Volume Equations and Tables for Rajkoroi (*Albizia richardiana* King and Prain) Planted in the Southern Part of Bangladesh

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Abstract

Rajkoroi (*Albizia richardiana* King and Prain) is an important tree species extensively planted as fuel wood and timber in home garden and road sides as avenue tree in the southern part of Bangladesh. Volume table of this rajkoroi species has been prepared by deriving volume equations. 15 selected model were tested for deriving volume equation by regression technique. Among them the logarithmic model log(V) = a + b log (G) for one way and log (V) = a + b log (G) + c log(H) for two way analysis appeared to be the best model for estimating the rajkoroi tree volume. Estimated volume table is applicable for any size of rajkoroi tree planted of the southern part of Bangladesh.

সারসংক্ষেপ

রাজকরই, বাংলাদেশের দক্ষিণ অঞ্চলে বসত বাড়িতে জ্বালানী কাঠ, টিম্বার এবং রাস্তার ধারে শোভাবর্ধনে লাগানো গুরুত্বপূর্ণ বৃক্ষ প্রজাতি। এ অঞ্চলে লাগানো রাজকরই গাছের আয়তনের সমীকরণ নির্ণয় করে ভল্যুম টেবল তৈরি করা হয়েছে। রিগ্রেশন পদ্ধতির মাধ্যমে আয়তন নির্ণয়ের নির্বাচিত ১৫টি মডেলের মধ্যে একমুখী এবং দ্বিমুখী লগারিদম মডেল যথাক্রমে log(V) = a+b log(G) এবং log(V) = a+b log(G) + c log(H) সর্বোপযুক্ত হয়েছে। এ ভল্যুম টেবল ব্যবহার করে এ অঞ্চলে রোপিত যে কোন আকারের রাজকরই গাছের আয়তন বের করা যাবে।

Key words: *Albizia richardiana*, Bangladesh, rajkoroi , tree volume, tree girth

Introduction

Rajkoroi (*Albizia richardiana* King and Prain) is an exotic tree species introduced from Madagascar (Africa). It is a lofty handsome evergreen tree with horizontal dichotomous branching with a beautiful crown (Das and Alam 2001). It is very fast growing tree with smooth, pale grayish bark, well-shaped, slender branches minute feathery bipinnate leaves, flowers whitish, minute in cluster. It is locally known as rajkoroi, chambole and gagan-shirish. It is generally planted as avenue and shade tree in around garden (Khatun 1987). Rajkoroi now become a dominant plantation timber species in home garden and road-side plantation for fuel wood and timbers both in public and private land in the southern part of Bangladesh. Rajkoroi wood is whitish, often without coloured sapwood, hard and sustainable. Wood is being used for boat building at Barisal of Bangladesh and it is also used as one-time cheap furniture and as fuel wood in local markets (Das and Alam 2001).

A good number of rajkoroi tree species has become mature for harvesting both in private and public land. But, volume tables for rajkoroi tree species planted are not available in the southern part of Bangladesh. The volume tables of trees are necessary for economic evaluation, future management, utilization, research purposes and to estimate the quantity of wood during harvest of the tree species (Latif and Islam 2001). This paper presents the method and equations derived for volume estimation and stand volume tables preparation for rajkoroi on the basis of equations best suited.

Materials and Methods

Measurement of trees

Data were collected from road side plantation and homesteads in the southern districts namely Faridpur, Barisal, Borgona, Jhalakathi, Pirojpur and Patuakhali district of Bangladesh during March 2008 to June 2009. 511 standing trees representing different girth classes were selected at random for preparation of mathematical volume function and tables. Tree girth at breast height (GBH) in cm and total height in meter were measured with measuring tape and Haga-altimeter respectively. The collected data were categorized on the basis of GBH and height of the trees. The GBH-height class distribution of the sample trees are given in Table 1. The girth and bark thickness at one meter intervals were measured by climbing the trees with a ladder. The bark thicknesses of the samples were measured with a bark gauge.

Table 1. GBH and total height class distribution of the sampled trees selected for volume estimation of rajkoroi.

GBH (cm)	Height (m)							
	5	**10**	**15**	**20**	**25**	**30**	**35**	**Total**
20-40	3	1						4
40-60	5	42	8					55
60-80		24	31	4	1			60
80-100		3	23	32	9	3		70
100-120		1	21	43	16	9		90
120-140			18	40	29	6		93
140-160				25	33	13		71
160-180			1	3	14	13	1	32
180-200				1	7	4	1	13
200-200				1	3	4		8
220-240					1	4		5
>240					3	7		10
Total	**8**	**71**	**102**	**149**	**116**	**63**	**2**	**511**

Compilation of data

Volumes of all sections except top and bottom section were determined by using the mean cross-sectional areas of the two ends of each section following Smalian's formula (Anon. 2011) cubic volume = $[(B+b)/2]L$, where B= the cross-sectional area at the large end of the log, b= the cross-sectional area at the small end of the log, and L= log length. In determining the volume of bottom sections, the formulae used for calculating the volume of a cylinder was considered. Assuming the top section as cone the volume was computed to one third of the cylindrical volume of the portion. We considered the top end diameter measurement for each tree as the base diameter of the cone. In computing the under bark volume of the tree the volume of top section i.e. cone was ignored. The volume of the tree is the sum of the volume of total sections found in a tree. The individual tree volumes (V), GBH (G) and total height (H) were variable in regression techniques using various functions and transformations as required in the models.

Computation of volume function

Multiple regression analysis techniques were used to select the best suited model equations. The following 15 models were tested 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. $V = bG + cG^2$
5. $V = a + bG^2H$
6. $V = a + bG + cH$
7. $V = a + bG + cG^2H$
8. $V = a + bG + cGH$
9. $V = a + bG + cH + dGH$
10. $V = a + bG + cH + dG^2H$
11. $V = a + bG^2 + cH + dGH$
12. $V = a + bG^2 + cH + dG^2H$
13. $V = a + bG^2 + cGH + dG^2H$
14. $log(V) = a + blog\ (G)$
15. $log(V) = a + blog\ (G) + clog(H)$

Where:

V = total volume in cubic meters,

G = girth at breast height in centimeters,

H = total height in meters,

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

The logarithmic functions are to the base e.

Following original and transformed variables were used to select the best suited regression models:

Dependent variables: V, log (V),

Independent variables: G, G^2, H, GH, G^2H, log (G), log (H)

The dependent variables mentioned above were regressed with the independent variables.

The equations of the best fit based on the highest multiple coefficients of determination; F-ratio and lowest residual mean square were chosen. Models for estimation of the total volume over bark were selected and conversion factors to estimate under bark volume and under bark volume to top end girth of approximately 30, 35, 40 and 45 cm under bark from total volume over bark were estimated. The

volumes up to 45 cm top end girth may be used as timber for the species. The volumes less upto 45 cm may be used for poles, house posts and fuel wood. The selected models were also transformed for estimation of volume from girth at breast height (G).

Model validation

Statistical validation: The best suited models were tested with a set of data recollected from 30 trees of different girth class and complied in the same procedure as earlier. The actual volumes of these trees were collectively compared with the corresponding volume predicted by the selected models. The independent tests for validation were the absolute deviation percent, paired t-test, chi-square test and 45 degree line test (Islam *et al.* 1992).

Biological principle tests: The predicted values were plotted against girth at breast height (one way) for different segment. The biological requirement is that the yield curves should be monotonically increasing (Latif and Islam 2001).

Results and Discussion

The regression models number 14 and 15 showed the highest value of coefficients of determination for one way and two way volume equations. The volume equations have been selected for estimation of the total volume over bark (V) and conversion factors to estimate under bark volume and under bark volume to different top end diameters of 30, 35, 40 and 45 cm form these models. The coefficients of determination for selected volume equations are over 0.96. This means that the selected models describe over 96 percent of the total variations. The best fitted models were selected for estimation of volume on GBH and total height. The selected volume equations' conversion factor equations are given in Table 2.

Table 2. Volume equations and conversion factor equation to estimate volume upto different top end girths for rajkoroi.

Volume equations	R-squared	Observation
$\log(V)=-10.996396+2.247808\times\log(G)$	**0.98**	511
$\log(V)=-10.831293+1.699319\times\log(G)+0.813706\times\log(H)$	**0.98**	511
$F_{ub}=G/(3.620321+1.050948\times G-0.000049\times G^2)$	**0.99**	511
$F_{30}=0.425764+0.0069\times G-0.000021\times G^2$ 0.9236 is Constant from GBH 90 cm	0.76	511
$F_{35}=0.343096+0.007632\times G-0.000022\times G^2$ 0.8975 is Constant from GBH 94 cm	**0.82**	498
$F_{40}=0.217338+0.009023\times G-0.000026\times G^2$ 0.8869 is Constant from GBH 102 cm	**0.84**	489
$F_{45}=0.092893+0.010254\times G-0.000029\times G^2$ 0.8699 is Constant from GBH 110 cm	**0.86**	474
$F_{Branch}=-0.04419+0.004127\times G-0.0000079G^2$	**0.71**	356

Where:

G = girth at breast height in centimeter

H = total height in meters

V = total volume overbark in cubic meters

F_{ub} = conversion factor for underbark volume

F_{30} = conversion factor for the volume to 30 cm top end girth

F_{35} = conversion factor for the volume to 35 cm top end girth

F_{40} = conversion factor for the volume to 40 cm top end girth

F_{45} = conversion factor for the volume to 45 cm top end girth

$F_{Branches}$ = conversion factor for the volume of branches

Validation of the selected models

The models developed for volume estimation of rajkoroi were verified with the volume of 30 trees measured for rajkoroi tree species with paired t-test, chi-square test for goodness of fit and 45 degree line test. The computed, t-values and chi-square are less than the tabular values (t=2.045 and χ^2 =42.56) at 5% level of significance. The predicted values tend to make an angle of about 45 degree. This means that there is no significant difference between the observed and the predicted values. The t-values, chi-square and slopes are given below:

Type of model	t-value	chi-square value	slope (Degree)
1-way	-0.31	1.70	43
2-way	-0.43	0.68	44

Therefore, the selected models may be used for rajkoroi tree species within the data range for preparation of the volume tables. After the validation test, volume tables and conversion factors were prepared for ready use presented in Table 3 and 4 respectively.

The selected volume models of three segments namely total volume over bark, total volume under bark and timber volume of rajkoroi also satisfied biological criteria of yield curves. The predicted value of total volume over bark, total volume under bark and timber volume were plotted against girth at breast height. The yield curves conform with the ideal attributes of biological yield

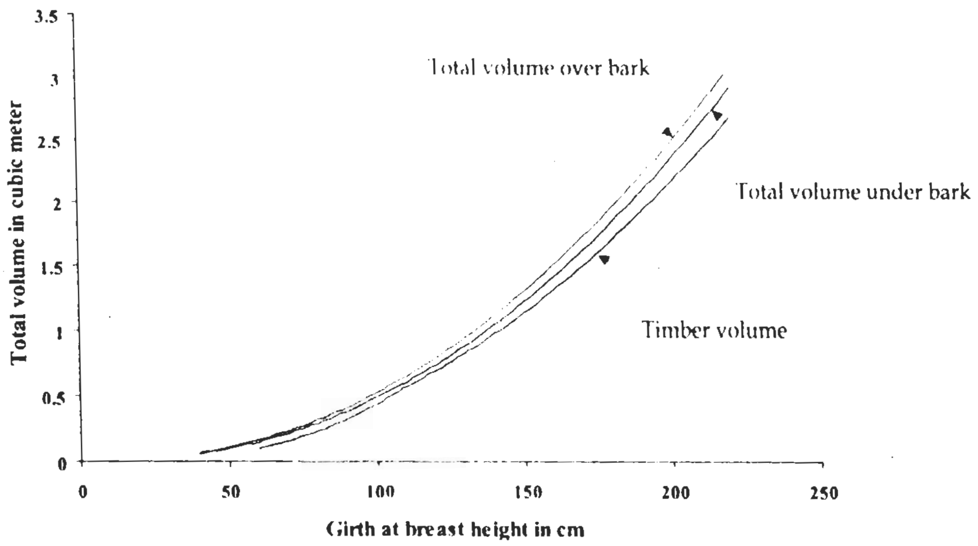

Figure 1. Yield curves of rajkoroi in different segment.

Table 3. One and two way volumes in cubic meter for rajkoroi.

GBH (cm)	One way volume table (m^3)	Two way volume table													
		Volume in cubic meter for following heights													
		8	10	12	14	16	18	20	22	24	26	28	30	32	34
40	0.067	0.057	0.068	0.079	0.089	0.100	0.110	0.119	0.129	0.139	0.148	0.157	0.166	0.175	0.184
42	0.075	0.062	0.074	0.086	0.097	0.108	0.119	0.130	0.140	0.150	0.161	0.171	0.180	0.190	0.200
44	0.083	0.067	0.080	0.093	0.105	0.117	0.129	0.140	0.152	0.163	0.174	0.185	0.195	0.206	0.216
46	0.092	0.072	0.086	0.100	0.113	0.126	0.139	0.151	0.164	0.176	0.187	0.199	0.211	0.222	0.233
48	0.101	0.077	0.093	0.107	0.122	0.136	0.149	0.163	0.176	0.189	0.202	0.214	0.226	0.239	0.251
50	0.110	0.083	0.099	0.115	0.131	0.146	0.160	0.174	0.189	0.202	0.216	0.229	0.243	0.256	0.269
52	0.121	0.088	0.106	0.123	0.140	0.156	0.171	0.187	0.202	0.216	0.231	0.245	0.259	0.273	0.287
54	0.131	0.094	0.113	0.131	0.149	0.166	0.183	0.199	0.215	0.231	0.246	0.262	0.277	0.292	0.306
56	0.143	0.100	0.120	0.140	0.158	0.176	0.194	0.212	0.229	0.245	0.262	0.278	0.294	0.310	0.326
58	0.154	0.107	0.128	0.148	0.168	0.187	0.206	0.225	0.243	0.260	0.278	0.295	0.312	0.329	0.346
60	0.166	0.113	0.135	0.157	0.178	0.198	0.218	0.238	0.257	0.276	0.294	0.313	0.331	0.349	0.366
62	0.179	0.119	0.143	0.166	0.188	0.210	0.231	0.251	0.272	0.292	0.311	0.331	0.350	0.369	0.387
64	0.192	0.126	0.151	0.175	0.199	0.221	0.244	0.265	0.287	0.308	0.329	0.349	0.369	0.389	0.409
66	0.206	0.133	0.159	0.185	0.209	0.233	0.257	0.280	0.302	0.324	0.346	0.368	0.389	0.410	0.431
68	0.221	0.140	0.167	0.194	0.220	0.245	0.270	0.294	0.318	0.341	0.364	0.387	0.409	0.431	0.453
70	0.235	0.147	0.176	0.204	0.231	0.258	0.284	0.309	0.334	0.359	0.383	0.406	0.430	0.453	0.476
72	0.251	0.154	0.184	0.214	0.243	0.270	0.298	0.324	0.350	0.376	0.401	0.426	0.451	0.475	0.499
74	0.267	0.161	0.193	0.224	0.254	0.283	0.312	0.340	0.367	0.394	0.421	0.447	0.472	0.498	0.523
76	0.283	0.169	0.202	0.235	0.266	0.296	0.326	0.355	0.384	0.412	0.440	0.467	0.494	0.521	0.547
78	0.300	0.176	0.211	0.245	0.278	0.310	0.341	0.371	0.401	0.431	0.460	0.488	0.517	0.545	0.572
80	0.318	0.184	0.221	0.256	0.290	0.323	0.356	0.388	0.419	0.450	0.480	0.510	0.539	0.569	0.597
82	0.336	0.192	0.230	0.267	0.303	0.337	0.371	0.404	0.437	0.469	0.501	0.532	0.563	0.593	0.623
84	0.355	0.200	0.240	0.278	0.315	0.351	0.387	0.421	0.455	0.489	0.522	0.554	0.586	0.618	0.649
86	0.374	0.208	0.249	0.289	0.328	0.366	0.403	0.439	0.474	0.509	0.543	0.577	0.610	0.643	0.675
88	0.394	0.216	0.259	0.301	0.341	0.380	0.419	0.456	0.493	0.529	0.565	0.600	0.634	0.668	0.702
90	0.414	0.225	0.270	0.313	0.354	0.395	0.435	0.474	0.512	0.550	0.587	0.623	0.659	0.694	0.730
92	0.435	0.233	0.280	0.325	0.368	0.410	0.451	0.492	0.531	0.570	0.609	0.647	0.684	0.721	0.757
94	0.457	0.242	0.290	0.337	0.382	0.425	0.468	0.510	0.551	0.592	0.632	0.671	0.709	0.748	0.786
96	0.479	0.251	0.301	0.349	0.396	0.441	0.485	0.529	0.571	0.613	0.655	0.695	0.735	0.775	0.814
98	0.501	0.260	0.312	0.361	0.410	0.457	0.503	0.548	0.592	0.635	0.678	0.720	0.762	0.803	0.843

GBH (cm)	One way volume table (m^3)	Two way volume table Volume in cubic meter for following heights													
		8	10	12	14	16	18	20	22	24	26	28	30	32	34
100	0.525	0.269	0.322	0.374	0.424	0.473	0.520	0.567	0.612	0.657	0.702	0.745	0.788	0.831	0.873
102	0.549	0.278	0.333	0.387	0.438	0.489	0.538	0.586	0.633	0.680	0.726	0.771	0.815	0.859	0.903
104	0.573	0.287	0.345	0.400	0.453	0.505	0.556	0.606	0.655	0.703	0.750	0.796	0.842	0.888	0.933
106	0.598	0.297	0.356	0.413	0.468	0.522	0.574	0.626	0.676	0.726	0.775	0.823	0.870	0.917	0.963
108	0.624	0.306	0.367	0.426	0.483	0.539	0.593	0.646	0.698	0.749	0.800	0.849	0.898	0.947	0.995
110	0.650	0.316	0.379	0.440	0.498	0.556	0.612	0.666	0.720	0.773	0.825	0.876	0.927	0.977	1.026
112	0.677	0.326	0.391	0.453	0.514	0.573	0.631	0.687	0.742	0.797	0.851	0.903	0.956	1.007	1.058
114	0.704	0.336	0.403	0.467	0.530	0.590	0.650	0.708	0.765	0.821	0.876	0.931	0.985	1.038	1.090
116	0.733	0.346	0.415	0.481	0.546	0.608	0.669	0.729	0.788	0.846	0.903	0.959	1.014	1.069	1.123
118	0.761	0.356	0.427	0.495	0.562	0.626	0.689	0.751	0.811	0.871	0.929	0.987	1.044	1.100	1.156
120	0.791	0.366	0.439	0.510	0.578	0.644	0.709	0.772	0.835	0.896	0.956	1.016	1.074	1.132	1.190
122	0.820	0.377	0.452	0.524	0.594	0.663	0.729	0.794	0.859	0.922	0.984	1.045	1.105	1.165	1.223
124	0.851	0.387	0.465	0.539	0.611	0.681	0.750	0.817	0.883	0.947	1.011	1.074	1.136	1.197	1.258
126	0.882	0.398	0.477	0.554	0.628	0.700	0.770	0.839	0.907	0.973	1.039	1.104	1.167	1.230	1.292
128	0.914	0.409	0.490	0.569	0.645	0.719	0.791	0.862	0.932	1.000	1.067	1.133	1.199	1.264	1.327
130	0.946	0.420	0.504	0.584	0.662	0.738	0.812	0.885	0.956	1.027	1.096	1.164	1.231	1.297	1.363
132	0.979	0.431	0.517	0.599	0.679	0.757	0.834	0.908	0.982	1.054	1.124	1.194	1.263	1.331	1.399
134	1.013	0.442	0.530	0.615	0.697	0.777	0.855	0.932	1.007	1.081	1.154	1.225	1.296	1.366	1.435
136	1.047	0.453	0.544	0.631	0.715	0.797	0.877	0.956	1.03	1.108	1.183	1.256	1.329	1.401	1.472
138	1.082	0.465	0.557	0.646	0.733	0.817	0.899	0.980	1.059	1.136	1.213	1.288	1.362	1.436	1.508
140	1.118	0.476	0.571	0.662	0.751	0.837	0.921	1.004	1.085	1.164	1.243	1.320	1.396	1.471	1.546
142	1.154	0.488	0.585	0.679	0.769	0.858	0.944	1.028	1.111	1.193	1.273	1.352	1.430	1.507	1.584
144	1.191	0.500	0.599	0.695	0.788	0.878	0.966	1.053	1.138	1.221	1.304	1.385	1.465	1.544	1.622
146	1.228	0.511	0.613	0.711	0.806	0.899	0.989	1.078	1.165	1.250	1.335	1.417	1.499	1.58 0	1.660
148	1.267	0.523	0.628	0.728	0.825	0.920	1.013	1.103	1.192	1.280	1.366	1.451	1.534	1.617	1.699
150	1.305	0.535	0.642	0.745	0.844	0.941	1.036	1.129	1.220	1.309	1.397	1.484	1.570	1.654	1.738
152	1.345	0.548	0.657	0.762	0.864	0.963	1.060	1.154	1.247	1.339	1.429	1.518	1.606	1.692	1.778
154	1.385	0.560	0.671	0.779	0.883	0.984	1.083	1.180	1.275	1.369	1.461	1.552	1.642	1.730	1.818
156	1.426	0.572	0.686	0.796	0.903	1.006	1.107	1.206	1.304	1.399	1.494	1.586	1.678	1.768	1.858
158	1.467	0.585	0.701	0.814	0.922	1.028	1.132	1.233	1.332	1.430	1.526	1.621	1.715	1.807	1.899
160	1.509	0.598	0.717	0.831	0.942	1.050	1.156	1.259	1.361	1.461	1.559	1.656	1.752	1.846	1.940
162	1.552	0.610	0.732	0.849	0.962	1.073	1.181	1.286	1.390	1.492	1.592	1.691	1.789	1.886	1.981

GBH (cm)	One way volume table (m^3)	Two way volume table Volume in cubic meter for following heights													
		8	10	12	14	16	18	20	22	24	26	28	30	32	34
164	1.595	0.623	0.747	0.867	0.983	1.095	1.206	1.313	1.419	1.524	1.626	1.727	1.827	1.925	2.023
166	1.639	0.636	0.763	0.885	1.003	1.118	1.231	1.341	1.449	1.555	1.660	1.763	1.865	1.965	2.065
168	1.684	0.649	0.778	0.903	1.024	1.141	1.256	1.368	1.479	1.587	1.694	1.799	1.903	2.006	2.107
170	1.730	0.662	0.794	0.921	1.044	1.164	1.281	1.396	1.509	1.619	1.728	1.836	1.942	2.047	2.150
172	1.776	0.676	0.810	0.940	1.065	1.188	1.307	1.424	1.539	1.652	1.763	1.873	1.981	2.088	2.193
174	1.822	0.689	0.826	0.958	1.087	1.211	1.333	1.452	1.570	1.685	1.798	1.910	2.020	2.129	2.237
176	1.870	0.703	0.843	0.977	1.108	1.235	1.35	1.481	1.600	1.718	1.833	1.947	2.060	2.171	2.281
178	1.918	0.716	0.859	0.996	1.129	1.259	1.386	1.510	1.631	1.751	1.869	1.985	2.100	2.213	2.325
180	1.967	0.730	0.875	1.015	1.151	1.283	1.412	1.539	1.663	1.785	1.905	2.023	2.140	2.255	2.369
182	2.016	0.744	0.892	1.035	1.173	1.307	1.439	1.568	1.694	1.818	1.941	2.061	2.180	2.298	2.414
184	2.066	0.758	0.909	1.054	1.195	1.332	1.466	1.597	1.726	1.853	1.977	2.100	2.221	2.341	2.460
186	2.117	0.772	0.925	1.073	1.217	1.357	1.493	1.627	1.758	1.887	2.014	2.139	2.263	2.385	2.505
188	2.169	0.786	0.942	1.093	1.239	1.381	1.520	1.657	1.790	1.921	2.051	2.178	2.304	2.428	2.551
190	2.221	0.800	0.960	1.113	1.262	1.407	1.548	1.687	1.823	1.956	2.088	2.218	2.346	2.472	2.597
192	2.274	0.815	0.977	1.133	1.284	1.432	1.576	1.717	1.855	1.991	2.125	2.258	2.388	2.517	2.644
194	2.327	0.829	0.994	1.153	1.307	1.457	1.604	1.747	1.888	2.027	2.163	2.298	2.430	2.561	2.691
196	2.382	0.844	1.012	1.173	1.330	1.483	1.632	1.778	1.922	2.062	2.201	2.338	2.473	2.606	2.738
198	2.437	0.858	1.029	1.194	1.353	1.509	1.660	1.809	1.955	2.098	2.240	2.379	2.516	2.652	2.786
200	2.492	0.873	1.047	1.214	1.377	1.535	1.689	1.840	1.989	2.135	2.278	2.420	2.560	2.698	2.834
202	2.549	0.888	1.065	1.235	1.400	1.561	1.718	1.872	2.023	2.171	2.317	2.461	2.603	2.744	2.882
204	2.606	0.903	1.083	1.256	1.424	1.587	1.747	1.903	2.057	2.208	2.356	2.503	2.647	2.790	2.931
206	2.664	0.918	1.101	1.277	1.448	1.614	1.776	1.935	2.091	2.244	2.396	2.544	2.691	2.836	2.980
208	2.722	0.933	1.119	1.298	1.472	1.640	1.805	1.967	2.126	2.282	2.435	2.587	2.736	2.883	3.029
210	2.781	0.949	1.137	1.319	1.496	1.667	1.835	1.999	2.161	2.319	2.475	2.629	2.781	2.931	3.079
212	2.841	0.964	1.156	1.341	1.520	1.694	1.865	2.032	2.196	2.357	2.515	2.672	2.826	2.978	3.129
214	2.902	0.979	1.175	1.362	1.544	1.722	1.895	2.064	2.231	2.395	2.556	2.715	2.871	3.026	3.179
216	2.963	0.995	1.193	1.384	1.569	1.749	1.925	2.097	2.266	2.433	2.596	2.758	2.917	3.074	3.230
218	3.025	1.011	1.212	1.406	1.594	1.777	1.955	2.130	2.302	2.471	2.637	2.801	2.963	3.123	3.281
220	3.088	1.027	1.231	1.428	1.619	1.804	1.986	2.164	2.338	2.510	2.679	2.845	3.010	3.172	3.332
222	3.151	1.043	1.250	1.450	1.644	1.832	2.017	2.197	2.374	2.549	2.720	2.889	3.056	3.221	3.384

Table 4. Conversion factor for underbark volumes of different top end girth of rajkoroi.

GBH (cm)	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}	$F_{Branches}$
40	0.878	0.668	0.613	0.537	0.457	0.108
42	0.881	0.754	0.675	0.598	0.472	0.115
44	0.884	0.762	0.684	0.609	0.488	0.122
46	0.887	0.770	0.693	0.620	0.503	0.129
48	0.890	0.777	0.703	0.630	0.518	0.136
50	0.892	0.785	0.712	0.641	0.533	0.142
52	0.894	0.793	0.721	0.651	0.548	0.149
54	0.897	0.800	0.730	0.662	0.562	0.156
56	0.899	0.807	0.739	0.672	0.576	0.162
58	0.900	0.815	0.748	0.682	0.590	0.169
60	0.902	0.822	0.757	0.692	0.604	0.175
62	0.904	0.829	0.766	0.702	0.617	0.181
64	0.905	0.836	0.775	0.712	0.630	0.188
66	0.907	0.844	0.784	0.722	0.643	0.194
68	0.908	0.851	0.792	0.7320	.656	0.200
70	0.910	0.857	0.801	0.742	0.669	0.206
72	0.911	0.864	0.810	0.752	0.681	0.212
74	0.912	0.871	0.818	0.761	0.693	0.218
76	0.913	0.878	0.826	0.771	0.705	0.224
78	0.914	0.885	0.834	0.7800	.716	0.230
80	0.916	0.891	0.842	0.789	0.728	0.235
82	0.917	0.898	0.850	0.799	0.739	0.241
84	0.917	0.904	0.858	0.808	0.750	0.247
86	0.918	0.911	0.866	0.817	0.760	0.252
88	0.919	0.917	0.874	0.826	0.771	0.258
90	0.920	0.924	0.882	0.835	0.781	0.263
92	0.921	0.924	0.890	0.844	0.791	0.269
94	0.922	0.924	0.898	0.853	0.801	0.274
96	0.923	0.924	0.898	0.861	0.810	0.279
98	0.923	0.924	0.898	0.870	0.819	0.284

GBH (cm)	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}	$F_{Branches}$
100	0.924	0.924	0.898	0.878	0.828	0.290
102	0.925	0.924	0.898	0.887	0.837	0.295
104	0.925	0.924	0.898	0.887	0.846	0.300
106	0.926	0.924	0.898	0.887	0.854	0.305
108	0.927	0.924	0.898	0.887	0.862	0.309
110	0.927	0.924	0.898	0.887	0.870	0.314
112	0.928	0.924	0.898	0.887	0.870	0.319
114	0.928	0.924	0.898	0.887	0.870	0.324
116	0.929	0.924	0.898	0.887	0.870	0.328
118	0.930	0.924	0.898	0.887	0.870	0.333
120	0.930	0.924	0.898	0.887	0.870	0.337
122	0.931	0.924	0.898	0.887	0.870	0.342
124	0.931	0.924	0.898	0.887	0.870	0.346
126	0.932	0.924	0.898	0.887	0.870	0.350
128	0.932	0.924	0.898	0.887	0.870	0.355
130	0.932	0.924	0.898	0.887	0.870	0.359
132	0.933	0.924	0.898	0.887	0.870	0.363
134	0.933	0.924	0.898	0.887	0.870	0.367
136	0.934	0.924	0.898	0.887	0.870	0.371
138	0.934	0.924	0.898	0.887	0.870	0.375
140	0.935	0.924	0.898	0.887	0.870	0.379
142	0.935	0.924	0.898	0.887	0.870	0.383
144	0.935	0.924	0.898	0.887	0.870	0.386
146	0.936	0.924	0.898	0.887	0.870	0.390
148	0.936	0.924	0.898	0.887	0.870	0.394
150	0.937	0.924	0.898	0.887	0.870	0.397
152	0.937	0.924	0.898	0.887	0.870	0.401
154	0.937	0.924	0.898	0.887	0.870	0.404
156	0.938	0.924	0.898	0.887	0.870	0.407
158	0.938	0.924	0.898	0.887	0.870	0.411

GBH (cm)	F_{ub}	F_{30}	F_{35}	F_{40}	F_{45}	$F_{Branches}$
160	0.938	0.924	0.898	0.887	0.870	0.414
162	0.939	0.924	0.898	0.887	0.870	0.417
164	0.939	0.924	0.898	0.887	0.870	0.420
166	0.939	0.924	0.898	0.887	0.870	0.423
168	0.940	0.924	0.898	0.887	0.870	0.426
170	0.940	0.924	0.898	0.887	0.870	0.429
172	0.940	0.924	0.898	0.887	0.870	0.432
174	0.941	0.924	0.898	0.887	0.870	0.435
176	0.941	0.924	0.898	0.887	0.870	0.437
178	0.941	0.924	0.898	0.887	0.870	0.440
180	0.941	0.924	0.898	0.887	0.870	0.443
182	0.942	0.924	0.898	0.887	0.870	0.445
184	0.942	0.924	0.898	0.887	0.870	0.448
186	0.942	0.924	0.898	0.887	0.870	0.450
188	0.943	0.924	0.898	0.887	0.870	0.452
190	0.943	0.924	0.898	0.887	0.870	0.455
192	0.943	0.924	0.898	0.887	0.870	0.457
194	0.943	0.924	0.898	0.887	0.870	0.459
196	0.944	0.924	0.898	0.887	0.870	0.461
198	0.944	0.924	0.898	0.887	0.870	0.463
200	0.944	0.924	0.898	0.887	0.870	0.465
202	0.944	0.924	0.898	0.887	0.870	0.467
204	0.945	0.924	0.898	0.887	0.870	0.469
206	0.945	0.924	0.898	0.887	0.870	0.471
208	0.945	0.924	0.898	0.887	0.870	0.472
210	0.945	0.924	0.898	0.887	0.870	0.474
212	0.946	0.924	0.898	0.887	0.870	0.476
214	0.946	0.924	0.898	0.887	0.870	0.477
216	0.946	0.924	0.898	0.887	0.870	0.479
218	0.946	0.924	0.898	0.887	0.870	0.480
220	0.946	0.924	0.898	0.887	0.870	0.481

curve. The yield curves are monotonically increasing (Fig. 1) with girth at breast height.

Procedures to use volume tables and conversion factors

Take the measurements of girth(s) at breast height (GBH) and total height(s) of the desired tree(s). Then, choose the corresponding total volume over bark from the volume tables or estimate the total over bark volume by using the volume equation of the selected species first. Then, convert this total volume over bark volume to under bark volume for desired top end diameter limit by multiplying with the corresponding conversion factor. For example, let the GBH and height of a selected rajkoroi tree are 80 cm and 20 m respectively. Then, the total volume for this tree is:

$$Log(V) = -10.831293+1.699319 x log(G)+0.813706 x log(H)$$

$$= -10.831293+1.699319 x log(80)+0.813706 x log(20)$$

$$= -0.94718$$

$$V = Exp.(log(V)) = 0.3878 \text{ m}^3$$

Multiply this total volume over bark with the corresponding conversion factor to estimate the under bark volume to different top end diameter limits. For examples, under bark volume (V_{ub}) will be estimated as given below:

$$V_{ub} = V \times F_{ub} = 0.3878 \times 0.915514 = 0.3551 \text{ m}^3$$

Similarly, under bark volume up to top end girth of 30 cm and 40 cm may be estimated as given below:

$$V_{30} = V \times F_{30} = 0.3878 \times 0.891328 = 0.345685 \text{ m}^3$$

$$V_{40} = V \times F_{40} = 0.3878 \times 0.789357 = 0.306138 \text{ m}^3$$

If the measured GBH and total height coincide with the tabular GBH and total height then the tabular values may only be used directly. Otherwise, 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 table (GBH-volume tables and equations) may similarly be used.

The girths have been divided by the factor 2.54 to convert inches from centimeters. The height should be multiplied with 3.281 to convert meter into feet. Similarly, volume should be multiplied by the factor 35.32 to get cubic feet from cubic meters. The different top end diameters limit will be used for different uses as per local requirements and management practices.

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