Stump Diameter-DBH-Volume Relationships for Teli Garjan (*Dipterocarpus turbinatus*), Dhakijam (*Sygyzium grande*) and Teak (*Tectona grandis*) in Bangladesh

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Abstract

Teli garjan *(Dipterocarpus turbinatus)*, dhakijam *(Sygyzium grande)* and teak *(Tectona grandis)* are the three most important timber species included in the plantation programme in Bangladesh. Sometimes, trees are being removed without recording the diameter at breast height (dbh) and total height. As such it is not possible to estimate the volumes of the removed trees. But, it is necessary to have an estimate of volumes of the removed trees for different purposes. The stump diameters can be measured while the stumps are still there after removal of the trees. Therefore, stump diameter and dbh relationships have been established in the present paper so that we can estimate the dbh of removed trees first followed by estimation of the volumes using the dbh volume relationships. It was identified that some mistakes were done in converting the previously selected imperial volume equations to metric units for the species teli garjan and dhakijam. These equations and tables have also been corrected.

সারসংক্ষেপ

তেলীগর্জন, ঢাকিজাম এবং সেগুন বাংলাদেশের বনায়ন কর্মসূচীতে ব্যবহারযোগ্য কাষ্ঠ উৎপাদনকারী প্রধান তিনটি প্রজাতির গাছ । অনেক সময় এ সকল প্রজাতির গাছের বুক উচ্চতায় ব্যাসের মাপ না নিয়ে বিভিন্ন কারণে কাটা হয় । পরবর্তীতে উক্ত কাটা গাছের ভল্যুম অনুমান করা সম্ভব হয় না । কিন্তু অনেক কারণে এসব গাছের ভল্যুম অনুমান করার প্রয়োজন হয় । গাছ কাটার পরে গাছের মোথা মাটিতে থাকা অবস্থায় মোথার ব্যাস পরিমাপ করা যায় । তাই আলোচ্য প্রবন্ধে গাছের মোথার ব্যাসের সাথে বুক উচ্চতায় ব্যাসের সম্পর্ক নির্ণয় করে বর্তমানে প্রচলিত ভল্যুম টেবল ব্যবহারোপযোগী সমীকরণ ও টেবল তৈরী করা হয়েছে । এ ছাড়া গর্জন ও ঢাকিজামের ইতিপূর্বের নির্বাচিত মেট্রিক পদ্ধতির সমীকরণ ও টেবিলে যে ভুল ধরা পড়ে তাও সংশোধন করা হয় ।

Key words : Bangladesh, *Dipterocarpus turbinatus*, stump diameter, *Sygyzium grande*, *Tectona grandis*, volume

Introduction

The history of establishment of plantations in Bangladesh dates back to 1876. Teli garjan *(Dipterocarpus turbinatus* Gaertn. f.), dhakijam *(Sygyzium grande* Wt. Wild) and teak *(Tectona*

grandis L.), are the three most important timber species included in the long rotation plantation programme in Bangladesh. The timbers of the species are good for construction and furniture. The species are planted in pure stands and also in the mixed form.

Sometimes the trees are being removed without recording the diameter at breast height (dbh) and total height. As such it is not possible to estimate the volumes of the removed trees. But, it is necessary to have the estimates of volumes of the removed trees to have an account of the harvest from a forest area. The estimates of the volumes of the removed trees are also required to obtain a precise picture for monitoring and inventory of the growth in the absence of actual data. The stump diameters can be measured while the stumps are still there after removal of the trees without recording the dbh and height.

Therefore, some ways are required to estimate the volumes of those trees from stump diameter. At present, volume tables for these species are available based on dbh (D) and dbh and height (H) (Latif and Islam 1984a, Latif and Islam 1984b and Latif *et al.* 1985). If the stump diameter and dbh relationships can be established, we can estimate the dbh of removed trees first and subsequently the volumes, using the dbh and volume relationships.

The existing volume tables for teak give acceptable estimate of volumes for both imperial and metric units. The tables for the species teli garjan and dhakijam give good estimate of volumes in imperial unites (cubic feet) but in metric units these tables or equations give higher estimates in comparison to the actual volumes. The original data for preparation of these volume tables were collected in imperial units. Subsequently, computer processing and models were selected at Oxford Forestry Institute with the technical assistance of Prof. H. L. Wright. The original equations were selected for imperial units. These selected equations were transformed into metric units to estimate the volumes in metric unit. The mistakes were done during transformations of the imperial polynomial equations to metric units. Therefore, these models also need corrections. Under the above circumstances, it was felt necessary to publish corrected volume tables and also volume tables based on stump diameters for these species to serve the purpose. As such the present study was undertaken, and the results of the study are presented in the paper.

Materials and methods

Stump diameter-volume relationship : Major plantations of teli garjan, dhakijam and teak are available in the Forest Divisions of Chittagong, Cox's Bazar, Chittagong Hill Tracts (South) and Sylhet. These species are planted at a spacing of 1.8 m x 1.8 m in general. From field observations, it was noticed that maximum of the trees are within the dbh range of 5-60 cm. This range was divided into 5.0 cm dbh classes, and an attempt was made to collect data of sufficient number of trees from each dbh class. Larger trees were also included whenever available. Trees having average to better stem form in a plantation were selected at random for data collection.

Dbh of the standing trees were measured first. This was followed by taking measurement of diameters at 15 cm and 30 cm above ground level. Then the data were entered into computer and grouped in 5.0 cm dbh classes (Table 1). These were plotted in the screen of the computer, and it was observed that linear relationships exist among dbh and stump diameter. Therefore, linear regressions were tried to find out the desired equations.

Table 1. DBH class distribution of sample trees for estimation of stump diameter and dbh relationships.

DBH (cm)	Dhakijam	Teak	Teli garjan
5 - 10	34	34	101
10 - 15	40	72	50
15 - 20	24	80	24
20 - 25	51	81	30
25 - 30	96	52	31
30 - 35	80	46	38
35 - 40	46	41	39
40 - 45	17	22	45
45 - 50	7	11	22
50 - 55	3	15	30
55 - 60	1	20	24
60 - 65	0	4	22
65 - 70	0	1	14
70 - 75	0	3	9
over 75	0	7	31
Total	399	489	510

Correction of incorrect volume equations : After thorough investigations, it was found that for deriving the two-way metric volume equation for teli garjan and both for one- and two-ways dhakijam, mistakes were done during the transformations of the polynomial imperial equations to metric equations. Therefore, the coefficients of D, D^2, DH and D^2H were divided by the factors 2.54, $(2.54^2=)$ 6.45, $(3.281/2.54=)1.29$ and $(3.281^2/54^2=) 0.51$ respectively followed by other necessary corrections to transform the imperial equations into metric units. These were done as mathematical procedures to transform the units from imperial to metric ones. It was also found that the conversion factor to estimate the volume under bark for dhakijam was also wrong. Therefore, this model was also corrected with mathematical procedures.

Results and discussion

DBH-stump diameter equations : Diameters at breast height (dbh) may be estimated from stump diameters as long as the stumps are in position. Subsequently, volumes can be estimated from these estimated dbh. Therefore, dbh and stump diameters at 15 cm and 30 cm above ground level relationships were determined. The results of the regressions showed that the linear equations give good fit. The equations of best fits with their different statistics are given in Table 2.

Where, D_{15} = Stump diameter at 15 cm above ground level.

D_{30} = Stump diameter at 30 cm above ground level and

k = the regression coefficient.

It was observed that the selected equations describe about 98.00, 98.5 ; 96.6, 97.1 and 96.5, 97.7 percent of the total variations for the species teli garjan, dhakijam and teak respectively. There-

Table 2. Statistics for the selection of suitable model estimation of diameter at breast height from stump diameter.

Species	Equation	Regression coefficient	Std. error of coefficient	Std. error of Y estimate	R^2	Number of observations
Dhakijam	DBH=kD_{15}	0.755543	0.002525	1.91	0.966	399
	DBH=kD_{30}	0.812361	0.002531	1.78	0.971	
Teli garjan	DBH=kD_{15}	0.792437	0.002785	3.30	0.980	510
	DBH=kD_{30}	0.834998	0.002505	2.82	0.985	
Teak	DBH=kD_{15}	0.751072	0.003138	2.89	0.965	489
	DBH=kD_{30}	0.811416	0.002755	2.35	0.977	

fore, the selected models give good estimates of dbh from stump diameters. Hence, if we know the stump diameters we can estimate the dbh. As such by the system of simultaneous equation methods at first we can estimate the dbh of the removed trees followed by estimation of the desired volumes of the tree. As heights of the felled trees are not known, the dbh - volume relationship is recommended to use for the purpose.

Corrected tree volume equations: There were mistakes in transforming the two-way volume equation for teli garjan and both for one- and two-way volume equations and factor for estimation of under bark volume from over bark total volume for dhakijam in metric units published by Latif and Islam (1984a, 1984b). The original data for preparation of volume tables of these species were collected in imperial units. Subsequently, computer processing and models were selected at Oxford. The original equations were selected for imperial units. These selected equations were converted into metric units to estimate the volume in metric units. The mistakes were done during transformation processes. The erroneous models were corrected as given below :

Dhakijam :

$$V = 0.00552016 - 0.0028213\,D + 0.00078431\,D^2$$

$$V = 0.00018987 + 0.0000299\,D^2 + 0.00024887\,DH + 0.000024466\,D^2H$$

Corrected conversion factor to estimate under bark volume from overbark volume :

$$F = D/(-0.235311 + 1.281747\,D - 0.0028786\,D^2)$$

Teli garjan :

$$V = 0.00252114 + 0.00010003\,D^2 + 0.00014779\,DH + 0.000024065\,D^2H.$$

The dbh and volumes up to different top end diameters were estimated and are given in Table 3, 4 and 5 for the species teli garjan, dhakijam and teak respectively for ready use. To have precise estimates, it is recommended to use the system of equations. The tables may be directly used when the stump diameter coincides with the figures given in the tables. But if the measured stump diameters do not coincide with the figures in the tables, the dbh should be estimated first by the equations given in the paper. Then this estimated dbh may be put in one-way (dbh-volume) equations to get the desired volumes.

Previous equations used in the present study:

The equations of the original publications used to estimate the volumes in metric units up to different top end diameters are given as below :

Dhakijam :

Conversion factor to estimate the volume up to 10 cm and 20 cm underbark from overbark volume are given below :

$$F_{10} = 0.98404\,(1-e^{-0.241842*D})\,16.65083$$

$$F_{20} = 0.940938\,(1-e^{-0.17372189*D})\,66.24374$$

Teli garjan :

Conversion factors to estimate underbark volume, underbark volume up to 10 cm and 20 cm top end diameter from over bark volume are given below :

$$F = 0.7549622 + 0.00302795\,D - 0.0000195105\,D^2$$

$$F_{10} = 0.9817652*\,(1-e^{-0.3558229*D})\,69.50948$$

$$F_{20} = 0.9280634*\,(1-e^{-0.27812992*D})\,1156.116$$

Teak :

Total volume over bark :

$$Log\,(V) = -7.567916 + 2.12337\,log\,(D)$$

Conversion factors to estimate underbark volume, underbark volume up to 10 cm and 20 cm top end diameter from over bark volume are given below :

$$F = D/(3.01537 + 1.08688*D - 0.0003429*D^2)$$

$$F_{10} = 0.9979585*\,(1-e^{-0.0687285*D})\,0.310291$$

$$F_{20} = 0.97739 - 3.72804*e^{-0.08793882*D}$$

The correct volume estimations as given in the original publications are given below for use by the interested persons :

·Dhakijam :

Imperial units

$$V = 0.194971 - 0.253102 * D + 0.178721 * D^2$$
$$V = 0.00670627 + 0.00681399 * D^2$$
$$+ 0.00680484 \; DH + 0.001699227 \; D^2H$$

Teli garjan :

Imperial units :

$$\log (V) = - 2.75168 + 2.35556 \log (D)$$
$$V = 0.0890463 + 0.022793 \; D^2 + 0.00404101$$
$$D \; H + 0.00167134 \; D^2H$$

Metric units :

$$\log (V) = - 8.5116354 + 2.35556 \log (D)$$

Teak :

Imperial units :

$$\text{Log} (V) = - 2.0244 + 2.12337 \log (D)$$
$$\text{Log} (V) = - 5.78932 + 1.62116 \log (D)$$
$$+ 1.16483 \log (H)$$

Metric units :

$$\text{Log} (V) = - 9.48076 + 1.62116 \log (D)$$
$$+ 1.16483 \log (H)$$

Table 3. Revised volume table for teli garjan in Bangladesh.

Dbh (cm)	Diameter at 0.15 m above ground (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m^3)	Under bark volume (m^3)	Underbark volume up to 10 cm top end diameter (m^3)	Underbark volume up to 20 cm top diameter (m^3)
10	12.6	12.0	0.0456	0.0357	0.0047	0.0000
12	15.1	14.4	0.0701	0.0552	0.0204	0.0000
14	17.7	16.8	0.1007	0.0799	0.0486	0.0000
16	20.2	19.2	0.1380	0.1102	0.0855	0.0000
18	22.7	21.6	0.1821	0.1463	0.1280	0.0001
20	25.2	24.0	0.2334	0.1885	0.1749	0.0021
22	27.8	26.3	0.2921	0.2373	0.2266	0.0172
24	30.3	28.7	0.3586	0.2928	0.2835	0.0631
26	32.8	31.1	0.4330	0.3553	0.3465	0.1428
28	35.3	33.5	0.5156	0.4251	0.4160	0.2442
30	37.9	35.9	0.6066	0.5024	0.4924	0.3542
32	40.4	38.3	0.7062	0.5875	0.5763	0.4657
34	42.9	40.7	0.8146	0.6805	0.6678	0.5769
36	45.4	43.1	0.9320	0.7816	0.7672	0.6888
38	48.0	45.5	1.0586	0.8912	0.8748	0.8028
40	50.5	47.9	1.1945	1.0092	0.9908	0.9208
42	53.0	50.3	1.3400	1.1359	1.1152	1.0440
44	55.5	52.7	1.4952	1.2715	1.2483	1.1735
46	58.0	55.1	1.6602	1.4161	1.3903	1.3100
48	60.6	57.5	1.8353	1.5698	1.5412	1.4542
50	63.1	59.9	2.0205	1.7328	1.7012	1.6064
52	65.6	62.3	2.2161	1.9051	1.8704	1.7670
54	68.1	64.7	2.4222	2.0869	2.0488	1.9361

Table 3 . Contd.

Dbh (cm)	Diameter at 0.15 m above ground (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m³)	Under bark volume (m³)	Underbark volume up to 10 cm top end diameter (m³)	Underbark volume up to 20 cm top diameter (m³)
56	70.7	67.1	2.6388	2.2782	2.2366	2.1139
58	73.2	69.5	2.8662	2.4791	2.4339	2.3005
60	75.7	71.9	3.1045	2.6897	2.6407	2.4961
62	78.2	74.3	3.3537	2.9100	2.8570	2.7006
64	80.8	76.6	3.6142	3.1401	3.0829	2.9142
66	83.3	79.0	3.8859	3.3800	3.3184	3.1368
68	85.8	81.4	4.1690	3.6297	3.5635	3.3686
70	88.3	83.8	4.4636	3.8892	3.8183	3.6094
72	90.9	86.2	4.7698	4.1585	4.0827	3.8593
74	93.4	88.6	5.0878	4.4375	4.3566	4.1183
76	95.9	91.0	5.4177	4.7263	4.6402	4.3863
78	98.4	93.4	5.7595	5.0248	4.9332	4.6634
80	101.0	95.8	6.1134	5.3330	5.2357	4.9493
82	103.5	98.2	6.4796	5.6506	5.5476	5.2441
84	106.0	100.6	6.8580	5.9778	5.8688	5.5477
86	108.5	103.0	7.2489	6.3143	6.1991	5.8600
88	111.0	105.4	7.6523	6.6600	6.5386	6.1809
90	113.6	107.8	8.0682	7.0149	6.8870	6.5103

Table 4. Revised volume table for dhakijam in Bangladesh.

Dbh (cm)	Diameter at 0.15 m above ground . (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m³)	Total volume under bark (m³)	Total volume under bark up to 10 cm top end diameter (m³)	Total volume under bark up to 20 cm top end diameter (m³)
10	13.2	12.3	0.0557	0.0453	0.0094	0.0000
12	15.9	14.8	0.0846	0.0689	0.0265	0.0000
14	18.5	17.2	0.1197	0.0978	0.0542	0.0002
16	21.2	19.7	0.1612	0.1320	0.0914	0.0018
18	23.8	22.2	0.2089	0.1716	0.1361	0.0083
20	26.5	24.6	0.2628	0.2168	0.1868	0.0254
22	29.1	27.1	0.3231	0.2675	0.2426	0.0581
24	31.8	29.5	0.3896	0.3239	0.3031	0.1085

Table 4. Contd.

Dbh (cm)	Diameter at 0.15 m above ground (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m³)	Total volume under bark (m³)	Total volume under bark up to 10 cm top end diameter (m³)	Total volume under bark up to 20 cm top end diameter (m³)
26	34.4	32.0	0.4624	0.3860	0.3682	0.1754
28	37.1	34.5	0.5414	0.4539	0.4382	0.2557
30	39.7	36.9	0.6268	0.5278	0.5133	0.3457
32	42.4	39.4	0.7184	0.6076	0.5936	0.4427
34	45.0	41.9	0.8163	0.6935	0.6794	0.5448
36	47.6	44.3	0.9204	0.7856	0.7710	0.6507
38	50.3	46.8	1.0309	0.8840	0.8684	0.7601
40	52.9	49.2	1.1476	0.9887	0.9719	0.8729
42	55.6	51.7	1.2706	1.0998	1.0816	0.9894
44	58.2	54.2	1.3998	1.2175	1.1976	1.1098
46	60.9	56.6	1.5353	1.3418	1.3201	1.2346
48	63.5	59.1	1.6771	1.4729	1.4492	1.3641
50	66.2	61.5	1.8252	1.6108	1.5850	1.4988
52	68.8	64.0	1.9796	1.7557	1.7276	1.6390
54	71.5	66.5	2.1402	1.9076	1.8771	1.7849
56	74.1	68.9	2.3071	2.0667	2.0337	1.9370
58	76.8	71.4	2.4803	2.2330	2.1974	2.0953
60	79.4	73.9	2.6598	2.4068	2.3684	2.2602
62	82.1	76.3	2.8455	2.5880	2.5467	2.4318
64	84.7	78.8	3.0375	2.7769	2.7326	2.6103
66	87.4	78.8	3.2358	2.9735	2.9261	2.7960
68	90.0	83.7	3.4403	3.1780	3.1273	2.9888
70	92.3	88.2	3.6512	3.3905	3.3364	3.1891
72	95.3	88.6	3.8683	3.6111	3.5534	3.3970
74	97.9	91.1	4.0916	3.8399	3.7786	3.6125
76	100.6	93.6	4.3213	4.0772	4.0121	3.8359
78	103.2	96.0	4.5572	4.3229	4.2539	4.0672
80	105.9	98.5	4.7994	4.5773	4.5043	4.3067
82	108.5	100.9	5.0479	4.8405	4.7633	4.5545
84	111.2	103.4	5.3026	5.1127	5.0311	4.8106
86	113.8	105.9	5.5636	5.3940	5.3079	5.0753
88	116.5	108.3	5.8309	5.6845	5.5938	5.3487
90	119.1	110.8	6.1045	5.9845	5.8890	5.6310

Table 5. Revised volume table for teak in Bangladesh.

Dbh (cm)	Diameter at 0.15 m above ground (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m^3)	Total volume under bark (m^3)	Total volume under bark up to 10 cm top end diameter (m^3)	Total volume under bark up to 20 cm top end diameter (m^3)
10	13.3	12.3	0.0687	0.0496	0.0398	0.0000
12	16.0	14.8	0.1011	0.0758	0.0632	0.0000
14	18.6	17.3	0.1403	0.1081	0.0929	0.0000
16	21.3	19.7	0.1862	0.1467	0.1291	0.0095
18	24.0	22.2	0.2392	0.1916	0.1719	0.0406
20	26.6	24.6	0.2991	0.2430	0.2216	0.0815
22	29.3	27.1	0.3662	0.3011	0.2781	0.1321
24	32.0	29.6	0.4405	0.3658	0.3417	0.1923
26	34.6	32.0	0.5222	0.4373	0.4123	0.2618
28	37.3	34.5	0.6111	0.5158	0.4901	0.3402
30	39.9	37.0	0.7076	0.6011	0.5751	0.4273
32	42.6	39.4	0.8115	0.6935	0.6673	0.5228
34	45.3	41.9	0.9230	0.7930	0.7668	0.6264
36	47.9	44.4	1.0421	0.8997	0.8737	0.7379
38	50.6	46.8	1.1689	1.0136	0.9879	0.8570
40	53.3	49.3	1.3034	1.1348	1.1095	0.0836
42	55.9	51.8	1.4456	1.2634	1.2385	1.1176
44	58.6	54.2	1.5957	1.3993	1.3751	1.2588
46	61.2	56.7	1.7537	1.5428	1.5191	1.4072
48	63.9	59.2	1.9195	1.6938	1.6708	1.5628
50	66.6	61.6	2.0933	1.8524	1.8300	1.7255
52	69.2	64.1	2.2751	2.0187	1.9969	1.8953
54	71.9	66.6	2.4650	2.1926	2.1714	2.0722
56	74.6	69.0	2.6628	2.3743	2.3537	2.2563
58	77.2	71.5	2.8688	2.5638	2.5437	2.4476
60	79.9	73.9	3.0830	2.7611	2.7416	2.6461
62	82.5	76.4	3.3053	2.9663	2.9473	2.8519
64	85.2	78.9	3.5358	3.1795	3.1609	3.0650
66	87.9	81.3	3.7745	3.4007	3.3824	3.2855
68	90.5	83.8	4.0215	3.6298	3.6119	3.5135
70	93.2	86.3	4.2768	3.8671	3.8494	3.7491

Table 5·Contd.

Dbh (cm)	Diameter at 0.15 m above ground (cm)	Diameter at 0.30 m above ground (cm)	Total volume over bark (m³)	Total volume under bark (m³)	Total volume under bark up to 10 cm top end diameter (m³)	Total volume under bark up to 20 cm top end diameter (m³)
72	95.9	88.7	4.5405	4.1125	4.0950	3.9922
74	98.5	91.2	4.8125	4.3660	4.3487	4.2430
76	101.2	93.7	5.0928	4.6278	4.6106	4.5015
78	103.9	96.1	5.3816	4.8978	4.8806	4.7679
80	106.5	98.6	5.6788	5.1760	5.1589	5.0420
82	109.2	101.1	5.9845	5.4627	5.4455	5.3241
84	111.8	103.5	6.2987	5.7577	5.7404	5.6142
86	114.5	106.0	6.6214	6.0611	6.0436	5.9123
88	117.2	108.5	6.9527	6.3729	6.3553	6.2185
90	119.8	110.9	7.2925	6.6933	6.6754	6.5328

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