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Dhanyashri PV
Department of Silviculture and
Agroforestry, College of Forestry,
Ponnampet, Kodagu, Karnataka,
India

Hareesh TS
Department of Forest Products
and Utilization, College of
Forestry, Ponnampet, Kodagu,
Karnataka, India

Nayak BG
Department of Silviculture and
Agroforestry, College of Forestry,
Ponnampet, Kodagu, Karnataka,
India

Sathish BN
Department of Forest Products
and Utilization, College of
Forestry, Ponnampet, Kodagu,
Karnataka, India

Maheswarappa V
Keladi Shivappa Nayaka
University of Agricultural and
Horticultural Sciences
(KSNUAHS), Iruvakk, Shivamogga, Karnataka, India

Ramakrishna Hegde
Keladi Shivappa Nayaka
University of Agricultural and
Horticultural Sciences
(KSNUAHS), Iruvakk, Shivamogga, Karnataka, India

Corresponding Author:

Dhanyashri PV
Department of Silviculture and
Agroforestry, College of Forestry,
Ponnampet, Kodagu, Karnataka,
India

Influence of spacing and nutrient regimes on soil physical and chemical properties under *Dendrocalamus brandisii* (Munro) Kurz. plantation

Dhanyashri PV, Hareesh TS, Nayak BG, Sathish BN, Maheswarappa V and Ramakrishna Hegde

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Abstract

The present study evaluated the influence of spacing and nutrient regimes on soil physical and chemical properties in a three-year-old *Dendrocalamus brandisii* (Munro) Kurz. plantation established in the humid tropical region of Kodagu, Karnataka. The experiment was laid out in a Split Plot Design with three replications, comprising two spacing regimes as main plots [M₁: 4.0 × 5.0 m and M₂: 5.0 × 5.0 m] and three nutrient regimes as sub-plots [S₁: recommended dose of NPK (25:9:25 g N:P₂O₅:K₂O plant⁻¹ year⁻¹), S₂: 25% higher than recommended dose, and S₃: 50% higher than recommended dose]. Soil samples were collected from two depths (0–15 cm and 15–30 cm) and analyzed for soil moisture content, bulk density, pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P₂O₅), potassium (K₂O), sulphur (S), exchangeable calcium (Ca), and magnesium (Mg). Analysis of variance revealed that spacing regimes, nutrient levels, and their interaction had no statistically significant influence on soil moisture content, bulk density, organic carbon, or available nutrients during the study period. However, nutrient regimes significantly influenced soil pH and electrical conductivity, although observed variations remained within optimal ranges for bamboo growth. The wider spacing (M₂) generally maintained marginally higher soil moisture and available nutrient levels, whereas higher fertilizer application (S₃) exhibited slight increases in surface moisture retention and soil salinity indicators. The limited treatment response was attributed to the young age of the plantation and slow turnover dynamics typical of perennial bamboo ecosystems.

Keywords: *Dendrocalamus brandisii*, soil moisture, bulk density, soil fertility, nutrient management, spacing regimes, organic carbon, electrical conductivity

Introduction

Soil physical and chemical properties serve as fundamental indicators of soil health and play a decisive role in determining the overall productivity, sustainability, and ecological functionality of perennial plantation systems. Key physical parameters, including soil moisture retention capacity and bulk density, directly govern water availability, aeration, root elongation, and soil mechanical resistance (Brady and Weil, 2017) [3]. Simultaneously, soil chemical traits such as soil reaction (pH), electrical conductivity (EC), organic carbon accumulation, and macronutrient/micronutrient pools regulate biochemical reactions, soil microbial activity, and plant nutrient uptake dynamics. Maintaining favorable physical and chemical soil conditions is therefore essential for optimizing biomass accumulation and economic output in intensively managed forest plantations. Bamboo is universally recognized as one of the fastest-growing perennial woody grasses globally, possessing exceptional ecological and socio-economic value. Owing to its extensive subterranean rhizome-root networks, dense canopy cover, and substantial annual litter production, bamboo plays a key role in soil conservation, soil aggregate stabilization, and carbon sequestration (Nath *et al.*, 2015) [10]. Continuous litterfall accumulation and subsequent microbial decomposition add significant organic matter to the upper soil layers, enhancing cation exchange capacity (CEC), improving moisture retention, and promoting efficient biological nutrient cycling (Nair *et al.*, 2010; Kumar and Nair, 2011) [9, 7]. Consequently, bamboo-based production systems are widely advocated for land rehabilitation, watershed protection, and sustainable agroforestry development across tropical and subtropical regions. Among silvicultural

intervention strategies, planting geometry (spacing) and nutrient management represent two critical operational levers dictating plantation structure and soil quality. Plantation spacing directly dictates spatial stocking density, light interception, microclimatic buffering, canopy closure speed, and root competition volume (Singh *et al.*, 2017) ^[14]. Optimum planting geometry balances spatial resource utilization while preventing severe inter-clump competition for soil moisture and nutrients. Concurrently, targeted inorganic or organic fertilizer applications fulfill high nutrient demands during early vegetative establishment, supporting rapid culm production and biomass accumulation. However, inadequate or excessive fertilizer inputs can alter soil chemical balances, accelerate soil acidification, or cause nutrient leaching losses under high rainfall regimes (Tripathi and Singh, 2018) ^[16]. *Dendrocalamus brandisii* (Munro) Kurz., commonly known as Sweet Bamboo or Velvet Leaf Bamboo, is a high-yielding, multipurpose tropical clump-forming species valued for industrial timber, paper pulp, structural construction, and edible shoot production. Given its fast growth rate and high biomass yield, *D. brandisii* exerts significant nutritional demands on soil reserves. Systematic evaluation of soil physical and chemical parameters under varying management regimes is vital for developing science-based nutrient management protocols (Yadav *et al.*, 2019) ^[18]. Therefore, the present investigation was undertaken to evaluate the influence of two spacing regimes and three nutrient levels on soil physical and chemical properties under a three-year-old *Dendrocalamus brandisii* plantation in the humid tropical region of Kodagu, Karnataka, India.

Materials and Methods

The investigation was conducted during 2022–2023 in an established *Dendrocalamus brandisii* plantation at the experimental field station of the College of Forestry, Ponnampet, Kodagu, Karnataka (12°08' N latitude, 75°53' E longitude, and 840 m above mean sea level). The experimental site is located in the Western Ghats region of southern India and experiences a humid tropical climate with heavy southwest monsoonal rainfall averaging 2,500–3,000 mm annually. The soils of the site are deep, well-drained red latosols (Alfisols/Ultisols) with an acidic reaction and moderate organic matter content. The experiment was laid out in a Split Plot Design with three replications, comprising two main plot treatments and three sub-plot treatments. The main plot factor consisted of two spacing regimes: M₁ (4.0 × 5.0 m; 500 plants ha⁻¹) and M₂ (5.0 × 5.0 m; 400 plants ha⁻¹). The sub-plot factor consisted of three nutrient regimes: S₁ (recommended dose of 25 g N, 9 g P₂O₅, and 25 g K₂O plant⁻¹ year⁻¹), S₂ (25% higher than the recommended dose, i.e., 31.25 g N, 11.25 g P₂O₅, and 31.25 g K₂O plant⁻¹ year⁻¹), and S₃ (50% higher than the recommended dose, i.e., 37.50 g N, 13.50 g P₂O₅, and 37.50 g K₂O plant⁻¹ year⁻¹). Soil samples were collected after completion of the 2022–2023 annual growth cycle from two standardized depths, namely surface soil (D₁: 0–15 cm) and subsurface soil (D₂: 15–30 cm). Composite samples were prepared by thoroughly mixing sub-samples collected from five random locations within the active rooting zone of each experimental plot using a stainless-steel auger. For chemical analysis, the samples were air-dried under shade, gently crushed using a wooden mallet, passed through a 2-mm stainless-steel sieve, and stored in polyethylene bags, while separate undisturbed soil cores were collected using calibrated cylindrical steel core samplers for bulk density estimation. Soil moisture content was

determined by the gravimetric method, wherein fresh soil samples were weighed immediately after collection, oven-dried at 105 ± 2 °C for 24 hours to constant weight, and moisture percentage was calculated as [(Fresh Weight – Oven Dry Weight)/Oven Dry Weight] × 100. Soil bulk density was estimated using the core method by dividing the oven-dry mass of soil by the known volume of the sampling core and expressed in g cm⁻³. Soil pH and electrical conductivity (EC) were measured in a 1:2.5 soil-to-water suspension using a digital pH meter and conductivity meter, respectively, following the procedure described by Richards (1954) ^[13], with EC expressed in dS m⁻¹ at 25 °C.

Soil organic carbon was estimated using the Walkley and Black wet oxidation method involving potassium dichromate and concentrated sulphuric acid followed by back titration with ferrous ammonium sulphate (Walkley and Black, 1934; Nelson and Sommers, 1996) ^[17, 11], and expressed in g kg⁻¹. Available nitrogen was determined by the alkaline potassium permanganate distillation method (Subbiah and Asija, 1956) ^[15], wherein the liberated ammonia was absorbed in boric acid and titrated against standard sulphuric acid, and results were expressed in kg ha⁻¹. Available phosphorus was extracted using Bray's No. 1 extractant (0.03 N NH₄F + 0.025 N HCl), appropriate for acidic soils, and quantified spectrophotometrically at 882 nm using the ascorbic acid blue colour method (Bray and Kurtz, 1945) ^[4], while available potassium was extracted with neutral 1 N ammonium acetate (pH 7.0) and measured using a flame photometer (Jackson, 1973) ^[6]. Available sulphur was extracted with 0.15% calcium chloride solution and estimated turbidimetrically using barium chloride at 420 nm (Jackson, 1973) ^[6], whereas exchangeable calcium and magnesium were extracted with neutral 1 N ammonium acetate and determined by complexometric EDTA titration using Calcon and Eriochrome Black T indicators (Jackson, 1973) ^[6], with values expressed in cmol(+) kg⁻¹. The experimental data on all soil physical and chemical properties were subjected to analysis of variance (ANOVA) appropriate for the Factorial Split Plot Design, and treatment means were compared using the Critical Difference (CD) test at the 5% level of significance (P = 0.05). Non-significant treatment effects were denoted as "NS". Gravimetric soil moisture data were subjected to arcsine transformation before statistical analysis, although the original untransformed means are presented in the tables along with the transformed values.

Results and Discussion

Soil Physical Properties

Statistical analysis revealed that spacing, nutrient regimes, and their interaction had no significant effect (P > 0.05) on soil moisture content or bulk density at either soil depth. M₂ (5.0 × 5.0 m) recorded slightly higher surface soil moisture (20.79%), while M₁ showed higher moisture at 15–30 cm (19.84%). Among nutrient regimes, S₂ recorded the highest surface moisture (20.93%) and S₃ the highest subsurface moisture (19.87%), with M₂S₂ and M₁S₃ producing the maximum surface (21.85%) and subsurface (20.53%) moisture, respectively. Bulk density ranged from 1.19–1.46 g cm⁻³ (0–15 cm) and 1.28–1.38 g cm⁻³ (15–30 cm), with the highest value under S₃ (1.43 g cm⁻³), though differences were non-significant. The results indicate that soil physical properties change slowly in young bamboo plantations, consistent with the findings of Singh *et al.* (2017) ^[14], Nath *et al.* (2015) ^[10], and Yadav *et al.* (2019) ^[18].

Table 1: Effect of different spacing and nutrient regimes on soil physical properties at two soil depths during 2022–2023

Treatment	Moisture Content (%)		Bulk Density (g cm ⁻³)	
	0–15 cm (D ₁)	15–30 cm (D ₂)	0–15 cm (D ₁)	15–30 cm (D ₂)
Spacing Regimes (Main Plot)				
M ₁ (4.0 × 5.0 m)	20.30 (26.78)	19.84 (26.45)	1.33	1.34
M ₂ (5.0 × 5.0 m)	20.79 (27.12)	18.91 (25.78)	1.34	1.33
S.E.m (±)	0.0560	0.0067	0.2100	0.1900
CD (@ 5%)	NS	NS	NS	NS
Nutrient Regimes (Sub Plot)				
S ₁ (Recommended NPK)	20.24 (26.73)	18.87 (25.74)	1.26	1.32
S ₂ (25% higher NPK)	20.93 (27.22)	19.40 (26.13)	1.32	1.36
S ₃ (50% higher NPK)	20.46 (26.89)	19.87 (26.46)	1.43	1.33
S.E.m (±)	0.0692	0.0208	0.2200	0.1900
CD (@ 5%)	NS	NS	NS	NS
Interaction (Spacing × Nutrient Regimes)				
M ₁ S ₁	19.89 (26.48)	19.20 (25.99)	1.19	1.30
M ₁ S ₂	20.02 (26.58)	19.78 (26.41)	1.36	1.35
M ₁ S ₃	20.99 (27.27)	20.53 (26.94)	1.46	1.38
M ₂ S ₁	20.59 (26.98)	18.53 (25.49)	1.32	1.34
M ₂ S ₂	21.85 (27.86)	19.01 (25.85)	1.39	1.36
M ₂ S ₃	19.93 (26.51)	19.20 (25.99)	1.40	1.28
S.E.m (±)	0.0978	0.0293	0.2100	0.2000
CD (@ 5%)	NS	NS	NS	NS

*Parenthetical values are arcsine transformed values; CD = Critical Difference; NS = Non-significant ($P > 0.05$).

Soil pH and Electrical Conductivity (EC)

Spacing had no significant effect ($P > 0.05$) on soil pH, whereas nutrient regimes significantly influenced pH at both 0–15 cm ($P = 0.0166$) and 15–30 cm ($P = 0.0243$). Treatment S₁ recorded the highest pH (6.28), while S₂ and S₃ caused slight acidification (6.18–6.20), likely due to H⁺ ion release during nitrification of applied nitrogen fertilizers. Electrical conductivity (EC) also varied significantly among nutrient regimes ($p < 0.05$), ranging

from 0.98 to 1.00 dS m⁻¹, with slightly higher values under S₂ and S₃ because of increased soluble fertilizer salts. However, all EC values remained below the critical salinity threshold (<2.0 dS m⁻¹), indicating suitable conditions for bamboo growth. The interaction between spacing and nutrient regimes was non-significant for both pH and EC. Similar results were reported by Tripathi *et al.* (2018) [16], Banik *et al.* (2020) [2], and Nath *et al.* (2015) [10].

Table 2: Changes in Soil pH and Electrical Conductivity (EC) under *Dendrocalamus brandisii* across spacing and nutrient regimes during 2022–2023

Treatment	Soil pH		Electrical Conductivity (dS m ⁻¹)	
	0–15 cm (D ₁)	15–30 cm (D ₂)	0–15 cm (D ₁)	15–30 cm (D ₂)
Spacing Regimes (Main Plot)				
M ₁ (4.0 × 5.0 m)	6.18	6.18	0.98	0.99
M ₂ (5.0 × 5.0 m)	6.24	6.27	0.98	0.98
S.E.m (±)	0.0042	0.0047	0.0008	0.0002
CD (@ 5%)	NS	NS	NS	NS
Nutrient Regimes (Sub Plot)				
S ₁ (Recommended NPK)	6.28	6.28	0.98	0.99
S ₂ (25% higher NPK)	6.18	6.20	0.98	1.00
S ₃ (50% higher NPK)	6.18	6.20	0.99	0.98
S.E.m (±)	0.0051	0.0075	0.0025	0.0004
CD (@ 5%)	0.0166*	0.0243*	0.0083*	0.0013*
Interaction (Spacing × Nutrient Regimes)				
M ₁ S ₁	6.29	6.26	0.98	0.99
M ₁ S ₂	6.16	6.17	0.98	0.99
M ₁ S ₃	6.08	6.11	0.99	0.98
M ₂ S ₁	6.26	6.29	0.98	0.99
M ₂ S ₂	6.19	6.22	0.98	0.99
M ₂ S ₃	6.27	6.29	0.98	0.98
S.E.m (±)	0.0072	0.0105	0.0036	0.0006
CD (@ 5%)	NS	NS	NS	NS

*Statistically significant main effects ($p < 0.05$) highlighted. CD = Critical Difference; NS = Non-significant.

Soil Chemical Properties

Statistical analysis showed that spacing, nutrient regimes, and their interaction had no significant effect ($P > 0.05$) on soil organic carbon (OC), primary macronutrients (N, P₂O₅, K₂O), or secondary nutrients (S, Ca, Mg). Surface OC ranged from 10.58–14.10 g kg⁻¹ and subsurface OC from 11.36–20.56 g kg⁻¹, with

wider spacing (M₂) recording higher subsurface OC (17.19 g kg⁻¹), and the maximum value under M₂S₁ (20.56 g kg⁻¹). Available N ranged from 167.49–194.07 kg ha⁻¹, P₂O₅ from 13.75–16.75 kg ha⁻¹, and K₂O from 248.22–287.79 kg ha⁻¹, with M₂ generally maintaining higher nutrient levels. Available S ranged from 2.30–4.17 mg kg⁻¹, while exchangeable Ca and Mg

varied from 2.47–4.27 and 2.42–3.88 cmol(+) kg⁻¹, respectively. The non-significant response indicates that soil nutrient dynamics change gradually in young bamboo plantations and become more

evident with stand maturation, consistent with Nath *et al.* (2015)^[10], Singh *et al.* (2017)^[14], and Kumar *et al.* (2021)^[8].

Table 3: Influence of spacing and nutrient regimes on soil chemical properties under *Dendrocalamus brandisii* during 2022–2023

Treatment	Depth	OC (g kg ⁻¹)	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)	S (mg kg ⁻¹)	Ca (cmol(+) kg ⁻¹)	Mg (cmol(+) kg ⁻¹)
Spacing Regimes (Main Plot)								
M ₁ (4.0 × 5.0 m)	D ₁	12.87	168.87	14.53	261.91	3.34	2.83	3.12
	D ₂	13.90	175.04	15.46	260.43	2.96	3.26	3.18
M ₂ (5.0 × 5.0 m)	D ₁	11.14	193.15	16.00	277.89	3.63	2.69	3.22
	D ₂	17.19	187.41	14.67	266.89	3.09	3.93	3.05
S.Em (±)	D ₁ /D ₂	0.03/0.00	0.14/0.03	0.01/0.04	0.04/0.05	0.02/0.02	0.01/0.02	0.02/0.03
CD (@ 5%)	D ₁ /D ₂	NS	NS	NS	NS	NS	NS	NS
Nutrient Regimes (Sub Plot)								
S ₁ (Optimum)	D ₁	11.17	179.73	15.09	272.74	2.94	2.83	3.06
	D ₂	17.46	183.09	14.98	267.66	2.90	3.10	3.13
S ₂ (+25%)	D ₁	12.50	182.17	15.73	273.80	3.60	2.78	2.61
	D ₂	14.36	181.44	15.26	260.74	2.49	3.90	3.11
S ₃ (+50%)	D ₁	12.34	181.13	14.99	263.15	3.93	2.67	3.85
	D ₂	14.81	179.15	14.96	262.57	3.69	3.79	3.11
S.Em (±)	D ₁ /D ₂	0.04/0.00	0.02/0.02	0.01/0.09	0.05/0.08	0.02/0.02	0.00/0.03	0.01/0.03
CD (@ 5%)	D ₁ /D ₂	NS	NS	NS	NS	NS	NS	NS
Interaction (Spacing × Nutrient Regimes)								
M ₁ S ₁	D ₁	11.44	167.49	13.75	270.80	2.62	2.77	3.06
	D ₂	14.36	173.67	15.69	269.74	2.89	2.67	3.07
M ₁ S ₂	D ₁	13.06	170.26	14.70	259.81	3.22	2.85	2.42
	D ₂	11.36	175.22	14.93	248.22	2.30	3.52	3.21
M ₁ S ₃	D ₁	14.10	168.87	15.14	255.12	4.17	2.88	3.88
	D ₂	15.96	176.23	15.76	263.32	3.70	3.58	3.26
M ₂ S ₁	D ₁	10.90	191.98	16.43	274.69	3.25	2.89	3.05
	D ₂	20.56	192.51	14.27	265.57	2.91	3.54	3.18
M ₂ S ₂	D ₁	11.94	194.07	16.75	287.79	3.97	2.71	2.80
	D ₂	17.36	187.66	15.58	273.26	2.67	4.27	3.00
M ₂ S ₃	D ₁	10.58	193.40	14.83	271.18	3.69	2.47	3.82
	D ₂	13.65	182.07	14.17	261.83	3.68	3.99	2.96
S.Em (±)	D ₁ /D ₂	0.05/0.01	0.02/0.03	0.02/0.13	0.07/0.12	0.02/0.03	0.00/0.05	0.01/0.05
CD (@ 5%)	D ₁ /D ₂	NS	NS	NS	NS	NS	NS	NS

*D₁ = 0–15 cm depth; D₂ = 15–30 cm depth; CD = Critical Difference; NS = Non-significant (P > 0.05).

Conclusion

The study revealed that spacing and nutrient regimes had limited influence on the soil physical and chemical properties of a three-year-old *Dendrocalamus brandisii* plantation. Soil bulk density, moisture content, organic carbon, and available nutrients (N, P, K, S, Ca, and Mg) did not differ significantly among treatments, indicating stable soil conditions under managed bamboo cultivation. Significant effects were observed only for soil pH and electrical conductivity, with higher fertilizer levels causing slight acidification and increased EC, although both remained within the optimum range for bamboo growth. Wider spacing (5.0 × 5.0 m) generally maintained higher soil moisture and nutrient availability due to reduced plant competition. The limited treatment effects are mainly attributed to the young age of the plantation, as improvements in soil properties under bamboo develop gradually through litter decomposition and root turnover. Overall, *Dendrocalamus brandisii* shows strong potential for sustaining soil health and fertility under appropriate silvicultural management.

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