation is given in Table 5. Variables all entering or removing variables, reveals the independent variables namely D, H and D^2H are part of the equation and V is the dependent variable. The model summary of the output of the volume of teak trees is a function of the multiple correlation coefficient (R= 0.989, R^2=0.978, SE= 0.007) had its D, H and D^2H. The ANOVA confirmed that regression of V on D, H and D^2H was highly significant ($Fp < 0.001$). This denotes that one variability in volume of teak trees is directly regulated by independent variables such as D, H and D^2H. The coefficients of the output give us the values that we need in order to write the regression equation.

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. It was found that all cases, actual volume resembled closely with predicted volumes. The volume tables give volume in cubic meters for each one meter height class and 2 cm DBH class based on best fit regression equations. The correlation between actual and computed volume for 72 trees, was found to be highly significant at 0.01 levels (99% confidence level). Since the accuracy of the volume table has been tested statistically, it can be safely used to predict the volume of single trees of different dimensions, in efficient and scientific forest management. The general volume table was used for preparing the above ground biomass using the formula: wood density of teak (g cm^{-3} = tonne m^{-3}) x volume of tree (m^{-3}) x BEF (Biomass Expansion Factor). 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 0.0038 and 2.3978 tonne $tree^{-1}$, respectively (Table 6). The minimum and maximum below ground biomass was found to be 0.0009 and 0.5994 tonne $tree^{-1}$, respectively (Table 7). The total minimum and maximum biomass was found to be 0.0047 and 2.9972 tonne tree^{-1}, respectively (Table 8). The minimum and maximum values of carbon content were 0.0023 and 1.4986 tonne tree^{-1}, respectively (Table 9).

Table 5. The Statistical Summary of the Data Based on Best Fit Equation

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	D^2H, D, D^2[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	0.989[a]	0.979	0.978	0.0070497

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

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.223	3	0.074	1496.900	0.000[a]
	Residual	0.005	96	0.000		
	Total	0.228	99			

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

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-0.009	0.003		-3.129	0.002
	D	0.003	0.001	0.330	4.360	0.000
	D^2	0.000	0.000	-0.423	-3.120	0.002
	D^2H	$4.889E^{-5}$	0.000	1.099	13.809	0.000

a. Dependent Variable: V

Table 6. Above Ground Biomass (Wood Density =0.50*V) table of *Tectona grandis*

Ab. Biomass (tonne)	Total Height (m)																							
DBH (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
4	0.004	0.004	0.005	0.005	0.006	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.011	0.011	0.012	0.012	0.013	0.014	0.014	0.014	0.015	0.016	0.017	0.017
6	0.010	0.011	0.012	0.014	0.015	0.016	0.017	0.019	0.020	0.021	0.023	0.024	0.026	0.026	0.028	0.029	0.031	0.032	0.033	0.035	0.036	0.037	0.038	0.040
8	0.016	0.018	0.021	0.023	0.026	0.028	0.030	0.032	0.035	0.037	0.040	0.042	0.044	0.047	0.049	0.051	0.053	0.056	0.059	0.061	0.063	0.065	0.068	0.070
10	0.023	0.027	0.031	0.034	0.038	0.041	0.045	0.049	0.053	0.056	0.060	0.064	0.067	0.071	0.074	0.078	0.082	0.086	0.089	0.093	0.097	0.100	0.104	0.107
12	0.031	0.036	0.041	0.047	0.052	0.057	0.062	0.068	0.073	0.078	0.083	0.089	0.095	0.100	0.105	0.110	0.116	0.121	0.126	0.131	0.137	0.142	0.147	0.152
14	0.039	0.047	0.053	0.061	0.068	0.075	0.083	0.089	0.097	0.104	0.111	0.119	0.125	0.133	0.140	0.147	0.154	0.161	0.169	0.176	0.183	0.190	0.197	0.205
16	0.048	0.058	0.067	0.077	0.086	0.095	0.104	0.114	0.123	0.133	0.142	0.152	0.161	0.170	0.179	0.189	0.198	0.208	0.217	0.227	0.236	0.245	0.254	0.264
18	0.058	0.070	0.081	0.093	0.105	0.117	0.129	0.141	0.152	0.164	0.176	0.188	0.200	0.212	0.224	0.236	0.248	0.260	0.272	0.284	0.295	0.307	0.319	0.331
20	0.068	0.083	0.097	0.112	0.126	0.141	0.155	0.170	0.185	0.200	0.215	0.229	0.244	0.258	0.273	0.287	0.302	0.317	0.332	0.347	0.361	0.376	0.390	0.405
22	0.078	0.096	0.114	0.131	0.149	0.167	0.185	0.203	0.221	0.238	0.256	0.274	0.291	0.309	0.327	0.344	0.362	0.380	0.398	0.416	0.434	0.451	0.469	0.487
24	0.089	0.110	0.132	0.153	0.174	0.195	0.216	0.237	0.259	0.280	0.301	0.322	0.343	0.364	0.386	0.407	0.428	0.449	0.470	0.491	0.512	0.533	0.554	0.575
26	0.101	0.126	0.151	0.176	0.200	0.225	0.250	0.275	0.299	0.325	0.350	0.374	0.399	0.424	0.449	0.473	0.498	0.523	0.548	0.572	0.597	0.622	0.647	0.671
28	0.114	0.143	0.171	0.200	0.229	0.257	0.287	0.315	0.344	0.373	0.401	0.430	0.459	0.488	0.516	0.545	0.574	0.602	0.632	0.660	0.689	0.718	0.746	0.775
30	0.127	0.160	0.193	0.226	0.259	0.292	0.325	0.358	0.391	0.424	0.457	0.490	0.523	0.556	0.589	0.622	0.655	0.688	0.721	0.754	0.787	0.820	0.853	0.886
32	0.140	0.178	0.215	0.253	0.290	0.328	0.366	0.404	0.441	0.479	0.516	0.554	0.591	0.629	0.666	0.704	0.741	0.779	0.816	0.854	0.891	0.929	0.967	1.004
34	0.155	0.197	0.239	0.282	0.324	0.367	0.409	0.452	0.494	0.536	0.578	0.621	0.663	0.706	0.748	0.791	0.833	0.875	0.917	0.960	1.002	1.045	1.087	1.130
36	0.170	0.217	0.264	0.312	0.359	0.407	0.455	0.502	0.550	0.597	0.644	0.692	0.740	0.787	0.835	0.882	0.930	0.977	1.025	1.073	1.120	1.167	1.215	1.262
38	0.185	0.238	0.290	0.344	0.397	0.449	0.503	0.555	0.608	0.662	0.714	0.767	0.820	0.873	0.926	0.979	1.032	1.085	1.138	1.191	1.244	1.297	1.349	1.403
40	0.200	0.260	0.318	0.377	0.435	0.494	0.553	0.611	0.670	0.728	0.788	0.846	0.905	0.963	1.022	1.081	1.139	1.198	1.256	1.316	1.374	1.433	1.491	1.550
42	0.217	0.282	0.347	0.411	0.476	0.541	0.605	0.670	0.734	0.800	0.864	0.929	0.993	1.058	1.123	1.187	1.252	1.317	1.382	1.446	1.511	1.576	1.640	1.705
44	0.234	0.305	0.377	0.447	0.518	0.590	0.660	0.731	0.803	0.873	0.944	1.015	1.086	1.157	1.228	1.299	1.370	1.441	1.512	1.583	1.654	1.725	1.796	1.867
46	0.252	0.329	0.407	0.485	0.563	0.640	0.718	0.795	0.873	0.950	1.028	1.106	1.183	1.261	1.338	1.416	1.493	1.571	1.649	1.726	1.804	1.881	1.959	2.036
48	0.270	0.355	0.440	0.524	0.608	0.692	0.777	0.862	0.946	1.031	1.115	1.199	1.284	1.369	1.453	1.538	1.622	1.706	1.791	1.875	1.960	2.045	2.129	2.213
50	0.289	0.381	0.473	0.564	0.656	0.748	0.839	0.931	1.022	1.114	1.206	1.298	1.389	1.481	1.573	1.664	1.756	1.847	1.940	2.031	2.123	2.214	2.306	2.398

Note: figure outside the thick lines are beyond to range of observed data.

Table 7. Below Ground Biomass (25% of the above ground biomass) Table of *Tectona Grandis*

Below G Biomass (tonne)	Total Height (m)																							
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004
6	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.005	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.009	0.009	0.009	0.010	0.010
8	0.004	0.005	0.005	0.006	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.011	0.011	0.012	0.012	0.013	0.013	0.014	0.015	0.015	0.016	0.016	0.017	0.017
10	0.006	0.007	0.008	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.020	0.021	0.022	0.023	0.024	0.025	0.026	0.027
12	0.008	0.009	0.010	0.012	0.013	0.014	0.016	0.017	0.018	0.020	0.021	0.022	0.024	0.025	0.026	0.028	0.029	0.030	0.032	0.033	0.034	0.035	0.037	0.038
14	0.010	0.012	0.013	0.015	0.017	0.019	0.021	0.022	0.024	0.026	0.028	0.030	0.031	0.033	0.035	0.037	0.038	0.040	0.042	0.044	0.046	0.047	0.049	0.051
16	0.012	0.014	0.017	0.019	0.021	0.024	0.026	0.029	0.031	0.033	0.035	0.038	0.040	0.043	0.045	0.047	0.050	0.052	0.054	0.057	0.059	0.061	0.064	0.066
18	0.014	0.017	0.020	0.023	0.026	0.029	0.032	0.035	0.038	0.041	0.044	0.047	0.050	0.053	0.056	0.059	0.062	0.065	0.068	0.071	0.074	0.077	0.080	0.083
20	0.017	0.021	0.024	0.028	0.032	0.035	0.039	0.043	0.046	0.050	0.054	0.057	0.061	0.065	0.068	0.072	0.076	0.079	0.083	0.087	0.090	0.094	0.098	0.101
22	0.020	0.024	0.029	0.033	0.037	0.042	0.046	0.051	0.055	0.059	0.064	0.068	0.073	0.077	0.082	0.086	0.091	0.095	0.099	0.104	0.108	0.113	0.117	0.122
24	0.022	0.028	0.033	0.038	0.044	0.049	0.054	0.059	0.065	0.070	0.075	0.080	0.086	0.091	0.096	0.102	0.107	0.112	0.117	0.123	0.128	0.133	0.139	0.144
26	0.025	0.032	0.038	0.044	0.050	0.056	0.062	0.069	0.075	0.081	0.087	0.094	0.100	0.106	0.112	0.118	0.125	0.131	0.137	0.143	0.149	0.155	0.162	0.168
28	0.029	0.036	0.043	0.050	0.057	0.064	0.072	0.079	0.086	0.093	0.100	0.107	0.115	0.122	0.129	0.136	0.143	0.151	0.158	0.165	0.172	0.179	0.187	0.194
30	0.032	0.040	0.048	0.056	0.065	0.073	0.081	0.089	0.098	0.106	0.114	0.122	0.131	0.139	0.147	0.155	0.164	0.172	0.180	0.188	0.197	0.205	0.213	0.221
32	0.035	0.044	0.054	0.063	0.073	0.082	0.092	0.101	0.110	0.120	0.129	0.138	0.148	0.157	0.167	0.176	0.185	0.195	0.204	0.213	0.223	0.232	0.242	0.251
34	0.039	0.049	0.060	0.071	0.081	0.092	0.102	0.113	0.123	0.134	0.145	0.155	0.166	0.176	0.187	0.198	0.208	0.219	0.229	0.240	0.251	0.261	0.272	0.282
36	0.042	0.054	0.066	0.078	0.090	0.102	0.114	0.125	0.137	0.149	0.161	0.173	0.185	0.197	0.209	0.221	0.233	0.244	0.256	0.268	0.280	0.292	0.304	0.316
38	0.046	0.059	0.073	0.086	0.099	0.112	0.126	0.139	0.152	0.165	0.179	0.192	0.205	0.218	0.232	0.245	0.258	0.271	0.284	0.298	0.311	0.324	0.337	0.351
40	0.050	0.065	0.080	0.094	0.109	0.124	0.138	0.153	0.167	0.182	0.197	0.212	0.226	0.241	0.256	0.270	0.285	0.299	0.314	0.329	0.344	0.358	0.373	0.388
42	0.054	0.071	0.087	0.103	0.119	0.135	0.151	0.167	0.184	0.200	0.216	0.232	0.248	0.265	0.281	0.297	0.313	0.329	0.345	0.362	0.378	0.394	0.410	0.426
44	0.059	0.076	0.094	0.112	0.130	0.147	0.165	0.183	0.201	0.218	0.236	0.254	0.272	0.289	0.307	0.325	0.343	0.360	0.378	0.396	0.413	0.431	0.449	0.467
46	0.063	0.082	0.102	0.121	0.141	0.160	0.179	0.199	0.218	0.238	0.257	0.276	0.296	0.315	0.335	0.354	0.373	0.393	0.412	0.431	0.451	0.470	0.490	0.509
48	0.068	0.089	0.110	0.131	0.152	0.173	0.194	0.215	0.236	0.258	0.279	0.300	0.321	0.342	0.363	0.384	0.406	0.427	0.448	0.469	0.490	0.511	0.532	0.553
50	0.072	0.095	0.118	0.141	0.164	0.187	0.210	0.233	0.256	0.278	0.302	0.324	0.347	0.370	0.393	0.416	0.439	0.462	0.485	0.508	0.531	0.554	0.576	0.599

Note: figure outside the thick lines are beyond to range of observed data.

Table 8. Total Biomass (Above ground + Below ground biomass) Table of *Tectona Grandis*

Total Biomass (tonne)	Total Height (m)																							
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4	0.005	0.005	0.006	0.007	0.008	0.008	0.008	0.009	0.010	0.011	0.011	0.012	0.013	0.014	0.015	0.015	0.016	0.017	0.018	0.018	0.019	0.020	0.021	0.022
6	0.012	0.013	0.015	0.017	0.019	0.020	0.022	0.023	0.025	0.026	0.028	0.030	0.032	0.033	0.035	0.037	0.038	0.039	0.041	0.043	0.045	0.046	0.048	0.050
8	0.020	0.023	0.026	0.029	0.032	0.035	0.038	0.040	0.043	0.046	0.050	0.053	0.055	0.058	0.061	0.064	0.067	0.069	0.073	0.076	0.079	0.082	0.084	0.087
10	0.029	0.034	0.038	0.042	0.047	0.052	0.056	0.061	0.066	0.070	0.075	0.080	0.083	0.088	0.093	0.098	0.102	0.107	0.112	0.116	0.121	0.125	0.129	0.134
12	0.038	0.045	0.052	0.058	0.065	0.071	0.078	0.084	0.091	0.098	0.104	0.112	0.118	0.125	0.131	0.138	0.144	0.151	0.158	0.164	0.171	0.177	0.184	0.190
14	0.049	0.058	0.067	0.076	0.084	0.094	0.103	0.112	0.121	0.129	0.139	0.148	0.157	0.166	0.174	0.184	0.192	0.202	0.211	0.219	0.229	0.237	0.247	0.256
16	0.060	0.072	0.083	0.096	0.107	0.119	0.130	0.143	0.154	0.166	0.177	0.189	0.201	0.213	0.224	0.236	0.248	0.260	0.271	0.283	0.294	0.307	0.318	0.330
18	0.072	0.087	0.101	0.116	0.131	0.146	0.161	0.176	0.190	0.205	0.220	0.235	0.250	0.265	0.279	0.294	0.309	0.324	0.339	0.354	0.368	0.383	0.398	0.413
20	0.084	0.103	0.121	0.140	0.158	0.176	0.194	0.213	0.232	0.249	0.268	0.286	0.305	0.323	0.341	0.359	0.378	0.397	0.414	0.433	0.451	0.470	0.488	0.506
22	0.098	0.120	0.143	0.164	0.187	0.209	0.231	0.253	0.276	0.297	0.320	0.342	0.364	0.386	0.409	0.430	0.453	0.475	0.497	0.519	0.542	0.563	0.586	0.608
24	0.112	0.138	0.165	0.191	0.218	0.244	0.270	0.296	0.323	0.350	0.376	0.402	0.428	0.455	0.482	0.508	0.534	0.561	0.587	0.613	0.640	0.667	0.693	0.719
26	0.127	0.158	0.188	0.219	0.250	0.281	0.312	0.343	0.374	0.406	0.437	0.468	0.499	0.530	0.561	0.592	0.623	0.653	0.684	0.715	0.746	0.777	0.808	0.839
28	0.143	0.178	0.214	0.250	0.286	0.322	0.358	0.394	0.429	0.466	0.502	0.537	0.574	0.609	0.645	0.682	0.717	0.753	0.789	0.825	0.861	0.897	0.933	0.968
30	0.158	0.200	0.241	0.282	0.323	0.365	0.406	0.447	0.488	0.530	0.571	0.612	0.653	0.695	0.736	0.777	0.818	0.860	0.901	0.942	0.983	1.025	1.066	1.107
32	0.175	0.222	0.269	0.316	0.363	0.410	0.458	0.504	0.551	0.598	0.645	0.692	0.739	0.786	0.833	0.879	0.926	0.973	1.020	1.067	1.114	1.161	1.208	1.255
34	0.193	0.247	0.299	0.353	0.405	0.458	0.511	0.564	0.617	0.670	0.723	0.776	0.829	0.882	0.935	0.988	1.041	1.094	1.147	1.200	1.253	1.306	1.358	1.412
36	0.212	0.271	0.330	0.390	0.449	0.509	0.568	0.627	0.687	0.746	0.805	0.865	0.924	0.983	1.043	1.103	1.163	1.222	1.281	1.341	1.400	1.459	1.519	1.578
38	0.231	0.297	0.363	0.429	0.496	0.562	0.628	0.694	0.760	0.827	0.893	0.959	1.025	1.091	1.158	1.223	1.290	1.356	1.422	1.489	1.554	1.621	1.687	1.753
40	0.250	0.324	0.398	0.471	0.544	0.618	0.691	0.764	0.837	0.910	0.984	1.058	1.131	1.204	1.278	1.351	1.424	1.497	1.570	1.644	1.718	1.791	1.864	1.938
42	0.271	0.353	0.433	0.514	0.594	0.676	0.757	0.837	0.918	0.999	1.080	1.161	1.241	1.323	1.403	1.484	1.565	1.646	1.727	1.808	1.888	1.970	2.050	2.131
44	0.293	0.382	0.471	0.559	0.648	0.737	0.825	0.914	1.003	1.091	1.180	1.268	1.358	1.447	1.535	1.624	1.713	1.801	1.890	1.979	2.067	2.156	2.245	2.333
46	0.315	0.412	0.509	0.606	0.703	0.800	0.897	0.994	1.091	1.188	1.284	1.382	1.478	1.576	1.673	1.770	1.867	1.964	2.061	2.157	2.255	2.351	2.449	2.545
48	0.338	0.443	0.549	0.654	0.760	0.865	0.971	1.077	1.182	1.288	1.394	1.499	1.605	1.711	1.816	1.922	2.028	2.133	2.239	2.344	2.450	2.556	2.661	2.767
50	0.361	0.476	0.591	0.705	0.819	0.935	1.049	1.163	1.278	1.392	1.508	1.622	1.736	1.851	1.966	2.080	2.195	2.309	2.424	2.539	2.653	2.768	2.882	2.997

Note: figure outside the thick lines are beyond to range of observed data.

Table 9. Wood carbon (Total Biomass*0.5) table of *Tectona Grandis*

Wood Carbon (tonne)	Total Height (m)																							
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4	0.002	0.002	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.006	0.006	0.006	0.007	0.007	0.008	0.008	0.008	0.008	0.009	0.009	0.009	0.010	0.010	0.011
6	0.006	0.007	0.008	0.008	0.009	0.010	0.011	0.012	0.013	0.013	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.023	0.024	0.025
8	0.010	0.011	0.013	0.015	0.016	0.017	0.019	0.020	0.022	0.023	0.025	0.026	0.028	0.029	0.030	0.032	0.033	0.035	0.037	0.038	0.039	0.041	0.042	0.044
10	0.015	0.017	0.019	0.021	0.023	0.026	0.028	0.030	0.033	0.035	0.038	0.040	0.042	0.044	0.046	0.049	0.051	0.053	0.056	0.058	0.060	0.062	0.065	0.067
12	0.019	0.023	0.026	0.029	0.032	0.036	0.039	0.042	0.045	0.049	0.052	0.056	0.059	0.062	0.066	0.069	0.072	0.075	0.079	0.082	0.085	0.089	0.092	0.095
14	0.024	0.029	0.033	0.038	0.042	0.047	0.052	0.056	0.060	0.065	0.069	0.074	0.078	0.083	0.087	0.092	0.096	0.101	0.105	0.110	0.114	0.119	0.123	0.128
16	0.030	0.036	0.042	0.048	0.053	0.060	0.065	0.071	0.077	0.083	0.089	0.095	0.100	0.106	0.112	0.118	0.124	0.130	0.135	0.142	0.147	0.153	0.159	0.165
18	0.036	0.044	0.051	0.058	0.066	0.073	0.081	0.088	0.095	0.103	0.110	0.118	0.125	0.133	0.140	0.147	0.155	0.162	0.170	0.177	0.184	0.192	0.199	0.207
20	0.042	0.052	0.060	0.070	0.079	0.088	0.097	0.106	0.116	0.125	0.134	0.143	0.152	0.161	0.171	0.180	0.189	0.198	0.207	0.217	0.225	0.235	0.244	0.253
22	0.049	0.060	0.071	0.082	0.093	0.105	0.115	0.127	0.138	0.149	0.160	0.171	0.182	0.193	0.204	0.215	0.226	0.238	0.248	0.260	0.271	0.282	0.293	0.304
24	0.056	0.069	0.083	0.096	0.109	0.122	0.135	0.148	0.162	0.175	0.188	0.201	0.214	0.227	0.241	0.254	0.267	0.280	0.293	0.307	0.320	0.333	0.346	0.360
26	0.063	0.079	0.094	0.110	0.125	0.141	0.156	0.172	0.187	0.203	0.218	0.234	0.249	0.265	0.280	0.296	0.311	0.327	0.342	0.358	0.373	0.389	0.404	0.420
28	0.071	0.089	0.107	0.125	0.143	0.161	0.179	0.197	0.215	0.233	0.251	0.269	0.287	0.305	0.323	0.341	0.359	0.376	0.395	0.413	0.430	0.449	0.466	0.484
30	0.079	0.100	0.120	0.141	0.162	0.182	0.203	0.224	0.244	0.265	0.285	0.306	0.327	0.347	0.368	0.389	0.409	0.430	0.450	0.471	0.492	0.512	0.533	0.554
32	0.088	0.111	0.135	0.158	0.181	0.205	0.229	0.252	0.276	0.299	0.323	0.346	0.369	0.393	0.416	0.440	0.463	0.487	0.510	0.533	0.557	0.580	0.604	0.628
34	0.097	0.123	0.150	0.176	0.203	0.229	0.255	0.282	0.308	0.335	0.361	0.388	0.414	0.441	0.467	0.494	0.520	0.547	0.573	0.600	0.626	0.653	0.679	0.706
36	0.106	0.135	0.165	0.195	0.225	0.255	0.284	0.314	0.344	0.373	0.403	0.433	0.462	0.492	0.522	0.551	0.581	0.611	0.640	0.670	0.700	0.729	0.759	0.789
38	0.115	0.149	0.181	0.215	0.248	0.281	0.314	0.347	0.380	0.413	0.446	0.480	0.512	0.546	0.579	0.612	0.645	0.678	0.711	0.744	0.777	0.810	0.843	0.877
40	0.125	0.162	0.199	0.235	0.272	0.309	0.345	0.382	0.419	0.455	0.492	0.529	0.565	0.602	0.639	0.675	0.712	0.749	0.785	0.822	0.859	0.895	0.932	0.969
42	0.135	0.176	0.217	0.257	0.297	0.338	0.378	0.419	0.459	0.500	0.540	0.580	0.621	0.661	0.702	0.742	0.782	0.823	0.863	0.904	0.944	0.985	1.025	1.065
44	0.146	0.191	0.235	0.279	0.324	0.368	0.413	0.457	0.502	0.546	0.590	0.634	0.679	0.723	0.767	0.812	0.856	0.900	0.945	0.990	1.034	1.078	1.123	1.167
46	0.158	0.206	0.255	0.303	0.352	0.400	0.449	0.497	0.546	0.594	0.642	0.691	0.739	0.788	0.836	0.885	0.933	0.982	1.030	1.079	1.127	1.176	1.224	1.273
48	0.169	0.222	0.275	0.327	0.380	0.433	0.486	0.539	0.591	0.644	0.697	0.750	0.803	0.855	0.908	0.961	1.014	1.066	1.119	1.172	1.225	1.278	1.330	1.383
50	0.180	0.238	0.295	0.353	0.410	0.467	0.525	0.582	0.639	0.696	0.754	0.811	0.868	0.925	0.983	1.040	1.097	1.155	1.212	1.269	1.327	1.384	1.441	1.499

Note: figure outside the thick lines are beyond to range of observed data.

3.2. Gmelina Arborea

3.2.1. Estimation of biomass and carbon of standing trees of *Gmelina arborea*: Forty nine trees (each having ≥ 5 cm DBH) were randomly selected from total trees to quantify their biomass and carbon. The diameter and girth at breast height varied widely from 3.82 cm and 22.91 cm and 12 to 72 cm, mainly due to variation in the age of tree in different plantations. Total height ranged from 5 to 15 m. The height varied significantly within a GBH or DBH class, denoting that vertical growth of trees varied among different sites due to variation in growth factors. For example, the height of trees with DBH of 8.273 cm varied from 5.23 to 8.50 m. Such variations were observed in all age classes. The volume of trees varied positively and linearly in response to variation in its basal area (Figure 2, r=0.986, r^2=0.974). The variation in basal area could explain nearly 97% of the variation in volume. Therefore, basal area can be a good predictor of volume in trees. The total biomass of trees varied positively and linearly with variation in its basal area ((Figure 2, r=0.986, r^2=0.974). Basal area explained a higher proportion (*i.e.*, 97%) of variation recorded in total biomass. Though, diameter at breast height was used to estimate basal area, it could explain relatively lower amount of variation in volume (Figure 2 r=0.939, r^2=883). DBH could hardly explain 88% of variation recoded in volume of trees.

The minimum and maximum volume values of trees were computed between 0.00372 m^3 and 0.21644 m^3, minimum and maximum total biomass values of trees ranged between 0.0029 tonne $tree^{-1}$ and 0.1664 tonne $tree^{-1}$ and the value of carbon sequestered varied from 0.0014 (minimum) to 0.0832 tonne $tree^{-1}$ (maximum), respectively. The linear correlation between basal area and volume, DBH and volume, and basal area and total biomass among 49 trees taken for actual measurement was found to be significant with the values of R^2 being 0.974, 0.883 and 0.974, respectively, as depicted in Figure 2. The values of R^2 are closer to 1, which indicates that the better the line fits the data.

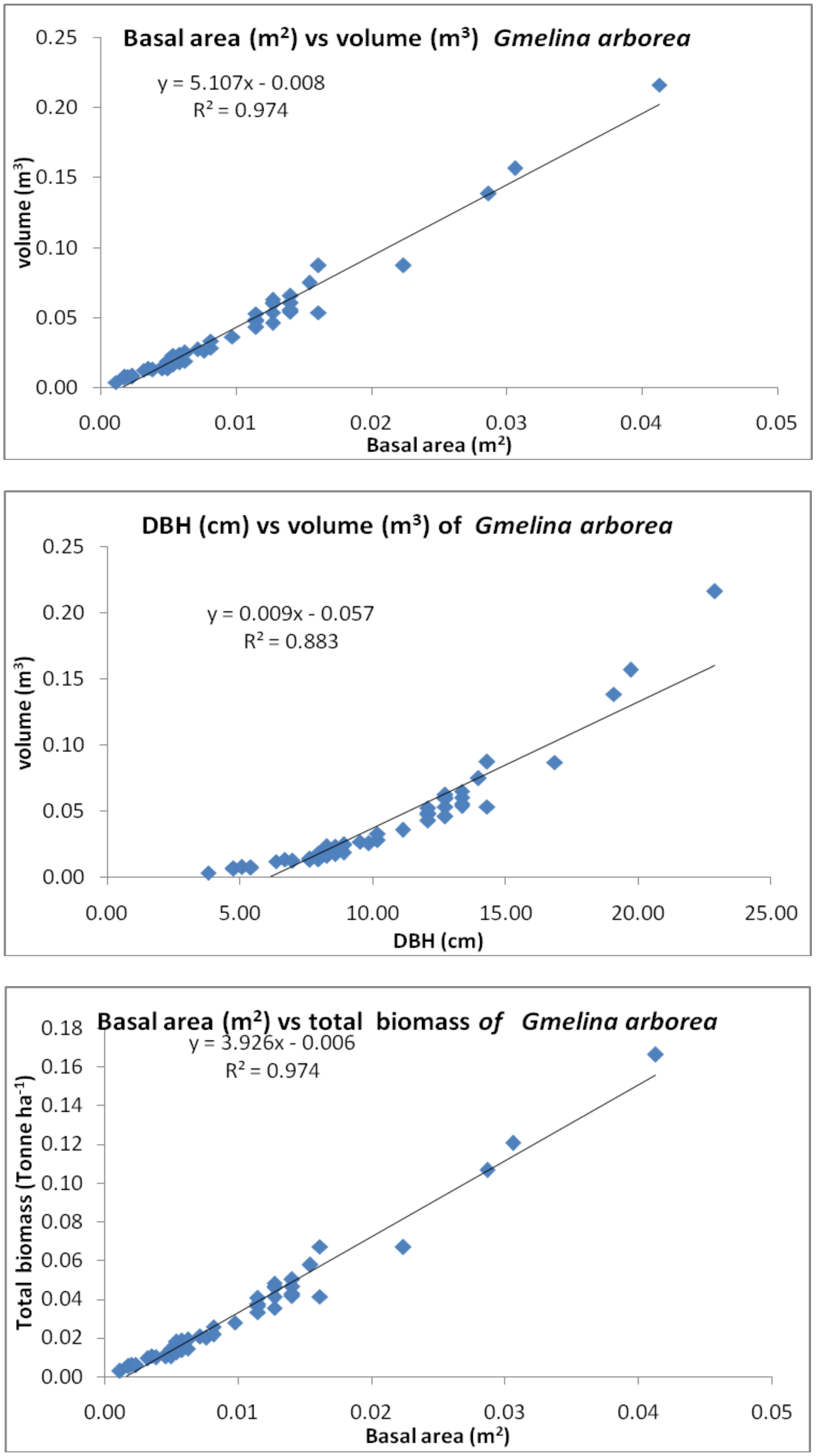

Figure 2. Relationship among Different Growth Parameters in *Gmelina arborea*

3.2.2. Net accumulation of biomass and carbon during growth of *Gmelina arborea* in plantation forests: The 49 trees measured for estimation of biomass accumulation and carbon sequestration were taken from 6, 9 and 10 years old plantations raised on OB Sites in different OCP project. The seedlings used for plantations had the average height of 0.60 m. The average DBH in different year's plantations showed increasing trend with the advancement of age. In different aged plantations of 6, 9 and 10 years the average DBH were 7.6 cm, 19.7 cm and 21.0 cm, and average height were 5.68 m, 8.50 m and 10.56 m, respectively (Table 10).

On critical examination of the data, the biomass accumulation from the seedling stage to sapling and tree stage in plantations of 6, 9 and 10 years was found to be 45.80, 290.83 and 371.54 tonne ha^{-1}, respectively, showing the increasing trend of biomass accumulation (Table 11). The values of mean annual increments in terms of total biomass were 7.63, 32.31 and 37.15 tonne ha^{-1} yr^{-1} and for carbon content were 3.82, 16.16 and 18.58 tonne ha^{-1} yr^{-1} in 6, 9 and 10 years old plantations, respectively (Table 12).

Table 10. Biomass and Carbon Content in *Gmelina arborea* According to Age of the Plantations (values are mean ± standard deviation)

S. No.	Plantation year	Age (years)	Av. DBH (cm)	Av. Height (m)	Above ground Biomass (Tonne ha^{-1})	Below ground Biomass (Tonne ha^{-1})	Total Biomass (Tonne ha^{-1})	Carbon (Tonne ha^{-1})	CO_2 (Tonne ha^{-1})
Seedling used for planting		1/2 (6 month)	-	0.60	0.007	0.003	0.010	0.005	0.018
1	2003-04 (Jhingurdah)	6	7.6 ±0.92	5.68 ±1.19	36.65 ±9.50	9.17 ±2.37	45.81 ±11.88	22.91 ±5.94	84.00 ±21.78
2	2000-01 (Jhingurdah)	9	19.7 ±2.20	8.50 ±1.41	232.68 ±53.21	58.17 ±13.30	290.84 ±66.51	145.43 ±33.25	533.21 ±121.94
3	1999-00 (Nigahi)	10	21.0 ±2.95	10.56 ±1.99	297.24 ±49.42	74.31 ±12.35	371.55 ±61.78	185.78 ±30.89	681.18 ±113.27

Table 11. Net Accumulation of Biomass and Carbon during Growth of *Gmelina arborea* in Plantation Forests

S. No.	Plantation year	Age (years)	Biomass and carbon content accumulation after planting (Biomass accumulation - Biomass of seedling)				
			Above ground Biomass (Tonne ha^{-1})	Below ground Biomass (Tonne ha^{-1})	Total Biomass (Tonne ha^{-1})	Carbon (Tonne ha^{-1})	CO_2 (Tonne ha^{-1})
1	2003-04 (Jhingurdah)	6	36.64	9.16	45.80	22.90	83.98
2	2000-01 (Jhingurdah)	9	232.67	58.17	290.83	145.42	533.19
3	1999-00 (Nigahi)	10	297.23	74.31	371.54	185.77	681.16

Table 12. Rate of Accumulation of Biomass and Carbon by *Gmelina arborea* in Plantation Forests

S. No.	Plantation year	Age (years)	Mean annual accumulation of biomass and carbon content after planting (Biomass accumulation by subtracting seedling biomass / Age of plantation)				
			Above ground Biomass (Tonne ha^{-1} y^{-1})	Below ground Biomass (Tonne ha^{-1} y^{-1})	Total Biomass (Tonne ha^{-1} y^{-1})	Carbon (Tonne ha^{-1} y^{-1})	CO_2 (Tonne ha^{-1} y^{-1})
1	2003-04 (Jhingurdah)	6	6.11	1.53	7.63	3.82	14.00
2	2000-01 (Jhingurdah)	9	25.85	6.46	32.31	16.16	59.24
3	1999-00 (Nigahi)	10	29.72	7.43	37.15	18.58	68.12

3.2.3. Preparation of volume, biomass and carbon tables of *Gmelina arborea*: Multiple regression equations were tried to work out the relationship between the DBH (diameter over bark) and height and also between DBH and volume. The best fit equation was determined using SPSS software to prepare volume growth tables. Multiple regression equations were tried to find out best fit equation (Table 13).

Table 13. Multiple Regression Equations to Work Out Best Fit Equation for Volume Growth Tables

S.N.	Equations	R^2	SE
1	$VOB = 0.010 + 2.731 \times 10^{-5} D^2H$	0.969	0.0073251157
2	$VOB = -0.013 + 0.003D + 1.998 \times 10^{-5}D^2H$	0.986	0.0049806621
3	$VOB = -0.003 + 0.000 D^2 + 7.165 \times 10^{-10} (D^2H)^2$	0.982	0.0055600533
4	$VOB = -0.012 + 0.003D + 2.044 \times 10^{-5}D^2H - 4.448 \times 10^{-11}(D^2H)^2$	0.986	0.0050348583
5	$VOB = -0.017 + 0.003D + 0.0014H + 1.899 \times 10^{-5} D^2H$	0.986	0.0049702113
6	$VOB = -0.009 + 0.002 D + 7.546 \times 10^{-5} D^2 + 1.738 \times 10^{-5} D^2H$	0.986	0.0050143069
7	$Log_eVOB = -9.138 + 1.887 Log_eD + 0.646 Log_eH$	0.989	0.0964343727
8	$VOB/D^2H = 4.504 \times 10^{-5} - 3.113 \times 10^{-9} D^2H$	0.536	0.0000043131
9	$VOB/D^2H = 4.227 \times 10^{-5} - 2.438 \times 10^{-9} D^2H + 0.001 \times 1/D^2H$	0.626	0.0000039167

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

$$VOB = -0.017 + 0.003D + 0.0014H + 1.899 \times 10^{-5} D^2H$$

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 14. Variables all entering or removing variables, reveals the independent variables namely D, H and D^2H are part of the equation and V is the dependent variable. The model summary of the output of the volume of *Gmelina arborea* trees is a function of the multiple correlation coefficient (R= 0.993, R^2=0.986, SE= 0.0049702113) had its D, H and D^2H. The

ANOVA confirmed that regression of V on D, H and D^2H was highly significant (Fp < 0.001). This denotes that one variability in volume of *Gmelina arborea* trees is directly regulated by independent variables such as D, H and D^2H. The coefficients of the output give us the values that we need in order to write the regression equation. 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. It was found that all cases, actual volume resembled closely with predicted volumes. Tables based on best fit regression equations were then prepared for a DBH interval of 2 meter and height interval of 1 meter.

The correlation between actual and computed volume for 49 trees, as was found to be highly significant at 0.01 levels (99% confidence level). Since the accuracy of the volume table was tested statistically, it could be safely used to predict the volume of single trees of different dimensions, in efficient and scientific forest management. The general volume table was then used for preparing the above ground biomass using the formula: wood density (g/cm^3 = $tonne/m^3$) 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 0.0009 and 0.8271 tonne $tree^{-1}$, respectively (Table 15). The minimum and maximum below ground biomass was found to be 0.0002 and 0.2068 tonne $tree^{-1}$, respectively (Table 16). The total minimum and maximum biomass was found to be 0.0012 and 1.0339 tonne $tree^{-1}$, respectively (Table 17). The minimum and maximum values of carbon content were 0.0006 and 0.5169 tonne $tree^{-1}$, respectively (Table 18).

Table 14. The Statistical Summary of the Best Fit Equation for *Gmelina arborea* in Plantation Forests

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	D^2H, D, H[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	.993[a]	.986	.985	.0049702113

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

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.079	3	.026	1068.396	.000[a]
	Residual	.001	45	.000		
	Total	.080	48			

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

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.017	.005		-3.343	.002
	D	.003	.000	.283	6.938	.000
	H	.001	.001	.050	1.093	.280
	D^2H	1.899E-5	.000	.684	13.366	.000

a. Dependent Variable: V

Table 15. Above Ground Biomass (Wood Density =0.41*V) Table of *Gmelina Arborea*

Above ground Biomass	Total Height (m)																							
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4				0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.007	0.008	0.009	0.010	0.011	0.011	0.012	0.013	0.014	0.015	0.015	0.016	0.017
6	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025	0.027
8	0.007	0.008	0.010	0.011	0.012	0.014	0.015	0.017	0.018	0.019	0.021	0.022	0.023	0.025	0.026	0.027	0.029	0.030	0.032	0.033	0.034	0.036	0.037	0.038
10	0.012	0.013	0.015	0.017	0.019	0.020	0.022	0.024	0.026	0.028	0.029	0.031	0.033	0.035	0.037	0.038	0.040	0.042	0.044	0.045	0.047	0.049	0.051	0.053
12	0.016	0.019	0.021	0.023	0.025	0.028	0.030	0.032	0.035	0.037	0.039	0.042	0.044	0.046	0.048	0.051	0.053	0.055	0.058	0.060	0.062	0.065	0.067	0.069
14	0.021	0.024	0.027	0.030	0.033	0.036	0.039	0.042	0.044	0.047	0.050	0.053	0.056	0.059	0.062	0.065	0.068	0.071	0.073	0.076	0.079	0.082	0.085	0.088
16	0.026	0.030	0.033	0.037	0.041	0.044	0.048	0.052	0.055	0.059	0.062	0.066	0.070	0.073	0.077	0.080	0.084	0.088	0.091	0.095	0.098	0.102	0.106	0.109
18	0.032	0.036	0.040	0.045	0.049	0.054	0.058	0.062	0.067	0.071	0.076	0.080	0.084	0.089	0.093	0.098	0.102	0.106	0.111	0.115	0.120	0.124	0.128	0.133
20	0.037	0.042	0.048	0.053	0.058	0.063	0.069	0.074	0.079	0.085	0.090	0.095	0.100	0.106	0.111	0.116	0.122	0.127	0.132	0.137	0.143	0.148	0.153	0.159
22	0.043	0.049	0.055	0.061	0.068	0.074	0.080	0.087	0.093	0.099	0.105	0.112	0.118	0.124	0.130	0.137	0.143	0.149	0.155	0.162	0.168	0.174	0.181	0.187
24	0.049	0.056	0.063	0.071	0.078	0.085	0.093	0.100	0.107	0.115	0.122	0.129	0.137	0.144	0.151	0.159	0.166	0.173	0.181	0.188	0.195	0.203	0.210	0.217
26	0.055	0.063	0.072	0.080	0.089	0.097	0.106	0.114	0.123	0.131	0.140	0.148	0.157	0.165	0.174	0.182	0.191	0.199	0.208	0.216	0.225	0.233	0.242	0.250
28	0.061	0.071	0.080	0.090	0.100	0.110	0.119	0.129	0.139	0.149	0.158	0.168	0.178	0.188	0.198	0.207	0.217	0.227	0.237	0.246	0.256	0.266	0.276	0.285
30	0.067	0.078	0.089	0.101	0.112	0.123	0.134	0.145	0.156	0.167	0.178	0.190	0.201	0.212	0.223	0.234	0.245	0.256	0.267	0.279	0.290	0.301	0.312	0.323
32	0.074	0.086	0.099	0.111	0.124	0.137	0.149	0.162	0.174	0.187	0.199	0.212	0.225	0.237	0.250	0.262	0.275	0.287	0.300	0.313	0.325	0.338	0.350	0.363
34	0.081	0.095	0.109	0.123	0.137	0.151	0.165	0.179	0.193	0.208	0.222	0.236	0.250	0.264	0.278	0.292	0.306	0.320	0.335	0.349	0.363	0.377	0.391	0.405
36	0.087	0.103	0.119	0.135	0.150	0.166	0.182	0.198	0.213	0.229	0.245	0.261	0.276	0.292	0.308	0.324	0.339	0.355	0.371	0.387	0.402	0.418	0.434	0.450
38	0.095	0.112	0.130	0.147	0.165	0.182	0.199	0.217	0.234	0.252	0.269	0.287	0.304	0.322	0.339	0.357	0.374	0.392	0.409	0.427	0.444	0.462	0.479	0.497
40	0.102	0.121	0.141	0.160	0.179	0.198	0.218	0.237	0.256	0.276	0.295	0.314	0.334	0.353	0.372	0.391	0.411	0.430	0.449	0.469	0.488	0.507	0.527	0.546
42	0.109	0.131	0.152	0.173	0.194	0.216	0.237	0.258	0.279	0.300	0.322	0.343	0.364	0.385	0.406	0.428	0.449	0.470	0.491	0.513	0.534	0.555	0.576	0.597
44	0.117	0.140	0.164	0.187	0.210	0.233	0.257	0.280	0.303	0.326	0.349	0.373	0.396	0.419	0.442	0.466	0.489	0.512	0.535	0.558	0.582	0.605	0.628	0.651
46	0.125	0.150	0.176	0.201	0.226	0.252	0.277	0.302	0.328	0.353	0.378	0.404	0.429	0.454	0.480	0.505	0.530	0.556	0.581	0.606	0.632	0.657	0.682	0.708
48	0.133	0.161	0.188	0.216	0.243	0.271	0.298	0.326	0.353	0.381	0.408	0.436	0.463	0.491	0.518	0.546	0.574	0.601	0.629	0.656	0.684	0.711	0.739	0.766
50	0.141	0.171	0.201	0.231	0.261	0.290	0.320	0.350	0.380	0.410	0.440	0.469	0.499	0.529	0.559	0.589	0.618	0.648	0.678	0.708	0.738	0.767	0.797	0.827

Note: figure outside the thick lines are beyond to range of observed data.

Table 16. Below Ground Biomass (25% of the above ground biomass) Table of *Gmelina Arborea*

Below ground Biomass	Total Height (m)																							
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4				0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004
6	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.007
8	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.009	0.009	0.009	0.010
10	0.003	0.003	0.004	0.004	0.005	0.005	0.006	0.006	0.006	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
12	0.004	0.005	0.005	0.006	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.011	0.012	0.012	0.013	0.013	0.014	0.014	0.015	0.016	0.016	0.017	0.017
14	0.005	0.006	0.007	0.007	0.008	0.009	0.010	0.010	0.011	0.012	0.013	0.013	0.014	0.015	0.015	0.016	0.017	0.018	0.018	0.019	0.020	0.021	0.021	0.022
16	0.007	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025	0.025	0.026	0.027
18	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025	0.027	0.028	0.029	0.030	0.031	0.032	0.033
20	0.009	0.011	0.012	0.013	0.015	0.016	0.017	0.019	0.020	0.021	0.022	0.024	0.025	0.026	0.028	0.029	0.030	0.032	0.033	0.034	0.036	0.037	0.038	0.040
22	0.011	0.012	0.014	0.015	0.017	0.019	0.020	0.022	0.023	0.025	0.026	0.028	0.029	0.031	0.033	0.034	0.036	0.037	0.039	0.040	0.042	0.044	0.045	0.047
24	0.012	0.014	0.016	0.018	0.019	0.021	0.023	0.025	0.027	0.029	0.030	0.032	0.034	0.036	0.038	0.040	0.041	0.043	0.045	0.047	0.049	0.051	0.053	0.054
26	0.014	0.016	0.018	0.020	0.022	0.024	0.026	0.029	0.031	0.033	0.035	0.037	0.039	0.041	0.043	0.046	0.048	0.050	0.052	0.054	0.056	0.058	0.060	0.063
28	0.015	0.018	0.020	0.023	0.025	0.027	0.030	0.032	0.035	0.037	0.040	0.042	0.045	0.047	0.049	0.052	0.054	0.057	0.059	0.062	0.064	0.066	0.069	0.071
30	0.017	0.020	0.022	0.025	0.028	0.031	0.033	0.036	0.039	0.042	0.045	0.047	0.050	0.053	0.056	0.059	0.061	0.064	0.067	0.070	0.072	0.075	0.078	0.081
32	0.018	0.022	0.025	0.028	0.031	0.034	0.037	0.040	0.044	0.047	0.050	0.053	0.056	0.059	0.062	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.088	0.091
34	0.020	0.024	0.027	0.031	0.034	0.038	0.041	0.045	0.048	0.052	0.055	0.059	0.062	0.066	0.070	0.073	0.077	0.080	0.084	0.087	0.091	0.094	0.098	0.101
36	0.022	0.026	0.030	0.034	0.038	0.042	0.045	0.049	0.053	0.057	0.061	0.065	0.069	0.073	0.077	0.081	0.085	0.089	0.093	0.097	0.101	0.105	0.108	0.112
38	0.024	0.028	0.032	0.037	0.041	0.046	0.050	0.054	0.059	0.063	0.067	0.072	0.076	0.080	0.085	0.089	0.094	0.098	0.102	0.107	0.111	0.115	0.120	0.124
40	0.025	0.030	0.035	0.040	0.045	0.050	0.054	0.059	0.064	0.069	0.074	0.079	0.083	0.088	0.093	0.098	0.103	0.108	0.112	0.117	0.122	0.127	0.132	0.136
42	0.027	0.033	0.038	0.043	0.049	0.054	0.059	0.064	0.070	0.075	0.080	0.086	0.091	0.096	0.102	0.107	0.112	0.118	0.123	0.128	0.133	0.139	0.144	0.149
44	0.029	0.035	0.041	0.047	0.053	0.058	0.064	0.070	0.076	0.082	0.087	0.093	0.099	0.105	0.111	0.116	0.122	0.128	0.134	0.140	0.145	0.151	0.157	0.163
46	0.031	0.038	0.044	0.050	0.057	0.063	0.069	0.076	0.082	0.088	0.095	0.101	0.107	0.114	0.120	0.126	0.133	0.139	0.145	0.152	0.158	0.164	0.171	0.177
48	0.033	0.040	0.047	0.054	0.061	0.068	0.075	0.081	0.088	0.095	0.102	0.109	0.116	0.123	0.130	0.136	0.143	0.150	0.157	0.164	0.171	0.178	0.185	0.192
50	0.035	0.043	0.050	0.058	0.065	0.073	0.080	0.088	0.095	0.102	0.110	0.117	0.125	0.132	0.140	0.147	0.155	0.162	0.170	0.177	0.184	0.192	0.199	0.207

Note: figure outside the thick lines are beyond to range of observed data.

Table 17. Total Biomass (Above ground + Below ground biomass) Table of Gmelina *Arborea*

Total Biomass	Total Height (m)																						
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4				0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021
6	0.003	0.005	0.006	0.007	0.009	0.010	0.011	0.012	0.014	0.015	0.016	0.018	0.019	0.020	0.021	0.023	0.024	0.025	0.027	0.028	0.029	0.031	0.032	0.033
8	0.009	0.010	0.012	0.014	0.016	0.017	0.019	0.021	0.022	0.024	0.026	0.028	0.029	0.031	0.033	0.034	0.036	0.038	0.039	0.041	0.043	0.045	0.046	0.048
10	0.014	0.017	0.019	0.021	0.023	0.026	0.028	0.030	0.032	0.035	0.037	0.039	0.041	0.043	0.046	0.048	0.050	0.052	0.055	0.057	0.059	0.061	0.063	0.066
12	0.020	0.023	0.026	0.029	0.032	0.035	0.038	0.040	0.043	0.046	0.049	0.052	0.055	0.058	0.061	0.063	0.066	0.069	0.072	0.075	0.078	0.081	0.084	0.086
14	0.026	0.030	0.034	0.037	0.041	0.045	0.048	0.052	0.056	0.059	0.063	0.066	0.070	0.074	0.077	0.081	0.085	0.088	0.092	0.095	0.099	0.103	0.106	0.110
16	0.033	0.037	0.042	0.046	0.051	0.055	0.060	0.064	0.069	0.073	0.078	0.082	0.087	0.091	0.096	0.100	0.105	0.109	0.114	0.118	0.123	0.127	0.132	0.136
18	0.039	0.045	0.050	0.056	0.061	0.067	0.072	0.078	0.083	0.089	0.094	0.100	0.105	0.111	0.116	0.122	0.127	0.133	0.138	0.144	0.149	0.155	0.160	0.166
20	0.046	0.053	0.059	0.066	0.073	0.079	0.086	0.093	0.099	0.106	0.112	0.119	0.126	0.132	0.139	0.145	0.152	0.159	0.165	0.172	0.178	0.185	0.192	0.198
22	0.053	0.061	0.069	0.077	0.085	0.093	0.100	0.108	0.116	0.124	0.132	0.140	0.147	0.155	0.163	0.171	0.179	0.187	0.194	0.202	0.210	0.218	0.226	0.234
24	0.061	0.070	0.079	0.088	0.097	0.107	0.116	0.125	0.134	0.143	0.152	0.162	0.171	0.180	0.189	0.198	0.207	0.217	0.226	0.235	0.244	0.253	0.263	0.272
26	0.068	0.079	0.089	0.100	0.111	0.121	0.132	0.143	0.153	0.164	0.175	0.185	0.196	0.206	0.217	0.228	0.238	0.249	0.260	0.270	0.281	0.292	0.302	0.313
28	0.076	0.088	0.100	0.113	0.125	0.137	0.149	0.161	0.174	0.186	0.198	0.210	0.223	0.235	0.247	0.259	0.271	0.284	0.296	0.308	0.320	0.332	0.345	0.357
30	0.084	0.098	0.112	0.126	0.140	0.153	0.167	0.181	0.195	0.209	0.223	0.237	0.251	0.265	0.279	0.293	0.306	0.320	0.334	0.348	0.362	0.376	0.390	0.404
32	0.092	0.108	0.124	0.139	0.155	0.171	0.186	0.202	0.218	0.234	0.249	0.265	0.281	0.296	0.312	0.328	0.344	0.359	0.375	0.391	0.407	0.422	0.438	0.454
34	0.101	0.118	0.136	0.154	0.171	0.189	0.207	0.224	0.242	0.259	0.277	0.295	0.312	0.330	0.348	0.365	0.383	0.401	0.418	0.436	0.454	0.471	0.489	0.506
36	0.109	0.129	0.149	0.168	0.188	0.208	0.227	0.247	0.267	0.287	0.306	0.326	0.346	0.365	0.385	0.405	0.424	0.444	0.464	0.483	0.503	0.523	0.542	0.562
38	0.118	0.140	0.162	0.184	0.206	0.228	0.249	0.271	0.293	0.315	0.337	0.359	0.380	0.402	0.424	0.446	0.468	0.490	0.512	0.533	0.555	0.577	0.599	0.621
40	0.127	0.152	0.176	0.200	0.224	0.248	0.272	0.296	0.320	0.345	0.369	0.393	0.417	0.441	0.465	0.489	0.513	0.538	0.562	0.586	0.610	0.634	0.658	0.682
42	0.137	0.163	0.190	0.216	0.243	0.269	0.296	0.322	0.349	0.376	0.402	0.429	0.455	0.482	0.508	0.535	0.561	0.588	0.614	0.641	0.667	0.694	0.720	0.747
44	0.146	0.176	0.205	0.234	0.263	0.292	0.321	0.350	0.379	0.408	0.437	0.466	0.495	0.524	0.553	0.582	0.611	0.640	0.669	0.698	0.727	0.756	0.785	0.814
46	0.156	0.188	0.220	0.251	0.283	0.315	0.346	0.378	0.410	0.441	0.473	0.505	0.536	0.568	0.600	0.631	0.663	0.695	0.726	0.758	0.790	0.821	0.853	0.885
48	0.166	0.201	0.235	0.270	0.304	0.338	0.373	0.407	0.442	0.476	0.510	0.545	0.579	0.614	0.648	0.682	0.717	0.751	0.786	0.820	0.855	0.889	0.923	0.958
50	0.177	0.214	0.251	0.289	0.326	0.363	0.400	0.438	0.475	0.512	0.549	0.587	0.624	0.661	0.698	0.736	0.773	0.810	0.848	0.885	0.922	0.959	0.997	1.034

Note: figure outside the thick lines are beyond to range of observed data.

Table 18. Wood Carbon (Total Biomass*0.5) Table of *Gmelina Arborea*

carbon tonne	Total Height (m)																						
DBH (cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
4				0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.005	0.006	0.006	0.007	0.007	0.008	0.008	0.009	0.009	0.010	0.010	0.011
6	0.002	0.002	0.003	0.004	0.004	0.005	0.006	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.011	0.011	0.012	0.013	0.013	0.014	0.015	0.015	0.016	0.017
8	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.010	0.011	0.012	0.013	0.014	0.015	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.021	0.022	0.023	0.024
10	0.007	0.008	0.009	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.021	0.022	0.023	0.024	0.025	0.026	0.027	0.028	0.030	0.031	0.032	0.033
12	0.010	0.012	0.013	0.014	0.016	0.017	0.019	0.020	0.022	0.023	0.025	0.026	0.027	0.029	0.030	0.032	0.033	0.035	0.036	0.037	0.039	0.040	0.042	0.043
14	0.013	0.015	0.017	0.019	0.020	0.022	0.024	0.026	0.028	0.030	0.031	0.033	0.035	0.037	0.039	0.040	0.042	0.044	0.046	0.048	0.050	0.051	0.053	0.055
16	0.016	0.019	0.021	0.023	0.025	0.028	0.030	0.032	0.034	0.037	0.039	0.041	0.043	0.046	0.048	0.050	0.052	0.055	0.057	0.059	0.061	0.064	0.066	0.068
18	0.020	0.022	0.025	0.028	0.031	0.033	0.036	0.039	0.042	0.044	0.047	0.050	0.053	0.055	0.058	0.061	0.064	0.066	0.069	0.072	0.075	0.077	0.080	0.083
20	0.023	0.026	0.030	0.033	0.036	0.040	0.043	0.046	0.050	0.053	0.056	0.059	0.063	0.066	0.069	0.073	0.076	0.079	0.083	0.086	0.089	0.093	0.096	0.099
22	0.027	0.031	0.035	0.038	0.042	0.046	0.050	0.054	0.058	0.062	0.066	0.070	0.074	0.078	0.082	0.085	0.089	0.093	0.097	0.101	0.105	0.109	0.113	0.117
24	0.030	0.035	0.039	0.044	0.049	0.053	0.058	0.062	0.067	0.072	0.076	0.081	0.085	0.090	0.095	0.099	0.104	0.108	0.113	0.118	0.122	0.127	0.131	0.136
26	0.034	0.039	0.045	0.050	0.055	0.061	0.066	0.071	0.077	0.082	0.087	0.093	0.098	0.103	0.109	0.114	0.119	0.125	0.130	0.135	0.140	0.146	0.151	0.156
28	0.038	0.044	0.050	0.056	0.062	0.069	0.075	0.081	0.087	0.093	0.099	0.105	0.111	0.117	0.123	0.130	0.136	0.142	0.148	0.154	0.160	0.166	0.172	0.178
30	0.042	0.049	0.056	0.063	0.070	0.077	0.084	0.091	0.098	0.105	0.112	0.118	0.125	0.132	0.139	0.146	0.153	0.160	0.167	0.174	0.181	0.188	0.195	0.202
32	0.046	0.054	0.062	0.070	0.078	0.085	0.093	0.101	0.109	0.117	0.125	0.133	0.140	0.148	0.156	0.164	0.172	0.180	0.188	0.195	0.203	0.211	0.219	0.227
34	0.050	0.059	0.068	0.077	0.086	0.094	0.103	0.112	0.121	0.130	0.139	0.147	0.156	0.165	0.174	0.183	0.191	0.200	0.209	0.218	0.227	0.236	0.244	0.253
36	0.055	0.065	0.074	0.084	0.094	0.104	0.114	0.124	0.133	0.143	0.153	0.163	0.173	0.183	0.192	0.202	0.212	0.222	0.232	0.242	0.252	0.261	0.271	0.281
38	0.059	0.070	0.081	0.092	0.103	0.114	0.125	0.136	0.147	0.157	0.168	0.179	0.190	0.201	0.212	0.223	0.234	0.245	0.256	0.267	0.278	0.289	0.299	0.310
40	0.064	0.076	0.088	0.100	0.112	0.124	0.136	0.148	0.160	0.172	0.184	0.196	0.208	0.221	0.233	0.245	0.257	0.269	0.281	0.293	0.305	0.317	0.329	0.341
42	0.068	0.082	0.095	0.108	0.121	0.135	0.148	0.161	0.174	0.188	0.201	0.214	0.228	0.241	0.254	0.267	0.281	0.294	0.307	0.320	0.334	0.347	0.360	0.373
44	0.073	0.088	0.102	0.117	0.131	0.146	0.160	0.175	0.189	0.204	0.218	0.233	0.247	0.262	0.276	0.291	0.305	0.320	0.335	0.349	0.364	0.378	0.393	0.407
46	0.078	0.094	0.110	0.126	0.141	0.157	0.173	0.189	0.205	0.221	0.236	0.252	0.268	0.284	0.300	0.316	0.331	0.347	0.363	0.379	0.395	0.411	0.426	0.442
48	0.083	0.100	0.118	0.135	0.152	0.169	0.186	0.204	0.221	0.238	0.255	0.272	0.290	0.307	0.324	0.341	0.358	0.376	0.393	0.410	0.427	0.444	0.462	0.479
50	0.088	0.107	0.126	0.144	0.163	0.182	0.200	0.219	0.237	0.256	0.275	0.293	0.312	0.331	0.349	0.368	0.387	0.405	0.424	0.442	0.461	0.480	0.498	0.517

Note: figure outside the thick lines are beyond to range of observed data.

4. Discussion

Perusal of data on biomass accumulation (above ground, below ground and total biomass) showed increasing trend with DBH and height classes. In the present study standing biomass was estimated using volume and wood density. The volume and subsequently, biomass was reported to be related with diameter (DBH) and height (H). For determining the best fit equation of volume, the volume as dependent variable and independent variables (diameter and height) such as (D), (D^2), D^2H, and (D), (H), D^2H were used for *Tectona grandis* and *Gmelina arborea*, respectively. The range of determination coefficient was found to be 98% and 99% for *Tectona grandis* and *Gmelina arborea, respectively*. This could be explained by the fact that volume (V) and above ground components of trees were dependent upon DBH and height (Bohre *et.al.*, 2012).

In terms of vertical and horizontal growth, *Gmelina arborea* proved better as compared to *Tectona grandis*. The results were in agreement with the findings of Negi *et al.* (1990), indicating average crop diameters of 21.1 cm and 25.4 cm for *T.grandis* and *G.arborea* with the corresponding heights of 20.4 m and 20.9 m, respectively in 20 years old plantations.

In the present study, the biomass accumulation in *G.arborea* was found to be 45.80 tonne ha^{-1} in 6 year old plantation, which was better as compared with biomass production of 30 tonne ha^{-1} found in its 6 year old plantation by Akachuku (1981). The better growth might be primarily due to well drained and highly porous texture of soil media as found in mined overburdens (Roberts *et al.*, 1988; Torbert *et al.*, 1990; Larson and Vimmersted, 1983).

The net biomass production of *Tectona grandis* was found to be 13.99 tonne ha^{-1} y^{-1}, which was comparable with the findings of Karmacharya and Singh (1992) who reported 14 tonne ha^{-1} y^{-1} net production of *T.grandis* adopting non harvesting techniques in dry tropical regions in India. Buvaneswaran *et al.* (2006) compared biomass of *T.grandis* plantations in Tamilnadu ,India and Costa Rica, Central America and reported that the best fit modals developed for one zone cannot be used for other zone. The variation in biomass estimation and carbon sequestration were species and site specific and can be reduced to a minimum only by employing site-specific equations (Wang *et al.,* 1995).

In terms of biomass accumulation and carbon sequestration, both *T.grandis* and *G.arborea* were proved as effective species as shown through the biomass and carbon tables of these species and the literature review (Kaul *et al.,* 1979; Hase and Foelster, 1983; Alfaro and Camino, 2002; Jain and Ansari, 2012).

5. Conclusion

Looking to the serious concern of carbon management, the role of *Tectona grandis* and *Gmelina arborea* to estimate the biomass accumulation and their contribution for sequestration of carbon in mined out areas, the following conclusions were derived:

1. In both 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 net biomass accumulation in 10 year old plantation was found to be 279.89 tonne ha^{-1} and 371.54 tonne ha^{-1} in *T.grandis* and *G.arborea* with corresponding carbon of 139.91 tonne ha^{-1} and 185.77 tonne ha^{-1}, respectively.
3. The minimum and maximum total biomass (above ground + below ground) was found to be 0.007 tonne $tree^{-1}$ (with 4 cm dbh and 5 m height) and 2.997 tonne $tree^{-1}$ (with 50 cm dbh and 25 m height) for *T.grandis* and 0.001 tonne $tree^{-1}$ (with 4 cm dbh and 5 m

height) and 1.034 tonne $tree^{-1}$ (with 50 cm dbh and 25 m height) for *G.arborea*, respectively.

4. The minimum and maximum values of carbon sequestered by trees of different dimensions were 0.003 tonne $tree^{-1}$ (with 4 cm dbh and 5 m height) and 1.499 tonne $tree^{-1}$ (with 50 cm dbh and 25 m height) for *T.grandis* and 0.001 tonne $tree^{-1}$ (with 4 cm dbh and 5 m height) and 0.517 tonne $tree^{-1}$ (with 50 cm dbh and 25 m height) for *G.arborea*, respectively.

Keeping above in view, both *Tectona grandis* and *Gmelina arborea* proved as efficient species pertaining to biomass and carbon accumulation for restoration of reduced ecosystems and for measuring its potential to serve as an efficient carbon offset.

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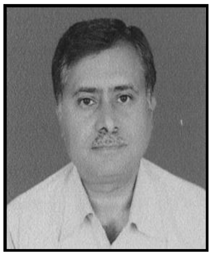

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