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Rhizosphere physicochemical properties and enzyme activities under different forest tree plantation

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Abstract
The present investigation was undertaken to study the "Rhizosphere Physicochemical Properties and Enzyme Activities under different Forest Tree Plantations". The experiment was conducted at Central Campus, Department of Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri, during 2023-2024. The experiment was conducted in Randomized Block Design (RBD) with four replications and six treatments with two soil depths 0-15 and 15-30 cm. The treatments comprised of T_1: Bamboo (*Bambusa vulgaris*), T_2: Teak wood (*Tectona grandis*), T_3: Eucalyptus (*Eucalyptus globulus*), T_4: Neem (*Azadirachta indica*), T_5: Acacia (*Acacia nilotica*), T_6: Karanj (*Millettia pinnata*). The results revealed that significantly highest clay content (57.43% and 57.67%) were recorded in treatment T_1 (*Bambusa vulgaris*), bulk density (1.43 and 1.46 Mg m^{-3}) were recorded in treatment T_5 (*Acacia nilotica*), pH (8.27 and 8.33), EC (0.35 and 0.33 dS m^{-1}) were recorded in treatment T_6 (*Millettia pinnata*), Organic carbon (6.1 and 6.0 g kg^{-1}) recorded in treatment T_1 (*Bambusa vulgaris*), nutrient availability (Nitrogen 227.36 and 220.30 kg ha^{-1}, Phosphorus 21.92 and 20.37 kg ha^{-1} were recorded in treatment T_5 (*Acacia nilotica*), Potassium (484.40 and 472.35 kg ha^{-1}) were recorded in treatment T_2 (*Tectona grandis*), Enzyme activities of dehydrogenase (43.37 and 42.05 µg TPF g^{-1} soil 24 hr^{-1}) were recorded in treatment T_5 (*Acacia nilotica*), β -glucosoidase activity ((95.49 and 94.35 µg P-Nitrophenol g^{-1} soil 24 hr^{-1}) were recorded in treatment T_1 (*Bambusa vulgaris*), acid and alkaline phosphatase activities ((52.91 and 52.15 µg P-Nitrophenol g^{-1} soil 24 hr^{-1}) were recorded in T_1 (*Bambusa vulgaris*) (73.63 and 72.39 µg P-Nitrophenol g^{-1} soil 24 hr^{-1}) were recorded in treatment T_5 (*Acacia nilotica*), urease activity (60.75 and 58.19 µg NH_4-N g^{-1} soil 24 hr^{-1}) were recorded in treatment T_5 Acacia (*Acacia nilotica*), SMBC and SMBN (218.00 and 211.10 µg C g^{-1} soil) (22.46 and 18.89 µg N g^{-1} soil) were recorded in the treatment T_6, Karanj (*Millettia pinnata*).

Keywords: Soil enzymes, rhizosphere, Acacia, Bamboo, organic carbon, nutrient cycling

1. Introduction

Soil fertility and ecosystem functioning are governed by a complex interaction between soil physicochemical properties and biological activity. Forest plantations modify the rhizosphere environment through organic matter inputs, root exudates, and litter quality, which in turn affect soil biochemical processes (Fierer & Jackson, 2006) [4]. Soil enzymes, secreted primarily by microorganisms, play crucial roles in nutrient cycling. Urease regulates nitrogen turnover by hydrolyzing urea into ammonium, phosphatase mobilizes organic phosphorus into plant-available forms, while sucrase enhances carbon cycling through sucrose breakdown (Deng *et al.*, 2019) [3].

Tree species vary in their influence on soil. Leguminous trees such as *Acacia nilotica* and *Millettia pinnata* enhance soil fertility by fixing atmospheric nitrogen and enriching soil organic matter (Cuong *et al.*, 2022) [2]. Bamboo contributes to phosphorus cycling through high litter deposition and microclimate regulation (Tu *et al.*, 2014) [14]. Neem is recognized for sustaining soil microbial activity, while Eucalyptus monocultures often reduce soil enzyme activities due to allelopathic effects and nutrient mining (Zhu *et al.*, 2019) [18].

The present study aimed to estimate the physicochemical properties and enzyme activities of rhizosphere soils under different forest tree plantations at MPKV, Rahuri, there by identifying tree species with positive impacts on soil health.

2. Materials and Methods

The field experiment was conducted during 2023-2024 at Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra (India). The region extends between 19o35’76’’-19o37’75’’ N latitude and 74o65’15’’- 74o66’90’’ E longitude and the altitude ranges from 515-534 m above mean sea level, was selected for collection of soil samples. The experiment was conducted in Randomized Block Design (RBD) with four replications and six treatments. The treatments comprised of (T_1) - Bamboo (Bambusa Vulgaris), (T_2) - Teak wood (Tectona grandis), (T_3) - Eucalyptus (Eucalyptus globulus), (T_4) - Neem (Azadirachta indica), (T_5) - Acacia (Acacia nilotica), (T_6) - Karanj (Millettia pinnata). Rhizosphere soil samples were collected at 0-15 cm and 15-30 cm depths in four replications per treatment.

3. Results and Discussion

Soil Texture

The data regarding soil texture under different forest tree plantations are shown in table 1. Results indicated that the soil texture under different treatments showed clay to silty clay. The soil texture varied across different forest tree plantations and depths (0-15 cm and 15-30 cm), indicating the influence of vegetative cover and associated rhizosphere activities on particle size distribution. Clay content was highest under Bamboo (T_1) and Acacia (T_5) at both soil depths (0-15 cm and 15-30 cm), indicating fine particles, which influence water retention and microbial activity. Teak wood (T_2) and Neem (T_4) recorded silty loam and silty clay, respectively, suggesting variation in parent material and organic matter accumulation under different species. Similar finding were reported by parmar et al (2021) [9] who observed that variations in soil texture of different horticulture-based agroforestry systems in South Gujarat.

Bulk Density

The data regarding the relative changes in bulk density under different forest tree plantations are shown in table 2. The bulk density of soil varied among the different tree plantations and soil depths. Results indicated that the bulk density under different forest tree plantation was generally increased with soil depth across all treatments. At 0-15 cm depth, the lowest bulk density was observed under Teak wood (T_2) (1.24 Mg m-3). Teak wood had significantly lower bulk density due to higher organic matter accumulation and root-induced aggregation. The highest bulk density was observed under Acacia (T_5) (1.43 Mg m-3). Similar trends were noticed at 15-30 cm depth of bulk density with range of 1.27 Mg m-3 to 1.46 Mg m-3.

The lower bulk density recorded under Teak wood and Bamboo plantations can be linked to the greater input of organic matter from litter fall, increased root biomass, and higher microbial activity, all of which promote soil aggregation and enhance porosity. In contrast, the relatively higher bulk density observed under Acacia and Neem plantations may be associated with limited organic matter contribution, higher clay fraction, and a comparatively compact soil structure beneath their canopy. Across all plantations, bulk density showed an increasing trend with soil depth, reflecting greater compaction and reduced organic matter in the subsurface horizons. Similar results were noted by Sundarapandian *et al.* (2016) [12].

pH

The data pertaining to changes in pH under different forest tree plantations are showed in table 2. Result indicating that the pH under different forest tree plantations, generally increased with soil depth at all treatments. At 0-15 cm depth significantly lowest pH (6.97) was recorded under Bamboo (T_1) and highest pH (8.27) was recorded under Karanj (T_6) and at par with treatment T_4, T_5 and T_2. However, at 15-30 cm depth significantly lowest pH was recorded under Bamboo (T_1) (7.05) and highest pH (8.33) was recorded under Karanj (T_6) and found at par with treatment T_4, T_5 and T_2.

The relatively higher soil pH under leguminous tree species such as Karanj and Acacia may be attributed to the accumulation of basic cations (Ca2+ Mg2+) through litter decomposition and biological nitrogen fixation. In contrast, non-leguminous species like Bamboo and Eucalyptus tended to maintain lower pH levels, possibly due to deposition of acidic litter and root exudates. Above results are in consonance with those of Zhang et al (2019) [17].

Electrical Conductivity

The data pertaining to changes in electrical conductivity under different forest tree plantations was presented in table 2. The EC values ranged between 0.14-0.35 dS m-1. There was significant increased in electrical conductivity at different depth was observed under forest tree plantations. Electrical conductivity generally decreased with increasing soil depth. The decrease in EC with soil depths is typically, as soluble salts tend to accumulate in the topsoil due to evaporation and plant nutrient uptake. At 0-15 cm depth, the lowest EC was recorded under Bamboo (0.17 dS m-1) and highest EC was observed under Karanj (0.35 dS m-1) overall the other treatment except T4. Neem which was statistically at par. Similar trend was observed at 15-30 cm soil depth.

A significant variation in electrical conductivity (EC) across soil depths was recorded under different forest tree plantations, with values generally declining in deeper layers. This trend is commonly explained by the accumulation of soluble salts in surface soils as a result of evapotranspiration and plant nutrient absorption, whereas subsurface horizons usually contain fewer salts (Brady and Weil, 2017) [1]. Elevated EC under leguminous species such as Karanj and Acacia may be linked to improved nutrient cycling and greater organic matter mineralization in the rhizosphere, which increase soluble ion concentrations in surface soils. Conversely, Bamboo plantations exhibited comparatively lower EC, possibly due to greater water uptake and reduced ionic contribution from litter and root secretions. Supporting evidence was provided by Lu *et al.* (2024) [6].

Organic Carbon

Soil organic carbon content under different forest tree plantations was recorded in table 2. It can be seen that, the organic carbon content decreased with soil depths. At 0-15 cm Bamboo (T_1) recorded highest organic carbon 6.1 g kg-1 and 6.0 g kg-1 at 15-30 cm soil depth. Bamboo suggests a greater contribution of organic matter to the soil, likely due to litterfall and root exudates. However, lowest organic carbon was recorded under Karanj (T_6) 4.2 g kg-1 and 3.8 g kg-1 at 0-15 and 15-30 cm soil depth, respectively. Overall the treatments except T4 and T5 which were at par.

Higher soil organic carbon under Bamboo, Neem, and Acacia plantations may be due to greater litter fall, fine root turnover, and higher microbial activity, which promote the accumulation of organic carbon in the soil. While, lower soil organic carbon under Karanj and Eucalyptus could be due to less litter input, slower decomposition rates, or more recalcitrant litter (Zhang *et al.*, 2019; Wang *et al.*, 2022) [15, 17]. Similar observations have been reported by Li *et al.* (2022) [7].

Available nitrogen

The data presented in Table 2 revealed that the available nitrogen was ranged from 144.20 to 227.36 kg ha-1. At 0-15 cm depth, result indicated that the significantly highest available nitrogen (227.36 kg ha-1) was observed under Acacia (T_5). Acacia is a leguminous tree, fixes atmospheric nitrogen through symbiotic rhizobium and it was significantly superior to other treatments, and lowest available nitrogen (158.70 kg ha-1) was recorded under Karanj (T_6). Similar trend was observed at 15-30 cm depth and range of available nitrogen was 220.30 kg ha-1 to 144.20 kg ha-1. It can be seen that the available nitrogen decreased with depths. Similar findings have been reported by Cuong *et al.* (2022) [2] observed that soil total nitrogen stocks increased with plantation age in Acacia mangium plantations, highlighting the role of tree age in nitrogen accumulation

Table 1: Soil texture under different forest tree plantations

Tr. No	Treatments	Depth (cm)	Particle size analysis (%)			Textural class
			Sand	Silt	Clay	
T_1	Bamboo (*Bambusa vulgaris*)	0-15	12.36	30.21	57.43	Clay
		15-30	12.50	29.83	57.67	
T_2	Teak wood (*Tectona grandis*)	0-15	18.48	50.66	30.86	Silty clay
		15-30	17.18	50.91	31.91	
T_3	Eucalyptus (*Eucalyptus globulus*)	0-15	16.62	31.18	52.20	Clay
		15-30	16.18	30.07	53.75	
T_4	Neem (*Azadirachta indica*)	0-15	18.57	50.67	30.76	Silty loam
		15-30	18.28	50.63	31.09	
T_5	Acacia (*Acacia nilotica*)	0-15	17.60	29.78	52.52	Clay
		15-30	17.19	29.28	53.53	
T_6	Karanj (*Millettia pinnata*)	0-15	16.14	53.11	30.75	Silty clay
		15-30	12.18	56.82	31.00	

Available phosphorous

The data reported in table 2. represents the available phosphorous content under different forest tree plantations. Available phosphorous content generally decreased with soil depths. At 0-15 cm depth, significantly highest available phosphorous was recorded under Acacia (21.92 kg ha-1) and lowest available phosphorous was recorded under Bamboo (15.45 kg ha-1). However at 15-30 cm depth highest available phosphorous was recorded under Acacia (20.37 kg ha-1) and lowest available phosphorous was recorded under Bamboo (14.22 kg ha-1). Available phosphorous under Acacia plantation are significant potential due to phosphate solubilizing bacteria.

Decrease in available phosphorous with increasing soil depth was observed across all treatments. This trend is consistent with higher microbial activity, litter decomposition, and nutrient mineralization in the topsoil, which enriches available phosphorus in the surface layer. Leguminous species such as Acacia are known to enhance soil phosphorus availability through various mechanisms, including the release of organic acids and root exudates that mobilize phosphorus from soil particles. This ability contributes to higher available P in the soil under these species. In contrast, non-leguminous species like Karanj and Eucalyptus have lower phosphorus mobilization capabilities, resulting in comparatively lower available P levels. Similar findings have been reported by Russell *et al.* (2025) [10].

Available potassium

The results of soil available potassium (K) under different forest tree plantations are presented in table 3. The available potassium content varied significantly among treatments and soil depths, ranging from 389.10 to 484.40 kg ha^{-1}. The significantly highest available potassium was observed under Teak (Tectona grandis) 484.40 kg ha^{-1} at 0-15 cm and 472.35 kg ha^{-1} at 15-30 cm soil depth, followed by Eucalyptus (Eucalyptus globulus) 479.32 kg ha-1 at 0-15 cm and 465.41 kg ha-1. At 15-30 cm and it was statistically at par with T4 and T5. The lowest potassium content was recorded under Bamboo (Bambusa vulgaris) (397.60 and 389.10 kg ha^{-1}) and Karanj (Millettia pinnata) (412.63 and 401.27 kg ha^{-1}) at both soil depths.

Tree species significantly influenced soil potassium content, with higher values under deep-rooted species like Teak, Eucalyptus, and Acacia. The ability of certain tree species to release K through litter decomposition and root exudates plays a major role in maintaining soil fertility. Similar observations have been reported by Tejkaran *et al.* (2017) [13] observed that Acacia and Casuarina plantations significantly enhanced soil K content through litter decomposition and rhizosphere activity.

Dehydrogenase Activity

The dehydrogenase activity (DHA) of soil under different forest tree plantations, measured in µg TPF g^{-1} soil 24 hr^{-1}, is presented in Table 3. It can be seen that, the dehydrogenase activity decreased gradually with depth. Significantly highest dehydrogenase activity was recorded under Acacia (Acacia nilotica) with 43.37 µg TPF g^{-1} soil 24 hr^{-1} at 0-15 cm and 42.05 µg TPF g^{-1} soil 24 hr^{-1} at 15-30 cm, followed by Teak (Tectona grandis) (42.98 and 41.96 µg TPF g^{-1} soil 24 hr^{-1}) and Eucalyptus (Eucalyptus globulus) (41.85 and 39.95 µg TPF g^{-1} soil 24 hr^{-1}). The lowest dehydrogenase activity was observed under Karanj (Millettia pinnata) (36.96 µg TPF g^{-1} soil 24 hr^{-1} at 0-15 cm and 35.35 µg TPF g^{-1} soil h^{-1} at 15-30 cm). Overall other treatments except T_2 and T_3 were at par.

The significantly higher DHA in Acacia, Teak, and Eucalyptus plantations may be due to increased root exudation, litter deposition, and enhanced microbial population in the rhizosphere. Leguminous species like Acacia contribute nitrogen-rich litter, which stimulates microbial metabolism and enzymatic activity. In contrast, lower DHA in Karanj and Bamboo might be linked to lower organic matter input and relatively lower microbial abundance. Similar finding observed by Mir et al (2023) [8].

β-Glucosidase Activity

The results (Table 3.) revealed significant variation in β - glucosidase activity among different forest tree plantations and soil depths. At the 0-15 cm depth, the highest β -glucosidase activity was recorded under Bamboo (T_1) (95.49 µg P-Nitrophenol g-1 soil 24 hr-1) while, the lowest activity was found in Karanj (T_6) (85.12 µg P-Nitrophenol g-1 soil 24 hr-1). A similar trend was observed at the 15-30 cm depth, where Bamboo showed the highest activity (94.35 µg P-Nitrophenol g-1 soil 24 hr-1) and Karanj the lowest (82.55 µg P-Nitrophenol g-1 soil 24 hr-1).

Higher β-glucosidase activity under Bamboo, Acacia, and Neem plantations may be attributed to greater litter fall, root exudates, and organic matter input, which stimulate microbial populations responsible for enzyme production. The lower activity under Karanj and Eucalyptus may result from comparatively lower organic matter content and microbial biomass. Similar results observed by Kaushal *et al.* (2020) [5].

Acid and Alkaline Phosphatase Activities

The acid and alkaline phosphatase activities under various forest tree plantations at two soil depths is presented in Table 3. Acid phosphatase activity at 0-15 cm depth, Bamboo (T_1) recorded the highest acid phosphatase activity (52.91 µg P-Nitrophenol g-1 soil 24 hr-1) followed by Eucalyptus (T_3) (50.94 µg P-Nitrophenol g-1 soil 24 hr-1) and Teak wood (T_2) (48.37 µg P-Nitrophenol g-1 soil 24 hr-1). The lowest activity was found under Karanj (T_6) (45.33 µg P-Nitrophenol g-1 soil 24 hr-1). A similar trend was observed at the 15-30 cm soil depth, with the maximum activity under Bamboo (52.15 µg P-Nitrophenol g-1 soil 24 hr-1) and the lowest under Karanj (44.95 µg P-Nitrophenol g-1 soil 24 hr-1). Acid phosphatase activity was slightly reduced at the subsoil depth for all treatments, likely due to reduced organic matter and microbial biomass.

At 0-15 cm, the highest alkaline phosphatase activity was recorded under Acacia (T_5) (73.63 µg P-Nitrophenol g-1 soil 24 hr-1), the lowest activity was observed under Karanj (T_6) (64.43 µg P-Nitrophenol g-1 soil 24 hr-1). At 15-30 cm Acacia showed the highest activity (72.39 µg P-Nitrophenol g-1 soil 24 hr-1) while, Karanj recorded the lowest (63.25 µg P-Nitrophenol g-1 soil 24 hr-1)

It was further observed that enzyme activities were consistently higher in the surface soil (0-15 cm) compared to the subsurface (15-30 cm). This may be due to greater microbial biomass, higher root density, and organic matter availability in surface horizons, which stimulate phosphatase secretion. Similar finding observed by Wang *et al.* (2022) [15].

Urease Activity

The urease activity under various forest tree plantations at two soil depths is presented in Table 4. The activity varied notably among treatments, indicating a strong influence of tree species on soil biochemical functioning At the surface depth, the highest urease activity was obseved under Acacia (T_5) plantation (60.75 µg NH4-N g-1 soil 24 hr-1) while, Bamboo (T_1) and Karanj (T_6) recorded the lowest activity (53.65 and 52.00 µg NH4-N g-1 Soil 24 hr-1, respectively). At 15-30 cm similar trend was seen at the subsurface depth. Acacia maintained the highest urease activity (58.19 µg NH4-N g-1 soil 24 hr-1), and Karanj remained Lowest (50.62 µg NH4-N g-1 soil 24 hr-1). There was a slightly reduction in enzyme activity with soil depth in all treatments, consistent with lower microbial activity and reduced organic matter availability in deeper soil layers.

The observed higher urease activity in surface soils corroborates the findings of Similarly, Mir *et al.* (2023) [8].

Table 2: Soil bulk density, pH, Electrical conductivity, Organic carbon, Available nitrogen, and Available.

Tr. No.	Treatments	Bulk density (Mg m^{-3})		pH (1:2.5)		EC (dS m^{-1})		OC (g kg^{-1})		N (kg ha^{-1})		P (kg ha^{-1})	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Bamboo (*Bambusa vulgaris*)	1.26	1.32	6.97	7.05	0.17	0.14	6.1	6.0	183.46	178.32	15.45	14.22
T_2	Teak wood (*Tectona grandis*)	1.24	1.27	7.81	7.87	0.28	0.23	5.0	4.7	221.70	215.22	19.37	18.73
T_3	Eucalyptus (*Eucalyptus globulus*)	1.35	1.39	7.51	7.57	0.25	0.21	4.6	4.2	174.30	167.45	18.09	17.53
T_4	Neem (*Azadirachta indica*)	1.40	1.43	8.13	8.19	0.33	0.29	5.9	5.7	165.21	153.66	16.81	15.76
T_5	Acacia (*Acacia nilotica*)	1.43	1.46	7.93	8.00	0.27	0.26	5.8	5.6	227.36	220.30	21.92	20.37
T_6	Karanj (*Millettia pinnata*)	1.31	1.34	8.27	8.33	0.35	0.33	4.2	3.8	158.70	144.20	15.75	14.62
	SE(m)±	0.02	0.02	0.16	0.16	0.02	0.02	0.11	0.12	4.52	3.96	0.30	0.30
	CD at 5%	0.07	0.07	0.50	0.50	0.05	0.05	0.34	0.36	13.63	12.04	0.93	0.90

Table 3: Soil Available Potassium, Dehydrogenase activity, β -glucosidase activity, Acid phosphatase and alkaline

Tr. No.	Treatments	K (kg ha^{-1})		DHA (µg TPF g^{-1} soil 24 hr^{-1})		β-Glucosidase (µg PNP g-1 soil 24 hr^{-1})		Acid Phosphatase (µg PNP g^{-1} soil 24 hr^{-1})		Alkaline Phosphatase (µg PNP g^{-1} soil 24 hr^{-1})	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Bamboo (*Bambusa vulgaris*)	397.60	389.10	37.24	35.65	95.49	94.35	52.91	52.15	65.51	64.42
T_2	Teak wood (*Tectona grandis*)	484.40	472.35	42.98	41.96	88.06	86.92	48.37	47.51	72.22	71.07
T_3	Eucalyptus (*Eucalyptus globulus*)	479.32	465.41	41.85	39.95	86.35	83.42	50.94	49.27	70.96	68.72
T_4	Neem (*Azadirachta indica*)	436.92	424.54	39.90	37.62	92.40	91.00	46.00	45.07	67.16	65.02
T_5	Acacia (*Acacia nilotica*)	465.72	452.37	43.37	42.05	92.85	91.54	46.73	45.37	73.63	72.39
T_6	Karanj (*Millettia*	412.63	401.27	36.96	35.35	85.12	82.55	45.33	44.95	64.43	63.25

	pinnata)										
	SE(m)±	9.03	9.86	0.99	0.97	1.06	1.15	1.10	1.11	1.50	1.54
	CD at 5%	27.22	29.72	2.99	2.97	3.21	3.48	3.32	3.35	4.52	4.66

Table 4: Soil Urease activity, Soil microbial biomass carbon and Soil microbial biomass nitrogen under different

Tr. No.	Treatments	Urease (µg NH_4-N g^{-1}soil 24 hr^{-1})		SMBC (µg C g^{-1} soil)		SMBN (µg N g^{-1} soil)	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1	Bamboo (*Bambusa vulgaris*)	53.65	52.06	147.00	133.90	14.22	11.93
T_2	Teak wood (*Tectona grandis*)	58.38	57.33	199.98	194.30	16.77	14.78
T_3	Eucalyptus (*Eucalyptus globulus*)	57.00	56.68	151.80	149.50	15.83	13.35
T_4	Neem (*Azadirachta indica*)	55.88	53.81	211.25	204.25	19.73	17.97
T_5	Acacia (*Acacia nilotica*)	60.75	58.19	202.80	194.65	18.29	16.28
T_6	Karanj (*Millettia pinnata*)	52.00	50.62	218.00	211.10	22.46	18.89
	SE(m)±	1.26	1.36	3.89	4.22	0.04	0.03
	CD at 5%	3.81	4.12	11.74	12.75	0.13	0.11

Soil Microbial Biomass Carbon

The result (Table 4.) reveal significant differences in soil microbial biomass carbon across different forest tree plantations and soil depths. At the surface layer, the highest Soil microbial biomass carbon was recorded under Karanj (T_6) plantation (218.00 µg C g-1 soil), Followed by Neem (T_4) (211.25 µg C g-1 soil) and Acacia (T_5) (202.80 µg C g-1 soil). These Values reflect a highly active microbial population, likely due to higher organic matter content, root biomass, and favorable rhizospheric conditions. Teak wood (T_2) and Eucalyptus (T_3) also showed appreciable SMBC values, while, the lowest microbial biomass carbon was observed under Bamboo (T_1) (147.00 µg C g-1 soil), possibly due to differences in litter quality or microbial diversity. The subsurface soil layer followed a similar trend, with the highest SMBC again under Karanj (T6) (211.10 µg C g-1soil) and lowest under Bamboo (133.90 µg C g-1 soil). SMBC generally decreased with soil depth in all treatments.

These findings are in agreement with those of similarly, Mir *et al.* (2023) [8].

Soil Microbial Biomass Nitrogen

The data presented in Table 4. Show significant variation in SMBN across the six forest tree plantations and at two soil depths. At 0-15 cm the highest SMBN was observed under Karanj (T_6) plantation (22.46 µg g-1 soil), while, the lowest SMBN was found under Bamboo (T_1) (14.22 µg N g-1 soil). In the subsurface layer, the SMBN followed a similar pattern, with the highest under Karanj (18.89 µg N g-1 soil) and lowest under Bamboo (11.93 µg N g-1 soil).

The relatively higher SMBN under Karanj, Neem, and Acacia plantations may be attributed to their nitrogen-fixing ability and deposition of high-quality litter rich in N, which enhances microbial growth and nitrogen immobilization. On the other hand, Bamboo and Eucalyptus plantations showed comparatively lower SMBN, possibly due to nutrient-poor and slowly decomposing litter with higher lignin and polyphenol content, which restrict microbial biomass development. The present findings are in close agreement with the results of Singh *et al.* (2017) [11].

4. Conclusion

Rhizosphere soil properties and enzyme activities varied significantly among tree plantations. Karanj and Bamboo improved soil nitrogen and organic carbon, Acacia enhanced phosphorus availability, while Acacia supported higher urease activity. Eucalyptus plantations exhibited relatively lower soil biochemical activity. The findings emphasize that tree species selection plays a pivotal role in improving soil fertility and should be prioritized in afforestation and sustainable agroforestry systems.

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