



ISSN Print: 2664-844X
 ISSN Online: 2664-8458
 NAAS Rating (2026): NAAS
 Rating (2026): 4.97
 IJAFA 2026; 8(9): 584-588
www.agriculturaljournals.com
 Received: 01-07-2026
 Accepted: 17-08-2026
 Published: 25-08-2026

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Soil properties and carbon dynamics under commercially important bamboo species

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DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i9h.1920>

ABSTRACT

The influence of commercially important bamboo species on soil physical and chemical properties, soil organic carbon fractions and soil carbon dynamics was assessed during 2025–26 at the AICRP on Agroforestry, Futala Farm, College of Agriculture, Nagpur, Maharashtra, India. Eight bamboo species, namely *Dendrocalamus strictus*, *Bambusa vulgaris* (Yellow), *B. vulgaris* (Green), *B. tulda*, *B. nutan*, *B. balcooa*, *B. brandicee* and *B. bamboose*, were compared with fallow land. Soil samples from 0–30 cm depth were analysed for bulk density, hydraulic conductivity, pH, electrical conductivity, CaCO₃, available N, P and K, organic carbon, total organic carbon, carbon fractions, active and passive carbon pools, carbon indices and soil carbon stock. Bamboo plantations generally improved soil physical condition and carbon status relative to fallow land. *Bambusa nutan* recorded the lowest bulk density (1.28 Mg m⁻³), highest hydraulic conductivity (2.50 cm h⁻¹), lowest pH (7.35), lowest EC (0.164 dS m⁻¹), and highest organic carbon (10.20 g kg⁻¹) and total organic carbon (13.81 g kg⁻¹). It also recorded the highest available N (296.00 kg ha⁻¹), P (20.17 kg ha⁻¹) and K (274.33 kg ha⁻¹). Very labile carbon and non-labile carbon were maximum under *B. nutan* (5.83 and 3.61 g kg⁻¹, respectively), while active and passive carbon pools reached 8.18 and 5.63 g kg⁻¹. The highest carbon pool index (1.92), carbon management index (335.94) and soil carbon stock (52.90 t ha⁻¹) were also recorded under *B. nutan*. The results indicate that species-specific differences in litter input, root activity and organic matter turnover substantially influence soil quality and carbon dynamics, with *B. nutan* showing the greatest potential for improving soil carbon status under the prevailing conditions.

Keywords: Bamboo, Carbon management index, Carbon fractions, Soil organic carbon, Soil properties

Introduction

Soil organic carbon is a key component of soil quality because it influences nutrient availability, aggregation, water movement and the long-term capacity of soils to function as a carbon sink. Perennial vegetation systems can improve soil carbon status through continuous litter deposition, root biomass addition and reduced soil disturbance. Bamboo is particularly important in this context because of its rapid growth, high biomass turnover, extensive root–rhizome system and continuous regeneration. These characteristics can promote organic matter accumulation and nutrient recycling in the soil.

Bamboo-based systems have been reported to improve soil physical properties and soil organic carbon compared with open or fallow land. Continuous additions of leaves, roots and other plant residues may increase biologically active carbon fractions, while aggregation and humification processes can promote stabilization of more persistent carbon pools. The distribution of very labile, labile, less labile and non-labile carbon fractions provides additional information on both the quantity and quality of soil organic carbon and can be integrated through indices such as the carbon pool index (CPI) and carbon management index (CMI).

Commercially important bamboo species differ considerably in biomass production, litter quality, root activity and adaptation to local conditions. Consequently, their influence on soil physical and chemical properties and soil carbon dynamics may also differ. Information comparing soil properties and carbon fractions under commercially important bamboo species is limited for the subtropical conditions of the Nagpur region. Therefore, the present investigation was undertaken to evaluate the soil physical and chemical properties, available macronutrients, soil organic carbon fractions, carbon pools, carbon indices and soil carbon stock under different commercially important bamboo species.

Materials and methods

Experimental site and treatments

The investigation was conducted during 2025–26 at the AICRP on Agroforestry, Futala Farm, College of Agriculture, Nagpur, Maharashtra, India. The plantation was established during 2015–16. The experiment was laid out in a randomized block design with three replications and consisted of nine treatments, comprising eight commercially important bamboo species and fallow land. The spacing of bamboo was 5 × 5 m, and the soil was classified as Inceptisols.

Table 1. Treatment details

Treatment	Species
T ₁	<i>Dendrocalamus strictus</i>
T ₂	<i>Bambusa vulgaris</i> (Yellow)
T ₃	<i>Bambusa vulgaris</i> (Green)
T ₄	<i>Bambusa tulda</i>
T ₅	<i>Bambusa nutan</i>
T ₆	<i>Bambusa balcooa</i>
T ₇	<i>Bambusa brandicee</i>
T ₈	<i>Bambusa bamboose</i>
T ₉	Fallow land

Soil sampling and analysis

Representative soil samples were collected from 0–30 cm depth from the respective treatments. Samples were shade-dried, gently ground and passed through a 2-mm sieve; subsamples intended for organic carbon determination were further prepared according to the analytical requirements. Bulk density was determined by the core method (Blake *et al.*, 1986) [1], while saturated hydraulic conductivity was measured by the constant-head method (Richards, 1954) [2]. Soil pH and electrical conductivity were determined using standard procedures described by Jackson (1973) [3]. Organic carbon was determined by the Walkley and Black wet oxidation method (Walkley *et al.*, 1934) [4], and CaCO₃ was estimated following Piper (1966) [5]. Available nitrogen was estimated by the alkaline permanganate method (Subbiah *et al.*, 1956) [6], available phosphorus by the Olsen method (Olsen *et al.*, 1982) [7], and available potassium by neutral normal ammonium acetate extraction followed by flame photometry (Jackson, 1973) [3].

Soil carbon fractions and indices

Soil organic carbon fractions were determined using the modified Walkley and Black oxidation procedure described by Chan *et al.* (2001) [8]. Very labile, labile and less labile carbon fractions were determined using progressively stronger sulphuric acid concentrations, while non-labile carbon was obtained by difference from total organic carbon. Total organic carbon was determined using a TOC analyser following the procedure cited in the thesis methodology (Tiessen *et al.*, 1993) [9]. Active carbon pool was calculated as the sum of very labile and labile carbon, whereas passive carbon pool was calculated as the sum of less labile and non-labile carbon. The lability index, carbon pool index and carbon management index were calculated according to the procedures described in the thesis methodology and relevant literature, with fallow land serving as the reference treatment for the carbon pool index and carbon management assessment.

Statistical analysis

The experiment was analysed according to the randomized block design. Treatment means were compared using the statistical procedure adopted in the thesis. Statistical significance was interpreted at the 5% probability level wherever applicable.

Results and discussion

Soil physical properties

Bulk density and hydraulic conductivity varied among bamboo species and fallow land (Table 2). Bulk density ranged from 1.28 to 1.44 Mg m⁻³. The lowest value was recorded under *B. nutan* (T₅), followed by *B. balcooa* (1.29 Mg m⁻³), whereas fallow land recorded the highest bulk density. Hydraulic conductivity ranged from 1.50 to 2.50 cm h⁻¹ and was highest under *B. nutan* and lowest under fallow land. The lower bulk density and greater hydraulic conductivity under bamboo plantations indicate improved soil structure, pore continuity and water movement. These changes may be associated with continuous organic matter inputs, root activity and improved aggregation under perennial bamboo vegetation.

Table 2. Bulk density and hydraulic conductivity under different treatments

Treatment	Bulk density (Mg m ⁻³)	Hydraulic conductivity (cm h ⁻¹)
T ₁ <i>D. strictus</i>	1.32	2.2
T ₂ <i>B. vulgaris</i> (Yellow)	1.33	2.1
T ₃ <i>B. vulgaris</i> (Green)	1.34	2.0
T ₄ <i>B. tulda</i>	1.36	1.9
T ₅ <i>B. nutan</i>	1.28	2.5
T ₆ <i>B. balcooa</i>	1.29	2.4
T ₇ <i>B. brandicee</i>	1.35	2.1
T ₈ <i>B. bamboose</i>	1.30	2.3
T ₉ Fallow land	1.44	1.5

Soil reaction, electrical conductivity and calcium carbonate

Soil pH ranged from 7.35 to 7.50, EC from 0.164 to 0.238 dS m⁻¹ and CaCO₃ from 3.40 to 4.80% (Table 3). The lowest pH, EC and CaCO₃ were recorded under *B. nutan*, whereas fallow land recorded the highest values. The comparatively lower pH and EC under bamboo species may be related to differences in organic matter accumulation, nutrient uptake and nutrient cycling. Continuous litter decomposition may also influence soil reaction through the formation of organic acids and changes in the soil solution.

Organic carbon, total organic carbon and available macronutrients

Organic carbon and total organic carbon were consistently higher under bamboo plantations than under fallow land (Table 4). Organic carbon ranged from 5.22 to 10.20 g kg⁻¹ and total organic carbon ranged from 7.21 to 13.81 g kg⁻¹. *B. nutan* recorded the highest values for both parameters, while fallow land recorded the lowest values. The greater carbon accumulation under bamboo species can be attributed to continuous litter deposition, root turnover and organic residue inputs.

Table 3. pH, EC and CaCO₃ of soil under different treatments

Treatment	pH	EC (dS m ⁻¹)	CaCO ₃ (%)
T ₁ <i>D. strictus</i>	7.45	0.195	4.3
T ₂ <i>B. vulgaris</i> (Yellow)	7.40	0.192	3.9
T ₃ <i>B. vulgaris</i> (Green)	7.41	0.188	4.1
T ₄ <i>B. tulda</i>	7.48	0.201	4.6
T ₅ <i>B. nutan</i>	7.35	0.164	3.4
T ₆ <i>B. balcooa</i>	7.37	0.172	3.6
T ₇ <i>B. brandicee</i>	7.46	0.187	4.3

(continued on next page)

Treatment	pH	EC (dS m ⁻¹)	CaCO ₃ (%)
T8 <i>B. bamboose</i>	7.38	0.183	3.7
T9 Fallow land	7.50	0.238	4.8

Available nitrogen, phosphorus and potassium also showed higher values under bamboo plantations than under fallow land (Table 5). *B. nutan* recorded the highest available N (296.00 kg ha⁻¹), P (20.17 kg ha⁻¹) and K (274.33 kg ha⁻¹), while fallow land recorded the minimum values. The improved nutrient status may be associated with continuous litter deposition, root biomass addition, microbial mineralization and nutrient recycling under bamboo vegetation.

Treatment	Organic carbon (g kg ⁻¹)	Total organic carbon (g kg ⁻¹)
T1 <i>D. strictus</i>	9.50	11.20

Table 4. Organic carbon and total organic carbon under different treatment

Treatment	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
T1 <i>D. strictus</i>	279.50	16.40	256.00
T2 <i>B. vulgaris</i> (Yellow)	286.50	18.13	263.00
T3 <i>B. vulgaris</i> (Green)	281.30	17.10	260.00
T4 <i>B. tulda</i>	275.30	15.30	251.30
T5 <i>B. nutan</i>	296.00	20.17	274.33
T6 <i>B. balcooa</i>	290.67	19.83	269.00
T7 <i>B. brandicee</i>	278.05	16.10	254.20
T8 <i>B. bamboose</i>	288.50	19.10	267.33
T9 Fallow land	245.30	13.90	235.28

Soil organic carbon fractions

The distribution of very labile carbon (VLC), labile carbon (LC), less labile carbon (LLC) and non-labile carbon (NLC) differed among the treatments (Table 6). VLC ranged from 2.72 to 5.83 g kg⁻¹, LC from 1.43 to 2.50 g kg⁻¹, LLC from 1.07 to 2.04 g kg⁻¹ and NLC from 1.50 to 3.61 g kg⁻¹. The highest VLC and NLC were recorded under

Treatment	Organic carbon (g kg ⁻¹)	Total organic carbon (g kg ⁻¹)
T2 <i>B. vulgaris</i> (Yellow)	9.80	12.28
T3 <i>B. vulgaris</i> (Green)	9.74	11.98
T4 <i>B. tulda</i>	9.10	10.60
T5 <i>B. nutan</i>	10.20	13.81
T6 <i>B. balcooa</i>	9.94	13.38
T7 <i>B. brandicee</i>	9.30	10.90
T8 <i>B. bamboose</i>	9.85	12.81
T9 Fallow land	5.22	7.21

Table 5. Available macronutrient status of soil under different treatments

B. nutan, indicating greater accumulation of both readily oxidizable and relatively stable carbon fractions. LC was highest under *B. vulgaris* (Yellow) and *B. brandicee*, while LLC was highest under *B. tulda*. The lower values under fallow land indicate comparatively lower organic residue input and carbon turnover. Species differences in carbon fractions may reflect differences in litter quantity and quality, root biomass and decomposition dynamics.

Table 6. Soil Organic carbon fraction under different treatments

Treatment	VLC	LC	LLC	NLC
T1 <i>D. strictus</i>	5.03	2.44	2.03	1.70
T2 <i>B. vulgaris</i> (Yellow)	5.32	2.50	1.97	2.48
T3 <i>B. vulgaris</i> (Green)	5.31	2.47	1.95	2.24
T4 <i>B. tulda</i>	4.68	2.38	2.04	1.50
T5 <i>B. nutan</i>	5.83	2.36	2.02	3.61
T6 <i>B. balcooa</i>	5.61	2.38	1.95	3.44
T7 <i>B. brandicee</i>	4.94	2.50	1.85	1.60
T8 <i>B. bamboose</i>	5.47	2.42	1.97	2.96
T9 Fallow land	2.72	1.43	1.07	1.99

Active and passive carbon pools

Active carbon pool ranged from 4.15 to 8.18 g kg⁻¹ and passive carbon pool from 3.05 to 5.63 g kg⁻¹ (Table 7). *B. nutan* recorded the maximum active and passive carbon pools, followed closely by *B. balcooa* for passive carbon. The greater accumulation of active carbon under bamboo plantations indicates continuous supply of fresh organic substrates, whereas the higher passive pool indicates enhanced stabilization of carbon through aggregation and humification. Together, these results demonstrate that bamboo vegetation can improve both short-term carbon cycling and longer-term carbon storage.

Carbon indices and soil carbon stock

Carbon indices further demonstrated the improvement in soil carbon status under bamboo plantations (Table 8). The lability index ranged from 1.68 to 1.99, with the maximum value under *B. brandicee*. The carbon pool index ranged from 1.00 under fallow land to 1.92 under *B. nutan*, while the carbon management index ranged from 167.80 to 335.94. The highest CPI and CMI under *B. nutan* indicate greater accumulation of soil carbon and improved carbon management relative to fallow land.

Table 7. Soil organic carbon pools under different treatments

Treatment	Active carbon pool (g kg ⁻¹)	Passive carbon pool (g kg ⁻¹)
T1 <i>D. strictus</i>	7.47	3.73
T2 <i>B. vulgaris</i> (Yellow)	7.83	4.45
T3 <i>B. vulgaris</i> (Green)	7.79	4.19

Treatment	Active carbon pool (g kg ⁻¹)	Passive carbon pool (g kg ⁻¹)
T4 <i>B. tulda</i>	7.06	3.54
T5 <i>B. nutan</i>	8.18	5.63
T6 <i>B. balcooa</i>	7.99	5.39
T7 <i>B. brandicee</i>	7.45	3.45
T8 <i>B. bamboose</i>	7.89	4.93
T9 Fallow land	4.15	3.05

Table 8. Lability index, carbon pool index and carbon management index under different treatments

Treatment	Lability index	Carbon pool index	Carbon management index
T1 <i>D. strictus</i>	1.96	1.55	303.84
T2 <i>B. vulgaris</i> (Yellow)	1.87	1.70	317.79
T3 <i>B. vulgaris</i> (Green)	1.91	1.66	316.93
T4 <i>B. tulda</i>	1.97	1.47	289.17
T5 <i>B. nutan</i>	1.75	1.92	335.94
T6 <i>B. balcooa</i>	1.76	1.86	326.64
T7 <i>B. brandicee</i>	1.99	1.51	300.97
T8 <i>B. bamboose</i>	1.81	1.78	322.11
T9 Fallow land	1.68	1.00	167.80

Conclusion

Commercially important bamboo species differed markedly in their influence on soil physical and chemical properties and soil carbon dynamics. Compared with fallow land, bamboo plantations generally reduced bulk density, increased hydraulic conductivity, improved organic carbon status and enhanced available macronutrient availability. They also promoted the accumulation of different soil organic carbon fractions and increased active and passive carbon pools.

Among the evaluated species, *Bambusa nutan* consistently showed the most favourable soil response. It recorded the lowest bulk density, highest hydraulic conductivity, maximum organic carbon and total organic carbon, highest available N, P and K, maximum very labile and non-labile carbon, maximum active and passive carbon pools, highest carbon pool index and carbon management index. The results suggest that *Bambusa nutan* has strong potential for improving soil quality and enhancing soil carbon accumulation under the prevailing agro-climatic conditions of Nagpur, Maharashtra.

Acknowledgement

The authors acknowledge the facilities and support provided by the Soil Science Section and AICRP on Agroforestry, College of Agriculture, Nagpur, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India.

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How to cite this article: Danish M, Raut MM, Kuchanwar OD, Raut P, Ilorkar V, Bhosale A, et al. Soil properties and carbon dynamics under commercially important bamboo species. *International Journal of Agriculture and Food Science*. 2026;8(9):584-588. doi: <https://www.doi.org/10.33545/2664844X.2026.v8.i9h.1920>

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