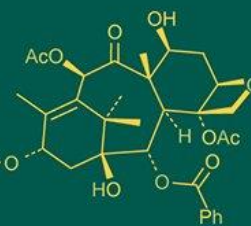
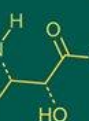
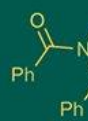
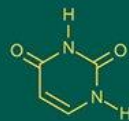
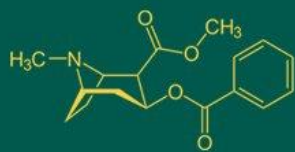


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(7): 2104-2107
www.biochemjournal.com
Received: 08-05-2026
Accepted: 12-06-2026

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Influence of spacing and nutrient regimes on aboveground biomass production of *Dendrocalamus brandisii* (Munro) Kurz. in abandoned rice field of Kodagu, Karnataka

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i7Sy.9366>

Abstract

Dendrocalamus brandisii (Munro) Kurz. is a commercially important tropical bamboo species recognized for its rapid growth, high biomass productivity, and considerable carbon sequestration potential. The present study evaluated the influence of spacing and nutrient regimes on aboveground biomass (AGB) production in a three-year-old *D. brandisii* plantation established on an abandoned lowland rice field at Halligattu village, Kodagu, Karnataka, India. The experiment was conducted in a Factorial Split-Plot Design with three replications, comprising two spacing regimes as main plots [M₁: 4.0 × 5.0 m (500 clumps ha⁻¹) and M₂: 5.0 × 5.0 m (400 clumps ha⁻¹)] and three nutrient regimes as sub-plots [S₁: Recommended Dose of Fertilizer (25:9:25 g N:P₂O₅:K₂O plant⁻¹ year⁻¹), S₂, and S₃]. Aboveground biomass was estimated through destructive sampling of culms grouped into four age classes (<1, 1-2, 2-3, and 3-4 years) and partitioned into culm, branch, and leaf components. Analysis of variance revealed that spacing, nutrient regimes, and their interaction had no significant effect (p>0.05) on total stand biomass. Nevertheless, numerical differences were evident, with the closer spacing (M₁) recording a slightly higher mean biomass (60.75 t ha⁻¹) than the wider spacing (M₂: 59.39 t ha⁻¹), mainly due to its higher planting density. Biomass production increased with fertilizer application, and the highest value was recorded under S₃ (64.10 t ha⁻¹). Among the treatment combinations, M₂S₃ (64.20 t ha⁻¹) produced the greatest biomass, closely followed by M₁S₃ (64.00 t ha⁻¹). Biomass allocation across culm age classes showed that juvenile culms (<1 year) contributed more than 52% of the total aboveground biomass, followed by 1-2-year-old (26%), 2-3-year-old (14%), and 3-4-year-old culms (8%). Although treatment effects were not statistically significant during the early stage of plantation development, the observed numerical trends indicate that increased nutrient supply and appropriate planting density enhance biomass accumulation and stand productivity. These findings provide valuable information for developing sustainable management strategies aimed at maximizing biomass production and carbon sequestration in tropical bamboo plantations for bioenergy and climate change mitigation.

Keywords: *Dendrocalamus brandisii*, aboveground biomass, spacing regimes, nutrient management, plantation forestry, carbon sequestration

Introduction

Bamboo is an exceptionally fast-growing, non-timber forest resource that plays an increasingly vital role in global sustainable development, bioenergy production, and land restoration (Liese and Kohl, 2015) [9]. As a perennial woody grass, bamboo exhibits biomass accumulation rates that rival or exceed many fast-growing hardwood plantation species (Nath *et al.*, 2015; Yen, 2016) [13, 22]. Beyond its economic utility, bamboo provides critical ecosystem services including soil stabilization, watershed conservation, and rapid carbon sequestration, making it a key candidate for climate change mitigation frameworks (Song *et al.*, 2011; FAO, 2020) [19, 6]. Worldwide, bamboo covers over 35 million hectares across tropical and subtropical zones, supporting complex rural value chains and industrial applications (FAO, 2020) [6]. India represents one of the primary centers of bamboo diversity, hosting approximately 136 species across 36 genera (National Bamboo Mission, 2020) [14].

Among indigenous and naturalized tropical species, *Dendrocalamus brandisii* (Munro) Kurz., commonly known as Sweet Bamboo or Velvet Leaf Bamboo, is distinguished by its large dimensions, thick culm walls, high tensile strength, and edible young shoots (Tewari, 1992; Bisht *et al.*, 2010) [21, 1]. Cultivated widely across South and Southeast Asia, *D. brandisii* is increasingly integrated into plantation forestry and agroforestry systems aimed at pulp production, engineered structural timber, biochar, and bio-energy feedstocks (Singh *et al.*, 2018) [17].

The productivity of managed bamboo plantations is governed primarily by silvicultural decisions regarding stand density (spacing) and soil fertility management (nutrients) (Kleinhenz and Midmore, 2001) [8]. Spacing directly controls light interception, canopy closure, root spatial competition, and culm recruitment rates (Shanmughavel and Francis, 1996; Nath *et al.*, 2009) [16, 12]. High planting densities maximize initial stand-level biomass per unit area, whereas wider spacings promote individual clump vigor, diameter growth, and lower mortality due to reduced intra-specific competition (Kleinhenz and Midmore, 2001; Emberton, 2008) [8, 4]. Simultaneously, nutrient management is paramount during early establishment. Sympodial bamboos demand substantial macro-nutrients (N, P, and K) to sustain rapid seasonal shoot emergence and rapid culm elongation (Rao *et al.*, 1990; Suos *et al.*, 2020) [15, 20]. Nitrogen drives vegetative vigor and photosynthetic activity, phosphorus facilitates subterranean rhizome branching and root expansion, and potassium improves osmotic regulation and structural tissue lignification (Nath and Das, 2011; Mailappa *et al.*, 2017) [11, 10]. Although the standalone responses of bamboo species like *Bambusa bambos*, *Dendrocalamus strictus*, and *Phyllostachys pubescens* to fertilization or spacing are well-documented (Shanmughavel and Francis, 1996; Mailappa *et al.*, 2017) [16, 10], empirical research evaluating the interactive effects of spacing and nutrient regimes on *D. brandisii*—particularly when established on marginal or degraded agricultural lands such as abandoned paddy fields remains sparse. Therefore, this study investigated the influence of two spacing treatments and three NPK nutrient levels on the aboveground biomass partitioning and total yield of *D. brandisii* in the humid tropics of Kodagu, Karnataka, India.

Materials and Methods

The experiment was conducted during 2024-2025 at Halligattu village near the College of Forestry, Ponnampet, Kodagu district, Karnataka, India (12°08' N, 75°55' E; 867 m above mean sea level), situated in the Hilly Zone (Zone 9) of Karnataka, which experiences a humid tropical climate with an annual rainfall of 2,500-3,500 mm received mainly during the southwest monsoon (June-September). The study site comprised an abandoned lowland rice (*Oryza sativa*) field of approximately 0.96 ha with sandy loam soil, acidic pH (5.1-5.4), and poor natural drainage. To prevent seasonal waterlogging, a drainage system consisting of main collector trenches (1.0 m × 1.5 m) and secondary sub-trenches (0.35 m × 0.45 m) was established before transplanting. The experiment was laid out in a Split-Plot Design with three replications using healthy, uniform tissue-cultured seedlings of *Dendrocalamus brandisii*, transplanted in June 2020 at the onset of the monsoon. At the time of destructive sampling during 2023-2024, the plantation was three years old. The treatments consisted of two spacing regimes, namely M1 (4.0

× 5.0 m; 500 clumps ha⁻¹) and M2 (5.0 × 5.0 m; 400 clumps ha⁻¹), combined with three nutrient regimes: S₁ (recommended dose of fertilizer, 25 g N: 9 g P₂O₅: 25 g K₂O plant⁻¹ year⁻¹), S₂ (31.25 g N: 11.25 g P₂O₅: 31.25 g K₂O plant⁻¹ year⁻¹), and S₃ (37.50 g N: 13.50 g P₂O₅: 37.50 g K₂O plant⁻¹ year⁻¹). Nutrients were supplied through urea (46% N), single superphosphate (16% P₂O₅), and muriate of potash (60% K₂O), applied in two equal splits during May and September using a circular trench method at a 30 cm radius from the clump margin. Aboveground biomass (AGB) was estimated using destructive harvesting following standard procedures for sympodial bamboo (Brown, 1997; FAO, 2004) [2, 5]. Culms were classified into four age classes (<1, 1-2, 2-3, and 3-4 years) based on sheath retention, culm colour, and branch development. Representative culms from each age class and treatment combination were harvested at ground level (<10 cm stubble height) and separated into culm, branch, and leaf components. Fresh weights were recorded using a digital hanging balance (±0.01 kg), after which approximately 1 kg subsamples of each component were oven-dried at 75 °C to constant weight for determination of moisture content and dry biomass. Total culm biomass was obtained by summing the dry biomass of culm, branches, and leaves. Clump biomass was estimated by multiplying the mean dry biomass of each age class by the corresponding number of culms per clump and summing across all age classes, while stand biomass (t ha⁻¹) was calculated by multiplying clump biomass by the planting density of the respective spacing treatment (500 clumps ha⁻¹ for M1 and 400 clumps ha⁻¹ for M2). The observations recorded on growth parameters of bamboo and soil properties were statistically analyzed following the procedures outlined by Jayaraman (2001) [7]. The experimental data were subjected to analysis of variance (ANOVA) appropriate for a split plot design using GRAPES statistical software.

Results and Discussion

Main Effects of Spacing and Nutrient Regimes

ANOVA revealed that neither spacing regimes, nutrient levels, nor their interactions produced statistically significant differences ($p > 0.05$) in total aboveground stand biomass of three-year-old *D. brandisii* (Table 1). Despite the lack of statistical significance, clear numerical patterns were observed across treatments. Closer spacing (M₁: 4.0 × 5.0 m) achieved a higher mean stand biomass (60.75 t ha⁻¹) than wider spacing (M₂: 5.0 × 5.0 m, 59.39 t ha⁻¹). The 2.3% yield increase in M₁ was largely attributable to greater initial stem density (500 vs. 400 clumps ha⁻¹) rather than greater individual clump weight. Individual clumps in wider spacing (M₂) demonstrated higher average clump biomass, indicating reduced lateral light competition and broader root expansion room, which partially compensated for lower stocking density. These findings align with Shanmughavel and Francis (1996) [16] for *Bambusa bambos* and Nath *et al.* (2009) [12] for *Dendrocalamus hamiltonii*, where stand density acted as the primary driver of total area-based yield during early establishment phases. The application of enhanced fertilizer levels resulted in a positive numerical response in total biomass accumulation. The S₃ treatment achieved the highest biomass production (64.10 t ha⁻¹), followed by S₂ (59.82 t ha⁻¹) and S₁ (56.29 t ha⁻¹). The 13.88% increase in biomass from S₁ to S₃ underlines the responsiveness of young bamboo stands to increased macro-nutrient inputs. Nitrogen and potassium supplementation accelerate leaf area development

and net assimilation rates during annual shoot expansion cycles, as previously highlighted by Rao *et al.* (1990) [15] and Mailappa *et al.* (2017) [10]. The interaction treatment M₂S₃ (5.0 × 5.0 m) registered the highest absolute biomass (64.20 t ha⁻¹), closely followed by M₁S₃ (64.00 t ha⁻¹). Under wider spacing, individual clumps faced less canopy overlap, enabling them to convert higher fertilizer availability into structural biomass more efficiently. This interaction trend suggests that as plantations mature, wider spacing coupled with adequate fertilization may optimize individual clump yield and simplify long-term harvest management (Das and Chaturvedi, 2006; Singnar *et al.*, 2017) [3, 18].

Age-Class Biomass Allocation Patterns: Biomass contribution varied significantly across culm age classes. Young culms (<1 year) accounted for over 52% of total aboveground stand biomass across all treatments. The 1-2 year age class contributed approximately 26%, while older culms (2-3 and 3-4 years) contributed 14% and 8% respectively. This structural allocation reflects the physiological growth strategy of sympodial species: young shoots complete their primary height and diameter growth within a single growing season (3-4 months) using stored rhizome reserves and current-year photosynthates (Liese and Kohl, 2015) [9]. Consequently, initial stand productivity is heavily dictated by annual shoot emergence rates and survival during early growth stages.

Table 1: Effect of spacing and nutrient regimes on biomass production of *Dendrocalamus brandisii* across age classes

Biomass (kg per clump)						Biomass (kg per ha)				
Treatments	Red	Yellow	Blue	Green	Total	Red	Yellow	Blue	Green	Total
Spacing regimes										
M1	68.53	42.89	14.95	3.44	129.81	32071.84	20070.35	6996.17	1611.00	60749.36
M2	67.68	40.73	14.88	3.61	126.89	31672.45	19059.18	6962.90	1691.45	59385.99
S. Em (±)	4.8800	2.0600	1.0300	0.3200	8.2000	2282.4500	964.9400	484.2400	147.4900	3837.6900
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient regimes										
S1	65.94	46.99	14.38	3.02	130.34	30860.85	21995.19	6727.94	1415.01	60998.99
S2	61.70	38.87	13.92	3.25	117.74	28875.09	18190.16	6514.51	1520.88	55100.64
S3	76.67	39.55	16.45	4.31	136.97	35880.49	18508.95	7696.16	2017.78	64103.38
S. Em (±)	5.6500	3.2700	1.2300	0.3600	10.4400	2642.6200	1528.0400	575.4700	170.5300	4881.5200
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Spacing regimes × Nutrient regimes										
M1S1	66.66	49.86	14.54	2.98	134.04	31197.62	23332.00	6806.01	1394.43	62730.05
M1S2	65.14	40.87	14.45	3.20	123.67	30486.86	19128.76	6760.58	1499.55	57875.76
M1S3	73.78	37.93	15.86	4.14	131.71	34531.06	17750.30	7421.92	1939.00	61642.28
M2S1	65.22	44.14	14.21	3.07	126.64	30524.09	20658.40	6649.86	1435.59	59267.93
M2S2	58.26	36.86	13.39	3.30	111.81	27263.33	17251.56	6268.43	1542.21	52325.53
M2S3	79.55	41.17	17.03	4.48	142.23	37229.93	19267.60	7970.41	2096.5500	66564.4900
S. Em (±)	7.9900	4.6200	1.7400	0.5153	14.7511	3737.22	2160.9800	813.8400	241.1600	6903.5000
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

RED- one year old culm, YELLOW - Two year old culm, BLUE- Three year old culm, GREEN - Four year old culm

Figures with same letter are not significantly different; CD-Critical difference; NS-Non-significant; M₁-4.00 m × 5.00 m; M₂-5.00 m × 5.00 m; S₁-Optimum level of NPK; S₂-25% more than optimum; S₃-50% more than optimum

Conclusion

This study evaluated the effects of spacing and nutrient management on the aboveground biomass of *Dendrocalamus brandisii* established on an abandoned paddy field in Kodagu, Karnataka. Spacing, nutrient regimes, and their interactions did not yield statistically significant differences in stand-level biomass at three years of age ($p > 0.05$). However, biological trends showed that close spacing (4.0 × 5.0 m) produced higher total stand biomass (60.75 t ha⁻¹), while higher fertilizer application achieved maximum biomass yield (64.10 t ha⁻¹). Culms under one year of age accounted for more than half of the total aboveground biomass. These results provide useful baseline parameters for establishing commercial *D. brandisii* plantations and integrating bamboo into tropical carbon offset and land rehabilitation programs.

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