*J. Bamboo and Rattan*, Vol. 4, No. 1, pp. 33–39 (2005)

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# Biomass estimation of *Bambusa tulda* grown at Eastern Terai, Nepal

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**Abstract**—With a view to prepare biomass tables of *Bambusa tulda* grown at Belbari, Morang district of Eastern Nepal, a total of 153 culms was selected from 59 clumps. Measurements of diameter at 15 cm of the base ($D_{15}$), vertical height of the culm, green weight of the culm, branches and foliage were taken in the field. The samples were oven dried in laboratory at Kathmandu. To estimate the biomass, a regression model was developed on the basis of oven dry and green weight. The model used was $W = a + b \times (D^2L)$. Based on the oven dry weight, the $R^2$ values were obtained for culm, branch and foliage components, which were 92, 81 and 83%, respectively. Similarly, $R^2$ values for culm and foliage components on the basis of green weight were 92 and 82%, respectively. The $R^2$ values obtained for branch and foliage components were slightly lower as compared to the culm. This equation could be useful in estimating bamboo biomass of managed natural stands or plantations in similar site conditions.

*Key words*: Biomass; bamboo; *Bambusa tulda*; Nepal.

## INTRODUCTION

Bamboos are the most widely used products, as they are used every day by about 2.5 billion people in the world [1]. In Nepal, they are one of the most common plant species grown on farmland [2]. People perceive this species as an alternate to timber tree species. Moreover, it is also considered as an important component of livelihood strategies of the rural households [2]. With its varied uses such as construction materials, woven products, agricultural implements, fodder, vegetables and scaffolding and in stabilizing slip-prone slopes, bamboos are in great demand by the rural households in Nepal. Occurrence of bamboo is more common in the eastern half of the country from Dhaulagiri to the Sikkim border, as high as 4000 m [3]. In Nepal, so far 12 genera and more than 50 species of bamboo have been recorded [4]. Out of the 75 districts of Nepal, 73 are known to have one

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or more species of bamboo. It has been estimated that the total growing stock of bamboo in Nepal is around 15 million $m^3$ with an approximate biomass value of 1060 million tons [5].

*Bambusa tulda* is occasionally found in the Terai region of Nepal, especially around the Chitwan district of the Central region. It has strong upright culms, but some are very short crooked, with swollen nodes and with heavy branches. Such culms reach a maximum diameter of 7 cm and a length of 15 m, although they are often smaller. As they are very thick-walled, they are used for construction purposes. Leaves can be used for fodder and the shoots are not edible [3].

Despite the multiple benefits obtained from bamboos, limited documentation has been published on the biomass production potential. On the basis of oven dry and green weight, a biomass table of *B. nutans* subspecies *nutans* has been prepared [6]. Previous studies focused more on distribution, growth performance and culm production aspects. At 4.5 years age, the average diameter, height and survival of plants at Belbari of Morang district were 4.2 cm, 8.7 m and 67%, respectively [7]. As there is a growing demand of bamboo products in the country, information on the estimation of biomass would be beneficial for managing the bamboo resources. This paper records information on biomass of *B. tulda*, useful to forestry professionals, private growers and other interested parties.

## MATERIALS AND METHODS

The Department of Forest Research and Survey conducted a trial on establishment and management of bamboo at Belbari, Morang district of eastern Nepal in 1991. *B. nutans* subspecies *nutans* (Taru Bans), *B. nutans* subspecies *cupulata* (Mal Bans), *B. tulda* (Japhta Bans), *B. balcooa* (Dhanu Bans) and *Dendrocalamus giganteus* (Rakshasi Bans) were planted at Belbari [7]. Of the 5 bamboo species planted, *B. tulda* was selected for the study. The reason for selecting this species for biomass estimation was its varied use and wide occurrence in Nepal and lack of comprehensive documentation on biomass estimation of the species.

The site is located at an altitude of 155 m above sea level (asl) and the soil is loamy to silt loam in nature. There was Sal (*Shorea robusta)* forest 3 to 4 years before the establishment of the trial. The average annual rainfall is 1737 mm and average maximum and minimum temperature are 30°C and 18.2°C, respectively [8]. The plants produced from single node culm cuttings taken from Sunsari district of eastern Nepal were the source of materials for planting. The cuttings were propagated in the Tarahara nursery located at Sunsari district, before they were taken for planting site at Belbari. Soil heaping was carried out in each clump in 1993 and the oldest culms were cut and removed in the winter of 1996 [7]. The age of the culms was estimated with the help of watchers who have been working at the research plot since its establishment.

The age of all the clumps is 12 years, since it was established in 1991. Fifty-nine clumps comprising culms of varying age (from 1 to 12 years) and diameter classes ($D_{15}$ from 4 to 12 cm) were chosen. The total number of culms from each clump was counted. From each clump, at least 2 culms of various age and diameter classes totalling 153 were cut 15 cm from the ground for the study. Measurements of diameter at 15 cm of the base ($D_{15}$), vertical height of the culm, green weight of the culm, branches and foliage were taken in the field. Seventeen representative culms were selected for sub-samples of culm, branch and foliage. These sub-samples were brought into the laboratory in Kathmandu and oven-dried at 105°C until a constant weight was attained.

To convert the fresh weight of culm, branch and foliage components into oven dry weight, sub-sample's percentage dry matter values were used. We used the formula

$$\text{dry matter value} = ((\text{oven dry weight}/\text{fresh weight}) \times 100)$$

to obtain a conversion factor of 0.480, 0.531 and 0.359 for converting fresh weight to oven dry weight of culm, branch and foliage, respectively. Out of 153 datasets, 135 datasets were used to develop the regression equation and the remaining 18 datasets representative of all diameter classes were used for validation purposes. To estimate the biomass, a regression model was developed on the basis of oven dry weight. Biomass tables for culm and foliage were also prepared on the basis of green weight. Of the various models tested with the use of 135 datasets, the model developed was $W = a + b \times (D^2L)$, where $W$ is the weight in kg, $D$ is the diameter at 15 cm, $L$ is the vertical length of the culm, and $a$ and $b$ are the regression constants. A prediction error for oven-dried weight of culms, branch and foliage was calculated to measure the validity of the model [10]. Similarly, a prediction error was calculated for green weight of the culm, as follows:

$$\begin{aligned}\text{prediction error} = ((&\text{sum of actual weight}\\ &-\text{sum of predicted weight}/\text{sum of actual weight}) \times 100).\end{aligned}$$

## RESULTS AND DISCUSSION

### *Dry matter content*

A total of 53.1% dry matter content was found in the branch of *B. tulda*. The dry matter content values of culm and foliage are 48 and 35.9%. The dry matter content of culm, branch and foliage components of *B. nutans* subspecies *nutans* grown at the same site were 47.3, 41.1 and 38.2%, respectively [6]. The figures of dry matter content of culms and foliage of both the species were close, except for the branches where there is a big difference.

### *Biomass estimation on the basis of oven dry weight*

Using the regression model of $W = a + b \times (D^2L)$, the biomass of all the components (culm, branch and foliage) was calculated. Based on the oven-dried weight, the $R^2$ values obtained for culm, branch and foliage components were 92,

**Table 1.**
Biomass for culm on the basis of oven dry weight (in kg)

| $D_{15}$ (cm) | Height (m) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 4 | 2.52 | 2.68 | 2.84 | — | — | — | — | — | — | — | — | — | — | — |
| 5 | 2.97 | 3.22 | 3.47 | 3.72 | 3.97 | — | — | — | — | — | — | — | — | — |
| 6 | — | 3.88 | 4.24 | 4.60 | 4.96 | 5.32 | — | — | — | — | — | — | — | — |
| 7 | — | — | 5.15 | 5.64 | 6.13 | 6.62 | 7.11 | 7.60 | — | — | — | — | — | — |
| 8 | — | — | — | 6.84 | 7.48 | 8.12 | 8.76 | 9.40 | 10.04 | 10.68 | — | — | — | — |
| 9 | — | — | — | — | 9.01 | 9.82 | 10.63 | 11.44 | 12.25 | 13.06 | 13.87 | — | — | — |
| 10 | — | — | — | — | — | 11.72 | 12.72 | 13.72 | 14.72 | 15.72 | 16.72 | 17.72 | 18.72 | 19.72 |
| 11 | — | — | — | — | — | — | 15.03 | 16.24 | 17.45 | 18.66 | 19.87 | 21.08 | 22.29 | 23.50 |
| 12 | — | — | — | — | — | — | — | 19.00 | 20.44 | 21.88 | 23.32 | 24.76 | 26.20 | 27.64 |

All tables provide information on the estimated biomass of the culms, branches and foliage prepared on the basis of oven dry or green weight. The $R^2$ value of more than 90% shows the good estimation of culm biomass; less than 90% is a less reliable estimation. $a = 1.72$, $b = 0.01$, standard error $= 1.46$, $R^2 = 92\%$.

**Table 2.**
Biomass table for branch on the basis of oven dry weight (in kg)

| $D_{15}$ (cm) | Height (m) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 4 | 0.73 | 0.77 | 0.81 | — | — | — | — | — | — | — | — | — | — | — |
| 5 | 0.84 | 0.89 | 0.95 | 1.01 | 1.07 | — | — | — | — | — | — | — | — | — |
| 6 | — | 1.04 | 1.13 | 1.21 | 1.29 | 1.38 | — | — | — | — | — | — | — | — |
| 7 | — | — | 1.34 | 1.45 | 1.56 | 1.68 | 1.79 | 1.90 | — | — | — | — | — | — |
| 8 | — | — | - | 1.73 | 1.87 | 2.02 | 2.17 | 2.31 | 2.46 | 2.61 | — | — | — | — |
| 9 | — | — | — | — | 2.22 | 2.41 | 2.60 | 2.78 | 2.97 | 3.16 | 3.34 | — | — | — |
| 10 | — | — | — | — | — | 2.85 | 3.08 | 3.31 | 3.54 | 3.77 | 4.00 | 4.23 | 4.46 | 4.69 |
| 11 | — | — | — | — | — | — | 3.61 | 3.89 | 4.17 | 4.44 | 4.72 | 5.00 | 5.28 | 5.56 |
| 12 | — | — | — | — | — | — | — | 4.52 | 4.85 | 5.18 | 5.52 | 5.85 | 6.18 | 6.51 |

$a = 0.548$, $b = 0.0023$, standard error $= 0.61$, $R^2 = 81\%$.

81 and 82.5% respectively (Tables 1–3). The $R^2$ values for branch and foliage were slightly lower as compared to the culm. The prediction error calculated for oven-dried weight of culms, branch and foliage components were 4, 22 and 19%, respectively. It has been reported that prediction error of less than 15% validates the models [10]. While estimating culm biomass on the basis of oven dry weight, the prediction error is only 4%, which verifies the validity of the model. However, it would be better to test the model for estimating biomass in different site conditions.

Due to the large variation in branching pattern in similar sized culms of this species, the prediction error became higher (22%) than for the culm and foliage component. The prediction error for foliage was found to be 19%. It is argued that the prediction of leaf yield from biomass equations is less accurate and more site-

**Table 3.**
Biomass table for foliage on the basis of oven dry weight (in kg)

| $D_{15}$ (cm) | Height (m) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 4 | 0.03 | 0.05 | 0.06 | — | — | — | — | — | — | — | — | — | — | — |
| 5 | 0.07 | 0.09 | 0.11 | 0.13 | 0.15 | — | — | — | — | — | — | — | — | — |
| 6 | — | 0.14 | 0.17 | 0.20 | 0.23 | 0.26 | — | — | — | — | — | — | — | — |
| 7 | — | — | 0.24 | 0.28 | 0.32 | 0.36 | 0.40 | 0.44 | — | — | — | — | — | — |
| 8 | — | — | — | 0.38 | 0.43 | 0.48 | 0.53 | 0.58 | 0.63 | 0.69 | — | — | — | — |
| 9 | — | — | — | — | 0.55 | 0.62 | 0.68 | 0.75 | 0.81 | 0.88 | 0.94 | — | — | — |
| 10 | — | — | — | — | — | 0.77 | 0.85 | 0.93 | 1.01 | 1.09 | 1.17 | 1.25 | 1.33 | 1.41 |
| 11 | — | — | — | — | — | — | 1.03 | 1.13 | 1.23 | 1.32 | 1.42 | 1.52 | 1.61 | 1.71 |
| 12 | — | — | — | — | — | — | — | 1.35 | 1.47 | 1.58 | 1.70 | 1.81 | 1.93 | 2.04 |

$a = -0.031$, $b = 0.0008$, standard error $= 0.198$, $R^2 = 82.5\%$.

**Table 4.**
Biomass table for culm on the basis of green weight (in kg)

| $D_{15}$ (cm) | Height (m) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 4 | 5.06 | 5.36 | 5.65 | — | — | — | — | — | — | — | — | — | — | — |
| 5 | 5.89 | 6.36 | 6.82 | 7.28 | 7.74 | — | — | — | — | — | — | — | — | — |
| 6 | — | 7.58 | 8.24 | 8.91 | 9.57 | 10.24 | — | — | — | — | — | — | — | — |
| 7 | — | — | 9.93 | 10.83 | 11.74 | 12.65 | 13.55 | 14.46 | — | — | — | — | — | — |
| 8 | — | — | — | 13.05 | 14.24 | 15.42 | 16.60 | 17.79 | 18.97 | 20.16 | — | — | — | — |
| 9 | — | — | — | — | 17.07 | 18.57 | 20.06 | 21.56 | 23.06 | 24.56 | 26.06 | — | — | — |
| 10 | — | — | — | — | — | 22.08 | 23.93 | 25.78 | 27.63 | 29.48 | 31.33 | 33.18 | 35.03 | 36.88 |
| 11 | — | — | — | — | — | — | 28.20 | 30.44 | 32.68 | 34.92 | 37.16 | 39.40 | 41.63 | 43.87 |
| 12 | — | — | — | — | — | — | — | 35.55 | 38.21 | 40.88 | 43.54 | 46.20 | 48.87 | 51.53 |

$a = 3.58$, $b = 0.0185$, standard error $= 3.04$, $R^2 = 92\%$.

specific than for the components of stem, branch and total tree weight [9]. Biomass tables for culm, branch and foliage components based on oven-dried weight are presented in Tables 1, 2 and 3, respectively.

*Biomass estimation on the basis of oven dry weight*

Biomass equations are normally prepared on an oven dry weight basis to facilitate comparison with other sites, species and seasons [10]. However, bamboo culms are sold on a fresh weight basis in both the rural and urban areas of Nepal. Therefore, a biomass table for culm based on green weight was also prepared (Table 4). Bamboo leaves are used as fodder in some areas where there is fodder deficit. Leaves of *B. tulda* can be used as fodder [3]. Hence, a biomass table for foliage was also prepared on the basis of green weight (Table 5). Based on the green weight, the $R^2$ values obtained for culm and foliage components were 92 and 82%, respectively.

**Table 5.**
Biomass table for foliage on the basis of green weight (in kg)

| $D_{15}$ (cm) | Height (m) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 4 | 0.08 | 0.11 | 0.14 | — | — | — | — | — | — | — | — | — | — | — |
| 5 | 0.17 | 0.22 | 0.27 | 0.32 | 0.37 | — | — | — | — | — | — | — | — | — |
| 6 | — | 0.35 | 0.42 | 0.49 | 0.56 | 0.64 | — | — | — | — | — | — | — | — |
| 7 | — | — | 0.60 | 0.70 | 0.80 | 0.90 | 0.99 | 1.09 | — | — | — | — | — | — |
| 8 | — | — | — | 0.94 | 1.07 | 1.20 | 1.32 | 1.45 | 1.58 | 1.71 | — | — | — | — |
| 9 | — | — | — | — | 1.37 | 1.54 | 1.70 | 1.86 | 2.02 | 2.18 | 2.35 | — | — | — |
| 10 | — | — | — | — | — | 1.92 | 2.12 | 2.32 | 2.52 | 2.72 | 2.92 | 3.12 | 3.32 | 3.52 |
| 11 | — | — | — | — | — | — | 2.58 | 2.82 | 3.06 | 3.30 | 3.55 | 3.79 | 4.03 | 4.27 |
| 12 | — | — | — | — | — | — | — | 3.37 | 3.66 | 3.95 | 4.24 | 4.52 | 4.81 | 5.10 |

$a = -0.085$, $b = 0.002$, standard error $= 0.55$, $R^2 = 82\%$.

The prediction error is only 7% while estimating culm biomass on the basis of green weight. Biomass tables based on green weight for culm and foliage are given in Tables 4 and 5, respectively.

It was reported from India that total biomass of planted *B. arundinacea* (retz.) wild of 3 years age was 8528 kg/ha [11]. The total above ground biomass of *D. strictus* in India was 4–22 tons/ha [12]. On the other hand, for *B. bambos* in India the figure ranges from 122–287 tons/ha [13].

## APPLICABILITY OF THE TABLES

Considering the wide use of bamboos these days, the biomass tables may provide useful information on above ground biomass to forestry professionals, bamboo growers, forest user groups and other interested parties. Although the biomass estimation is confined to the site condition of Belbari of Morang district, it can be applied to other similar site conditions as well. While estimating culm biomass on the basis of oven dry weight, the $R^2$ of more than 90% and prediction error of only 4% verifies the validity of the model. Similarly, the prediction error of 7% for the biomass estimation of culm on the basis of green weight also verifies the validity of the model. This equation could be useful in estimating bamboo biomass of managed natural stands or plantations in similar site conditions.

On the other hand, the biomass estimation on the basis of oven dry weight of branch and foliage components gave a higher prediction error than a normal range of within 15%. Therefore, it would be better to test the model for estimating biomass in different site conditions.

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