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Seasonal Dynamics and Tree Species Affect Soil Microbial Biomass Carbon in A Semi-Arid Forest of India

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ABSTRACT

Soil microbial biomass is an important component of soil organic carbon and plays a crucial role in organic matter decomposition and nutrient cycling. However, information on the effect of seasons and tree species on soil microbial biomass carbon is very scarce in the semi-arid region of India. We analyzed the impact of different native (*Ficus religiosa, Millettia pinnata,* and *Vachellia leucophloea*) and non-native tree species (*Albizia lebbeck, Azadirachta indica, Cassia fistula,* and *Prosopis juliflora*) along with a seasonal variation on soil microbial biomass carbon (SMBC) in a semi-arid forest of Delhi, India. The SMBC was determined by the chloroform-fumigation-extraction method and extracts were analyzed using Liqui TOC II Analyzer. SMBC was significantly higher during monsoon and low during the winter season. SMBC showed a significant positive correlation with soil moisture and temperature ($p < 0.05$). The highest SMBC observed under *Ficus religiosa* (156.85 µg g^{-1}), whereas the lowest under *Azadirachta indica* (8.69 µg g^{-1}) indicates the importance of native tree species over non-native ones. The pattern showed by tree species was: *F. religiosa* > *A. lebbeck* > *V. leucophloea* > *P. juliflora* > *M. pinnata* > *C. fistula* > *A. indica*. The result indicated that microbial biomass carbon is majorly affected by litter quality via its C/N ratio and soil moisture, affecting the overall microbial diversity and soil quality, helping in sustainable management of these vegetations.

Keywords: C/N ratio; chloroform-fumigation-extraction method; microbial biomass carbon; Native and non-native trees; semi-arid forest.

INTRODUCTION

Soil microorganisms participate in nutrient cycling and play an essential role in the decomposition and conversion of organic to inorganic matter (Wang et al. 2016, Wang et al. 2020). The soil microbial biomass represents the main labile pool of nutrients in the soil containing 1–5% of the soil organic matter and a principal labile pool of nutrients (Bharali et al. 2018). It plays an essential role in the retention and release of nutrients (Chen et al. 2005), and their supply has a turnover time of much less than a year. It can react rapidly to prerequisites of nutrients, moisture, temperature, and the kind and quantity of soil organic matter (Paul 1984). Vegetation cover greatly influences microbial community (Yu et al. 2018) and soil fertility affecting the soil microbial biomass and microbial efficiency in carbon utilization (Fanin et al. 2019, Kooch et al. 2020). The primary process through which forest vegetation affects the microbial activity of carbon and nitrogen cycles is via differences in quality and quantity of litters, root exudates, and soil properties (Bargali et al. 2015). Soil microbial biomass carbon (SMBC) helps understand the soil carbon cycle, soil carbon stability, chemical and biochemical characteristics of the soil. Research on soil microbial biomass carbon in different forest ecosystems of India has been reported by various researchers (Arunachalam et al. 1996, Devi and Yadava 2006, Bargali et al. 2018, Rawat et al. 2021). However, records on seasonal changes in the microbial biomass carbon in the semi-arid forest ecosystem are limited (Raghubanshi 1991, Patra et al. 1995, Singh and Singh 1995, Pandey et al. 2010, Yadav et al. 2011). Soil Physico-chemical traits also significantly affect microbial biomass and microbial production and can be used to measure soil quality (Mabuhay et al.

2006).

Climatic prerequisites directly affect microbial communities through soil moisture and temperature (Mureva and Ward 2017, Nicola and Baath 2019). However, they may also indirectly affect interactions with other factors such as vegetation, topography, and landscape (Myers et al. 2001). Seasons influence microbial number (Diaz- Ravina et al. 1993) and mass (Lynch and Panting 1980, Granatstein et al. 1987) both directly, by inducing microbial responses to soil changes, or indirectly, via influencing plant metabolism (Castro et al. 2019). However, information on the fluctuations in microbial biomass inside the annual cycle is scarce and most estimates have been made for agricultural soils, with some authors discovering huge annual fluctuations in the microbial biomass (Lynch and Panting 1980) while others observed solely small annual adjustments (Patra et al. 1990). The tree species selected in this study are commonly growing all over Delhi ridge areas and other similar semi-arid areas in India. Yet, the effects of these common tree species are not well-understood. Therefore, the current study was undertaken to (i) evaluate the seasonal fluctuation in SMBC and (ii) the influence of tree species on SMBC in a semi-arid forest of India.

STUDY AREA

This study was conducted during 2016-17 in the South-Central ridge area of Delhi, India, which is popularly known as Sanjay-Van (28°31’42.0”N and 77°10’21.0”E) (Fig. 1). The Delhi-Ridge area is the northern extension of the Aravalli hills. It is the most ancient mountain range of India, extending from Gujarat through Rajasthan to Haryana-Delhi. The Delhi ridge mainly comprises quartzite rocks (Sinha 2014) with a sandy-loam texture. Delhi has a ridge area that is primarily classified into four different forests which are (1) Southern Ridge (6200 ha) (2) Central Ridge (864 ha) (3) South-Central Ridge (626 ha) and (4) Northern Ridge (87 ha). The seasons were mainly classified based on rainfall patterns and temperature. Hence, the study site is classified into four main seasons, which are (1) Pre-monsoon (March-May), (2) Monsoon (June-August), (3) Post-monsoon (September-November), and (4) Winter (December-February). Soil temperature and moisture readings were recorded during the peak period of each month and averaged to get the seasonal values (Table 1). Monthly readings were taken to observe other ecological aspects of the study site like nitrogen mineralization and soil respiration.

The mean annual precipitation was 105.98 mm, out of which 88.1 % occur during late June to mid-September. In contrast, maximum air temperature ranged from 41°C during pre-monsoon to 21°C during winter (Fig. 2). The soil texture was sandy-loam with a bulk density of 1.05 g cm^{-3} in 0-10 cm and 1.06 g cm^{-3} in 10-20 cm depth. The study site is semi-arid.

Vegetation of the study site represents middle storied thorny trees dominated by *Prosopis juliflora* (Sw.) DC., an invasive species, was introduced to the Ridge during the 20th century and is now naturalized under present conditions. Many tree species have been introduced into the site while maintaining the natural patches of forest area (Table 2). Some other tree species presents are *Capparis decidua* (Forssk.) Edgew., *Morus alba* (L.), *Syzigium cumini* (L.) Skeels etc. Some of the common shrubs present are *Asparagus racemosus* (Willd.), *Capparis sepiaria* (L.), *Carissa spinarum* (L.), *Grewia tenax* (L.), *Justicia adathoda* (Medic.), *Lantana camara* (L.), etc. The herbaceous community is dominated by *Achyranthes aspera* (L.), *Brachiaria villosa* (Lam.) A. Camus, *Calotropis procera* (Aiton) W. T. Aiton, *Parthenium argentatum* A. Gray and *Tridax procumbens* (L.) etc.

MATERIALS AND METHODS

Selection of the tree species and soil sampling

The tree species were selected based on visual field observation and their contribution to the forest floor through leaf litter, canopy size, and abundance. The selected tree species also dominate other semi-arid regions of India. They would assist in estimating the effects of tree canopy cover on vital ecosystem processes and functions in the forest. The Flora of Delhi (Maheshwari 1963) was used to classify tree species into native and non-native to the Delhi Ridge area. The native tree species selected for the present study were *Ficus religiosa*, *Millettia pinnata*, *Vachellia leucophloea.* In contrast, non-native tree species were *Albizia lebbeck*, *Azadirachta indica*,

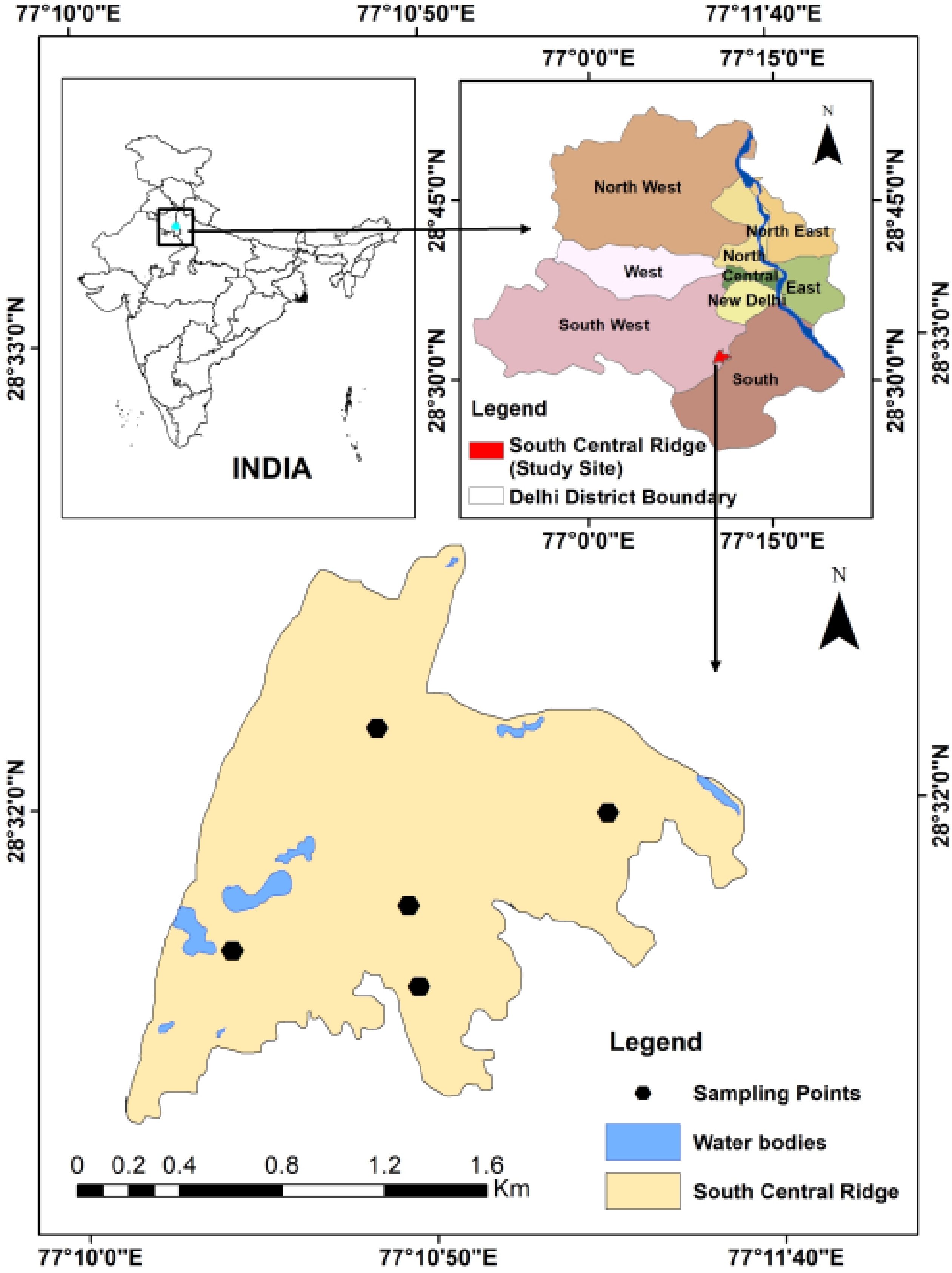

Figure 1. Map showing the study site and sampling points

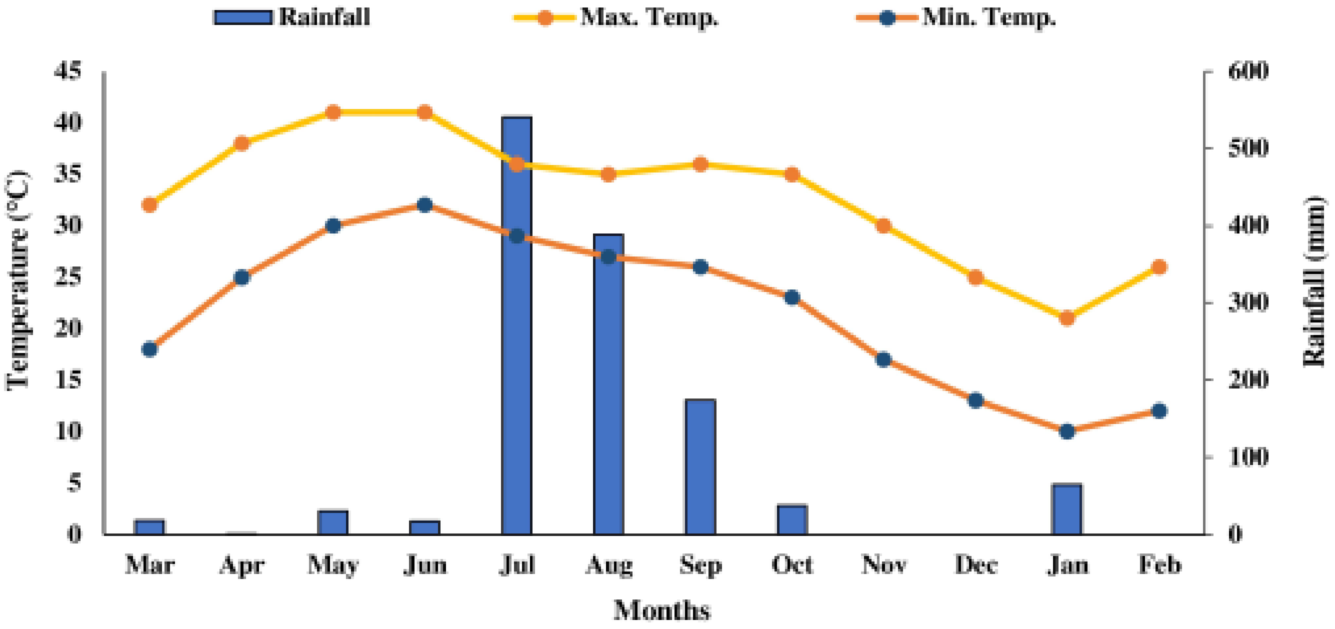

Figure 2. Monthly variation in rainfall and air temperature during the sampling year (2016-17) in Delhi *(Source: Agromet, Division of Agricultural Physics, IARI, New-Delhi)*

Table 1. Soil moisture at two depths (0-10 and 10-20 cm) and soil temperature under different tree species across different seasons. *VL - Vachellia leucophloea; FR - Ficus religiosa; MP - Millettia pinnata; AL - Albizia lebbeck; PJ - Prosopis juliflora; AI - Azadirachta indica; CF - Cassia fistula*

Parameter	Seasons	Depth(cm)	*VL*	*FR*	*MP*	*AL*	*PJ*	*AI*	*CF*
Soil Moisture (%)	Pre-monsoon	0-10	3.63	6.84	1.84	6.05	5.38	6.67	1.33
		10-20	3.10	6.24	1.64	4.72	5.27	6.61	0.12
	Monsoon	0-10	19.58	19.87	14.41	19.63	15.09	13.65	12.98
		10-20	12.89	13.61	8.36	11.58	10.79	8.82	6.96
	Post-monsoon	0-10	6.52	7.82	7.32	7.63	7.45	7.83	7.54
		10-20	4.83	5.53	5.33	5.44	5.45	5.93	5.43
	Winter	0-10	8.72	9.62	8.80	9.32	9.13	9.54	8.44
		10-20	6.23	6.93	6.33	6.83	6.15	6.82	6.13
Soil Temperature (°C)	Pre-monsoon	0-10	29.10	30.20	27.30	28.40	28.20	29.50	29.00
	Monsoon	0-10	25.40	26.70	24.20	26.10	25.60	26.30	26.20
	Post-monsoon	0-10	25.10	25.20	23.20	25.00	24.80	25.00	23.00
	Winter	0-10	19.80	20.20	20.00	20.10	20.00	20.00	20.00

Table 2. List of few native and non-native tree species in South-Central Ridge

Native	**Non-native**
Balanites roxburghii (Planch.)	*Albizia lebbeck* (L.) Benth
Ficus religiosa (L.)	*Azadirachta indica* (A.) Juss.
Millettia pinnata (L.)	*Bombax ceiba* (L.)
Salvedora oleoides (Decne.)	*Cassia fistula* (L.)
Vachellia catechu (L.f.) P. J. H. Hurter & Mabb.	*Ficus racemose* (L.)
Vachellia nilotica (L.) P. J. H. Hurter & Mabb	*Prosopis juliflora* (SW.) DC

Cassia fistula, and *Prosopis juliflora*. The distance between the individuals of tree species was approximately 5 m.

The soil sample was taken just beneath the tree canopy, approximately at a 5 cm distance from the tree trunk. Soil samples in triplicates were collected seasonally under the canopy of selected tree species, i.e., under each tree species, three soil samples were collected and homogenized, and for each tree species, three individuals were selected. Sampling was done during the peak month of each season. Soil sampling was confined to 20 cm as the majority of microbial activity is in this layer. The depth of the soil surface for sample collection was measured using a scale. The collected samples under each individual species were homogenized, packed in plastic bags, brought to the laboratory, and stored at 4°C for estimation of microbial biomass carbon within 48 hours. Coarse materials such as stones, roots, and litter were removed manually. The small soil microaggregates were mashed manually to separate the soil particles, and field moist soil was sieved with 2 mm mesh and divided into two parts. One part was stored at 4°C for analysis of soil microbial biomass carbon, while the other part was air-dried to analyze the soil organic carbon (SOC) and total carbon (TC).

Estimation of microbial biomass carbon, soil organic, inorganic and total carbon

The SMBC was studied for one year from pre-monsoon 2016 to winter 2017. To estimate SMBC, the chloroform fumigation extraction method (Vance et al. 1987) was followed. The soil samples were sieved to remove stones, coarse roots, and all visible litter. Soil samples of selected tree species in triplicates weighing 10±0.01 g each were prepared for fumigated and unfumigated sets. Fumigation was done using chloroform (alcohol-free), and unfumigated samples were directly extracted using 0.5 M potassium sulfate. To estimate SOC, the soil was soaked with few drops of conc. HCl and oven-dried at 105°C. The sample was kept in Liqui TOC II Analyzer (Elementar Analysis Systems GmbH, Germany) to get the results of SOC and TC. Soil inorganic carbon (SIC) was calculated by subtracting the values of total carbon with organic carbon. TC = SOC +SIC.

A vacuum desiccator was used for fumigation, and 30 ml chloroform was placed inside and sealed with a lid. The desiccator was vacuumed until the chloroform was evaporated. The fumigated soil samples inside the desiccator were stored in the dark for 5 days at 25°C. After 5 days, the soil samples were transferred to a watertight 125 ml extraction bottle. 50 ml of 0.5 M K_2SO_4 was added to the soil samples (fumigated and unfumigated), and the samples were shaken for 30 min. The extract was then filtered through Whatman filter paper No. 42 and the filtrate was retained for analysis. Extracts were analyzed for dissolved organic C using Liqui TOC II Analyzer (Elementar Analysis Systems GmbH, Germany). Carbon estimated from both the soil samples was then used to calculate the SMBC using equation by Vance et al. (1987), i.e., SMBC = $E_c \times 2.22$, where E_c = differences of K_2SO_4 – extractable organic C in fumigated and non-fumigated samples.

Leaf litter collection and analysis

Leaf litter was collected under the canopy of each individual of the same tree species from the study site. One litter trap in the middle of the tree canopy of 1 × 1m and 20 cm high above the ground, were laid under each tree species (n=3/species). Leaf litter was collected at seasonal intervals. The litter was taken to the laboratory and rinsed with fresh water. The dry weight of litter was determined by drying to a constant weight at 80°C for 24 to 48 h, and the mean seasonal value was expressed on a unit area basis (g m^{-2}). The seasonal litter data were then summed to obtain the annual leaf litter production. Carbon (C) and nitrogen (N) were analyzed using a CHNS analyzer after grinding the oven-dried (70-80 ºC) leaf litter samples. Three replicates were taken from an individual tree making a total of nine replicates for each tree species.

Statistical analysis

Three-way ANOVA was used to examine the effects of seasons, different tree species, and depth on SMBC, TC, and SOC. Tukey post-hoc test was performed to distinguish differences at the 0.05 confidence level. Pearson's correlation analysis was performed to establish the correlation between SMBC, soil moisture (SM), and soil temperature (ST). All statistical analysis were performed using

SPSS version 21.

RESULTS

Variation in soil microbial biomass carbon across different seasons

During the study period, the highest SMBC was observed in monsoon, i.e., 156.85 μg g^{-1} at 0-10 cm depth under *Ficus religiosa,* whereas the lowest was observed at 10-20 cm depth in winter, i.e., 8.69 μg g^{-1} under *Azadirachta indica* (Table 3). A statistically significant difference ($p < 0.05$) was observed across seasons in SMBC. The general trend observed in SMBC was monsoon > post-monsoon > pre-monsoon > winter.

Soil microbial biomass carbon under different tree species canopy

The SMBC varied significantly under different tree species ($p < 0.05$). Among all the native tree species selected, at 0-10 cm depth *F. religiosa* showed the maximum mean annual SMBC throughout the study period, i.e., 88.68 μg g^{-1} whereas the minimum was observed under *Millettia pinnata,* i.e., 59.75 μg g^{-1} (Table 3). Among non-native tree species, the highest mean annual SMBC was observed under *Albizia lebbeck,* i.e., 78.04 μg g^{-1}, and lowest under the canopy of *A. indica,* i.e., 35.46 μg g^{-1}. The trend

Table 3. SMBC, TC, SOC and SIC at two depths (0-10 and 10-20 cm) under different tree species across different seasons. *VL - Vachellia leucophloea; FR - Ficus religiosa; MP - Millettia pinnata; AL - Albizia lebbeck; PJ - Prosopis juliflora; AI - Azadirachta indica; CF - Cassia fistula*

Parameter	**Seasons**	**Depth**	***VL***	***FR***	***MP***	***AL***	***PJ***	***AI***	***CF***
SMBC (μg g^{-1})	**Pre-monsoon**	**0-10**	41.37±0.02	58.43±0.05	48.78±0.02	53.97±0.02	50.15±0.00	36.87±0.00	32.48±0.00
		10-20	35.67±0.06	48.67±0.05	39.15±0.01	42.06±0.03	30.56±0.04	23.43±0.02	15.16±0.05
	Monsoon	**0-10**	133.64±0.05	156.85±0.03	86.77±0.02	135.10±0.03	96.82±0.05	44.91±0.02	57.69±0.01
		10-20	97.14±0.04	89.51±0.06	68.19±0.05	76.45±0.01	42.35±0.04	28.34±0.04	41.23±0.06
	Post-monsoon	**0-10**	81.72±0.04	90.55±0.03	70.17±0.04	77.87±0.02	45.71±0.05	47.37±0.04	48.42±0.03
		10-20	58.89±0.06	80.14±0.04	45.67±0.05	69.18±0.01	19.20±0.06	26.78±0.04	18.54±0.03
	Winter	**0-10**	37.89±0.05	48.90±0.02	33.29±0.06	45.23±0.02	23.2±0.04	12.70±0.06	30.15±0.03
		10-20	12.56±0.03	20.78±0.04	21.76±0.04	17.45±0.03	15.56±0.06	8.69±0.06	15.49±0.02
TC(%)	**Pre-monsoon**	**0-10**	1.65±0.01	1.55±0.02	1.67±0.03	2.46±0.02	2.65±0.03	1.85±0.03	2.53±0.03
		10-20	1.23±0.02	1.45±0.02	1.30±0.02	1.19±0.01	2.17±0.01	0.78±0.03	2.31±0.02
	Monsoon	**0-10**	0.85±0.04	0.86±0.03	0.93±0.02	1.05±0.03	0.93±0.03	1.12±0.04	1.48±0.02
		10-20	1.45±0.04	0.62±0.03	0.68±0.03	0.69±0.02	0.77±0.02	0.97±0.02	0.21±0.03
	Post-monsoon	**0-10**	0.77±0.02	0.88±0.01	0.78±0.01	1.62±0.01	1.59±0.01	0.95±0.01	1.20±0.01
		10-20	0.99±0.01	0.68±0.03	0.67±0.04	1.57±0.04	1.76±0.03	1.22±0.03	0.98±0.02
	Winter	**0-10**	2.08±0.01	1.82±0.03	2.51±0.02	1.96±0.01	2.19±0.02	2.79±0.01	2.39±0.01
		10-20	1.15±0.04	1.59±0.03	1.23±0.03	1.61±0.04	1.80±0.03	1.08±0.01	1.68±0.03
SOC(%)	**Pre-monsoon**	**0-10**	1.43±0.004	1.10±0.001	1.23±0.003	1.21±0.013	1.57±0.007	1.73±0.006	1.63±0.007
		10-20	1.09±0.01	0.77±0.01	1.09±0.01	1.07±0.001	1.25±0.007	1.03±0.004	1.08±0.003
	Monsoon	**0-10**	0.68±0.004	0.62±0.006	0.68±0.002	0.69±0.005	0.91±0.008	0.99±0.005	0.82±0.004
		10-20	0.70±0.003	0.51±0.003	0.65±0.004	0.53±0.003	0.69±0.007	0.88±0.005	0.15±0.002
	Post-monsoon	**0-10**	0.67±0.006	0.50±0.004	0.69±0.003	0.64±0.006	0.88±0.006	0.88±0.005	0.83±0.004
		10-20	0.81±0.008	0.80±0.001	0.63±0.004	0.51±0.01	0.62±0.003	0.54±0.002	0.73±0.007
	Winter	**0-10**	1.46±0.002	1.13±0.002	1.77±0.003	1.52±0.006	1.81±0.002	1.73±0.003	1.92±0.005
		10-20	0.98±0.005	0.68±0.006	0.82±0.002	0.91±0.003	1.10±0.002	1.12±0.001	1.02±0.01
SIC(%)	**Pre-monsoon**	**0-10**	1.10	0.45	0.44	1.25	1.08	0.12	0.02
		10-20	1.22	0.01	0.21	0.12	0.92	0.42	0.15
	Monsoon	**0-10**	0.17	0.24	0.25	0.35	0.02	0.13	0.66
		10-20	0.75	0.11	0.04	0.16	0.08	0.09	0.06
	Post-monsoon	**0-10**	0.10	0.38	0.09	0.98	0.79	0.07	0.37
		10-20	0.18	0.42	0.04	1.06	1.14	0.14	0.25
	Winter	**0-10**	0.93	1.66	0.74	0.44	0.38	0.09	0.16
		10-20	0.70	0.40	0.41	0.70	0.70	0.47	0.13

Note: All data are presented as the mean ±standard deviation (± SD). The values under SIC (%) is without ± SD as it is the difference between TC (%) and SOC (%).

observed in SMBC rate among different tree species was as follows: - *Ficus religiosa* > *Albizia lebbeck* > *Vachellia leucophloea* > *Millettia pinnata* > *Prosopis juliflora* > *Cassia fistula* > *Azadirachta indica*. SMBC decreased with depth ranging from 8.69 to 97.14 µg g^{-1} at 10 - 20 cm depth during the entire study period. The lowest SMBC at 10 - 20 cm depth was observed under *A. indica,* whereas the highest was observed under *V. leucophloea.*

Correlation between SM, ST, SOC and SMBC

A positive correlation was observed in our study between SMBC, ST, and SM; however, the correlation between SMBC and ST was weak ($p > 0.05$). *A. indica* showed no correlation with either ST or SM. Although the correlation was not significant, i.e., $p > 0.05$ but a negative correlation was observed between SOC and SMBC under all the tree species at 0-10 (Table 4) and 10-20 cm (Table 5).

Table 4. Pearson's linear correlation coefficient (r) and p-values in parenthesis of SMBC with SOC, (in bold if significant) across different tree species in depth 0-10 cm

SMBC	**SOC**
V. leucophloea	-0.875 (0.125)
F. religiosa	-0.658 (0.342)
M. pinnata	-0.949 (0.051)
A. lebbeck	-0.838 (0.162)
P. juliflora	-0.688 (0.312)
A. indica	- 0.935 (0.065)
C. fistula	**-0.959 (0.041)**

Table 5. Pearson's linear correlation coefficient (r) and p-values in parenthesis of SMBC with SOC, (in bold if significant) across different tree species in depth 10-20 cm

SMBC	**SOC**
V. leucophloea	-0.844 (0.156)
F. religiosa	-0.285 (0.715)
M. pinnata	-0.485 (0.515)
A. lebbeck	-0.812 (0.188)
P. juliflora	-0.186 (0.814)
A. indica	- 0.674 (0.326)
C. fistula	**-0.970 (0.030)**

Leaf litter composition

Carbon and Nitrogen were analyzed from the leaf litter of the selected species. *F. religiosa* showed the highest carbon content and lowest C: N ratio, whereas *A. indica* showed the highest C: N ratio. The trend observed in C and N contents among different leaf litter are as followed: - 1) **C** – *F. religiosa* > *P. juliflora* > *A. lebbeck* > *A. indica* > *M. pinnata* > *V. leucophloea* > *C. fistula* 2) **N** – *F. religiosa* > *P. juliflora* > *A. lebbeck* > *V. leucophloea* > *M. pinnata* > *A. indica* > *C. fistula* 3) **C: N ratio** – *A. indica* > *C. fistula* > *P. juliflora* > *M. pinnata* > *A. lebbeck* > *V. leucophloea* > *F. religiosa* (Table 6).

Table 6. Carbon and Nitrogen analysis of leaf litter of different tree species

Species	**C (%)**	**N (%)**	**C: N ratio**
Vachellia leucophloea	22.52	1.48	15.21
Ficus religiosa	49.92	3.73	13.38
Millettia pinnata	26.92	1.28	21.03
Albizia lebbeck	35.35	1.76	20.08
Prosopis juliflora	43.15	2.04	21.15
Azadirachta indica	29.30	1.03	28.44
Cassia fistula	22.00	1.00	22.00

DISCUSSION

Changes in nutrient cycling processes that arise due to change in flora may reflect an alteration in the soil microbial community related to the differences in the quantities and qualities of inputs to the soil by different species of plants (Grierson and Adams 2000). It was observed and suggested that trees can modify soil properties through interaction between root and microbe, resulting in a distinct difference in the chemical nature of soil organic carbon in mixed forests (Chen et al. 2004). Thus, the effect of vegetation on soil carbon content is tree species-dependent (Finzi et al. 1998), which supports our study wherein under different tree species, the rate of SMBC was different due to varying litter quantity and quality, and their C/N ratio (Table 6). The range of SMBC reported in the present study (5.67 to 156.85 µg g^{-1}) is similar to the range reported by Henrot and Robertson (1994) for different temperate and tropical forest soils (61 to 2000 µg g^{-1}) and by

Ravindran and Yang (2015) for soils of subalpine mountain forest (140 to 1320 μg g^{-1}). Various factors have been suggested to explain the effects of vegetation type on microbial biomass in soils (Hackl et al. 2004, Yu et al. 2018). Differences in the quantity and quality of substrate inputs via varying litter and root types and associated nutrient specificity can be crucial drivers to influence the soil microbial biomass (Feng et al. 2009).

The soil microbial biomass carbon was significantly higher during the monsoon season ($p < 0.05$) and lower in the winter season under all the tree species across various seasons (Table 3). Seasonal variation in soil microbial biomass carbon reflects the degree of immobilization-mineralization of soil carbon. When there is an increase in microbial biomass, it competes with the soil for inorganic nutrients, and hence immobilization of nutrients occurs. When microbial biomass is less, the rate of mineralization of nutrients is more. So, when during monsoon the microbial biomass is more, it can affect the rate of mineralization-immobilization of nutrients. Mineralization of nutrients is greatly influenced by a decrease in soil microbial biomass, whereas an increase in microbial biomass may lead to immobilization of nutrients (Yang et al. 2010). We associated variation in soil moisture and temperature with different seasons and observed the effect of seasons on soil microbial biomass. There are other factors also which affect the microbial biomass, such as litter quality and quantity, microclimatic variables, soil type, vegetation, C/N ratio of soil and litter, soil pH, organic C. Like many other studies, in our study site also soil moisture was the limiting factor affecting microbial biomass C. Low values of SMBC in the winter season may be due to the unfavorable conditions for microbes to perform and hence low activities of microorganisms in a dry and cool period. Across the tree species, SMBC was maximum under *F. religiosa* followed by *A. lebbeck* and minimum under *A. indica* followed by *C. fistula,* which may be due to high SM content and less exposure to sunlight, and better quality of litter (Table 6) under *F. religiosa* favoring the growth of microbes. In addition, a relatively better quality of litter under *F. religiosa* also resulted in higher microbial activity.

Further, due to high relative humidity, the growth of fungi also increased during this season,thus contributing to the soil microbial biomass (Acea and Carballas 1990). The weak correlation of SMBC with ST in the current study shows that the lack of water limits the microbial biomass more than temperature since lower microbial biomass contents were observed in the dry period (pre-monsoon and winter season) than in the wet period (monsoon and post-monsoon season (Diaz-Ravina et al. 1995). Several studies on soil microbial biomass reported a close relationship between SM and microbial biomass (Acea and Carballas 1990; Diaz-Ravina et al. 1995). A similar observation was also reported by Lynch and Panting (1982) in the arable soil of Oxford shire, UK.

In the present study, SOC showed the highest value during the winter and lowest during the monsoon season. During the dry period, organic matter accumulates, which cease to enhance the activity of microbes and biomass during the wet period (Garcia-Oliva et al. 2003). A similar trend was observed in our study where the accumulation of SOC was observed during winter and pre-monsoon season (dry period), which gradually increased SMBC during monsoon and post-monsoon season when SM and ST became optimum for microbial growth. A negative correlation is observed between SOC and SMBC in the present study (Tables 4 and 5). Soil microbes are mainly responsible for the decomposition of SOC; thus, when microbial activity reduces, there is a decrease in SMBC, resulting in a reduction of SMBC, resulting in decreased decomposition of SOC, resulting in its accumulation (Xu et al. 2014).

CONCLUSIONS

The existing study show that the soil microbial biomass displays seasonality and is majorly influenced by soil moisture. Different tree species affect soil microbial processes via their litter quality and quantity. *F. religiosa* followed by *A. lebbeck* indicated a higher SMBC and substrate utilization eûciency of the soil microbial community, which sustain better soil quality, whereas *A. indica* followed by *C. fistula* indicated lowest SMBC. This indicates that diûerent plant species have different nutrient demands and produce different quality and quantity of litter, which affecting the microbial population. When we compare the value of soil MBC under different tree canopies, we observed that native tree species performed better than non-native ones. Hence, it can help the forest authority to implement proper strategies for plantation in the forest area to maintain soil fertility.We observed that tree plantations by the forest authority were done progressively in our study site to increase the vital ecosystem services and processes. Hence, further research should be conducted to examine the effects of biotic and abiotic factors, land-use land cover in regulating the soil microbial biomass.

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Author's contribution: R. Baishya designed, analyzed and supervised the experiment. S. Prasad carried out the experiments, collected samples and analyzed the data. S. Prasad wrote the manuscript, R. Baishya provided critical feedback and helped shape the research, analysis and submitted the manuscript.

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REFERENCES

Acea, M.J. and Carballas, T. 1990. Principal components analysis of the soil microbial population of humid zone of Galicia (Spain). Soil Biology and Biochemistry, 22(6), 749-759.

Arunachalam, A., Maithani, K., Pandey, H.N. and Tripathi, R.S. 1996. The impact of disturbance on detrital dynamics and soil microbial biomass of a Pinus kesiya forest in north-east India. Forest Ecology and Management, 88, 273-282.

Bargali, K., Manral, V., Padalia, K., Bargali, S.S. and Upadhayay, V.P. 2018. Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. Catena, 171, 125–135.

Bargali, S.S., Shukla, K., Singh, L., Ghosh, L. and Lakhera, M.L. 2015. Leaf litter decomposition and nutrient dynamics in four tree species of dry deciduous forest. Tropical Ecology, 56(2), 191- 200.

Bharali, A., Baruah, K.K., Baruah, S.G. and Bhattacharyya, P. 2018. Impacts of integrated nutrient management on methane emission, global warming potential and carbon storage capacity in rice grown in a northeast India soil. Environmental Science and Pollution Research, 25 (6), 5889-5901.

Castro, S.P., Cleland, E.E., Wagner, R., Sawad, R.AI. and Lipson, D.A. 2019. Soil microbial responses to drought and exotic plants shift carbon metabolism. The ISME Journal, 13(7), 1776-1787.

Chen, T.H., Chiu, C.Y. and Tian, G. 2005. Seasonal dynamics of soil microbial biomass in coastal sand dune forest. Pedobiologia, 49(6), 645-653.

Chen, C.R., Xu, Z.H. and Mathers, N.J. 2004. Soil carbon pools in adjacent natural and plantation forests of subtropical Australia. Soil Science Society of America Journal, 68(1), 282-291.

Devi, N.B. and Yadava, P.S. 2006. Seasonal dynamics in soil microbial biomass C, N and P in a mixed-oak forest ecosystem of Manipur, North-east India. Applied Soil Ecology, 31(3), 220-227.

Diaz-Ravina, M., Acea, M.J. and Carballas, T. 1993. Seasonal fluctuations in microbial populations and available nutrients in forest soils. Biology and Fertility of Soils, 16(3), 205-210.

Diaz-Ravina, M., Acea, M.J. and Carballas, T. 1995. Seasonal changes in microbial biomass and nutrient flush in forest soils. Biology and Fertility of Soils, 19, 220-226.

Fanin, N., Kardol, P., Farrell, M., Kempel, A., Ciobanu, M., Nilsson, M.C. and Wardle, D.A. 2019. Effects of plant functional group removal on structure and function of soil communities across contrasting ecosystems. Ecology Letters, 22(7), 1095-1103.

Feng, W., Zou, X. and Schaefer, D. 2009. Above-and belowground carbon inputs affect seasonal variations of soil microbial biomass in a subtropical monsoon forest of southwest China. Soil Biology and Biochemistry, 41(5), 978-983.

Finzi, A.C., Canham, C.D. and Van Breemen, N. 1998. Canopy tree–soil interactions within temperate forests: species effects on pH and cations. Ecological Applications, 8(2), 447-454.

Garcia-Oliva, F., Sveshtarova, B. and Oliva, M. 2003. Seasonal effects on soil organic carbon dynamics in a tropical deciduous forest ecosystem in western Mexico. Journal of Tropical Ecology, 19(2), 179-188.

Granatstein, D.M., Bezdicek, D.F., Cochran, V.L., Elliott, L.E. and Hammel, J. 1987. Long-term tillage and rotation effects on soil microbial biomass, carbon and nitrogen. Biology and Fertility of Soils, 5(3), 265-270.

Grierson, P.F. and Adams, A. 2000. Plant species affect acid phosphatase, ergosterol and microbial P in a Jarrah (*Eucalyptus marginata* Donn ex Sm.) forest in south-western Australia. Soil Biology and Biochemistry, 32(13), 1817-1827.

Hackl, E., Zechmeister-Boltenstern, S., Bodrossy, L. and Sessitsch, A. 2004. Comparison of diversities and compositions of bacterial populations inhabiting natural forest soils. Applied and Environmental Microbiology, 70(9), 5057-5065.

Henrot, J. and Robertson, G.P. 1994. Vegetation removal in two soils of the humid tropics: effect on microbial biomass. Soil Biology and Biochemistry, 26(1), 111-116.

Kooch, Y., Moghimian, N. and Alberti, G. 2020. C and N cycle under beech and hornbeam tree species in the Iranian old-growth forests. Catena, 187, 104406.

Lynch, J.M. and Panting, L.M. 1980. Variations in the size of the soil biomass. Soil Biology and Biochemistry, 12(6), 547-550.

Lynch, J.M. and Panting, L.M. 1982. Effects of season, cultivation and nitrogen fertiliser on the size of the soil microbial biomass. Journal of the Science of Food and Agriculture, 33(3), 249-252.

Mabuhay, J.A., Nakagoshi, N. and Isagi, Y. 2006. Soil microbial biomass, abundance, and diversity in a Japanese red pine forest: first year after fire. Journal of Forest Research, 11, 165-173.

Maheshwari, J.K. 1963. The Flora of Delhi, 1st ed. Council of Scientific and Educational Research, New Delhi.

Mureva, A. and Ward, D. 2017. Soil microbial biomass and functional diversity in shrub-encroached grasslands along a precipitation gradient. Pedobiologia, 63, 37-45.

Myers, R.T., Zak, D.R., White, D.C. and Peacock, A. 2001. Landscape-level patterns of microbial community composition and substrate use in upland forest ecosystems. Soil Science Society of America Journal, 65(2), 359-367.

Nicola, L. and Baath, E. 2019. The effect of temperature and moisture on lag phase length of bacterial growth in soil after substrate addition. Soil Biology and Biochemistry, 137, 107563.

Pandey, C.B., Singh, G.B., Singh, S.K. and Singh, R.K. 2010. Soil nitrogen and microbial biomass carbon dynamics in native forests and derived agricultural land uses in a humid tropical climate of India. Plant and Soil, 333 (1-2), 453-467.

Patra, D.D., Brookes, P.C., Coleman, K. and Jenkinson, D.S. 1990. Seasonal changes of soil microbial biomass in an arable and a grassland soil which have been under uniform management for many years. Soil Biology and Biochemistry, 22(6), 739-742.

Patra, D.D., Chand, S. and Anwar, M. 1995. Seasonal changes in microbial biomass in soils cropped with palmarosa (*Cymbopogon martinii* L.) and Japanese mint (*Mentha arvensis* L.) in subtropical India. Biology and Fertility of Soils, 19, 193-196.

Paul, E.A. 1984. Dynamics of organic matter in soils. Plant and Soil, 76, 275-285.

Raghubanshi, A.S. 1991. Dynamics of soil biomass C, N, and P in a dry tropical forest in India. Biology and Fertility of Soils, 12(1), 55-59.

Ravindran, A. and Yang, S.S. 2015. Effects of vegetation type on microbial biomass carbon and nitrogen in subalpine mountain forest soils. Journal of Microbiology, Immunology and Infection, 48(4), 362-369.

Rawat, M., Arunachalam, K. and Arunachalam, A. 2021. Seasonal dynamics in soil microbial biomass C, N and P in a temperate forest ecosystem of Uttarakhand, India. Tropical Ecology, https://doi.org/10.1007/s42965-021-00153-6.

Singh, S. and Singh, J.S. 1995. Microbial biomass associated with water-stable aggregates in forest, savanna and cropland soils of a seasonally dry tropical region, India. Soil Biology and Biochemistry, 27(8), 1027-1033.

Sinha, G.N. 2014. An Introduction to the Delhi Ridge. Department of Forests and Wildlife, Govt. of NCT of Delhi, New Delhi.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry, 19(6), 703-707.

Wang, C., Xue, L., Dong, Y., Wei, Y. and Jiao, R. 2020. Soil microbial community structure and composition in Chinese fir plantations of different ages in Fujian, Southeast China. Journal of Sustainable Forestry, 39, 1-23.

Wang, X., Sasaki, A., Toda, M. and Nakatsubo, T. 2016. Changes in soil microbial community and activity in warm temperate forests invaded by moso bamboo (*Phyllostachys pubescens*). Journal of Forest Research, 21, 235-243.

Xu, X., Schimel, J.P., Thornton, P.E., Song, X., Yuan, F. and Goswami, S. 2014. Substrate and environmental controls on microbial assimilation of soil organic carbon: a framework for Earth system models. Ecology Letters, 17(5), 547-555.

Yadav, R.S., Yadav, B.L., Chhipa, B.R., Dhyani, S.K. and Ram, M. 2011. Soil biological properties under different tree based traditional agroforestry systems in a semi-arid region of Rajasthan, India. Agroforestry Systems, 81(3), 195-202.

Yang, K., Zhu, J., Zhang, M., Yan, Q. and Sun, O.J. 2010. Soil microbial biomass carbon and nitrogen in forest ecosystems of Northeast China: a comparison between natural secondary forest and larch plantation. Journal of Plant Ecology, 3(3), 175-182.

Yu, S., She, G., Ye, S., Zhou, X., Yao, X. and Li, Y. 2018. Characteristics of soil microbial biomass and community composition in *Pinus yunnanensis* var. *Tenuifolia* secondary forests. Journal of Sustainable Forestry ,37(8), 753-770.

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