KFRI Research Report No. 413

ISSN 0970 - 8103

COMMERCIAL VOLUME TABLES FOR SELECTED HOME GARDEN TREES OF KERALA

(Final Report of Research Project KFRI/410/03)

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October 2011

CONTENTS

ACKNOWLEDGEMENTS

The author is thankful to: Dr. K. V. Sankaran, Director, KFRI, for his keen interest and encouragement; Dr. K. Swarupanandan, Research Coordinator; Dr. K. V. Bhat, Dr. P. Rugmini and Dr. M. Sivaram, for their valuable comments on the draft report; Mr. N. R. Pratheesh, Mr. Pradeep Chandran, Mr. T. A. Santhoshkumar, Mr. M. Bensen Thomas, Mr. Abhilash P. Jose and Mr. C. L. Baiju, for meticulous field work during tree felling in home gardens; tree owners, timber traders and tree felling skilled workers in different regions of Kerala, for their cooperation during the field work; and the Kerala State Council for Science, Technology and Environment, for funding this study.

ABSTRACT

Teak (*Tectona grandis* Linn.), jack (*Artocarpus heterophyllus* Lamk.), *anjily* (*A. hirsutus* Lamk.), *matty* (*Ailanthus triphysa* Dennst.) and mango (*Mangifera indica* Linn.) are the commercially and economically important trees in home gardens of Kerala. Different types of commercial volume prediction equations were developed for each species through regression analysis, using data on diameter (m) at breast-height of sample trees before felling and corresponding volume (m^3) of commercial timber measured after felling. Diameter of each tree was calculated from the girth over-bark measured at the breast-height level (1.37 m from ground). Volume was measured under-bark of logs or billets above 40 cm mid-girth over-bark of teak, *matty* and mango trees. It was measured under-sapwood of logs above 60 cm mid-girth over-bark of jack and *anjily* trees. Using the best fitting prediction equation selected from the set of equations estimated for each species, commercial volume estimates were predicted for those values of diameter corresponding to the values of girth at breast-height from 60 cm upwards with an interval of 5 cm. By tabulating the girth at breast-height in cm and volume in m^3, commercial volume tables were prepared for each species. The tables provide volume estimates corresponding to different values of girth at breast-height of trees which can easily be measured at site. The volume tables are useful to tree growers and purchasers including timber traders, for quickly obtaining an estimate of commercial volume in a tree without felling it and thereby calculating its stumpage price.

Key words: **Home garden trees, *Artocarpus heterophyllus*, *A. hirsutus*, *Ailanthus triphysa*, *Mangifera indica*, *Tectona grandis*, commercial timber, volume tables.**

1. INTRODUCTION

Trees are an important component of the multiple cropping home gardens in Kerala, contributing substantially to the supply of timber and industrial wood in the State (Krishnankutty, 1990; Krishnankutty *et al.*, 2008). Among trees in home gardens, teak (*Tectona grandis* Linn.), jack (*Artocarpus heterophyllus* Lamk.), *anjily* (*Artocarpus hirsutus* Lamk.), *matty* (*Ailanthus triphysa* Dennst.) and mango (*Mangifera indica* Linn.) are the most commercially and economically important trees. Teak is extensively grown in almost all home gardens for its very valuable timber for decorative doors, windows, furniture, fixtures, handicrafts and other constructions. Jack, grown for fruits and shade, produces premium timber for constructions, doors and windows, fixtures and furniture. *Anjily* tree provides a long straight bole and its timber is excellent for constructions, fixtures, house-boats, country-boats and truck-bodies. *Matty* is a popular species grown in home gardens and its wood is used by match industry for high quality splints and veneers. Although mango tree is grown for fruits and shade, its timber is an important industrial wood for packing cases.

When teak, jack and *anjily* trees are sold for timber, *matty* and mango trees are sold as industrial wood. Before selling a tree, the grower may like to know the price of the tree (stumpage price) that he can expect. Purchasers including timber traders are also interested in the volume of a tree before negotiating its stumpage price. For assessing the stumpage price, it is necessary to get an estimate of the merchantable volume of timber in the standing tree. Commercial volume tables provide volume of commercial timber in trees corresponding to different values of girth at breast-height of trees. Although commercial volume tables for forest trees (Nair, 1971) and that for acacia in forest plantations in Kerala (Jayaraman, 2004) are available, no study has been found in the literature on volume tables for any species in home gardens of Kerala or elsewhere. The objective of this study was to develop commercial volume prediction equations for teak, jack, *anjily*, *matty* and mango trees in home gardens of Kerala and thereby prepare commercial volume tables for these species.

2. METHODOLOGY

2.1. Selection of sample trees in home gardens: Commercial volume prediction equations were developed through regression analysis, using data on diameter (D) at breast-height of sample trees before felling and corresponding volume (V) of commercial timber measured after felling. In the case of teak, *matty* and mango trees, volume refers to that under-bark of logs or billets, which have 40 cm and above mid-girth over-bark. As the existing practice in the case of jack and *anjily* is the removal of sapwood from logs, volume of jack and *anjily* trees refers to that under-sapwood of logs with 60 cm and above mid-girth over-bark.

Professional tree cutters and timber traders in different villages in Kerala were identified through local enquiry by different teams, each consisting of two trained field assistants. The method of selecting trees, unlike that in a planned experiment in forest plantations where the felling operations were pre-planned, was more of an opportunistic type in which the field personnel were alert to anticipated tree felling in home gardens by growers, purchasers and traders. Information on tree felling was gathered from such traders and tree cutters. On the day of felling, home gardens were visited by the team. Measurements of trees before and after felling were made during felling and related operations. For each species, trees felled in home gardens in different regions were selected purposively with a view to obtain a sample representing trees with girth-classes from 60 cm to the largest, available during the survey of tree felling in Kerala.

2.2. Measurements on trees before and after felling: Before felling of a sample tree, girth at breast-height level (1.37 m from ground) was measured. After felling and converting the tree into logs or billets, length and girth under-bark of each log or billet were measured. All logs or billets which had the prescribed mid-girth over-bark were measured. Under-bark girth measurements were made after removing ring bark at the thicker-end, mid-position and thinner-end of each log or billet. For jack and *anjily*, girth under-sapwood at the thicker-end, mid-position and thinner-end of each log was measured. The length and girth of each log or billet of a tree, qualifying the minimum prescribed mid-girth over-bark, were recorded in a format corresponding to a sample tree. Altogether 359 trees (97 teak, 59 jack, 108 *anjily*, 57 *matty* and 38 mango trees) representing different girth-classes were measured. The girth at breast-height of sample trees ranged from 61 to 217 cm for teak, 73 to 329 cm for jack, 119 to 360 cm for *anjily*, 61 to 246 cm for *matty* and 96 to 357 cm for mango tree.

2.3. Calculation of timber volume in a felled tree: Commercial volume V (m^3) of timber obtained from a sample tree was calculated by aggregating the volumes of logs or billets from that tree, using the Newton's Formula given by

$$V = \sum_{i=1}^{n} l_i (g_{1i}^2 + 4g_{2i}^2 + g_{3i}^2)/24\pi,$$

where l_i stands for the length (m) of the i^{th} log or billet; g_{1i}, g_{2i} and g_{3i} represent for the girth (m) under-bark or under-sapwood of the i^{th} log or billet at the thicker-end, mid-position and thinner-end respectively and n denotes for the number of logs or billets obtained from a sample felled tree.

2.4. Developing volume prediction equations: From the values of girth at breast-height of sample trees before felling, corresponding values of diameter (***D***) at breast-height were calculated assuming circular approximation of basal area at breast-height. Scatter plot analysis was done to examine the presence of any outliers in the data on diameter ***D*** and corresponding commercial volume V of sample trees of each species. Different types of volume prediction equations were then fitted to the data of each species taking V or $ln\ V$ or $\sqrt{V}$ as regressand and ***D*** and its transformations as regressors, where *ln* stands for the natural logarithm. The assumptions of normality and homoscedasticity in each equation were tested by performing residual analysis. After fitting 27 different volume equations for each species, the best fitting prediction equation was identified as that equation which had the lowest value of Furnival Index and highest adjusted R^2 value, as the regressand varied from one set of equations to another (Furnival, 1961; Montgomery. and Peck, 1982). The Furnival Index of each of the estimated equations was calculated, by multiplying its root mean square error with the inverse of the appropriate geometric mean of the derivative of V or $ln\ V$ or $\sqrt{V}$ with respect to V, as: $\sqrt{E}$, for V as regressand; $\sqrt{E}.\ antilog\ (\Sigma\ ln\ V/m)$, for $ln\ V$ as regressand; and $\sqrt{E}.\ antilog\ (ln\ 2 + \Sigma\ ln\ V/2m)$, for $\sqrt{V}$ as regressand; where E represents for the mean square error, *antilog* stands for the natural antilogarithm and m denotes for the number of sample felled trees of a species.

3. COMMERCIAL VOLUME TABLES

3.1. Estimated volume prediction equations: The estimated commercial volume prediction equations for teak, jack, *anjily*, *matty* and mango trees, are presented in Appendices 1, 2, 3, 4 and 5, respectively. Along with each of the equations of a species, the values of adjusted R^2, mean square error and Furnival index are shown. From the set of estimated prediction equations of each species, the best fitting one was selected based on the lowest value of Furnival Index, statistical significance of the estimated regression coefficients, lowest number of terms in the equation and highest adjusted R^2 value. Equations 1, 2, 3, 4 and 5, are the best fitting volume prediction equations for teak, jack, *anjily*, *matty* and mango trees respectively. It may be noted that the type of the prediction model is the same for all the five tree species. The figures given in parentheses below the estimated coefficients of each equation are standard errors of the estimates which are all statistically significant at 1% probability level. The adjusted R^2 values are 0.95, 0.88, 0.88, 0.94 and 0.87 respectively. Since the adjusted R^2 values are above 0.87, the predictability of Equations 1, 2, 3, 4 and 5, is highly acceptable and therefore they were used for preparing the commercial volume tables.

$$ln\ V = \underset{(0.073)}{2.345^{**}} + \underset{(0.062)}{2.553^{**}}\ ln\ D, \quad (\text{Adj. } R^2 = 0.95) \quad \ldots\ldots (1)$$

$$ln\ V = \underset{(0.098)}{1.808^{**}} + \underset{(0.116)}{2.313^{**}}\ ln\ D, \quad (\text{Adj. } R^2 = 0.88) \quad \ldots\ldots (2)$$

$$ln\ V = \underset{(0.051)}{2.044^{**}} + \underset{(0.081)}{2.238^{**}}\ ln\ D, \quad (\text{Adj. } R^2 = 0.88) \quad \ldots\ldots (3)$$

$$ln\ V = \underset{(0.155)}{1.648^{**}} + \underset{(0.100)}{2.051^{**}}\ ln\ D, \quad (\text{Adj. } R^2 = 0.94) \quad \ldots\ldots (4)$$

$$ln\ V = \underset{(0.120)}{2.004^{**}} + \underset{(0.163)}{2.376^{**}}\ ln\ D. \quad (\text{Adj. } R^2 = 0.87) \quad \ldots\ldots (5)$$

3.2. Volume tables for selected species: Values of diameter (D) at breast-height corresponding to the values of girth from 60 cm upwards with 5 cm interval such as 60, 65, 70, etc. were generated. Using Equations 1, 2, 3, 4 and 5, volume (V) estimates were predicted for the values of diameter (D) corresponding to the girth from 60 cm upwards. Tables 1, 2, 3, 4 and 5, are the commercial volume tables for teak, jack, *anjily*, *matty* and mango trees respectively. Different ranges in girth-classes are given in the volume tables. The ranges are 60 to 255 cm for teak, 110 to 380 cm for jack, 110 to 405 cm for *anjily*, 60 to 255 cm for *matty* and 60 to 380 cm for mango tree. The ranges in girth-classes reflect the sizes of trees available in home gardens and logs with lower range are economically utilised in the markets. While jack, *anjily* and mango trees, grow to very big size and harvested normally at large dimension, teak and *matty* trees are harvested at relatively low dimension. In the commercial volume tables, girth at breast-height is given in cm and volume in m^3. If the volume estimate is required in cubic feet, it is required to multiply the volume figure, referred from the tables, with 35.3.

Table 1. Commercial volume table for teak trees in home gardens

Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)
60	0.152	100	0.561	140	1.324	180	2.515	220	4.197
65	0.187	105	0.635	145	1.448	185	2.697	225	4.445
70	0.226	110	0.715	150	1.579	190	2.887	230	4.702
75	0.269	115	0.801	155	1.717	195	3.085	235	4.967
80	0.317	120	0.893	160	1.862	200	3.291	240	5.241
85	0.370	125	0.991	165	2.014	205	3.505	245	5.524
90	0.428	130	1.096	170	2.173	210	3.727	250	5.817
95	0.492	135	1.206	175	2.340	215	3.958	255	6.119

Girth refers to the girth at breast-height (137 cm from the ground) of the tree and volume refers to that under-bark of logs or billets, above 40 cm mod-girth over-bark.

Table 2. Commercial volume table for jack trees in home gardens

Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)
110	0.538	165	1.374	220	2.672	275	4.478	330	6.827
115	0.596	170	1.472	225	2.815	280	4.668	335	7.068
120	0.658	175	1.574	230	2.962	285	4.863	340	7.315
125	0.723	180	1.680	235	3.113	290	5.063	345	7.566
130	0.791	185	1.790	240	3.268	295	5.267	350	7.822
135	0.864	190	1.904	245	3.428	300	5.476	355	8.083
140	0.939	195	2.022	250	3.592	305	5.690	360	8.349
145	1.019	200	2.144	255	3.760	310	5.908	365	8.619
150	1.102	205	2.270	260	3.933	315	6.130	370	8.895
155	1.189	210	2.400	265	4.110	320	6.358	375	9.175
160	1.279	215	2.534	270	4.292	325	6.590	380	9.461

Girth refers to the girth at breast-height (137 cm from the ground) of the tree and volume refers to that under-sapwood of logs above 60 cm mid-girth over-bark.

Table 3. Commercial volume table for *anjily* trees in home gardens

Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)
110	0.737	170	1.952	230	3.839	290	6.450	350	9.824
115	0.814	175	2.083	235	4.028	295	6.701	355	10.141
120	0.895	180	2.218	240	4.223	300	6.958	360	10.464
125	0.981	185	2.358	245	4.422	305	7.220	365	10.792
130	1.071	190	2.503	250	4.627	310	7.488	370	11.126
135	1.165	195	2.653	255	4.836	315	7.761	375	11.465
140	1.264	200	2.808	260	5.051	320	8.039	380	11.810
145	1.367	205	2.967	265	5.271	325	8.323	385	12.160
150	1.475	210	3.132	270	5.496	330	8.612	390	12.517
155	1.587	215	3.301	275	5.727	335	8.907	395	12.879
160	1.704	220	3.476	280	5.962	340	9.207	400	13.249
165	1.826	225	3.655	285	6.203	345	9.513	405	13.620

Girth refers to the girth at breast-height (137 cm from the ground) of the tree and volume refers to that under-sapwood of logs above 60 cm mid-girth over-bark.

Table 4. Commercial volume table for *matty* trees in home gardens

Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)
60	0.174	100	0.496	140	0.989	180	1.657	220	2.500
65	0.205	105	0.548	145	1.063	185	1.753	225	2.618
70	0.239	110	0.603	150	1.140	190	1.851	230	2.739
75	0.275	115	0.661	155	1.219	195	1.952	235	2.863
80	0.314	120	0.721	160	1.301	200	2.056	240	2.989
85	0.356	125	0.784	165	1.386	205	2.163	245	3.118
90	0.400	130	0.850	170	1.474	210	2.273	250	3.250
95	0.447	135	0.918	175	1.564	215	2.385	255	3.385

Girth refers to the girth at breast-height (137 cm from the ground) of the tree and Volume refers to that under-bark of logs or billets, above 40 cm mid-girth over-bark.

The commercial volume tables are suggested for field use in home gardens of Kerala and are useful to tree growers and purchasers including timber traders, for quickly and accurately assessing the volume of the tree even before felling. For obtaining an estimate of commercial volume in a teak tree with 180 cm girth at breast-height, it is required to refer the figure corresponding to 180 cm girth in Table 1 as 2.515 m^3. Similarly when the girth at breast-height of a jack tree is 315cm, an estimate of volume is 6.130 m^3 as given Table 2. The volume of an *anjily* tree with 350 cm girth at breast-height is 9.824 m^3 (Table 3) and that of a *matty* tree with 190 cm girth is 1.851 m^3 (Table 4). For a mango tree having 295 cm girth at breast-height, its volume can be referred from Table 5 as 6.382 m^3.

Table 5. Commercial volume table for mango trees in home gardens

Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth cm)	Volume (m^3)	Girth (cm)	Volume (m^3)	Girth (cm)	Volume (m^3)
60	0.145	125	0.830	190	2.244	255	4.515	320	7.743
65	0.175	130	0.911	195	2.387	260	4.728	325	8.034
70	0.209	135	0.996	200	2.535	265	4.947	330	8.331
75	0.247	140	1.086	205	2.688	270	5.171	335	8.634
80	0.287	145	1.181	210	2.846	275	5.402	340	8.943
85	0.332	150	1.280	215	3.010	280	5.638	345	9.259
90	0.380	155	1.383	220	3.179	285	5.880	350	9.581
95	0.432	160	1.492	225	3.353	290	6.128	355	9.909
100	0.488	165	1.605	230	3.533	295	6.382	360	10.244
105	0.548	170	1.723	235	3.718	300	6.642	365	10.585
110	0.612	175	1.846	240	3.909	305	6.908	370	10.933
115	0.681	180	1.973	245	4.105	310	7.181	375	11.287
120	0.753	185	2.106	250	4.307	315	7.459	380	11.648

Girth refers to the girth at breast-height (137 cm from the ground) of the tree and volume refers to that under-bark of logs or billets, above 40 cm mid-girth over-bark.

4. CONCLUSIONS

Teak, jack, *anjily*, *matty* and mango trees are the commercially and economically important trees in home gardens of Kerala. For each species, different types of commercial volume prediction equations were developed using data on diameter at breast-height level (1.37 m from ground) of sample trees before felling and corresponding volume of commercial timber measured after felling. Using the best fitting equation selected for each species, commercial volume tables were prepared. A commercial volume table provides volume (in m^3) of commercial timber in trees for different values of girth (in cm) at breast-height of trees, which can easily be measured at site. The volume tables can be used directly for obtaining estimates of commercial volume in a tree when the girth at breast-height of the tree is known. The volume estimate can be obtained by referring the table corresponding to the value of girth. If the volume estimate is required in cubic feet, it is required to multiply the volume figure in m^3 with 35.3. The commercial volume tables are useful to tree growers and purchasers including timber traders, for quickly estimating commercial volume in a tree without felling it and thereby calculating its stumpage price.

REFERENCES

Furnival, G. M. (1961). An index for comparing equations used in constructing volume tables, *Forest Science*, 7 (4), 337-341.

Jayaraman, K. (2004). *Preparation of commercial volume tables for Acacia auriculiformis and Acacia mangium plantations raised under Kerala Forestry Project.* KFRI Extension Report No. 67, Kerala Forest Research Institute, Peechi, India.

Krishnankutty, C. N. (1990). *Demand and supply of wood in Kerala and their future trends.* KFRI Research Report No. 67, Kerala Forest Research Institute, Peechi, India.

Krishnankutty, C. N., Thampi, K. B. and Chundamannil, M. (2008). Trees outside forests (TOF): a case study of the wood production-consumption situation in Kerala. *International Forestry Review*, 10 (2): 156-164.

Montgomery, D. C. and Peck, E.A. (1982). *Introduction to linear regression analysis*. John Wiley and Sons, New York.

Nair, N. R. (1971). *Commercial volume tables for the forest trees of Kerala.* Kerala Forest Department, Thiruvananthapuram.

Appendix 1

Estimated volume prediction equations of teak trees

Sl. No	Volume prediction equations	$Adj.R^2$	*MSE*	Furnival Index
01.	$V = -0.823^{**} + 4.695^{**} D$ (0.064) (0.182)	0.875	0.030	0.173
02.	$V = 2.266^{**} + 1.329^{**} \ln D$ (0.084) (0.071)	0.787	0.050	0.224
03.	$V = 1.809^{**} - 0.320^{**} D^{-1}$ (0.084) (0.024)	0.654	0.082	0.286
04.	$V = -0.010^{ns} - 0.749^{ns} D + 8.316^{**} D^2$ (0.151) (0.954) (1.437)	0.907	0.022	0.148
05.	$V = 4.267^{**} + 4.738^{**} \ln D + 1.343^{**} (\ln D)^2$ (0.199) (0.327) (0.128)	0.902	0.023	0.152
06.	$V = 3.596^{**} - 1.294^{**} D^{-1} + 0.115^{**} D^{-2}$ (0.161) (0.084) (0.010)	0.860	0.033	0.182
07.	$V = -2.165^{**} + 5.093^{**} D^{1/2}$ (0.133) (0.230)	0.838	0.038	0.195
08.	$V = 2.198^{**} - 11.139^{**} D^{1/2} + 14.703^{**} D$ (0.531) (1.949) (1.758)	0.907	0.022	0.148
09.	$V = -2.203^{**} + 6.940^{**} D + 0.190^{**} D^{-1}$ (0.259) (0.442) (0.035)	0.905	0.023	0.152
10.	$V = -10.265^{**} + 12.556^{**} D^{1/2} + 2.135^{**} D^{-1/2}$ (1.024) (0.956) (0.269)	0.903	0.023	0.152
11.	$V = -1.593^{**} - 0.266^{ns} \ln D - 2.169^{**} (\ln D)^{-1}$ (0.353) (0.151) (0.195)	0.908	0.022	0.148
12.	$V^{1/2} = -1.050^{**} + 3.258^{**} D^{1/2}$ (0.056) (0.097)	0.923	0.007	0.126
13.	$V^{1/2} = -0.146^{ns} - 0.103^{ns} D^{1/2} + 3.044^{**} D$ (0.279) (1.024) (0.924)	0.931	0.006	0.117
14.	$V^{1/2} = -0.174^{**} + 2.952^{**} D$ (0.029) (0.083)	0.931	0.006	0.118

15.	$V^{1/2} = -0.179^{ns} + 2.981^{**}\boldsymbol{D} - 0.045^{ns}\boldsymbol{D}^2$ (0.080) (0.503) (0.757)	0.931	0.006	0.118
16.	$V^{1/2} = -2.857^{**} + 4.923^{**}\boldsymbol{D}^{1/2} + 0.476^{ns}\boldsymbol{D}^{-1/2}$ (0.524) (0.489) (0.137)	0.932	0.006	0.118
17.	$ln\ V = -3.375^{**} + 8.377^{**}\boldsymbol{D}$ (0.096) (0.274)	0.907	0.067	0.148
18.	$ln\ V = 2.345^{**} + 2.553^{**}\ ln\ \boldsymbol{D}$ (0.073) (0.062)	0.947	0.038	0.111
19.	$ln\ V = -4.971^{**} + 19.052^{**}\boldsymbol{D} - 16.309^{**}\boldsymbol{D}^2$ (0.197) (1.242) (1.872)	0.949	0.038	0.111
20.	$ln\ V = 1.629^{**} - 0.664^{**}\boldsymbol{D}^{-1}$ (0.071) (0.020)	0.918	0.059	0.138
21.	$ln\ V = 2.847^{**} - 1.327^{**}\boldsymbol{D}^{-1} + 0.079^{**}\boldsymbol{D}^{-2}$ (0.169) (0.088) (0.010)	0.950	0.037	0.110
22.	$ln\ V = 2.145^{**} + 2.213^{**}ln\ \boldsymbol{D} - 0.134^{ns}(ln\ \boldsymbol{D})^2$ (0.254) (0.419) (0.163)	0.948	0.038	0.111
23.	$ln\ V = -5.963^{**} + 9.425^{**}\boldsymbol{D}^{1/2}$ (0.148) (0.255)	0.935	0.047	0.124
24.	$ln\ V = -9.346^{**} + 22.012^{**}\boldsymbol{D}^{1/2} - 11.402^{**}\boldsymbol{D}$ (0.691) (2.534) (2.286)	0.949	0.038	0.111
25.	$ln\ V = -0.670^{ns} + 3.976^{ns}\boldsymbol{D} - 0.372^{**}\boldsymbol{D}^{-1}$ (0.344) (0.586) (0.046)	0.945	0.040	0.114
26.	$ln\ V = 0.130^{ns} + 3.811^{**}\boldsymbol{D}^{1/2} - 1.606^{**}\boldsymbol{D}^{-1/2}$ (1.323) (1.235) (0.347)	0.947	0.039	0.113
27.	$ln\ V = 2.904^{**} + 2.784^{**}ln\ \boldsymbol{D} + 0.313^{ns}(ln\ \boldsymbol{D})^{-1}$ (0.463) (0.199) (0.256)	0.948	0.038	0.111

Figures in brackets are the standard errors of the coefficients.

* Significant at 5 % level.

**Significant at 1% level.

^{ns} Non-significant at 5 % level.

Appendix 2
Estimated volume prediction equations of jack trees

Sl. No	Volume prediction equations	$Adj.R^2$	MSE	Furnival Index
01.	$V = -1.882^{**} + 6.622^{**} D$ (0.178) (0.369)	0.850	0.139	0.373
02.	$V = 3.822^{**} + 3.279^{**} \ln D$ (0.194) (0.230)	0.780	0.204	0.452
03.	$V = 4.371^{**} - 1.382^{**} D^{-1}$ (0.318) (0.134)	0.650	0.325	0.570
04.	$V = -0.753^{ns} + 2.227^{ns} D + 3.913^{ns} D^2$ (0.592) (2.332) (1.961)	0.860	0.133	0.365
05.	$V = 5.061^{**} + 7.330^{**} \ln D + 2.837^{**} (\ln D)^2$ (0.253) (0.686) (0.464)	0.868	0.124	0.352
06.	$V = 8.181^{**} - 4.749^{**} D^{-1} + 0.703^{**} D^{-2}$ (0.526) (0.433) (0.088)	0.836	0.155	0.394
07.	$V = -5.219^{**} + 9.493^{**} D^{1/2}$ (0.397) (0.583)	0.823	0.164	0.405
08.	$V = 3.227^{ns} - 14.414^{*} D^{1/2} + 16.482^{**} D$ (2.082) (5.801) (3.983)	0.865	0.128	0.358
09.	$V = -4.356^{**} + 8.966^{**} D + 0.603^{**} D^{-1}$ (0.935) (0.939) (0.224)	0.867	0.126	0.355
10.	$V = -21.371^{**} + 20.821^{**} D^{1/2} + 5.649^{**} D^{-1/2}$ (3.715) (2.643) (1.294)	0.868	0.125	0.354
11.	$V = 3.307^{**} + 2.834^{ns} \ln D - 0.098^{*} (\ln D)^{-1}$ (0.321) (0.317) (0.049)	0.795	0.194	0.440
12.	$V^{1/2} = -1.496^{**} + 3.741^{**} D^{1/2}$ (0.129) (0.190)	0.872	0.017	0.255
13.	$V^{1/2} = -0.379^{ns} + 0.596^{ns} D^{1/2} + 2.168^{*} D$ (0.761) 2.120) (1.456)	0.877	0.017	0.255
14.	$V^{1/2} = -0.166^{**} + 2.576^{**} D$ (0.062) (0.128)	0.876	0.017	0.255

15.	$V^{1/2} = -0.289^{ns} + 3.056^{**} D - 0.427^{ns} D^2$ (0.212) (0.799) (0.702)	0.877	0.017	0.255
16.	$V^{1/2} = -3.793^{**} + 5.352^{**} D^{1/2} + 0.803^{ns} D^{-1/2}$ (1.368) (0.974) (0.476)	0.878	0.017	0.255
17.	$ln\ V = -2.082^{**} + 4.384^{**} D$ (0.123) (0.254)	0.839	0.066	0.245
18.	$ln\ V = 1.808^{**} + 2.313^{**} ln\ D$ (0.098) (0.116)	0.875	0.051	0.215
19.	$ln\ V = -3.517^{**} + 9.972^{**} D - 4.974^{**} D^2$ (0.372) (1.402) (1.232)	0.875	0.052	0.217
20.	$ln\ V = 2.370^{**} - 1.051^{**} D^{-1}$ (0.140) (0.059)	0.847	0.063	0.239
21.	$ln\ V = 3.335^{**} - 1.903^{**} D^{-1} + 0.178^{**} D^{-2}$ (0.308) (0.253) (0.052)	0.873	0.053	0.220
22.	$ln\ V = 1.753^{**} + 2.132^{**} ln\ D - 0.127^{ns} (ln\ D)^2$ (0.164) (0.445) (0.301)	0.875	0.052	0.217
23.	$ln\ V = -4.421^{**} + 6.478^{**} D^{1/2}$ (0.232) (0.341)	0.864	0.056	0.226
24.	$ln\ V = -7.465^{**} + 15.045^{**} D^{1/2} - 5.905^{*} D$ (1.330) (3.704) (2.543)	0.876	0.052	0.217
25.	$ln\ V = 0.285^{ns} + 2.143^{**} D - 0.577^{**} D^{-1}$ (0.605) (0.608) (0.145)	0.874	0.053	0.220
26.	$ln\ V = 1.053^{ns} + 2.639^{ns} D^{1/2} - 1.915^{*} D^{-1/2}$ (2.407) (1.713) (0.838)	0.875	0.052	0.217
27.	$ln\ V = 1.979^{**} + 2.460^{**} ln\ D + 0.032^{ns} (ln\ D)^{-1}$ (0.165) (0.163) (0.025)	0.879	0.051	0.215

Figures in brackets are the standard errors of the coefficients.

* Significant at 5 % level.

**Significant at 1% level.

^{ns} Non-significant at 5 % level.

Appendix 3
Estimated volume prediction equations of *anjily* trees

Sl. No	Volume prediction equations	$Adj.R^2$	MSE	Furnival Index
01.	$V = -3.951^{**} + 11.228^{**}D$ (0.279) (0.472)	0.844	0.516	0.718
02.	$V = 6.477^{**} + 6.825^{**} \ln D$ (0.229) (0.363)	0.771	0.756	0.869
03.	$V = 9.382^{**} - 3.747^{**}D^{-1}$ (0.480) (0.255)	0.673	1.078	1.038
04.	$V = -0.284^{ns} - 0.322^{ns}D + 8.434^{**}D^2$ (0.844) (2.571) (1.851)	0.870	0.434	0.659
05.	$V = 7.910^{**} + 14.583^{**} \ln D + 7.847^{**}(\ln D)^2$ (0.230) (0.885) (0.852)	0.874	0.420	0.648
06.	$V = 21.823^{**} - 18.260^{**}D^{-1} + 4.028^{**}D^{-2}$ (1.146) (1.294) (0.356)	0.853	0.488	0.699
07.	$V = -10.860^{**} + 17.756^{**}D^{1/2}$ (0.632) (0.834)	0.812	0.620	0.787
08.	$V = 11.965^{**} - 40.043^{**}D^{1/2} + 35.981^{**}D$ (3.285) (8.246) (5.115)	0.872	0.424	0.651
09.	$V = -12.382^{**} + 17.732^{**}D + 2.555^{**}D^{-1}$ (1.722) (1.382) (0.516)	0.873	0.421	0.649
10.	$V = 59.461^{**} + 48.418^{**}D^{1/2} + 18.951^{**}D^{-1/2}$ (6.832) (4.353) (2.656)	0.874	0.421	0.649
11.	$V = 6.460^{**} + 6.832^{**} \ln D - 0.013^{ns}(\ln D)^{-1}$ (0.231) (0.365) (0.020)	0.772	0.760	0.872
12.	$V^{1/2} = -2.112^{**} + 4.813\, D^{1/2}$ (0.136) (0.180)	0.872	0.029	0.492
13.	$V^{1/2} = 0.171^{ns} - 0.971^{ns}D^{1/2} + 3.600^{**}D$ (0.829) (2.080) (1.290)	0.881	0.027	0.475
14.	$V^{1/2} = -0.215^{**} + 3.000^{**}D$ (0.064) (0.108)	0.881	0.027	0.475

15.	$V^{1/2} = -0.159^{ns} + 2.823^{**} D + 0.129^{ns} D^2$ (0.2111) (0.642) (0.462)	0.881	0.027	0.475
16.	$V^{1/2} = -7.109^{**} + 7.965^{**} D^{1/2} + 1.948^{**} D^{-1/2}$ (1.726) (1.100) (0.671)	0.882	0.027	0.475
17.	$ln\ V = -1.257^{**} + 3.4769^{**} D$ (0.082) (0.138)	0.858	0.044	0.438
18.	$ln\ V = 2.044^{**} + 2.238^{**} ln\ D$ (0.051) (0.081)	0.879	0.037	0.401
19.	$ln\ V = -2.286^{**} + 6.717^{**} D - 2.367^{**} D^2$ (0.249) (0.758) (0.546)	0.880	0.037	0.401
20.	$ln\ V = 3.125^{**} - 1.298^{**} D^{-1}$ (0.097) (0.052)	0.857	0.044	0.438
21.	$ln\ V = 4.427^{**} - 2.817^{**} D^{-1} + 0.422^{**} D^{-2}$ (0.320) (0.362) (0.100)	0.878	0.038	0.407
22.	$ln\ V = 2.055^{**} + 2.297^{**} ln\ D + 0.060^{ns} (ln\ D)^2$ (0.069) (0.265) (0.256)	0.879	0.038	0.407
23.	$ln\ V = -3.517^{**} + 5.658^{**} D^{1/2}$ (0.158) (0.209)	0.875	0.039	0.412
24.	$ln\ V = -5.484^{**} + 10.642^{**} D^{1/2} - 3.103^{*} D$ (0.980) (2.460) (1.526)	0.880	0.038	0.407
25.	$ln\ V = 0.926^{ns} + 1.792^{**} D - 0.662^{**} D^{-1}$ (0.517) (0.415) (0.155)	0.879	0.038	0.407
26.	$ln\ V = 0.599^{ns} + 3.080^{*} D^{1/2} - 1.593^{*} D^{-1/2}$ (2.049) (1.306) (0.797)	0.879	0.038	0.407
27.	$ln\ V = 2.034^{**} + 2.242^{**} ln\ D - 0.008^{ns} (ln\ D)^{-1}$ (0.0514) (0.080) (0.004)	0.883	0.037	0.401

Figures in brackets are the standard errors of the coefficients.

* Significant at 5 % level.

**Significant at 1% level.

ns Non-significant at 5 % level.

Appendix 4

Estimated volume prediction equations of *matty* trees

Sl. No	Volume prediction equations	$Adj.R^2$	*MSE*	Furnival Index
01.	$V = -0.270^{**} + 2.427^{**}D$ (0.042) (0.173)	0.876	0.005	0.071
02.	$V = 1.013^{**} + 0.474^{**} \ln D$ (0.076) (0.049)	0.768	0.009	0.095
03.	$V = 0.659^{**} - 0.075^{**}D^{-1}$ (0.060) (0.012)	0.600	0.015	0.122
04.	$V = 0.072^{**} - 0.837^{**}D + 7.024^{**}D^2$ (0.093) (0.837) (1.777)	0.921	0.003	0.055
05.	$V = 2.172^{**} + 1.963^{**} \ln D + 0.453^{**}(\ln D)^2$ (0.193) (0.241) (0.073)	0.905	0.004	0.063
06.	$V = 1.275^{ns} - 0.303^{**}D^{-1} + 0.017^{**}D^{-2}$ (0.099) (0.034) (0.003)	0.850	0.006	0.077
07.	$V = -0.751^{**} + 2.198^{**}D^{1/2}$ (0.091) (0.188)	0.831	0.006	0.077
08.	$V = 0.856^{*} - 4.965^{**}D^{1/2} + 7.741^{**}D$ (0.312) (1.366) (1.470)	0.916	0.003	0.055
09.	$V = -0.724^{**} + 3.480^{**}D + 0.043^{**}D^{-1}$ (0.146) (0.361) (0.013)	0.910	0.004	0.063
10.	$V = -3.445^{**} + 5.174^{**}D^{1/2} + 0.589^{**}D^{-1/2}$ (0.583) (0.655) (0.127)	0.906	0.004	0.063
11.	$V = -1.535^{**} - 0.330^{**} \ln D - 1.916^{**}(\ln D)^{-1}$ (0.356) (0.115) (0.266)	0.920	0.003	0.055
12.	$V^{1/2} = -0.500^{**} + 2.130^{**}D^{1/2}$ (0.061) (0.126)	0.911	0.003	0.053
13.	$V^{1/2} = 0.205^{ns} - 1.009^{ns}D^{1/2} + 3.393^{**}D$ (0.263) (1.153) (1.240)	0.931	0.002	0.044
14.	$V^{1/2} = 0.024^{ns} + 2.313^{**}D$ (0.030) (0.121)	0.929	0.002	0.044

15.	$V^{1/2} = 0.050^{ns} + 1.607^{ns}\boldsymbol{D} + 1.520^{ns}\boldsymbol{D}^2$ (0.081) (0.725) (1.538)	0.931	0.002	0.044
16.	$V^{1/2} = -1.694^{**} + 3.450^{**}\boldsymbol{D}^{1/2} + 0.261^{ns}\boldsymbol{D}^{-1/2}$ (0.470) (0.528) (0.102)	0.929	0.002	0.044
17.	$ln\ \boldsymbol{V} = -3.720^{**} + 9.720^{**}\boldsymbol{D}$ (0.137) (0.559)	0.915	0.050	0.053
18.	$ln\ \boldsymbol{V} = 1.648^{**} + 2.051^{**} ln\ \boldsymbol{D}$ (0.155) (0.100)	0.937	0.037	0.046
19.	$ln\ \boldsymbol{V} = -4.650^{**} + 18.593^{**}\boldsymbol{D} - 19.096^{**}\boldsymbol{D}^2$ (0.326) (2.930) (6.218)	0.937	0.038	0.046
20.	$ln\ \boldsymbol{V} = 0.258^{ns} - 0.352^{**}\boldsymbol{D}^{-1}$ (0.132) (0.025)	0.873	0.075	0.065
21.	$ln\ \boldsymbol{V} = 1.481^{**} - 0.801^{ns}\boldsymbol{D}^{-1} + 0.035^{**}\boldsymbol{D}^{-2}$ (0.251) (0.087) (0.007)	0.937	0.038	0.046
22.	$ln\ \boldsymbol{V} = 2.164^{**} + 2.714^{**} ln\ \boldsymbol{D} + 0.202^{ns}(ln\ \boldsymbol{D})^2$ (0.602) (0.754) (0.228)	0.938	0.037	0.046
23.	$ln\ \boldsymbol{V} = -5.807^{**} + 9.137^{**}\boldsymbol{D}^{1/2}$ (0.220) (0.453)	0.935	0.038	0.046
24.	$ln\ \boldsymbol{V} = -7.098^{**} + 14.890^{**}\boldsymbol{D}^{1/2} - 6.218^{ns}\boldsymbol{D}$ (1.043) (4.570) (4.916)	0.939	0.037	0.046
25.	$ln\ \boldsymbol{V} = -2.243^{**} + 6.293^{**}\boldsymbol{D} - 0.140^{**}\boldsymbol{D}^{-1}$ (0.473) (1.166) (0.043)	0.939	0.037	0.046
26.	$ln\ \boldsymbol{V} = -3.458^{**} + 6.542^{**}\boldsymbol{D}^{1/2} - 0.514^{ns}\boldsymbol{D}^{-1/2}$ (1.836) (2.063) (0.399)	0.939	0.037	0.046
27.	$ln\ \boldsymbol{V} = 0.536^{ns} + 1.701^{**} ln\ \boldsymbol{D} - 0.837^{*}(ln\ \boldsymbol{D})^{-1}$ (1.220) (0.395) (0.910)	0.939	0.037	0.046

Figures in brackets are the standard errors of the coefficients.

* Significant at 5 % level.

**Significant at 1% level.

ns Non-significant at 5 % level.

Appendix 5

Estimated volume prediction equations of mango trees

Sl. No	Volume prediction equations	$Adj.R^2$	*MSE*	Furnival Index
01.	$V = -2.466^{**} + 8.109^{**}D$ (0.414) (0.792)	0.766	0.289	0.538
02.	$V = 4.329^{**} + 3.799^{**} \ln D$ (0.343) (0.465)	0.676	0.400	0.632
03.	$V = 5.078^{**} - 1.647^{**} D^{-1}$ (0.526) (0.247)	0.582	0.517	0.719
04.	$V = 3.074^{**} - 14.009^{**} D + 20.977^{**} D^2$ (1.001) (3.865) (3.627)	0.888	0.144	0.379
05.	$V = 7.457^{**} + 13.381^{**} \ln D + 6.573^{**} (\ln D)^2$ (0.611) (1.746) (1.176)	0.839	0.206	0.454
06.	$V = 12.516^{**} - 8.631^{**} D^{-1} + 1.548^{**} D^{-2}$ (1.598) (1.464) (0.322)	0.761	0.306	0.553
07.	$V = -6.286^{**} + 11.214^{**} D^{1/2}$ (0.877) (1.228)	0.723	0.343	0.586
08.	$V = 18.022^{**} - 58.166^{**} D^{1/2} + 48.849^{**} D$ (4.224) (11.958) (8.397)	0.867	0.169	0.411
09.	$V = -11.675^{**} + 17.209^{**} D - 2.206^{**} D^{-1}$ (2.320) (2.359) (0.550)	0.846	0.196	0.443
10.	$V = -51.116^{**} + 43.102^{**} D^{1/2} + 15.541^{**} D^{-1/2}$ (9.373) (6.716) (3.241)	0.841	0.203	0.451
11.	$V = -0.285^{ns} + 0.255^{ns} \ln D - 1.299^{**} (\ln D)^{-1}$ (0.518) (0.444) (0.137)	0.917	0.106	0.326
12.	$V^{1/2} = -1.696^{**} + 4.136^{**} D^{1/2}$ (0.225) (0.315)	0.843	0.023	0.359
13.	$V^{1/2} = 2.285^{ns} - 7.226^{ns} D^{1/2} + 8.000^{**} D$ (1.392) (3.948) (2.767)	0.876	0.018	0.318
14.	$V^{1/2} = -0.260^{**} + 2.938^{**} D$ (0.1089) (0.207)	0.863	0.020	0.335

15.	$V^{1/2} = 0.504^{ns} - 0.111^{ns}\boldsymbol{D} + 2.892^{**}\boldsymbol{D}^2$ (0.349) (1.346) (1.264)	0.883	0.017	0.309
16.	$V^{1/2} = -8.553^{**} + 9.013^{**}\boldsymbol{D}^{1/2} + 2.377^{ns}\boldsymbol{D}^{-1/2}$ (2.926) (2.096) (1.012)	0.867	0.020	0.335
17.	$ln\ V = -2.067^{**} + 4.722^{**}\boldsymbol{D}$ (0.180) (0.345)	0.854	0.055	0.329
18.	$ln\ V = 2.004^{**} + 2.376^{**} ln\ \boldsymbol{D}$ (0.120) (0.163)	0.869	0.049	0.311
19.	$ln\ V = -2.844^{**} + 7.826^{**}\boldsymbol{D} - 2.944^{ns}\boldsymbol{D}^2$ (0.612) (2.364) (2.218)	0.862	0.069	0.368
20.	$ln\ V = 2.628^{**} - 1.104^{**}\boldsymbol{D}^{-1}$ (0.168) (0.079)	0.860	0.053	0.323
21.	$ln\ V = 3.216^{**} - 1.657^{*}\boldsymbol{D}^{-1} + 0.123^{ns}\boldsymbol{D}^{-2}$ (0.664) (0.609) (0.134)	0.864	0.053	0.323
22.	$ln\ V = 1.960^{**} + 2.240^{*} ln\ \boldsymbol{D} - 0.093^{ns}(ln\ \boldsymbol{D})^2$ (0.303) (0.867) (0.584)	0.870	0.051	0.317
23.	$ln\ V = -4.460^{**} + 6.767^{**}\boldsymbol{D}^{1/2}$ (0.337) (0.473)	0.865	0.051	0.317
24.	$ln\ V = -6.188^{**} + 11.700^{ns}\boldsymbol{D}^{1/2} - 3.473^{ns}\boldsymbol{D}$ (2.331) (6.598) (4.633)	0.867	0.052	0.320
25.	$ln\ V = 0.504^{ns} + 2.182^{ns}\boldsymbol{D} - 0.616^{*}\boldsymbol{D}^{-1}$ (1.156) (1.176) (0.274)	0.874	0.049	0.311
26.	$ln\ V = 1.062^{ns} + 2.840^{ns}\boldsymbol{D}^{1/2} - 1.914^{ns}\boldsymbol{D}^{-1/2}$ (4.657) (3.337) (1.615)	0.871	0.050	0.314
27.	$ln\ V = 1.643^{**} + 2.099^{**} ln\ \boldsymbol{D} - 0.102^{ns}(ln\ \boldsymbol{D})^{-1}$ (0.352) (0.301) (0.093)	0.874	0.049	0.311

Figures in brackets are the standard errors of the coefficients.

* Significant at 5 % level.

**Significant at 1% level.

^{ns} Non-significant at 5 % level.