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Predicting the weight of a bamboo clump: commercial weight tables for *Bambusa bambos*

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Abstract—Commercial weight tables for bamboo (*Bambusa bambos*) for different clump-diameters are presented in this paper. As part of a sample survey of bamboo growing stock in the forests of Kerala, measurements were made in 610 clumps and culms enumerated. Using the data on commercial weight of green culms and clump-diameters, different weight prediction equations were estimated. Based on the best fitting equation, a commercial weight table for green culms in a clump was generated for different clump diameters. Similarly, a commercial weight table for all culms (including the dry ones in green weight equivalent) was also generated. The weight tables can be used directly for obtaining the commercial weight of culms in a standing clump when the clump-diameter is known. These tables are ready to use and facilitate making quick estimates of bamboo growing stock in forests.

Key words: *Bambusa bambos*; clump diameter; commercial weight tables.

INTRODUCTION

Of the many species of bamboo that occur in forests in different parts of India *Bambusa bambos* is the most important industrial species due to its abundance [1]. Bamboo is extensively used as an industrial raw material for paper and rayon manufacturing. The long-fibre property of bamboo makes it the ideal raw material for quality paper production. Estimation of growing stock of bamboo is possible both in number and weight of culms in the clump. Weight is the most frequently used unit for trade and also for industrial processing. Counting the number of culms is tedious and less useful than arriving at the weight of culms in the clump. Foresters and bamboo traders have their own personalised visual methods for assessing the weight of culms in a standing bamboo clump, the accuracy of which varies with experience. Errors of judgement in personalised methods would be costly mistakes for either party. In this context, commercial weight tables of bamboo, similar to

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commercial volume tables of trees, have great relevance in forestry. In commercial volume tables, the volume of the commercial timber available in a standing tree can be obtained for any value of the girth at breast height of the tree. Likewise, commercial weight-tables for bamboo can be developed to read out the commercial weight of culms in a clump for any value of the diameter at the base of the clump. The weight can be calculated without felling and weighing individual culms in the clump. No studies have been found in the literature on commercial weight tables of any species of bamboo [1, 2]. The commercial weight prediction equations and the weight tables for *Bambusa bamboos* are presented in this paper.

METHODOLOGY

As part of a study on bamboo resources in the forests of Kerala [3], the average growing stock per ha was estimated using the data of 48 samples from 0.4-ha plots selected on a stratified sampling plan covering pure, medium-density and low-density bamboo patches. Data collected from a plot included number of bamboo clumps and within each clump the number of green and dry culms. The culms in a clump were enumerated by culm-diameter classes. The culm-diameter refers to the diameter at the middle of the second internode from the bottom of the culm. The diameter classes were: <5.0 cm, 5.0–7.5 cm, 7.5–10.0 cm, 10.0–12.5 cm and 12.5–15.0 cm. In total, 5456 clumps were enumerated in all the plots.

Among the clumps enumerated, 610 un-worked clumps were identified during the survey and two diameters perpendicular to each other at the base of each such clump were measured. The mean of the two diameters perpendicular to each other at the base of the clump is referred to as the clump diameter (D). Shape of the base of most of the clumps was that of an ellipse. Direct measurement of the diameter at the base of a clump is usually difficult. Therefore, to arrive at the clump diameter (D), the method adopted was to consider two diameters perpendicular to each other at the base of each clump (Fig. 1). They were taken in such a way that the first diameter passed through the longest stretch of the clump. The first diameter was measured using a rope held parallel to it with other ropes held perpendicular to the first rope at the extremities of the clump. The second diameter was also taken in this way using ropes held parallel to it beside the clump and marking the extremities perpendicularly on it.

For developing the weight prediction equations, data pertaining to 610 un-worked clumps representing different clump-diameter classes were utilised. Already worked clumps were excluded since the stocking in such clumps was disturbed by the harvesting operations (working). Only data from un-worked clumps were used, since there was a natural pattern of new shoots emerging and old culms dying in a normal clump.

Commercial weight of culms in each clump was calculated. It refers to the sum of weights of utilisable portion of each culm in the clump. The average weight of freshly harvested green bamboo per culm in different culm-diameter classes is

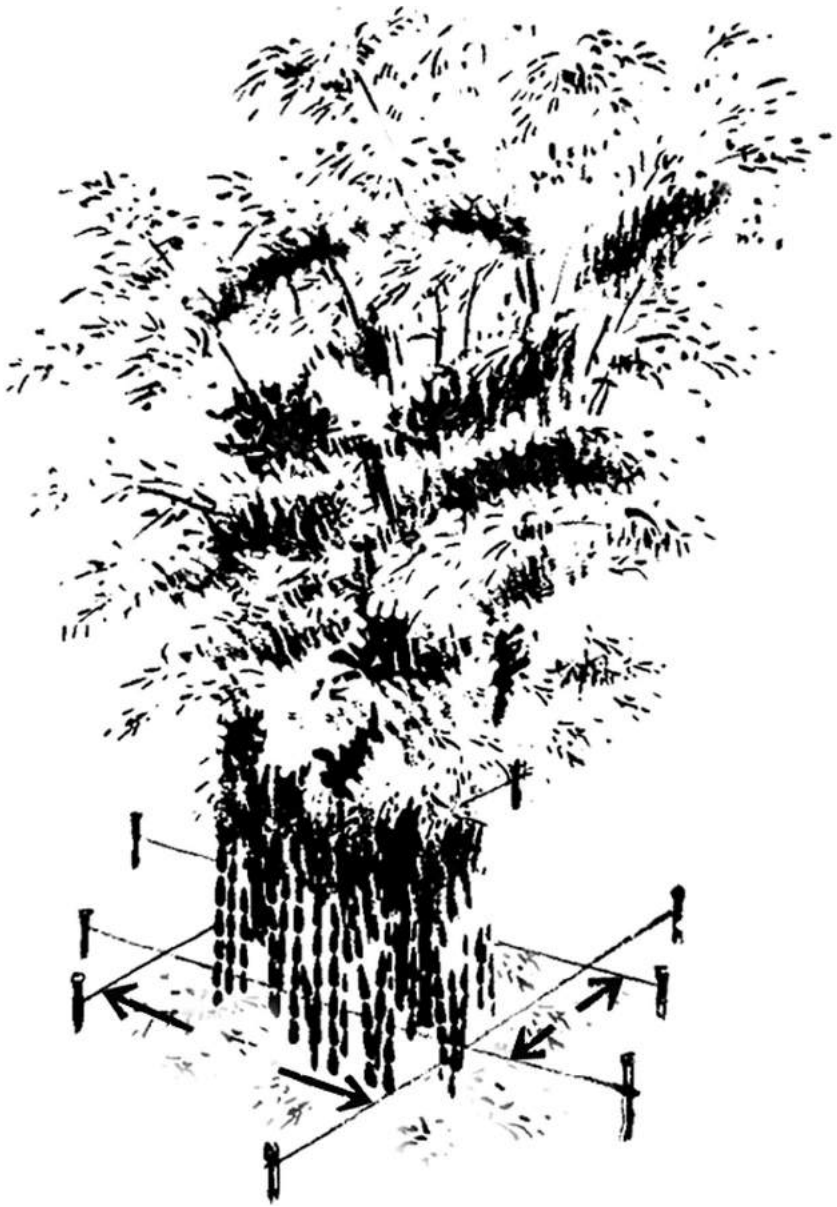

Figure 1. Method of measuring diameters at the base of bamboo clump.

available [3]. Using the data on number of green culms in different culm-diameter classes and the respective average weight of freshly harvested green bamboo per culm, the commercial weight of green culms in the clump (W_g) was calculated as the sum of product of the number and average weight. Using the data on number of all culms (including the dry ones) in different culm-diameter classes and the corresponding average weight of freshly harvested green bamboo per culm, the

commercial weight of all culms in the clump (W_a) was also calculated. W_a is actually the sum of the weight of green culms and the weight of dry culms in green weight equivalent. W_g, W_a and D were calculated for each clump. Values of D ranged from 0.7 to 10.6 m, based on results. Based on the data on weight (W_g) and clump-diameter (D) of 611 clumps, 27 different regression equations were estimated taking W_g, $\sqrt{W_g}$ and $\ln W_g$ as regressand with D and its transformations as regressors. The best-fit prediction equation was selected considering the adjusted R^2 value [4] and Furnival Index, since the regressand varies from one set of equations to another [5]. After obtaining the mean square error by fitting each equation to the data, the Furnival Index was calculated as the root mean square error multiplied by the inverse of the appropriate geometric mean of the derivative of various regressands with respect to D [5]. The equation, which has the highest adjusted R^2 value and smallest Furnival Index, was selected as the best fitting prediction equation. In a similar manner, the best-fit prediction equation for the weight of all culms (W_a) was determined.

RESULTS AND DISCUSSION

Equations (1) and (2) represent the best-fit prediction equations for the commercial weight of green culms (W_g) and all culms (W_a), respectively. The regression coefficients are statistically significant at 1% probability level. The figures given in parentheses below the coefficients are standard errors. The adjusted R^2 value of equation (1) is 0.97 and that of equation (2) is 0.95, and the Furnival Indices of the equations are 174 and 228, respectively.

$$\underset{}{\sqrt{W_g}} = \underset{(0.3)}{17.8} + \underset{(0.4)}{19.5}\ln D + \underset{(0.3)}{7.2}(\ln D)^2, \tag{1}$$

$$\underset{}{\sqrt{W_a}} = \underset{(1.5)}{19.8} + \underset{(0.8)}{18.6}\ln D + \underset{(0.5)}{8.1}(\ln D)^2, \tag{2}$$

where W_g is the weight (in kg) of green culms in the clump, W_a the weight (in kg) of all culms in the clump including the dry ones in green weight equivalent, D the clump-diameter (in m) and ln stands for the logarithm with *base e*.

The clump-diameter of a bamboo clump can be measured as explained in the methodology. If the commercial weight of green culms alone in the clump is required, equation (1) can be used. If the commercial weight of all culms including the dry ones in green weight equivalent is required, equation (2) can be used. Thus from the clump-diameter, the commercial weight of the clump can be estimated with reasonable accuracy. Based on equations (1) and (2), commercial weight tables were generated for different clump-diameters. Tables 1 and 2 represent the commercial weight tables for green culms and all culms respectively. In Tables 1 and 2, the clump diameter is given in metres and the weight in metric tonnes. The commercial

Table 1.
Clump diameter (D, in m) and commercial weight of green culms (W_g, in metric tonnes)

D	W_g	D	W_g	D	W_g	D	W_g	D	W_g
1.0	0.32	2.9	2.18	4.8	4.37	6.7	6.55	8.6	8.67
1.1	0.39	3.0	2.30	4.9	4.49	6.8	6.67	8.7	8.78
1.2	0.47	3.1	2.41	5.0	4.60	6.9	6.78	8.8	8.89
1.3	0.55	3.2	2.52	5.1	4.72	7.0	6.89	8.9	8.99
1.4	0.63	3.3	2.64	5.2	4.83	7.1	7.00	9.0	9.10
1.5	0.72	3.4	2.75	5.3	4.95	7.2	7.12	9.1	9.21
1.6	0.82	3.5	2.87	5.4	5.06	7.3	7.23	9.2	9.32
1.7	0.91	3.6	2.98	5.5	5.18	7.4	7.34	9.3	9.43
1.8	1.01	3.7	3.10	5.6	5.29	7.5	7.45	9.4	9.53
1.9	1.11	3.8	3.21	5.7	5.41	7.6	7.56	9.5	9.64
2.0	1.21	3.9	3.33	5.8	5.52	7.7	7.67	9.6	9.75
2.1	1.31	4.0	3.44	5.9	5.64	7.8	7.79	9.7	9.86
2.2	1.42	4.1	3.56	6.0	5.75	7.9	7.90	9.8	9.96
2.3	1.52	4.2	3.67	6.1	5.87	8.0	8.01	9.9	10.07
2.4	1.63	4.3	3.79	6.2	5.98	8.1	8.12	10.0	10.18
2.5	1.74	4.4	3.91	6.3	6.10	8.2	8.23	10.1	10.28
2.6	1.85	4.5	4.02	6.4	6.21	8.3	8.34	10.2	10.39
2.7	1.96	4.6	4.14	6.5	6.32	8.4	8.45	10.3	10.49
2.8	2.07	4.7	4.25	6.6	6.44	8.5	8.56	10.4	10.60

Table 2.
Clump-diameter (D, in m) and commercial weight of all culms (W_a, in metric tonnes)

D	W_a	D	W_a	D	W_a	D	W_a	D	W_a
1.0	0.39	2.9	2.38	4.8	4.75	6.7	7.14	8.6	9.47
1.1	0.47	3.0	2.50	4.9	4.88	6.8	7.26	8.7	9.59
1.2	0.55	3.1	2.62	5.0	5.00	6.9	7.39	8.8	9.71
1.3	0.64	3.2	2.75	5.1	5.13	7.0	7.51	8.9	9.83
1.4	0.73	3.3	2.87	5.2	5.25	7.1	7.64	9.0	9.96
1.5	0.82	3.4	2.99	5.3	5.38	7.2	7.76	9.1	10.08
1.6	0.92	3.5	3.12	5.4	5.51	7.3	7.88	9.2	10.20
1.7	1.02	3.6	3.24	5.5	5.63	7.4	8.01	9.3	10.31
1.8	1.12	3.7	3.37	5.6	5.76	7.5	8.13	9.4	10.43
1.9	1.23	3.8	3.49	5.7	5.88	7.6	8.25	9.5	10.55
2.0	1.34	3.9	3.61	5.8	6.01	7.7	8.38	9.6	10.67
2.1	1.45	4.0	3.74	5.9	6.14	7.8	8.50	9.7	10.79
2.2	1.56	4.1	3.87	6.0	6.26	7.9	8.62	9.8	10.91
2.3	1.67	4.2	3.99	6.1	6.39	8.0	8.74	9.9	11.03
2.4	1.79	4.3	4.12	6.2	6.51	8.1	8.87	10.0	11.15
2.5	1.91	4.4	4.24	6.3	6.64	8.2	8.99	10.1	11.26
2.6	2.02	4.5	4.37	6.4	6.76	8.3	9.11	10.2	11.38
2.7	2.14	4.6	4.50	6.5	6.89	8.4	9.23	10.3	11.50
2.8	2.26	4.7	4.62	6.6	7.01	8.5	9.35	10.4	11.62

weight of green culms and that of all culms (including the dry ones in green weight equivalent) in a bamboo clump can be directly obtained by referring the weight tables for the known value of the clump diameter.

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