12th World Bamboo Congress

Taiwan, 18-22 April, 2024

www.worldbamboo.net

A study on carbon sequestration potential of *Bambusa balcooa* through above ground biomass estimation in Uttarakhand: A Himalayan state of India

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Abstract

The carbon sequestration potential of *Bambusa balcooa* was evaluated in the Uttarakhand state of India. Estimation of above ground biomass was done using a linear regression model. As length and girth of culm are the main contributing parameters for the weight, three independent variables, length of culm, girth at the height of 1m and 1.5 m were taken in the linear regression equation. Above ground biomass was estimated on a fresh and dry weight basis. For dry weight estimation shade drying was done until a constant weight was achieved. The plantation was done in the year 2010 on a hill slope. In the year 2014, above ground biomass was recorded as 6.72 t ha^{-1} through harvesting of the poles whereas through regression it was estimated as 38.66, 100.98 & 223.00 t ha^{-1} on dry weight basis at three years interval in the years 2017, 2020 and 2023 respectively. The percentage increment in carbon sequestration was recorded as 475.3, 161.2 and 120.8 in the 3rd, 6th and 9th years respectively. The correlation study revealed a positive correlation of fresh and dry weight with culm height, girth at 1.0 & 1.5m. A negative correlation was observed between culm height and girth at 1.5m with decrease in dry weight over fresh weight.

Keywords carbon sequestration; *Bambusa balcooa*, Uttarakhand; biomass; correlation

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1. Introduction

The Himalayas are the world's longest and highest mountain range. The range is over 2,500 km long and 400 km wide. It includes most of Nepal, Bhutan, south Tibet and the extreme north of India. The Himalayan range is extremely sensitive to climate change and there is a great pressure on the forests in the rural areas for timber and fodder. India greatly depends on the Himalayan region for its forest's reserves. As a natural resource, bamboo not only plays a major role in the livelihood of rural people and industry but also has an important role in mitigating the impact of climate change. Bamboo species are astonishing for their biomass accumulation and therefore, sequester more carbon by removing CO_2 from the environment. Bamboos occur in a wide range of about 70 genera and more than 1000 species in the world (Gratani et al. 2008). India is second largest in the world in bamboo resources. 130 species belonging to 18 genera are found in India (Sharma 1987). *Bambusa*, large genus of clumping bamboos has many various species world-wide. *Bambusa balcooa* and *B. tulda* are two abundant tropical species and recognized as priority bamboo species by FAO (www.unep-wcmc.org, www.inbar.int) amongst eighteen other spp. (Shalini et al. 2013). *B. balcooa*, one of the strongest species is preferred mostly for construction purposes. It is the tallest bamboo with maximum girth of culms and rind thickness. The species is also valued for its edible tender shoots for food and pickle industry (Mudoi & Borthakur 2009). As it is extremely sturdy, *B. balcooa* is an important species in biomass production studies for its characteristic biometric parameters.

Biomass accumulation, carbon storage, net production and nutrient cycling in various species of bamboo have been reported by many groups in India (Choudhury et al. 2015; Nath & Das 2011; Nath et al. 2009, 2008; Kumar et al. 2005; Shanmughavel & Francis 2001) and abroad (Yen 2016; Chen et al. 2009; Isagi et al. 1997). In the mid Himalayan region, evaluation of above ground biomass produced by *Dendrocalamus asper* was studied on fresh and dry weight basis for two aspects (hill top and river bank) in a two-year-old plantation (Agarwal & Purwar 2009). Other studies in the mid Himalayan region were also conducted on various bamboo species. Use of bamboo as an alternative resource in sustaining the Himalayan ecosystem (Agarwal 2014), evaluation of altitudinal variation in carbon sequestration by micropropagated *D. asper* in the mid Himalayan region of India (Agarwal & Purwar 2015), estimation of carbon in young micropropagated plants of *D. asper* (Agarwal & Purwar 2016) and carbon sequestration potential of important Bambusa spp., *Dendrocalamus strictus* and *Phyllostachys nigra* in the Uttarakhand state of India (Agarwal & Purwar 2012, 2017 & 2018) has been reported.

The present study was conducted to evaluate the potential of carbon sequestration through above ground biomass by a very promising species of bamboo viz. *B. Balcooa* in the Himalayan state of Uttarakhand in India.

2. Material and Methods

The study was conducted during 2010-2023 at the Agriculture Research Station, Majhera, located in the Nainital district in Uttarakhand, India. The research station is situated at an altitude of 905m (a.s.l) on latitude 29°30.137'North and longitude 79°28.784'East. Plantation of *B. balcooa* was done on the hill slope of ARS, Majhera in the year 2010. Plantation was done with standard agronomic practices. Plant to plant spacing was maintained at 5 X 5m in a replicated manner. Average height of the plants at the time of plantation was 50-100 cm. One plant was considered as one replication and nine replications were maintained.

Sampling for the multiple regression model was done in the month of November 2014 after the plant had gained a stable growth regime. Three culms from three clumps with varying height and thickness were randomly selected. They were harvested by felling them at above the first node. Total length, girth of culms at 1.0 and 1.5m, fresh and dry weight was recorded. For dry weight estimation shade drying was done until a constant weight was achieved. On the basis of fresh and dry weight, linear regression equations were developed for the estimation of above ground biomass (Singh et al. 2009).

For the non-destructive estimation of AGB (on dry weight basis), length and girth of culms at 1.0m and 1.5m was recorded along with total number of culms in the years 2017, 2020 and 2023. In each clump, data of three culms was used for the estimation of above ground biomass (kg Pole^{-1}) through linear regression equations (Table 1). Biomass accumulation per clump was extrapolated to per ha basis by multiplying with 400 with a spacing of 5 X 5 m.

Carbon content estimation was done on the basis of 50 per cent of the total above ground biomass produced (Scurlock *et al*., 2000).

3. Results and Discussion

Model for the prediction of above ground biomass in *B. balcooa* was developed. With the help of this model, estimation of above ground biomass produced by *B. balcooa* at three-year interval (2017, 2020 and 2023) was done. The results indicated change in biomass on the basis of fresh and dry weight. The multiple regression study indicated that above ground biomass of *B. balcooa* depended on length of culm, girth to height at 1.0m & 1.5m by 99 and 98 per cent on fresh and dry weight basis. This study explained that the length of culm was directly proportional to the above ground biomass (kg pole^{-1}) on fresh and dry weight basis (Table 1). Agarwal & Purwar (2009) have also reported similar results in case of *Dendrocalamus asper*. In *D. asper,* above ground biomass was directly proportional to culm height on the basis of both fresh and dry weight. With one unit increase in girth at 1.5m, the above ground biomass of *B. balcooa* decreased by 304.61 and 194.23 per cent respectively on fresh and dry weight basis. In the previous study also, girth at 1.5m has been reported as the major deciding independent variable for biomass estimation in bamboos (Agarwal & Purwar, 2012). In *Guadua angustifolia*, 45 per cent of the whole fresh weight can be explained by the variation of DBH (Riano et al., 2002). A regression model for carbon stock estimation in *B. vulgaris, B. balcooa and B. cacharensis* was also developed with DBH as an independent variable (Nath & Das, 2011).

Table 1. Linear relationship between above ground biomass (y kg culm^{-1}) and height (x_1, m), girth to height at 1m (x_2, m) & girth to height at 1.5m(x_3, m) of *B. balcooa.*

S. No.	Biomass (kg culm^{-1})	Intercept (a)	Slope (x_1)	Slope (x_2)	Slope (x_3)	R^2
1.	Fresh weight	-20.44	0.50	510.90	-304.61	0.99
2.	Dry weight	-13.38	0.26	328.62	-194.23	0.98

Above ground biomass (AGB) on fresh and dry weight basis of *B. balcooa* at a three-year interval is presented in table 2. AGB depicted in the table for the year 2014 was calculated by the average weight of three culms from each clump after harvesting, whereas in the year 2017, 2020 and 2023 AGB was estimated through the regression equation by non-destructive method using the length and girth of culms at 1.0m and 1.5m which was 63.26, 162.48 and 356.66 t ha^{-1} respectively. Data of the year 2020 (35.36 kg) and 2023 (39.22 kg) depicts that biomass on per culm basis was almost at par (10.91 % increase) but per clump gain was much more i.e., 119.60

% on fresh weight basis (Table 3). This indicates that in subsequent years though the height and girth of culms increased but there was not much gain after 2020 (10 years of plantation) Addition of more culms per clump was mainly responsible for the increase in biomass.

Table 2: Estimation of above ground biomass of *B. balcooa* on fresh and dry weight basis at three-year interval after the plantation.

Above ground biomass	2014		2017		2020		2023	
	FW	DW	FW	DW	FW	DW	FW	DW
Biomass (kg culm^{-1})	4.45	2.40	17.12	10.45	35.36	21.95	39.22	24.48
Biomass (kg clump^{-1})	31.15	16.80	158.14	96.64	406.19	252.46	891.98	557.50
Biomass (t ha^{-1})	12.46	6.72	63.26	38.66	162.48	100.98	356.66	223.00

Table 3. Per cent increase in above ground biomass of *B. balcooa* on fresh and dry weight basis in subsequent years after the plantation

Year	Per cent increase Per culm			
	FW	DW	FW	DW
2017	284.72	334.42	407.67	475.24
2020	106.54	110.05	156.85	161.24
2023	10.91	11.52	119.60	120.82

However, highest per cent increase in biomass per culm (284.72) and per clump (407.70) from the year 2014 to 2017 on fresh weight basis signifies that growth of culms is much faster in the initial 6 years after plantation. As per the previous report (Agarwal & Purwar 2017) AGB produced by *B. tulda* in four years was 4.9 t ha^{-1} on dry weight basis. An increase in AGB of 100 per cent was observed in two years by *B. tulda* (Agarwal & Purwar 2018). In Thrissur, India, above ground biomass of *B. bambos* clumps averaged 2417 kg clump^{-1} with an average accumulation of 241.7 Mg ha^{-1} (Kumar et al. 2005).

On dry weight basis, carbon sequestered by *B. balcooa* was estimated 19.33t ha^{-1} in the year 2017 which was 475.3 per cent higher than the previous year 2014 (Table 4). However, per cent increment in carbon sequestration shows the same trend as dry weight because it is estimated on the basis of dry weight produced in one hectare. Carbon sequestration of *B. nutans* was evaluated in Assam, North-East region of India at a rate of 88.95 t ha^{-1} through above ground biomass and 96.46 t ha^{-1} through total biomass in four years (Choudhury et al. 2015).

Table 4. Estimation of carbon sequestered by *B. balcooa* on dry weight (AGB) basis and per cent increment at three-year interval.

Year	Carbon sequestered (t ha^{-1})	Per cent increment
2014	3.36	-
2017	19.33	475.24
2020	50.49	161.24
2023	111.50	120.82

Further, just to validate the accuracy of the regression equation, some culms from the plantation were harvested randomly; parameters on culm length, girth at 1.0m and 1.5m were recorded along with the fresh weight. Then the weight was estimated using the regression equation. Comparison of actual and estimated weight is depicted in Fig. 1. In some cases estimated weight is more than the actual weight (69%); the variation may be due to number of branches, twigs and leaves because weight of culms for developing regression was recorded of the whole culm. This comparison suggests that to develop regression for culm biomass estimation only the weight of culms should be recorded excluding the branches and leaves.

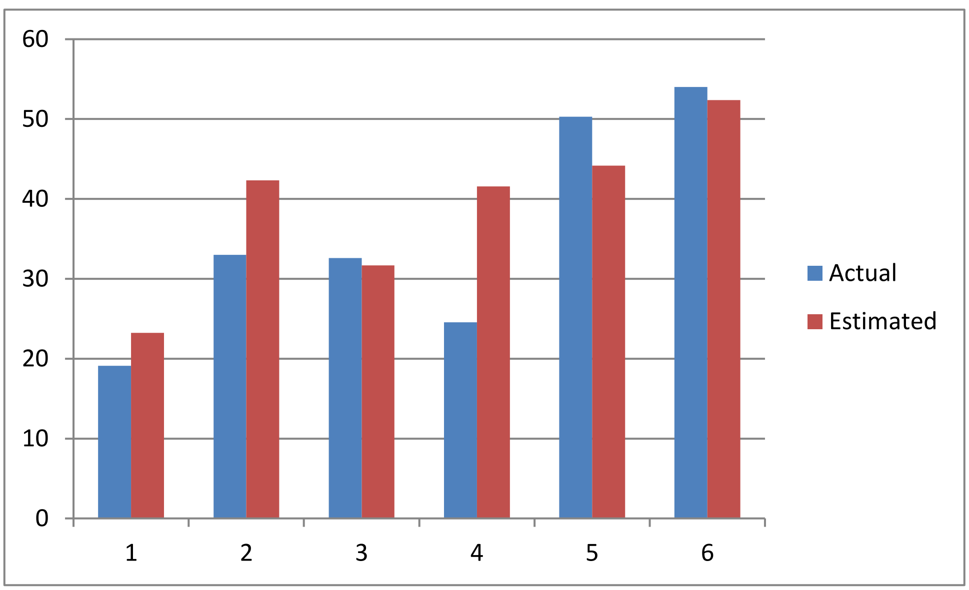

Fig. 1. Comparison of actual culm biomass and estimated using the regression equation

Estimation of above ground biomass showed significant ($p < 0.05$) correlation with culm height, girth at 1.0 & 1.5m both on fresh & dry weight basis (Table 5). Singh & Rai (2012) have also reported significant ($p < 0.01$) positive correlation with culm height, rind thickness, leaf length and number of internodes/culms.

Table 5. Correlation matrix of the biometric parameters and above ground biomass accumulation in *B. balcooa*.

	Length	Girth1 m	Girth 1.5m	FW	DW
Length	1				
Girth1 m	0.742813	1			
Girth 1.5m	0.746892	0.995970	1		
FW	0.785311	0.989861	0.975902	1	
DW	0.775121	0.990970	0.976836	0.999864	1

There was a negative correlation between culm height and girth at 1.5m with decrease in dry weight over fresh weight (Fig. 2 & 3). The regression equation Y= -0.561X + 46.12 indicated 18.3 per cent variation for culm length whereas it was 36 per cent for girth at 1.5m. The present study indicated that *B. balcooa* has vast potential for carbon sequestration in the mid Himalayan region as long as the poles are used in construction or making the furniture etc. Previous reports of other species like *B. bambos* and *B. nutans* estimated 20.52 and 20.41 t ha^{-1} above ground biomass produced in six years of the same geographical location. In *B. tulda* lowest AGB was observed in (9.62 t ha^{-1}) among all the four species (Agarwal & Purwar 2018). Whereas, *B. balcooa* produced almost double (38.66 t ha^{-1}) in the same time period.

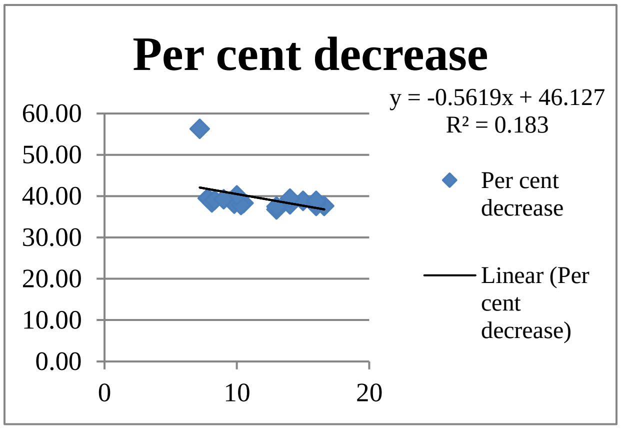

Fig. 2. Relationship between length of culm with per cent decrease in dry weight over fresh weight.

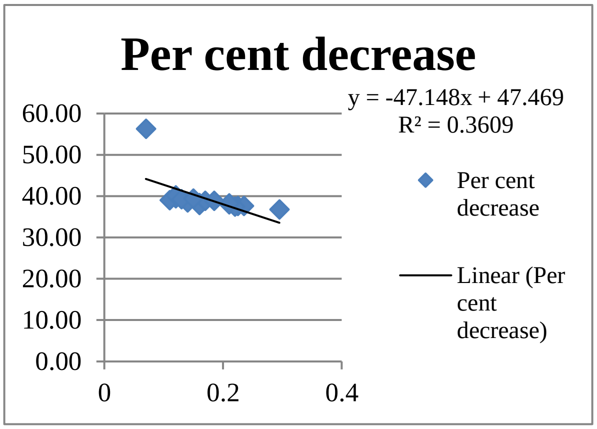

Fig. 3. Relationship between girth (at 1.5m) of culm with per cent decrease in dry weight over fresh weight.

Acknowledgement

Authors are thankful to the Department of Science & Technology, Govt. of India, New Delhi, India for financial assistance and the Director Experiment Station, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India for providing the necessary facilities.

Conflict of Interest

The authors declare there is no conflict of interest.

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