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Research Paper

Studies on biomass production, partitioning and allometry of different bamboo (*Bamboo spp.*) plant species grown in bamboosetum in Arunachal Pradesh

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ABSTRACT

The biomass production and partitioning of 30 bamboo species were evaluated at ICAR Research Complex for NEH Region, Arunachal Pradesh Center, Basar located in the humid sub-tropic. Bamboo species were planted in a bamboosetum on the hill with 25% slope at planting density of 2l8 clumps/ha. On the basis of mean annual aboveground biomass production and annual culms production, all the species were grouped into five distinct clusters at average linkage distance of 0.6. Bamboo species grouped in cluster III viz. *B. bambos, B. balcooa, D. giganteus, B. cacharensis, B. pallida type I, B. nutans, B. tulda, D. sikkimensis, D. hookeri* were the highest annual biomass producer (494.67 ± 260.36 t/ha). Culms constituted more than 90% of total biomass in *Arundinaria hirsuta*, *A. mannii*, *B. bambos* and *B. balcooa.* Leaves and branches constitute 45% of the total biomass in *Schizostachyum polymorphum.* Biomass production in bamboo had significant ($p < 0.01$) positive correlation with culms height (0.835), rind thickness (0.654), leaf length (0.0.659) and number of internodes/culms (0.716). Culms height, rind thickness and leaf length fitted into multiple linear regression models predicted 79% variability in the annual total biomass. Culms height, rind thickness and leaf length culms spacing explained about 90% variability in single culms weight of different species.

Key words **:** Bamboo, Biomass, Biomass partitioning, Culms production, Regression models

Bamboos have an important role in the rural and tribal livelihood. They are an important building material for low cost structures and provides raw materials for paper and cottage industries (Adkoli, 1991; Tiwari, 1992). Young bamboo shoots of many species are used for preparation of fresh and fermented dishes, steroids drugs and treatment of diseases (Singh, 2002 and Singh, 2006). Bamboo also helps in making an ecosystem sustainable by increasing carbon sequestration, water, water-reuse and soil and water conservation (Anonymous, 2010). Abundant bamboos growing in degraded land on the hill slopes of the eastern Himalayan plateau hold together the loose sandy-loam soil formed from geologically young rocks, helps in slope stability, and reduce run-off and soil erosion (Toky and Ramakrishnan, 1982).

India has the world's second largest bamboo reserve with 130 species that grow in 10 million hectares of forest land, homestead gardens and private plantations (NMBA, 2004). The natural bamboo resources are dwindling due to over exploitation, gregarious flowering, shifting cultivation and extensive fires (Shanmughvel and Francis, 2001). Plantation bamboos are increasingly becoming an important resource base for meeting the future demand of bamboo timber. Area under plantations has been increasing at a fast rate in South-East Asia and other parts of the world due to increased demand of bamboo for timber and edible shoots (Anonymous, 2010).

The success of the intensive bamboo plantation depends upon the selection of species with high biomass production potential. Northeast region of the country has huge diversity in bamboo plant species, Arunachal Pradesh alone harbors 63 species. Haridashan *et al.* (1987) and Hore (1998) had documented the important bamboo species of the region, their traditional uses, management and conservation. Biomass, nutrient accumulation and dynamics of some species has been studied in chronosequence (Shanmughavel *et al.*, 2001), but comparative performance for biomass production of different species found in the region has not been studied. Therefore, there is a need to evaluate different bamboo species of the region for biomass production and its partitioning in different plant parts under plantation conditions. Arunachal Pradesh center of the ICAR Research Complex for North Eastern Hill (NEH) Region is addressing these

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challenges through collection and evaluation of different bamboo species under plantation conditions in bamboosetum. The objectives of present study were to (1) evaluate the performance of 30 species of bamboos collected from different Himalayan states of India for aboveground biomass production and partitioning in different plant parts and (2) to characterize the biometric parameters of different bamboo species and developing allometric relationship for determination of aboveground biomass. Main objective was to record biometric data for assessing their behavior and evolving the selection criteria of choice species for timber production and developing non-destructive method for aboveground biomass estimation

MATERIALS AND METHODS

A long term study was started at the ICAR Research Complex for NEH Region, Arunachal Pradesh Center, Basar, India (27°95´N and 94° E) with an elevation of 660m above mean sea level (msl), during July 1988. The climate of experimental site is humid subtropical with a mean annual rainfall of 2,370 mm, distributed over a period of about 150 days. Most of the rainfall is received during the south-west monsoon (April - October). The mean maximum temperature ranges from 12.7°C (January) to 39°C (July -September) and mean minimum temperature varies from 3.3°C (February) to 28.3°C (August). The natural vegetation comprises of wet evergreen and tropical moist deciduous forests. The soil of experimental site was clay loam with udic soil moisture regime and hyperthermic soil temperature regime (Table 1). The particle size analysis was carried out by the international pipette method (Piper, 1996) using sodium- hexa-meta-phosphate as a dispersing agent. The textural class was determined using USDA textural triangle. The soil pH in soil: water (1:2.5) suspension was determined using glass electrode pH meter (Jackson, 1958). Organic C was analysed by Walkley and Black dichromate oxidation method, available P by Brays II extractant and the exchangeable cations and available micronutrients in the DTPA extract were determined using the standard procedure (Page *et al.*, 1982)

Table 1. Physico-chemical properties of the soil at study sites

Soil parameters	Values*
Soil pH (1:2.5 : Soil: Water suspension)	3.82
Organic carbon (%)	1.65
Available P (Brays P-II) (kg/ha)	4.1
Exchangeable K (kg/ha)	473
Exchangeable calcium (kg/ha)	180
Exchangeable Mg (kg/ha)	92
Available Zn (kg/ha)	2.71
Available Cu (kg/ha)	2.64
Available Mn (kg/ha)	98.12
Available Fe (kg/ha)	336.6
Soil texture	Clay loam

*Mean of composite soil sample at the time of planting

The rooted slips of 30 bamboo species namely *Arundinaria hirsuta*, *A. mannii*, *Bambusa bambos, B. balcoa, B. cacharensis, B. multiplex, B. nana, B. nutans, B. pallida* Type I, *B. pallida* Type II, *B. polymorpha*, *B. tulda*, *B. striata*, *B. wamin*, *Chimonobambusa armata*, *C. callosa*, *C. griffithiana*, *Dendrocalamus asper*, *D. giganteus*, *D. hamiltonii*, *D. hookerii*, *D. longispathus*, *D. sahnii*, *D. sikkimensis*, *Phyllostachys assamica*, *P. manni*, *P. pubescens*, *Schizostachyum pergracile*, *S. polymorphum* and *S. helferii* were collected from different locations (Table 2) and were planted in pits of 60 cm × 60 cm × 60 cm size in the bamboosetum during monsoon (July) of 1988-90. Five rooted slips of each species as one treatment were planted randomly in each block following randomized complete block design and they were in two replicated plots for each treatment unit. The inter and intra row spacing was 6 m giving a planting density of 278 clumps/ha. The only cultural operation applied to the experimental site was the manual weeding in the inter-row spaces every rainy season during the initial (5 years) growth period to check the growth of weeds. Biomass was determined by harvesting the matured culms every year. Harvesting of the matured culms started 6 years after planting and continued up to 14 years. At first harvest, all the matured culms (>3 years old) were harvested, thereafter, annually, culms >3 years old were harvested every December. Three clumps of each bamboo species were selected randomly from each replication for estimation of biomass production and partitioning into different above ground parts. Total number of culms and cumulative biomass produced per clump were recorded up to 14 year after planting. For biomass estimation two culms were harvested randomly from each clump at each harvesting; thus, 6 culms were harvested from each replication for all the 30 bamboo species. Each sampled culms were separated into stem, branches and leaves parts and their respective fresh weights were recorded. Sub samples of each component were oven dried at 70°C to a constant weight to calculate the dry matter of each component. Culm, branch and leaf biomass was determined from their respective dry weight to fresh weight ratio. Summing all the biomass components yielded the above ground total (leaves + branches + culms) dry biomass of each culm. The mean total biomass per culms in each bamboo was further extrapolated to biomass production on per hectare scale based on the number of culms produced. Three representative culms of each species were selected from each replication at the time of last harvest. Culms height (from ground to the tip of the culms at the top), length of internodes, girth of the internodes at breast height and number of internodes were recorded. Rind thickness and hollowness of the culms were also recorded at breast height. Five leaves each from lower and upper canopy of the selected culms were sampled and the longest measure (cm) along the length and width was recorded. Clump circumference and distance between two culms at 5th node were recorded at harvest to assess the spread of the clump and crowdedness of the culms, respectively.

All the statistical analyses were conducted using SAS 9.2 (2009). Mean annual biomass production, number of culms year^{-1} and biometric parameters were analyzed using standard statistical techniques to obtain the mean, standard deviation and coefficient of variation. The following data transformations were performed to give normal distributions for each variables: (1) leaf width and culm dry weight was log transformed after addition of 1; (2) culm spacing at 5th node, number of internodes/culm, internodes length, leaf weight/culm, branch weight/culm, annual culm dry matter production and annual total dry matter production were log transformed. The correlation was worked out to find out the relationship between culm characteristics, clump circumference, culm spacing and biomass production. Stepwise regression model selection based on R^2 maximization and Bayesian information criteria were used to identify the variable(s) capable of explaining the variability in annual biomass production and weight of a single culm. Cluster analysis was done to group the bamboo species using log transformed values of annual biomass and number of culms production data by Average Linkage Cluster Analysis method.

RESULTS AND DISCUSSION

Culms characteristics and biomass production

This study used the bamboo species from the sub Himalayan regions of India to examine the biomass accumulation and partitioning under plantation in bamboosetum. Annual biomass and culms production varied among the bamboo plant species, 64.69 and 127.69% variability was observed for number of culms and biomass produced, respectively. Statistical analysis indicated large variation for other biometric parameters (Table 2). The observed variability for leaf width (55.8%) and culms height (54.25) was highest amongst the culms. The leaf length and width of different species were in the range of 7.8 - 29.9 cm and 0.83 - 5.61 cm, respectively. Culms height varied in the range of 2.09 - 19.38 m (Table 2). Number of internodes and length of internodes were in the range of 10-57 and

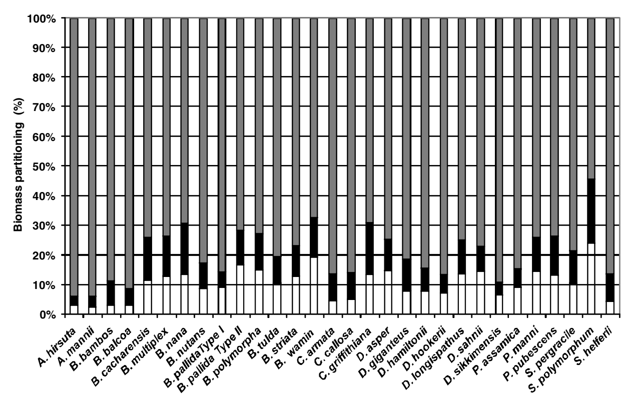

Fig. 1. Biomass partitioning in different bamboos plant species planted under acid soil conditions of NEH Region in India. (Lower, middle and upper portions of the bars indicates partitioning in leaf, branch and culms respectively)

Table 2. Summary statistics for biometric parameters of bamboo species

Variable	Mean	Std Dev	Min-Max	CV%
Culm variables				
Leaf length (cm)	17.81367	6.52541	7.80-29.90	35.96
Leaf width (cm)	2.41333	1.34729	0.83-5.61	55.83
Culm height (m)	9.70767	5.26442	2.09-19.38	54.23
Number of internodes/culm	28.13333	11.02578	10.00-57.00	38.78
Internodes length (cm)	29.49000	11.17819	9.50-46.50	37.91
Rind thickness (cm)	0.47433	0.21257	0.12-0.87	44.31
Internodes girth (cm)	11.39000	5.12643	3.10-23.40	45.5
Hollowness (cm)	3.13900	1.46199	0.29-6.59	46.63
Annual culms production (no./ha/year)	14835	9597	3928-42857	64.69
Clump variables				
Clump circumference (m)	7.56667	3.15684	1.50-16.75	42.53
Culm spacing at 5th node (cm)	26.18333	11.19775	4.00-65.00	42.72
Biomass variables				
Leaf dry weight (kg/culm)	1.20800	1.18447	0.05-4.80	98.05
Branch dry weight (kg/culm)	1.30333	1.37642	0.04-6.40	105.61
Culm dry weight (kg/culm)	12.63367	14.55785	0.16-49.60	115.23
Annual culm dry matter production (t/ha/year)	163.01583	218.58403	1.76-821.57	134.12
Annual total biomass production (t/ha/year)	191.88633	248.13122	2.38-924.43	127.69

9.5-46.5 cm, respectively. Rind thickness, girth of internodes and hollowness of stem varied in the range of 0.12-0.87, 3.1-23.4 and 0.29-6.59 cm, respectively. Variability in clump circumference (1.5 to 16.8 m) and culms spacing (4-65 cm) was 43% (Table 2). Considerable variations observed for various culms, clump and biomass variables were mainly due to inherent characteristics of different bamboo species. The maximum culms height observed was in the range of the values reported for natural forest comprising *Dendrocalamus* and *Bambusa* genera in the NEH region of India (Arunachalam and Arunachalam, 2001).

Cluster analysis using cumulative culms number and total biomass produced was carried out and all the natural clusters were created without applying stopping rule (Fig. 2). The Annual biomass accumulation in various species ranged from 2.4 to 924.4 t/ha (Table 3) Biomass production of the species grouped in cluster-III *viz. B. bambos*, *B. balcooa D. giganteus, B. cacharensis, B. pallida type I, B. nutans, B. tulda, D. sikkimensis* and *D. hookerii* were highest (494.67±260.36 t/ha) and the lowest in bamboo species of cluster-II (5.94±2.74 t/ha) *viz. B. wamin, P. pubescens, S. polymorphum* and *P. manii*. The mean annual biomass production in bamboo species grouped in clusters III and IV shows vast genetic potential of these genotypes in the growing condition at the experimental site. The average biomass production of the different bamboo species was found to be higher in comparison to the earlier reports for *B. bambos* (Shanmughavel and Francis, 1995; Kumar *et al*., 2005), *P. pubescens* (Isagi *et al*., 1997), *Dendrocalamus* spp. (Christanty *et al*., 1996), mixed bamboo stand of *B. balcooa, B. cacharensis* and *B. vulgaris* (Nath *et al*., 2009). Difference in biomass production in the present study from the earlier reports for different species may be due to the differences in the culms size, culms height, culms density and different environmental conditions. Higher number of the culms/ha observed in present study also corroborate with this hypothesis. In bamboosetum, favourable growing conditions and periodical harvesting of matured culms also promoted more culms recruitment and stabilized culms population structure in each clump, resulting in higher biomass production.

Varying degree of prolificacy in culms recruitment was observed amongst the species selected for this study. Bamboo species in cluster-I produced highest number of culms. The average numbers of culms produced by the species in cluster-I were 1.8-5.3 times higher than the species in other clusters (Table 3). Cluster I represent the bamboo species associated with highest number of culms and low biomass production. Cluster II represents the species with lowest number of culms and biomass production. Cluster III is of medium number of culms with highest biomass production. Cluster IV and V shows medium

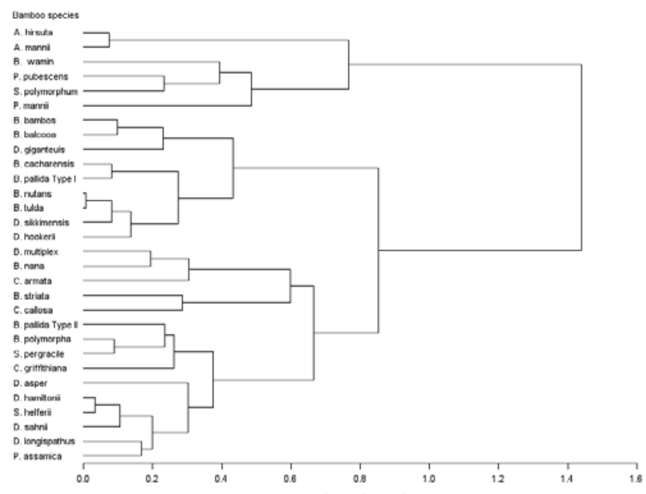

Fig. 2. Clustering pattern of different bamboo plant species based on annual culms number and biomass production

Table 3. Mean annual culms number and biomass production (oven dry weight basis) by different bamboos species

Cluster number	Bamboo species	Culm number (culm/ha) Mean	Culm number (culm/ha) Min -Max	Biomass production (t/ha) Mean	Biomass production (t/ha) Min -Max
I	*A. hirsuta, A. mannii,*	39286±5007	35714-39286	7.29	7.29*
II	*B. wamin, P. pubescens, S. polymorphum, P. mannii*	7450±3314	3929-11928	5.94±2.74	2.38-8.82
III	*B. bambos, B. balcooa, D. giganteus, B. cacharensis, B. pallida type I, B. nutans, B. tulda, D. sikkimensis, D. hookeri*	14309±3668	9289-21429	494.67±260.36	212.84 - 924.42
IV	*B. multiplex, B. nana, C. armata, B. striata, C. callosa,*	21929±10807	7500-34285	39.32±23.64	17.43-75.07
V	*B. pallida type II, B. polymorpha, S. pergracile, C. griffithiana, D. asper, D. hamiltonii, S. helferii, D. sahnii, D. longispathus, P. assamica,*	9829±3629	4857-15286	111.96±40.74	50.44-177.28
	Cv		64.69		127.69

number of culms with medium biomass production (Table 3). Kochchar *et al*. (1994) made similar observation on the behavior of culms production in several *Arundinaria*, *Bambusa, Chimonobambusa, Pseudostachyum* and *Dendrocalamus* species in the northeastern region. Arunachalam and Arunachalam (2001) also observed that under natural forest regenerated on abandoned *Jhum* land, total number of culms per plant was 5 times more in *B. nutans* than in the *B. bambos*.

Biomass partitioning

Biomass structure of different species is shown in fig 1. Culms represented major proportions of the total biomass in 13 species *viz. A. hirsuta* (96%), *A. mannii* (96), *B. bambos* (88%), *B. balcooa* (92%), *B. nutan* (83%), *B. pallida* Type-I (86%), *B. tulda* (81%), *D. giganteus* (82%), *D. hamiltonii* (85%), *D. hookerii* (87%), *D. sikkimensis* (89%), *P. assamica* (85%) and *S. helferii* (86%). *S. polymorphum, B. wamin* and *C. griffithiana* showed only 54, 68 and 69% of total biomass in culms. *S. polymorphum* (26%), *B. wamin* (19%) and *B. pallida* Type II (16.5%) had highest biomass in leaves. Biomass in branches were maximum in *S. polymorphum* (30%) followed by *C. griffithiana* (18%) and *B. nana* (16%). Different pattern of biomass allocation towards leaves, branches and culms observed in the present study can be attributed to the inherent characteristics of bamboo species. Pattern of biomass partitioning observed in *A. hirsuta*, *A. mannii*, *B. bambos*, *B. balcooa*, *B. nutan*, *B. pallida* Type-I, *B. tulda*, *D. giganteus*, *D. hamiltonii*, *D. hookerii*, *D. sikkimensis*, *P. assamica* and *S. helferii* were similar to the values reported earlier for *B. bambos* (Shanmughavel and Francis, 1996; Shanmughavel *et al*., 2001; Kumar *et al*., 2005) *B. bambos*, *B. cacharensis* and *B. vulgaris* (*Nath et al.*, 2009) and *Yushania alpina* (Embaye *et al*., 2005).

Correlation analysis of bamboos biometric parameters

Annual total biomass production and annual culms dry matter production showed significant ($p < 0.01$) correlation ($r > 0.8$) with culm height, dry weight of leaves, branches and culms (Table 5). There was also significant ($p < 0.01$) positive correlation between culms weight and culms variables such as culms height ($r < 0.8$), rind thickness ($r > 0.7$), internodes girth ($r > 0.7$), hollowness ($r > 0.7$), internodes length ($r > 0.6$) and internodes number ($r > 0.7$). The significant correlations were also observed between culms height and either number of internodes, or hollowness. Clump circumference and culms spacing had non-significant correlation coefficient with culms characteristics but clump circumference significantly ($p = 0.05$) affected the culms weight and annual (culms and total) biomass production ($r > 0.4$). Culms spacing significantly ($p = 0.05$) affected the leaf, branch and culms weight ($r > 0.37$).

Biomass of the culms showed positive correlation with culms characteristics such as culms height, number and length of internodes, rind thickness and internodes girth (Table 4). These observations were in conformity with the earlier reports stating internodes volume as more suitable criteria for selection than the internodes length or culms diameter alone (Kochhar *et al*., 1994). Biomass production depends on the size of the clumps due to its effect on the number of culms production (Kumar *et al*., 2005). The significant positive correlation observed between biomass

Table 4. Correlation matrix of the biometric parameters and biomass accumulation in different bamboo species

	1#	2	3	4	5	6	7	8	9	10	11	12	13	14
2	0.610**													
3	0.323^{ns}	0.558**												
4	0.630**	0.764**	0.722**											
5	0.718**	0.760**	0.531**	0.894**										
6	0.307^{ns}	0.354^{ns}	0.210^{ns}	0.229^{ns}	0.341^{ns}									
7	0.927**	0.479**	0.287^{ns}	0.596**	0.714**	0.234^{ns}								
8	0.363*	0.704**	0.543**	0.518**	0.386*	0.329^{ns}	0.240^{ns}							
9	0.543**	0.651**	0.391*	0.394*	0.437*	0.280^{ns}	0.442*	0.353^{ns}						
10	0.766**	0.741**	0.545**	0.796**	0.773**	0.246^{ns}	0.707**	0.523**	0.585**					
11	0.672**	0.806**	0.727**	0.814**	0.783**	0.360^{ns}	0.609**	0.637**	0.564**	0.912**				
12	0.695**	0.891**	0.709**	0.805**	0.773**	0.363*	0.585**	0.719**	0.658**	0.890**	0.941**			
13	0.630**	0.835**	0.637**	0.667**	0.686**	0.449*	0.507**	0.709**	0.701**	0.798**	0.880**	0.944**		
14	0.659**	0.835**	0.654**	0.679**	0.694**	0.435*	0.533**	0.716**	0.696**	0.816**	0.893**	0.953**	0.992**	
15	0.185^{ns}	0.318^{ns}	0.302^{ns}	0.178^{ns}	0.119^{ns}	0.324^{ns}	0.167^{ns}	0.332^{ns}	0.305^{ns}	0.374*	0.393*	0.414*	0.323^{ns}	0.333^{ns}

1 -Leaf length (cm); 2 - Culm height (m); 3 - Rind thickness (cm); 4-Internodes girth (cm); 5-Hollowness (cm); 6-Clump circumference (m); 7- log Leaf width (cm); 8-log (Number of internodes/culm); 9- log Internodes length (cm); 10- log Leaf dry weight (kg/culm); 11- log Branch dry weight (kg/culm); 12- log culm dry weight (kg/culm); 13- log annual culm dry matter production (t/year); 14- log annual total biomass production (t/year); 15- log Culm spacing at 5th node (cm).

ns-nonsignificant; * significant at $p < 0.05$; ** significant at $p < 0.01$

Table 5. Relationship between log culm weight/culm and biometric parameters of bamboos as shown by stepwise regression using data from 30 bamboo species

Model	Intercept	Culm height (m)	Rind thickness (cm)	Leaf length (cm)	R^2	ÄR^2
1	-0.029±0.096^{ns}	0.091±0.008***			0.7948	-
2.	-0.227±0.0.098*	0.073±0.0.009***	0.776±0.219**		0.8596	0.0649
3	-0.446±0.11***	0.057±0.009***	0.791±0.190***	0.02±0.006**	0.8985	0.0388

ns-non-significant; * significant at p=0.05; ** significant at p=0.01; *** significant at p<0.01

Table 6. Relationship between log annual total biomass yield (t/ha) and biometric parameters of bamboos as shown by stepwise regression using data from 30 bamboo species

Model	Intercept	Culm height (m)	Rind thickness (cm)	Leaf length (cm)	R^2	ÄR^2
1	0.762±0.155***	0.113±0.014***			0.6979	-
2	0.528±0.174**	0.092±0.015***	0.914±0.389*		0.7490	0.0512
3	0.242±0.211^{ns}	0.072±0.017***	0.935±0.366*	0.027±0.012*	0.7867	0.0377

ns-non-significant; * significant at p=0.05; ** significant at p=0.01; *** significant at p<0.01

production and clump circumference was also in conformity with these findings. The spacing between the two culms facilitating the extraction of the bamboo from the clump represents the crowdedness of the clump. More culms spacing favours the higher leaf, branch and culms weight of the single culms, resulting significant positive correlation between these parameters (Table 4).

Allometric equations

Stepwise generation of multiple linear regression models enabled the assessment of the bamboos biometric parameters for predicting biomass accumulation of different bamboo species (Tables 5 and 6). Different allometric equations developed explained up to 79 and 90% variability in annual total biomass and culms weight, respectively (Table 5 and 6). Inclusion of the culms height, rind thickness and leaf length in both the sets of the models showed general importance of these parameters in explaining the variability in biomass accumulation by different bamboo species. Culms height, rind thickness and leaf length explained about 90% variability in single culms weight of different species. Culms height alone explained 79% variability; inclusion of rind thickness and leaf length further increased the predictability of the model by 6 and 3%, respectively (Table 5). The regression results also showed that 79% variability in the annual total biomass produced in the plantation was explained by culms height, rind thickness and leaf length (Table 6). These models generated modestly accurate predictions for biomass accumulations in different bamboo species. These results suggest that while gross differences in culms height account for gross differences in biomass production of different bamboo species, properties such as rind thickness and, leaf length play a role in determining biomass of the single culms, which significantly impacted the annual total biomass production (r = 0.953, P < 0.01) (Table 5).

B. bambos, *B. balcooa* and *D. giganteus* has very high potential of biomass production. These species can find place in the bamboo plantation in the region. Other species of the choice for timber production are *B. cacharensis, B. pallida type I, B. nutans, B. tulda, D. sikkimensis* and *D. hookerii*. Culms height, rind thicknesses and leaf are important attributes for determining the aboveground biomass production in different bamboo species. Future studies involving testing of the bamboo species for timber production potential in other locations encompassing the entire agro ecosystem will help in identification of the site specific suitability of different bamboo species.

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