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Growth performance, biomass, carbon storage and carbon dioxide release abatement of bamboo plantation in Chhattisgarh plains of India

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This study was carried out in a bamboo (*Dendrocalamus strictus*) plantation (8 × 6 m spacing) at the forestry research farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, during 2018–19. The average population of bamboo was 33.38 culms per clumps during July 2018 after 8 months bamboo population was 45.0 culms per clumps during March 2019. The girth of clump was measured 5.66 m during March 2019. The average bamboo height was 8.35 ± 0.54 m and diameter 3.56 ± 0.77 cm at the third internode. The emerging number of new culms per clump was recorded highest in August (5.25 ± 1.91) and lowest in October (0.25 ± 0.45) with no emerging new culms per clumps during November to March. The total biomass, carbon storage and carbon dioxide release abatement were estimated as 63.85 Mg ha^{-1}, 30.01 Mg ha^{-1} and 110.13 Mg CO_2 eq ha^{-1} respectively.

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BAMBOOS are woody grasses of the Poaceae family and subfamily Bambusoideae. Bamboo is a crucial component of non-timber forest products, which are economically significant[1]. It is a versatile plant because of its adaptability and utility. It helps to improve livelihood and food security and to tackle environmental issues like greenhouse gas emission reduction due to high productivity[2,3]. Thus, it plays a significant role in carbon sequestration and the carbon budget in ecosystem services[4]. Bamboos are considered as trees for CDM afforestation and reforestation operations because of their large carbon sequestration potential[5]. Bamboo species play an important role as a carbon sink, assisting in the mitigation of climate change[6].

In Chhattisgarh, India, the total bamboo-bearing area is 10,467 sq. km, which has decreased by 788 sq. km within two years[7]. *Dendrocalamus strictus* is the most prevalent species in India, accounting for around 53% of the total bamboo area[8]. After 4–5 years of growth, it begins to produce commercial culms. The present study focuses on the growth status, biomass and carbon stock in a *D. strictus* plantation.

This study was carried out in a bamboo plantation at the forestry research farm of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, during 2018–19. The experimental site is situated in the southeastern part of the state. It lies at 21°76′N lat., 81°36′E long. at an altitude of 295 m msl. The spacing of the bamboo plantation is 8 m × 6 m.

The soil is classified as Vertisols or black cotton soil and is locally known as kanhar. It has a sticky nature, fine texture, angular blocky structure, low to medium nitrogen, low to medium phosphorus, high potassium and low organic matter. As a result of the annual addition of litter, the soil in the experimental area was exceptionally rich in organic carbon and other nutrients.

The study region has a dry, sub-humid, tropical environment with a mean annual rainfall of 1250 mm. The monsoon season from mid-June to mid-September receives majority of rainfall (90%). The mean monthly maximum temperature varied from 25.9°C to 34.5°C during July to March and the lowest temperature of 10.3°C was recorded in January. The highest relative humidity was reported from July to December, whereas the lowest was from January to March. From July 2018 to March 2019, the temperature ranged from 9.54°C to 37.36°C, relative humidity from 48.90% to 87.56%, sunshine from 0.44 to 8.78 h, wind speed from 0.82 to 8.01 kmph, and vapour pressure from 8.12 to 23.17 mm, the total rainfall received was 1208.20 mm.

Culm height of each clump was measured using a Ravi multimeter. The girth of a clump was measured at the base using a tape and the diameter was calculated according to the formula: girth/pi. The diameter of the culm at the third internode was measured using a calliper. The mature, young, dead and new culms per clump of the bamboo plantation were counted manually. All measurements were made twice during July 2018 and March 2019. The new emerging culms/clump were counted from July 2018 to March 2019.

The randomly 5–5 culms of dead, mature, young and new culms were cut down into 10 clumps. Thereafter, the culms, branches and leaves were separated and their fresh weight was estimated. Sub-samples of each category were dried at 75°C in a hot-air oven to estimate dry weight according to standard methods. The biomass of culms per clump was estimated, followed by the total clump biomass and bamboo plantation (Mg ha^{-1}).

The biomass value was multiplied by the carbon content value 0.47 to convert them to carbon storage[9]. By multiplying the carbon value by 3.67, the computed mega gram of carbon was converted to carbon dioxide equivalent (Mg CO_2 eq.)[10,11].

Correlation coefficient between total number of culms per ha^{-1}, girth of clump, height, collar diameter, biomass, C storage and CO_2 release abatement in bamboo plantation was analysed using IBM SPSS Statistics 20.

The growth status of bamboo plantation, viz. average number of culms per clump, total number of culm ha^{-1}, average clump diameter, average height of culm, average diameter of culm at the third internode and emerging of new culms per clumps was observed during the study, i.e. from July 2018 to March 2019 (Tables 1 and 2).

The average number of culms per clump was 33.38 ± 16.23 in July 2018 and after eight months, the average

Table 1. Growth status of bamboo plantation during July 2018–March 2019

Parameters	July 2018	March 2019
Total no. of clumps/ha	208.33	208.33
Average no. of culm/clump	33.38	45.00
Total no. of culms/ha	6953.01	9374.85
Mature	1809.87 (26.03)	1992.16 (21.25)
Young	4466.07 (64.23)	4049.41 (43.19)
Dead	677.07 (9.74)	911.4 (9.72)
New	0.0 (0.0)	2421.84 (25.83)
Average girth of clump (m)	4.68 ± 0.84	5.66 ± 0.99
Average height of culm (m)	7.27 ± 1.28	8.35 ± 0.54
Average diameter of culm at third internodes (cm)	3.34 ± 0.62	3.56 ± 0.77

Note: Values in parentheses show percentage share.

number of culms per clump was 45.0 ± 19.06 in March 2019. The total number of culms was estimated to be 6953.01 in July 2018, with the share of mature culms being 1809.87 (26.03%), followed by young culms 4466.07 (64.23%), and dead culms 677.07 (9.74%). After eight months of growth, i.e. in March 2019, the total number of culms was estimated as 9374.85, where the contribution of mature, young and dead culms was 1992.16 (21.25%), 4049.41 (43.19%) and 911.44 (9.72%) respectively. During these eight months, 2421.84 (25.83%) new culms had regenerated. Girth of clump was recorded as 4.68 ± 0.84 m in July 2018, which increased to 5.66 ± 0.99 m after eight months in March 2019. Thus, the increment in diameter was recorded as 20.94% (Table 1).

The average height of culm was recorded as 7.27 ± 1.28 m and 8.35 ± 0.54 m in July 2018 and March 2019 respectively. Thus, after eight months the average culm height had increased by 1.08 m (14.86%). The average diameter of culm at the third internode was recorded as 3.34 ± 0.62 and 3.56 ± 0.77 cm in July 2018 and March 2019 respectively, and the increment in diameter of culm was estimated as 0.22 cm (6.59%) after eight months (Table 1). The average number of emerging new culms per clump was the highest in August (5.25 ± 1.91) and lowest in October (0.25 ± 0.45), while from November to March no emergence of new culms per clump was observed (Table 2 and Figure 1).

The total bamboo biomass for the plantation was estimated as 63.85 Mg ha^{-1}, which was shared by different stages of culms in the order of dead, mature, new and young culms, i.e. 6.21 (9.73%), 13.57 (21.25%), 16.49 (25.83%) and 27.58 Mg ha^{-1} (43.19%) respectively (Table 3 and Figure 2).

The total carbon stock estimated for bamboo plantation was found at 30.01 Mg ha^{-1}, where the contribution was in the order of dead, mature, new and young culms, i.e. 2.92 (9.73%), 6.38 (21.26%), 7.75 (25.82%) and 12.96 Mg ha^{-1} (43.19%) respectively (Table 4 and Figure 3). Similarly, the total carbon dioxide emission reduction was 110.13 Mg CO_2 eq ha^{-1}. It was estimated as 10.71 (9.72%), 23.40 (21.25%), 28.45 (25.83%) and 47.57 Mg CO_2 eq ha^{-1} (43.19%) for dead, mature, new and young culms respectively (Table 5 and Figure 4).

Correlation analysis was performed to study the significant relationship between the total number of culms ha^{-1}, girth of clump, height, collar diameter, biomass, C storage and CO_2 release abatement in the bamboo plantation. Table 6 presents the results. Maximum correlation was observed between total number of culms ha^{-1} and biomass, C storage and CO_2 release abatement. There was a significant correlation between total number of culms ha^{-1} and height and collar diameter with R^2 values 0.64 and 0.51 respectively; was between height and girth of clump with R^2 values of 0.79 at 0.01 probability level; between height and biomass, C storage and CO_2 release abatement with R^2 value of 0.64 at 0.01 probability levels and between collar diameter and biomass, C storage and CO_2 release abatement with R^2 value of 0.51 at 0.05 probability levels.

Table 2. Emerging of new culms per clump during July 2018 to March 2019

Month	Emerging of new culms/clump
July	4.56 ± 1.55
August	5.25 ± 1.91
September	1.56 ± 1.15
October	0.25 ± 0.45
November	0.00 ± 0.00
December	0.00 ± 0.00
January	0.00 ± 0.00
February	0.00 ± 0.00
March	0.00 ± 0.00
Total	11.63 ± 4.30

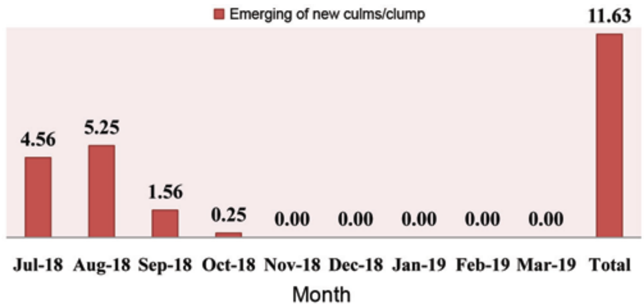

Figure 1. Emerging of new culms per clump during July 2018 to March 2019.

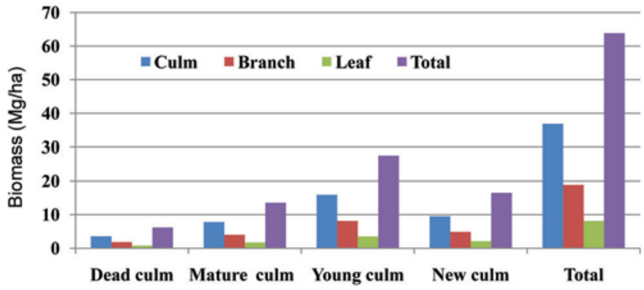

Figure 2. Biomass yield (Mg ha^{-1}) in bamboo plantation.

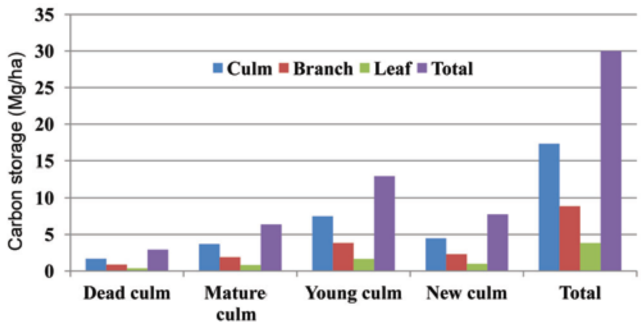

Figure 3. Carbon storage (Mg ha^{-1}) in bamboo plantation.

Table 3. Biomass yield (Mg ha^{-1}) of bamboo plantation

Parameters	Biomass yield (Mg ha^{-1})			
	Culms	Branches	Leaves	Total
Dead culm	3.58 (9.72)	1.83 (9.71)	0.79 (9.71)	6.21 (9.73)
Mature culm	7.83 (21.25)	4.01 (21.27)	1.73 (21.25)	13.57 (21.25)
Young culm	15.92 (43.20)	8.14 (43.18)	3.52 (43.24)	27.58 (43.19)
New culm	9.52 (25.83)	4.87 (25.84)	2.10 (25.80)	16.49 (25.83)
Total	36.85	18.85	8.14	63.85

Note: Values in parentheses show percentage share.

Table 4. Carbon storage in bamboo plantation

Parameters	Carbon storage (Mg ha^{-1})			
	Culms	Branches	Leaves	Total
Dead culm	1.68 (9.71)	0.86 (9.71)	0.37 (9.69)	2.92 (9.73)
Mature culm	3.68 (21.26)	1.88 (21.22)	0.81 (21.20)	6.38 (21.26)
Young culm	7.48 (43.21)	3.83 (43.23)	1.65 (43.19)	12.96 (43.19)
New culm	4.47 (25.82)	2.29 (25.85)	0.99 (25.92)	7.75 (25.82)
Total	17.31	8.86	3.82	30.01

Note: Values in parentheses show percentage share.

Table 5. Carbon dioxide release abatement in bamboo plantation

Parameters	Carbon dioxide release abatement (Mg CO_2 eq ha^{-1})			
	Culms	Branches	Leaves	Total
Dead culm	6.18 (9.72)	3.16 (9.72)	1.37 (9.74)	10.71 (9.72)
Mature culm	13.51 (21.26)	6.91 (21.25)	2.99 (21.27)	23.40 (21.25)
Young culm	27.45 (43.19)	14.04 (43.19)	6.07 (43.17)	47.57 (43.19)
New culm	16.42 (25.83)	8.40 (25.84)	3.63 (25.82)	28.45 (25.83)
Total	63.56	32.51	14.06	110.13

Note: Values in parentheses show percentage share.

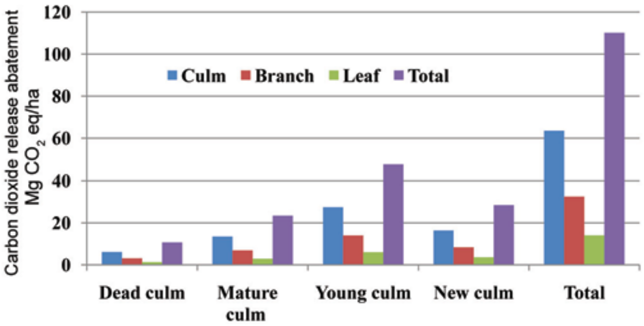

Figure 4. Carbon dioxide release abatement (Mg CO_2 eq ha^{-1}) in bamboo plantation.

Bamboos require extensive management in human-made ecosystems such as plantations[12], agroforestry and hedgerows on-farm boundaries, etc.[13]. The growth performance of bamboo stands was observed for clump diameter (cm), culm population, culm height (m) and diameter of the third internode of culms for morphology features, whereas the yield of fresh and oven-dry weight of culms, branches and leaves was estimated by the harvesting of mature culms. Growth and development behaviour of bamboo plantations also depends upon their genotype, environment and interactions. The cultivation of bamboo on farmlands generates regular yearly income after 3–4 years of plantation[14] and the harvesting of mature culms from the clumps opens the space at the ground and canopy level. The economic importance of bamboo is selling of mature culms in market[15].

Young plantation values ranged from 30 to 49 Mg/ha, which were lower than the 3–5-year-old *D. strictus* plantations[16]. The biomass density of *Schizostachyum polymerphum* and *Schizostachyum dullooa* bamboo species was found to be in the range of 43–45 Mg ha^{-1} in a 15–18-year-old Assam forest[6]. The total culm biomass density ranged from 13.27 to 48.34 Mg ha^{-1} (ref. 17). Variances in culm height, culm size, culm and clump density, culm behaviour, and rate of taper of the bamboo species may all contribute to differences in biomass density.

Bamboos can store carbon permanently because carbon lost from harvesting mature culms is balanced by carbon gained from young culms produced in the clump[18]. In *M. baccifera*, the highest carbon storage was found in the >5 cm diameter class (40.94 tCO_2 eq ha^{-1}). Plantation carbon

Table 6. Correlation between total number of culms ha^{-1}, girth of clump, height, collar diameter, biomass, carbon storage and carbon dioxide release abatement in bamboo plantation

Variables	Total no. of culm/ha	Girth of clump (m)	Height (m)	Collar diameter (cm)	Biomass	Carbon storage	Carbon dioxide release abatement
Total no. of culms/ha	1						
Girth of clump (m)	0.34	1					
Height (m)	0.64**	0.79**	1				
Collar diameter (cm)	0.51*	0.15	0.28	1			
Biomass	1.00**	0.34	0.64**	0.51*	1		
Carbon storage	1.00**	0.34	0.64**	0.51*	1.00**	1	
Carbon dioxide release abatement	1.00**	0.34	0.64**	0.51*	1.00**	1.00**	1

**Correlation is significant at the 0.01 level (two-tailed). *Correlation is significant at the 0.05 level (two-tailed).

mitigation capability is determined by tree density, structure, age and C concentration in various components[19]. Due to the many and varied uses of bamboos, the present study provides useful information to forestry practitioners, state Forest Departments, bamboo-growers and farmers, particularly in Madhya Pradesh, Arunachal Pradesh, Maharashtra, Odisha, Assam and Chhattisgarh[7].

In a plantation of *D. strictus* the total number of culms present was 9374.85 culms ha^{-1}. The average culm height was 8.35 m, with a diameter of 3.56 cm. The emergence of new culms per clump was highest in August. The total biomass, C storage and CO_2 release abatement were estimated to be 63.85 Mg ha^{-1}, 30.01 Mg ha^{-1} and 110.13 Mg CO_2 eq ha^{-1} respectively.

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