Volume Tables for Koroi (*Albizia procera*) and Arjun (*Terminalia arjuna*) Trees Planted in the Central Part of Bangladesh

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Abstract

Koroi (*Albizia procera*) and arjun (*Terminalia arjuna)* are the two important species included in the plantation programme in the central part of Bangladesh. Volume tables of these two species planted in the area have been prepared. These volume tables are applicable for small and medium sized trees of the respective species planted in the area.

সারসংক্ষেপ

করই এবং অর্জুন গাছ বাংলাদেশের কেন্দ্রীয় অঞ্চলে লাগানো হয়। এ অঞ্চলে লাগানো করই ও অর্জুন গাছের ভল্যুম বের করার জন্য ভল্যুম টেবল তৈরী করা হয়েছে। এ ভল্যুম টেবিল ব্যবহার করে এ অঞ্চলে রোপিত ছোট এবং মাঝারি আকারের করই ও অর্জুন গাছের ভল্যুম বের করা যাবে।

Key words: *Albizia procera,* Bangladesh, *Terminalia arjuna,* volume table

Introduction

Koroi (*Albizia procera*) and arjun (*Terminalia arjuna*) are the two important species grown in association with sal in the central part of Bangladesh. The wood of arjun is hard, and used for building, agricultural implements, carts and boats (Troup 1921). The bark is used for tannin and medicinal purposes. Koroi is used for house posts, furniture and agricultural implements. Volume tables for these species planted in the central part of Bangladesh are not available. These tables are necessary for their economic evaluation and future management. The present study is, therefore, undertaken with the request of Divisional Forest Officer, Tangail Forest Division, Tangail.

Materials and methods

Representative trees for each species and girth at breast height (GBH) classes were selected at random. First, The girths at breast height (GBH) and total heights of the standing trees were measured. Then the girths and bark thickness at one-metre intervals were measured by climbing on the trees with ladders. The data of 221 koroi trees and 177 arjun trees were collected for preparation of volume tables. The GBH-height class distributions of the sample trees measured is given in Table 1 and Table 2.

Compilation of data

Volumes of all the sections except top and bottom portions were computed by using the mean cross-sectional areas of the two ends of each section (Smallian formula). The bottom section was considered cylindrical. The top section assumed as cone and computed volume as one third of the cylindrical volume of the portion. The top end girth measurement for each tree considered as the base girth of the cone. The volume of the cone was ignored for estimation of under bark tree volume. The individual tree volume was estimated by summing up the volume of each section of a tree. Regression techniques were used to relate these individual tree volumes (V) to GBH (G) and total height (H) using various functions and transformations as required in the models.

Table 1. Height-GBH class distribution of the sample trees measured for estimation of volume of koroi.

GBH	Height in metres											
(cm)	5-7	7-9	9-11	11-13	13-15	15-17	17-19	19-21	21-23	23-25	25-27	Total
20-30	3	15										18
30-40		10	10		1							21
40-50			4	10	1							15
50-60				10	5	6	1					22
60-70				2	6	8	6					22
70-80				2	5	6	5	3				21
80-90					3	4	5	5	3	2		22
90-100					1	4	6	2	5	2		20
100-110						3	7	4	1	2	1	18
110-120						2	4	4	3	2	1	16
120-130						1	2		1		2	6
130 +							3	2	1	9	5	20
Total	3	25	14	24	22	34	39	20	14	17	9	221

Table 2. Height-GBH class distribution of the sample trees measured for estimation of volume of arjun.

GBH class	Number of trees in the height class in metres							
(cm)	4-6	6-8	8-10	10-12	12-14	14-16	16-18	Total
20-30	6	12	3					21
30-40	1	7	11					19
40-50		5	11	3				19
50-60		1	7	10				18
60-70			4	4	3			11
70-80			3	7	5			15
80-90			2	5	6			13
90-100			1	3	5	2		11
100-110				1	9	5	1	16
110-120					7	5	2	14
120 +					5	8	7	20
Total	7	25	42	33	40	20	10	177

The following original and transformed variables were used to select the best-suited regression models:

Dependent variables:

V, $\log(V)$, V/G^2 and V/G^2H

Independent variables:

G, G^2, H^2, G^2H, GH, $\log(G)$, $\log(H)$, $1/G^2$, $1/G$, $1/G^2H$, H/G^2, H/G.

Computation of volume function

Multiple regression analyses were done to select the best-suited equations. The following 15 models were tried to select the equation of best fit with different variables as follows:

1. $V = a + bG$
2. $V = a + bG + cG^2$
3. $V = a + bG^2$

4. $V = a + bG^2H$
5. $V = a + bG^2 + cH + dG^2H$
6. $V = a + bG + cGH + dG^2H$
7. $\log(V) = a + b\log(G)$
8. $\log(V) = a + b\log(G) + c\log(H)$
9. $V/G^2 = a + b/G^2 + c/G$
10. $V/G^2 = a + b/G$
11. $V/G^2H = a + b/G^2H$
12. $V/G^2H = a + b/G^2 + cH/G^2 + GH$
13. $V/G^2H = a + b/G^2H + c/H + d/G^2$
14. $V/G^2 = a + b/G^2 + cH/G + dH$
15. $V/G^2H = a + b/G^2H + c/H + d/G$

where,

V= total volume over bark in cubic metres
G = girth at breast height in cm
H = total height in metres

a is the regression constant and b, c and d are regression coefficients.

The logarithmic functions are to the base e.

The equations of the best fit were chosen based on the highest multiple coefficient of determination (R^2), F-ratio and lowest residual mean square. Models have been selected for estimation of the total volume over bark and conversion factors to estimate underbark volumes and underbark volumes to top end girths of approximately 16, 31, 47, and 63 cm overbark.

Results and discussions

Volume equations have been selected for estimation of total volume overbark (V) from girth, and girth and height. Conversion factors were also selected to estimate underbark volume (Fub) and underbark volumes to top end girth of approximately 16, 31, 47, and 63 cm underbark (F16, F31, F47 and F63). The selected volume equations and conversion factors are given in Table 3. Volumes and conversion factors have been estimated for ready use and are presented in Table 4 to 8.

Table 3. Volume ana conversion factor models for estimation of volume up to different top end girth limits for koroi and arjun in the central part of Bangladesh.

Volume models for koroi	
log(V) = -12.0901 + 2.502194*log(G)	$R^2 = 0.983$
log(V) = - 11.6632 + 1.941989*log(G) + 0.754839*log(H)	$R^2 = 0.991$
Fub = G/(8.232881 + 0.931363*G + 0.000409*G^2)	$R^2 = 0.997$
F16 = 0.449483 + 0.007209*G - 0.000029*G^2	$R^2 = 0.781$
F31 = - 0.17785 + 0.018051*G - 0.000073*G^2	$R^2 = 0.781$
F47 = - 0.6801 + 0.023664*G - 0.000088*G^2	$R^2 = 0.826$
F63 = - 1.34964 + 0.030888*G - 0.00011*G^2	$R^2 = 0.874$
Volume models for arjun	
log(V) = -11.1885 + 2.222144*log(G)	$R^2 = 0.986$
log(V) = - 11.3794 + 0.653558*log(H) + 1.896423*log(G)	$R^2 = 0.997$
Fub = G/(10.26619 + 0.84089*G + 0.001049*G^2) 0.954 is constant from GBH 94 cm.	$R^2 = 0.998$
F16 = 0.392728 + 0.010266*G - 0.000052*G^2 0.899 is constant from GBH 96 cm.	$R^2 = 0.809$
F31 = 1.158105 - 28.8941/G 0.837is constant from GBH 90 cm.	$R^2 = 0.929$
F47 = - 0.66863 + 0.024224*G - 0.000097*G^2 0.784 is constant from GBH 100 cm.	$R^2 = 0.929$
F63 = - 0.38981+ 0.011404*G - 0.000017*G^2	$R^2 = 0.881$

Table 4. One-way volume table for koroi and arjun planted in the central part of Bangladesh.

GBH (cm)	Koroi	Arjun
26	0.019	0.019
28	0.023	0.023
30	0.028	0.027
32	0.033	0.031
34	0.038	0.035
36	0.044	0.040
38	0.050	0.045
40	0.057	0.050
42	0.065	0.056
44	0.073	0.062
46	0.081	0.069
48	0.090	0.075
50	0.100	0.082
52	0.110	0.090
54	0.121	0.098
56	0.133	0.106
58	0.145	0.115
60	0.158	0.124
62	0.171	0.133
64	0.186	0.143
66	0.201	0.153
68	0.216	0.163
70	0.232	0.174
72	0.249	0.185
74	0.267	0.197
76	0.285	0.209
78	0.305	0.222
80	0.325	0.234
82	0.345	0.248
84	0.367	0.261
86	0.389	0.275
88	0.412	0.290
90	0.436	0.304
92	0.460	0.320
94	0.486	0.335
96	0.512	0.351
98	0.539	0.368
100	0.567	0.385
102	0.596	0.402
104	0.626	0.420
106	0.656	0.438
108	0.688	0.457
110	0.720	0.476
112	0.753	0.495
114	0.787	0.515
116	0.822	0.535
118	0.858	0.556
120	0.895	0.577

Confidence limit

These volume tables should not be used to estimate volumes of individual trees in a stand. These tables may be used for the mean tree of a stand, which may be multiplied, by the number of stem to get the total volume of the stand. Estimation of volumes for the trees out side the height and GBH range shown in the stand table should only be done with caution.

How to use volume tables and conversion factors

Take the measurements of GBH and total height (s) of the desired tree (s) first to have an estimate of the volume. Then, choose the corresponding total volume overbark from the volume tables or estimate the total overbark volume by using the volume equation of the selected species and convert this total overbark volume to underbark volume for desired top end girth limit. For example, let the girth and height of the selected koroi tree are 66 cm and 14 m respectively.

Then, the total volume for this koroi tree is:

log (V) = -11.6632 +1.941989* log (G)+0.754839
log (H) =-11.6632+1.941989* log (66)+0.754839*
log (14)= -1.53487 V = Exp. (log (V)) = 0.21548

Multiply this total volume overbark with the corresponding conversion factor to estimate the underbark volume to different top end girte limits. For examples, underbark volume (Vub) will be estimated as given below:

V ub = V X Fub = 0.21548X0.923 = 0.1989 cu m.

Similarly, underbark volume up to top end girth of 16 cm and 31 cm may be estimated as given below:

V16 = VXF16 = 0.21548 X 0.799 = 0.1722 cum.
V31 = VXF31 = 0.21548 X 0.696 = 0.1499 cum.

If the measured GBH and total heights coincide with the tabular GBH and total height then the tabular values may only be used directly. Other wise, the volumes and conversion factors should be estimated first by using the respective equations followed by estimation of desired volume as given above. The one-way volume tables (GBH-volume tables and equations) may similarly be used.

Table 5. Two-way volumes in cubic metres for koroi growing in the central part of Bangladesh.

GBH (cm)	Volume in cubic metres for height of							
	6	8	10	12	14	16	18	20
26	0.019	0.023	0.027	0.031	0.035	0.039	0.043	0.046
28	0.022	0.027	0.032	0.036	0.041	0.045	0.049	0.053
30	0.025	0.031	0.036	0.041	0.047	0.052	0.056	0.061
32	0.028	0.035	0.041	0.047	0.053	0.058	0.064	0.069
34	0.031	0.039	0.046	0.053	0.059	0.066	0.072	0.078
36	0.035	0.044	0.052	0.059	0.066	0.073	0.080	0.087
38	0.039	0.048	0.057	0.066	0.074	0.082	0.089	0.097
40	0.043	0.053	0.063	0.073	0.081	0.090	0.099	0.107
42	0.047	0.059	0.069	0.080	0.090	0.099	0.108	0.117
44	0.052	0.064	0.076	0.087	0.098	0.108	0.119	0.128
46	0.056	0.070	0.083	0.095	0.107	0.118	0.129	0.140
48	0.061	0.076	0.090	0.103	0.116	0.128	0.140	0.152
50	0.066	0.082	0.097	0.112	0.126	0.139	0.152	0.165
52	0.072	0.089	0.105	0.121	0.136	0.150	0.164	0.178
54	0.077	0.096	0.113	0.130	0.146	0.161	0.176	0.191
56	0.083	0.103	0.121	0.139	0.157	0.173	0.189	0.205
58	0.088	0.110	0.130	0.149	0.168	0.185	0.203	0.219
60	0.094	0.117	0.139	0.159	0.179	0.198	0.216	0.234
62	0.101	0.125	0.148	0.170	0.191	0.211	0.231	0.250
64	0.107	0.133	0.157	0.181	0.203	0.225	0.245	0.266
66	0.114	0.141	0.167	0.192	0.215	0.238	0.260	0.282
68	0.120	0.150	0.177	0.203	0.228	0.253	0.276	0.299
70	0.127	0.158	0.187	0.215	0.242	0.267	0.292	0.316
72	0.135	0.167	0.198	0.227	0.255	0.282	0.308	0.334
74	0.142	0.176	0.209	0.240	0.269	0.298	0.325	0.352
76	0.149	0.186	0.220	0.252	0.283	0.313	0.343	0.371
78	0.157	0.195	0.231	0.265	0.298	0.330	0.360	0.390
80	0.165	0.205	0.243	0.279	0.313	0.346	0.378	0.410
82	0.173	0.215	0.255	0.292	0.328	0.363	0.397	0.430
84	0.182	0.226	0.267	0.306	0.344	0.381	0.416	0.451
86	0.190	0.236	0.279	0.321	0.360	0.398	0.436	0.472
88	0.199	0.247	0.292	0.335	0.377	0.417	0.455	0.493
90	0.208	0.258	0.305	0.350	0.394	0.435	0.476	0.515
92	0.217	0.269	0.319	0.366	0.411	0.454	0.497	0.538
94	0.226	0.281	0.332	0.381	0.428	0.474	0.518	0.561
96	0.235	0.292	0.346	0.397	0.446	0.493	0.539	0.584
98	0.245	0.304	0.360	0.413	0.464	0.514	0.561	0.608
100	0.255	0.317	0.375	0.430	0.483	0.534	0.584	0.632
102	0.265	0.329	0.389	0.447	0.502	0.555	0.607	0.657
104	0.275	0.342	0.404	0.464	0.521	0.576	0.630	0.682
106	0.285	0.354	0.419	0.481	0.541	0.598	0.654	0.708
108	0.296	0.368	0.435	0.499	0.561	0.620	0.678	0.734
110	0.307	0.381	0.451	0.517	0.581	0.643	0.702	0.761
112	0.317	0.394	0.467	0.536	0.602	0.666	0.727	0.788
114	0.329	0.408	0.483	0.554	0.623	0.689	0.753	0.815
116	0.340	0.422	0.500	0.573	0.644	0.713	0.779	0.843
118	0.351	0.437	0.517	0.593	0.666	0.737	0.805	0.872
120	0.363	0.451	0.534	0.612	0.688	0.761	0.832	0.901

Table 6. Conversion factors to estimate the underbark volume of koroi

GBH (cm)	Fub	F16	F31	F47	F63
26	0.795	0.617	0.242		
28	0.809	0.629	0.270		
30	0.821	0.640	0.298		
32	0.832	0.650	0.325		
34	0.842	0.661	0.351		
36	0.851	0.671	0.377		
38	0.859	0.682	0.403	0.092	
40	0.867	0.691	0.427	0.126	
42	0.874	0.701	0.452	0.159	
44	0.880	0.711	0.475	0.191	
46	0.886	0.720	0.498	0.222	
48	0.891	0.729	0.520	0.253	
50	0.896	0.737	0.542	0.283	
52	0.900	0.746	0.563	0.312	
54	0.904	0.754	0.584	0.341	
56	0.908	0.762	0.604	0.369	
58	0.912	0.770	0.624	0.396	0.072
60	0.915	0.778	0.642	0.423	0.108
62	0.918	0.785	0.661	0.449	0.143
64	0.921	0.792	0.678	0.474	0.177
66	0.923	0.799	0.696	0.498	0.210
68	0.926	0.806	0.712	0.522	0.242
70	0.928	0.812	0.728	0.545	0.274
72	0.930	0.818	0.743	0.568	0.304
74	0.932	0.824	0.758	0.589	0.334
76	0.934	0.830	0.772	0.610	0.362
78	0.936	0.835	0.786	0.630	0.390
80	0.937	0.841	0.799	0.650	0.417
82	0.939	0.846	0.811	0.669	0.444
84	0.940	0.850	0.823	0.687	0.469
86	0.941	0.850	0.835	0.704	0.493
88	0.943	0.850	0.845	0.721	0.517
90	0.944	0.850	0.855	0.737	0.539
92	0.945	0.850	0.865	0.752	0.561
94	0.946	0.850	0.874	0.767	0.582
96	0.947	0.850	0.882	0.781	0.602
98	0.947	0.850	0.890	0.794	0.621
100	0.948	0.850	0.897	0.806	0.639
102	0.949	0.850	0.904	0.818	0.656
104	0.950	0.850	0.910	0.829	0.673
106	0.950	0.850	0.915	0.840	0.689
108	0.951	0.850	0.920	0.849	0.703
110	0.951	0.850	0.924	0.858	0.717
112	0.952	0.850	0.928	0.866	0.730
114	0.952	0.850	0.931	0.874	0.742
116	0.953	0.850	0.934	0.881	0.753
118	0.953	0.850	0.936	0.887	0.764
120	0.953	0.897	0.937	0.892	0.773

Table 7. Two-way volumes in cubic meters of arjun growing in the central part of Bangladesh.

GBH (cm)	Volume in cubic metres for height of							
	6	8	10	12	14	16	18	20
26	0.018	0.021	0.025	0.028	0.031	0.034	0.036	0.039
28	0.020	0.025	0.029	0.032	0.036	0.039	0.042	0.045
30	0.023	0.028	0.033	0.037	0.041	0.044	0.048	0.051
32	0.026	0.032	0.037	0.041	0.046	0.050	0.054	0.058
34	0.030	0.036	0.041	0.047	0.051	0.056	0.061	0.065
36	0.033	0.040	0.046	0.052	0.057	0.063	0.068	0.072
38	0.037	0.044	0.051	0.057	0.064	0.069	0.075	0.080
40	0.040	0.049	0.056	0.063	0.070	0.076	0.083	0.088
42	0.044	0.053	0.062	0.069	0.077	0.084	0.091	0.097
44	0.048	0.058	0.067	0.076	0.084	0.092	0.099	0.106
46	0.052	0.063	0.073	0.083	0.091	0.100	0.108	0.115
48	0.057	0.069	0.079	0.089	0.099	0.108	0.117	0.125
50	0.061	0.074	0.086	0.097	0.107	0.117	0.126	0.135
52	0.066	0.080	0.092	0.104	0.115	0.126	0.136	0.145
54	0.071	0.086	0.099	0.112	0.124	0.135	0.146	0.156
56	0.076	0.092	0.106	0.120	0.133	0.145	0.156	0.167
58	0.081	0.098	0.114	0.128	0.142	0.155	0.167	0.179
60	0.087	0.105	0.121	0.137	0.151	0.165	0.178	0.191
62	0.092	0.112	0.129	0.145	0.161	0.175	0.189	0.203
64	0.098	0.118	0.137	0.154	0.171	0.186	0.201	0.216
66	0.104	0.126	0.145	0.164	0.181	0.198	0.213	0.229
68	0.110	0.133	0.154	0.173	0.192	0.209	0.226	0.242
70	0.116	0.140	0.162	0.183	0.202	0.221	0.238	0.255
72	0.123	0.148	0.171	0.193	0.213	0.233	0.252	0.270
74	0.129	0.156	0.180	0.203	0.225	0.245	0.265	0.284
76	0.136	0.164	0.190	0.214	0.237	0.258	0.279	0.299
78	0.143	0.172	0.199	0.225	0.248	0.271	0.293	0.314
80	0.150	0.181	0.209	0.236	0.261	0.284	0.307	0.329
82	0.157	0.190	0.219	0.247	0.273	0.298	0.322	0.345
84	0.164	0.198	0.230	0.259	0.286	0.312	0.337	0.361
86	0.172	0.207	0.240	0.270	0.299	0.326	0.352	0.377
88	0.180	0.217	0.251	0.282	0.312	0.341	0.368	0.394
90	0.187	0.226	0.262	0.295	0.326	0.356	0.384	0.411
92	0.195	0.236	0.273	0.307	0.340	0.371	0.400	0.429
94	0.203	0.246	0.284	0.320	0.354	0.386	0.417	0.447
96	0.212	0.256	0.296	0.333	0.368	0.402	0.434	0.465
98	0.220	0.266	0.307	0.346	0.383	0.418	0.451	0.484
100	0.229	0.276	0.319	0.360	0.398	0.434	0.469	0.502
102	0.238	0.287	0.332	0.374	0.413	0.451	0.487	0.522
104	0.246	0.297	0.344	0.388	0.429	0.468	0.505	0.541
106	0.256	0.308	0.357	0.402	0.445	0.485	0.524	0.561
108	0.265	0.319	0.370	0.416	0.461	0.503	0.543	0.581
110	0.274	0.331	0.383	0.431	0.477	0.520	0.562	0.602
112	0.284	0.342	0.396	0.446	0.493	0.538	0.582	0.623
114	0.293	0.354	0.410	0.461	0.510	0.557	0.601	0.644
116	0.303	0.366	0.423	0.477	0.527	0.575	0.622	0.666
118	0.313	0.378	0.437	0.493	0.545	0.594	0.642	0.688
120	0.323	0.390	0.451	0.509	0.562	0.614	0.663	0.710

Table 8. Conversion factors to estimate the underbark volume of arjun planted in the central part of Bangladesh

GBH (cm)	Conversion factor to estimate under bark volume				
	Fub	F16	F31	F47	F63
26	0.792	0.624			
28	0.809	0.639	0.126		
30	0.823	0.654	0.195		
32	0.837	0.668	0.255		
34	0.849	0.682	0.308		
36	0.859	0.695	0.355	0.078	
38	0.869	0.708	0.398	0.112	
40	0.878	0.720	0.436	0.145	0.039
42	0.886	0.732	0.470	0.178	0.059
44	0.893	0.744	0.501	0.209	0.079
46	0.899	0.755	0.530	0.240	0.099
48	0.905	0.766	0.556	0.271	0.118
50	0.910	0.776	0.580	0.300	0.138
52	0.915	0.786	0.602	0.329	0.157
54	0.919	0.795	0.623	0.357	0.176
56	0.923	0.805	0.642	0.384	0.196
58	0.927	0.813	0.660	0.410	0.214
60	0.930	0.821	0.677	0.436	0.233
62	0.933	0.829	0.692	0.460	0.252
64	0.936	0.837	0.707	0.484	0.270
66	0.938	0.844	0.720	0.508	0.289
68	0.941	0.850	0.733	0.530	0.307
70	0.943	0.857	0.745	0.552	0.325
72	0.944	0.862	0.757	0.573	0.343
74	0.946	0.868	0.768	0.593	0.361
76	0.947	0.873	0.778	0.612	0.379
78	0.949	0.877	0.788	0.631	0.396
80	0.950	0.881	0.797	0.648	0.414
82	0.951	0.885	0.806	0.666	0.431
84	0.951	0.888	0.814	0.682	0.448
86	0.952	0.891	0.822	0.697	0.465
88	0.953	0.893	0.830	0.712	0.482
90	0.953	0.895	0.837	0.726	0.499
92	0.953	0.897	0.837	0.739	0.515
94	0.954	0.898	0.837	0.751	0.532
96	0.954	0.899	0.837	0.763	0.548
98	0.954	0.899	0.837	0.774	0.565
100	0.954	0.899	0.837	0.784	0.581
102	0.954	0.899	0.837	0.784	0.597
104	0.954	0.899	0.837	0.784	0.612
106	0.954	0.899	0.837	0.784	0.628
108	0.954	0.899	0.837	0.784	0.644
110	0.954	0.899	0.837	0.784	0.659
112	0.954	0.899	0.837	0.784	0.674
114	0.954	0.899	0.837	0.784	0.689
116	0.954	0.899	0.837	0.784	0.704
118	0.954	0.899	0.837	0.784	0.719
120	0.954	0.889	0.837	0.784	0.734

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