Microbial biomass carbon and nitrogen in relation to cropping systems in Central Himalaya, India

Kirtika Padalia, S. S. Bargali*, Kiran Bargali and Kapil Khulbe

Department of Botany, D.S.B. Campus, Kumaun University, Nainital 263 002, India

In this study, the impact of cropping systems on physicochemical properties of soil and microbial biomass was evaluated. Soil was collected from four cultivated fields (cropland, crop + single tree species, crop + multiple tree species and homegardens) and one uncultivated (agriculturally discarded) field and analysed. The outcome of the present study indicated that cultivated land squandered about 14% C and 5% N in 8 years of cultivation to the nearby uncultivated land. Soil microbial biomass of cultivated land with multiple tree species (C + mT) was greater than other systems and showed an appreciable seasonal variation. The microbial biomass carbon (C_{mic}) assorted from 166 to 266 μg g^{-1} and microbial biomass nitrogen (N_{mic}) from 11 to 41 μg g^{-1}. C_{mic} contributed 1.25–1.90% of soil C and N_{mic} 0.83–3.77% of soil N. Among cultivated land, maximum C_{mic} and N_{mic} were reported in C + mT system which suggested that tree plantation in cultivated land has significant positive effects on microbial biomass and other soil properties by shifting natural soil properties under the similar environmental circumstances.

Keywords: Cropping systems, microbial biomass, microbial activity, tree plantation.

THE soil microbial biomass, an imported soil indicator plays an efficient part in the formation of organic pool by decomposing organic matter and by controlling the nutrient dynamics which ultimately affect the primary productivity in various biogeochemical progressions in terrestrial ecosystems[1]. Therefore, microbial dynamics effectively influence fertility and stability of an ecosystem and has been accepted widely as a vital source of nutrients due to its quick turnover[2]. Agricultural trends in the last five decade have intensive production with increased exercise of commercial seeds, pesticides, fertilizers, etc. These practices have adverse consequences on soil health and hence, the urgency to develop new strategies that use ecological interaction[3]. Crop productivity primarily depends on the quantity of soil nutrients which reflects the fruitfulness of the soil typically obtained from the contribution of soil microbial biomass[4].

*For correspondence. (e-mail: surendrakiran@rediffmail.com)

Cultivation accelerates the loss of organic matter and microbial activities significantly[5] in the soil. Therefore it is necessary that nutrient uptake should be maintained by nutrient replacement[6]. The microbial biomass regulates nutrients accessibility in cropping systems. The management practices persuade interactions between soil and microorganisms by the input of organic remnants and their allocations, by physical changes and by nutrients supply in the soil[5]. Management has long-term assortment on soil ecology; for example disturbance of open crop land is quite different from the well managed land use system especially where trees are planted, because trees play a prominent task in ecosystem functioning and therefore, potentially generate the opportunities to restore efficient soil microbial communities that can endorse plant growth, nutrient cycling and promote soil health[7].

To uphold the soil eminence, maintenance is the only solution, whereas soil microbial biomass is used as a soil indicator[8]. Assessment of microbial biomass is a valuable tool for the divination of long-term productivity of soil in cropping systems. Studies on soil microbial biomass in this region with respect to change in cropping systems have not been done earlier. Hence, an attempt was made to analyse the soil microbial biomass carbon and nitrogen under different cropping systems practised in Indian Central Himalayan Bhabhar belt.

Materials and methods

Location and climate

The study was carried out in the Bhabhar belt of Nainital district between 29°25′ and 29°39′N lat. and 78°44′ and 79°07′E long. located at low altitude (424 m amsl). On the basis of cropping systems, four systems, viz. crop fields without tree/shrub species (OC), crop fields with single tree species (C + sT), crop fields with multiple tree species (C + mT) and home gardens (HG) were selected. In addition, agriculturally discarded land (ADL) was also selected as control, which was left uncultivated for the last 8 years. The characteristics of selected cropping system are given in Table 1.

Table 1. Description of cropping systems

Cropping systems	Tree species	Herb species
Open crop land (OC)	–	*Glycine max*/*Triticum aestivum* rotation
Single crop with single tree species (C + sT)	*Mangifera indica*	*Glycine max*/*Triticum aestivum* rotation
Single crop with multiple tree species (C + mT)	*Mangifera indica*, *Eucalyptus* sp., *Artocarpus heterophyllus*, *Litchi chinensis*, *Psidium guajava*, *Shorea robusta*, etc.	*Glycine max*/*Triticum aestivum* rotation
Multiple crops with multiple trees (HG)	*Carica papaya*, *Mangifera indica*, *Citrus limon*, *Litchi chinensis*, *Psidium guajava*, etc.	*Solanum melongena*, *Capsicum annuum*, *Colocasia esculenta*, *Curcuma longa*, and 25 other seasonal vegetables
Agriculturally discarded land (ADL)	*Shorea robusta*, *Mangifera indica*, *Phyllanthus emblica*, *Ficus glomerata*, *Cinnamomum tamala*, *Ziziphus jujuba*, *Azadirachta indica*, etc.	Wild herbs like *Cyperus rotundus*, *Arthraxon lancifolius*, *Ageratum conyzoides*, *Cannabis sativa*, *Commelina benghalensis*, *Cynodon dactylon*, *Parthenium* sp., *Poa annua*, etc.

The climate is sub-tropical, monsoonal and distinguished by clear seasonality. During the year, summer season comprised of 4 months (March–June), rainy season of 3 months (July–September) and winter season of 4 months (November–February). October is as an intermediary month between rainy and winter season. Temperature reached beyond 40°C during summer and below 5°C during winter.

Soil sampling and analysis

To analyse the soil physico-chemical properties, 10 soil samples were collected randomly during summer, rainy and winter seasons from two different depths, viz. the upper surface (0–15 cm) and deeper surface (15–30 cm), while to determine the microbial activity, only upper surface was taken because most microbial activities were confined to this layer[6]. A compound sample was prepared after mesh up of all collected samples in each season for a particular system. Three sub-samples were prepared from the compound sample to determine the soil characteristics. The texture was determined through the sieving of soil by nets of different sizes. Moisture content was calculated on dry weight basis, water holding capacity (WHC) and bulk density (BD) were estimated following Misra[9]. Chemical properties of the soil, i.e. pH, total organic carbon[10], total nitrogen[11] and phosphorus[12] were determined by standard methods. Chloroform fumigation and extraction (CFE) method[13] was applied to assess the C_{mic} and N_{mic}

$$C_{mic} = \frac{TC(F) - TC(NF)}{K_C},$$

$$N_{mic} = \frac{TN(F) - TN(NF)}{K_N},$$

where C_{mic} is the microbial biomass carbon, N_{mic} the microbial biomass nitrogen, TC the total carbon, TN the total nitrogen, F the fumigated soil, NF the non-fumigated soil, $K_C = 0.45$ (ref. 2), $K_N = 0.54$ (ref. 14).

Results

Soil physico-chemical characteristics

The detailed description of physico-chemical properties of the soil is given in Tables 2 and 3. All the systems were almost similar in texture which indicated that the soils were derived from similar parent matters and suggested differences occurred in chemical and biological characteristics owing to management practices instead of their native character. The highest sand percentage was observed in HG, silt in ADL and clay in C + mT. Compared to uncultivated land (1.05 g/cm^3), BD increased up to 12% in cultivated land (1.27 g/cm^3), indicating that cultivation increased the bulk density. The porosity ranged from 52.07 (C + sT) to 60.34% (ADL) while WHC ranged from 31.45 (OC) to 46.71 (C + mT). The soil temperature was speckled between 23.4°C (C + sT) and 25.1°C (OC), while the soil moisture varied from 4.80% (OC) to 7.70% (C + mT).

The highest pH value was recorded in OC system (7.9) while the other systems were sustained to the standard pH (6.8–7.2). The application of more chemical pesticides and fertilizers in crop fields might have increased the pH considerably. In this study, soil carbon was better recorded in the surface layer compared to deeper layer and decreased from 1.60% (C + mT) to 0.93% (OC). The total organic content ranged from 1.22% (OC) to 2.08% (C + mT) and soil carbon and nitrogen contents followed the same pattern. The soil phosphorus ranged from 26.34 (ADL) to 48.73 kg/ha (C + mT).

In the context of cultivation, the average carbon content (%) of cultivated land (systems 1 to 4) was 86% of uncultivated land. The marginal loss of nitrogen due to continuous cultivation was also observed from systems 1–4. In cultivated land, nitrogen represented 95% of the

Table 2. Physical properties of soil in different cropping systems

Parameters	Depth (cm)	Cropping systems				
		OC	C + sT	C + mT	HG	ADL
Sand (%)	0–15	45.71	44.56	41.67	46.49	45.25
	15–30	44.43	39.96	42.89	45.02	42.34
	Av ± SE	45.07 ± 0.64	42.26 ± 2.307	42.28 ± 0.612	45.76 ± 0.737	41.80 ± 0.547
Silt (%)	0–15	32.28	28.1	28.21	34.38	38.00
	15–30	31.36	31.41	24.98	34.14	37.23
	Av ± SE	31.82 ± 0.461	29.75 ± 1.660	26.59 ± 1.620	34.26 ± 0.120	38.61 ± 1.389
Clay (%)	0–15	22.01	27.34	30.12	19.13	16.75
	15–30	24.21	28.63	32.13	20.84	20.43
	Av ± SE	23.11 ± 1.103	27.99 ± 0.647	31.13 ± 1.008	19.99 ± 0.858	19.59 ± 1.845
Texture		Loam soil	Loam soil	Loam soil	Loam soil	Loam soil
BD (g/cm^3)	0–15	1.19	1.23	1.17	1.06	1.02
	15–30	1.29	1.31	1.25	1.11	1.09
	Av ± SE	1.24 ± 0.050	1.27 ± 0.040	1.21 ± 0.040	1.09 ± 0.025	1.05 ± 0.035
VR	0–15	1.23	1.16	1.27	1.50	1.61
	15–30	1.06	1.03	1.13	1.39	1.44
	Av ± SE	1.15 ± 0.085	1.10 ± 0.065	1.20 ± 0.070	1.45 ± 0.055	1.52 ± 0.085
Porosity (%)	0–15	55.09	53.58	55.84	59.88	61.65
	15–30	51.32	50.56	52.83	58.11	59.02
	Av ± SE	53.21 ± 1.891	52.07 ± 1.515	54.34 ± 1.509	59.00 ± 0.889	60.34 ± 1.319
WHC (%)	0–15	30.42	42.92	47.67	33.78	32.36
	15–30	32.47	40.02	45.74	30.81	42.08
	Av ± SE	31.45 ± 1.028	41.47 ± 1.454	46.71 ± 0.968	32.30 ± 1.489	37.22 ± 4.875
ST (°C)	0–15	25.22	23.54	23.99	25.35	23.56
	15–30	24.91	23.27	23.70	24.89	23.29
	Av ± SE	25.12 ± 0.155	23.40 ± 0.135	23.85 ± 0.145	25.07 ± 0.231	23.43 ± 0.135
SM (%)	0–15	5.09	7.00	8.43	5.45	5.88
	15–30	4.58	4.94	7.05	4.21	4.56
	Av ± SE	4.83 ± 0.256	5.97 ± 1.033	7.74 ± 0.692	4.84 ± 0.622	5.22 ± 0.662

OC, Open crop land; C + sT, Single crop with single tree species; C + mT, Single crop with multiple tree species; HG, Multiple crops with multiple trees; ADL, Agriculturally discarded land; BD, Bulk density; VR, Void ratio; WHC, Water holding capacity; ST, Soil temperature; SM, Soil moisture; Av + SE, Average with standard error.

uncultivated land. The difference in N content of cultivated and uncultivated lands was trivial due to the regular application of nitrogen-based fertilizers artificially to fullfil the loss of nitrogen.

Microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}).

The microbial biomass showed greater values in the cultivated land with multiple tree species as compared to other soils (Table 4). Across the systems, the average C_{mic} ranged from 178 μg g^{-1} (OC) to 254 μg g^{-1} (C + mT), while N_{mic} ranged from 15 μg g^{-1} (OC) to 40 μg g^{-1} (C + mT). These findings are possibly endorsed by the accumulation of more organic carbon under the cultivated land with multiple tree species. The microbial biomass were drastically ($P < 0.001$) affected by the cropping systems and seasons (Table 5). Temporal variation in microbial biomass has been accounted due to variations in microclimatic conditions of the soil, circumstances existing for vegetation growth and accessible substances. Compared to C_{mic}, N_{mic} showed more pronounced temporal variation (Figure 1 *a*), possibly due to the fact that microorganisms differ much more in their N content than in their C content, depending on their stage of growth.

The positive effects of the incorporation of multiple tree species in crop fields were attributed to numerous bases, viz. improved soil constitution, greater fine root density, diversity and availability of plant litter all over the year and alleviated microclimate. Contrast comparison revealed that C_{mic} and N_{mic} were lowest in OC followed by HG. This may be due to less amounts of crop remains left behind after crop harvesting. C_{mic} constitutes about 1.42% to 1.68% of the total soil carbon whereas N_{mic} accounted for 1.48% to 2.88% of the total soil nitrogen with the C : N ratio of 6.88 to 12.74.

Table 3. Chemical properties of soil in different cropping systems

Parameters	Depth (cm)	Cropping systems					
		Season	OC	C + sT	C + mT	HG	ADL
pH	0–15	S	7.6	7.2	7.1	6.9	7.4
		R	8.1	7	7.1	6.2	6.1
		W	7.9	7.1	7.2	6.9	6.5
	15–30	S	7.6	7.3	7.1	7.1	7.2
		R	8.3	7.1	7.2	6.3	6.4
		W	7.7	6.9	7.1	6.8	6.6
		Av ± SE	7.9 ± 0.117	7.1 ± 0.058	7.1 ± 0.021	6.7 ± 0.148	6.7 ± 0.203
C (%)	0–15	S	1.1	1.34	1.56	1.28	1.45
		R	1.26	1.51	2.10	1.31	1.56
		W	1.10	1.23	1.76	1.20	1.60
	15–30	S	0.67	1.02	1.35	1.01	1.24
		R	0.72	1.23	1.47	1.09	1.36
		W	0.75	1.13	1.34	1.02	1.39
		Av ± SE	0.93 ± 0.102	1.24 ± 0.069	1.60 ± 0.119	1.15 ± 0.053	1.43 ± 0.055
	kg/ha		11573.33	15790.33	19319.67	12553.17	15050.00
TOC	0–15	S	1.44	1.74	2.03	1.66	1.89
		R	1.64	1.96	2.73	1.70	2.03
		W	1.43	1.6	2.29	1.56	2.08
	15–30	S	0.87	1.33	1.76	1.31	1.61
		R	0.94	1.60	1.91	1.42	1.77
		W	0.98	1.47	1.74	1.33	1.81
		Av ± SE	1.22 ± 0.133	1.62 ± 0.089	2.08 ± 0.155	1.50 ± 0.069	1.87 ± 0.071
SOM	0–15	S	1.91	2.31	2.69	2.21	2.50
		R	2.17	2.60	3.62	2.26	2.69
		W	1.90	2.12	3.03	2.07	2.76
	15–30	S	1.16	1.76	2.33	1.74	2.14
		R	1.24	2.12	2.53	1.88	2.34
		W	1.29	1.95	2.31	1.76	2.40
		Av ± SE	1.61 ± 0.177	2.14 ± 0.119	2.75 ± 0.206	1.99 ± 0.093	2.47 ± 0.094
SCS (t C ha^{-1})	0–15	S	19.81	24.72	27.38	20.35	22.84
		R	22.49	27.86	36.86	20.83	24.57
		W	19.64	22.69	30.89	19.08	25.20
	15–30	S	12.96	20.04	25.31	16.82	19.53
		R	13.93	24.17	27.56	18.15	21.42
		W	14.51	22.20	25.13	16.98	21.89
		Av ± SE	17.22 ± 1.605	23.61 ± 1.087	28.86 ± 1.819	18.70 ± 0.691	22.58 ± 0.860
N (%)	0–15	S	0.070	0.071	0.104	0.066	0.093
		R	0.122	0.129	0.151	0.123	0.140
		W	0.133	0.154	0.164	0.147	0.151
	15–30	S	0.064	0.064	0.102	0.057	0.086
		R	0.119	0.120	0.147	0.128	0.132
		W	0.137	0.151	0.153	0.142	0.142
		Av ± SE	0.108 ± 0.013	0.115 ± 0.016	0.137 ± 0.011	0.111 ± 0.016	0.124 ± 0.011
		Kg/ha	1333.00	1458.38	1655.68	1204.45	1302.00
P (kg/ha)	0–15	S	42.58	30.78	50.27	39.5	27.19
		R	36.93	41.55	48.73	35.39	28.73
		W	35.39	52.32	49.24	31.29	25.65
	15–30	S	41.55	26.67	47.19	36.93	25.65
		R	33.34	40.52	48.22	33.34	25.65
		W	29.75	49.76	48.73	27.7	25.14
		Av ± SE	36.59 ± 2.003	40.27 ± 4.147	48.73 ± 0.420	34.03 ± 1.722	26.34 ± 0.559
C : N			08.68	10.83	11.67	10.42	11.56
C : P			316.30	392.14	396.46	368.94	571.48
N : P			36.43	36.22	33.98	35.40	49.44

OC, Open crop land; C + sT, Single crop with single tree species; C + mT, Single crop with multiple tree species; HG, Multiple crops with multiple trees; ADL, Agriculturally discarded land; C, Carbon; TOC, Total organic carbon; SOM, Soil organic matters; SCS, Soil carbon stock; N, Nitrogen; P, Phosphorus; Av ± SE, Average with standard error; S, Summer; R, Rainy; W, Winter.

Table 4. Soil microbial biomass carbon and nitrogen ($\mu g\ g^{-1}$) under different cropping systems

Cropping systems	Seasons	C_{mic} ($\mu g\ g^{-1}$)	N_{mic} ($\mu g\ g^{-1}$)	$C_{mic} : N_{mic}$	N in biomass* (%)	C_{mic}/C (%)	N_{mic}/N (%)
OC	Summer	166	12	13.83	3.61	1.51	1.71
	Rainy	193	23	8.39	5.96	1.53	1.89
	Winter	176	11	16.00	3.13	1.60	0.83
	Av ± SE	178.33 ± 7.881	15.33 ± 3.844	12.74 ± 2.263	4.23 ± 0.874	1.55 ± 0.027	1.48 ± 0.327
C + sT	Summer	211	14	15.07	3.32	1.57	1.97
	Rainy	229	36	6.36	7.86	1.52	2.79
	Winter	234	28	8.36	5.98	1.90	1.82
	Av ± SE	224.67 ± 6.984	26.00 ± 6.429	9.93 ± 2.634	5.72 ± 1.317	1.66 ± 0.119	2.19 ± 0.301
C + mT	Summer	235	31	7.58	6.60	1.51	2.98
	Rainy	266	57	4.67	10.71	1.27	3.77
	Winter	260	31	8.39	5.96	1.48	1.89
	Av ± SE	253.67 ± 9.493	39.67 ± 8.667	6.88 ± 1.130	7.76 ± 1.488	1.42 ± 0.076	2.88 ± 0.545
HG	Summer	194	13	14.92	3.35	1.52	1.97
	Rainy	229	28	8.18	6.11	1.75	2.28
	Winter	213	24	8.88	5.63	1.78	1.63
	Av ± SE	212.00 ± 10.116	21.67 ± 4.485	10.66 ± 2.140	5.03 ± 0.851	1.68 ± 0.082	1.96 ± 0.188
ADL	Summer	221	18	12.28	4.07	1.52	1.94
	Rainy	242	41	5.90	8.47	1.55	2.93
	Winter	239	31	7.71	6.49	1.49	2.05
	Av ± SE	234.00 ± 6.558	30.00 ± 6.659	8.63 ± 1.898	6.34 ± 1.272	1.52 ± 0.017	2.31 ± 0.313

*Assuming that dry biomass contains 50% C (ref. 15); OC, Open crop land; C + sT, Single crop with single tree species; C + mT, Single crop with multiple tree species; HG, Multiple crops with multiple trees; ADL, Agriculturally discarded land; C_{mic}, Soil microbial biomass carbon; N_{mic}, Soil microbial biomass nitrogen; Biomass C/total C (%), Microbial biomass carbon to total soil carbon; Biomass N/total N (%), Microbial biomass nitrogen to total soil nitrogen.

Table 5. ANOVA (one way) for microbial biomass with different parameters

		Mean square						
Parameters	d*f*	C_{mic}	N_{mic}	BD	pH	C	N	Mo
Systems	4	7048.07*	935.19*	0.059*	2.056*	0.694*	0.003^{NS}	6.582^{NS}
Seasons	2	2049.76*	1940.44*	0.000^{NS}	0.154^{NS}	0.274^{NS}	0.023*	414.10*

*Significant at $P < 0.001$; NS, Non significant; C_{mic}, Soil microbial biomass carbon; N_{mic}, Soil microbial biomass nitrogen; BD, Bulk density; C, Soil carbon; N, Soil nitrogen; Mo, Moisture.

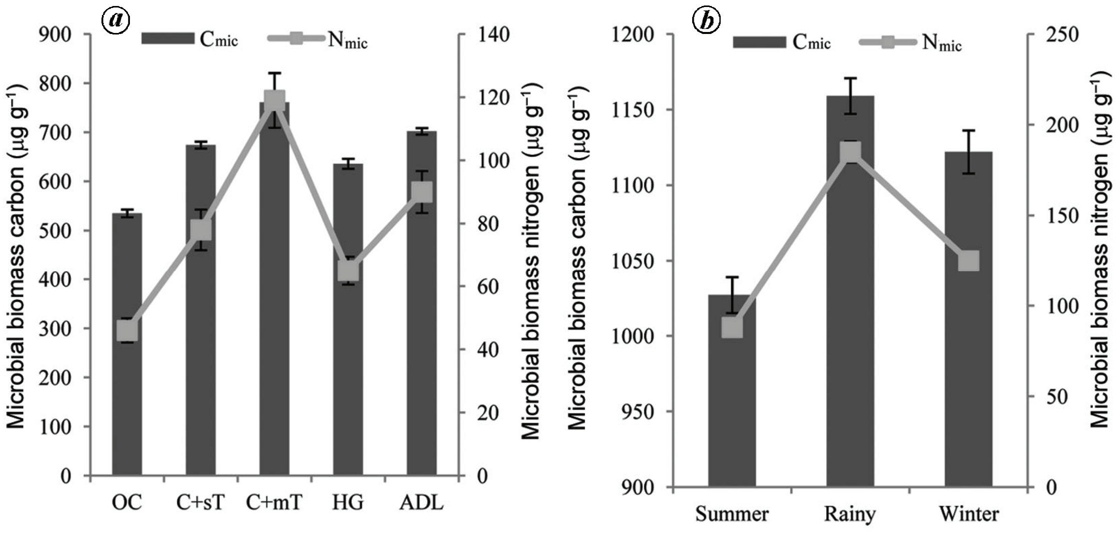

Figure 1. Effect of (*a*) cropping system and (*b*) season on soil microbial biomass carbon and nitrogen.

Table 6. Pearson's correlation coefficient between vegetation, soil microbial biomass and different physiochemical parameters

	S	Se	C_{mic}	N_{mic}	TOC	TN	P	pH	ST	SM	BD	Sa	Si	Cl	WHC
S	1														
Se	0.000	1													
C_{mic}	0.241	0.231	1												
N_{mic}	0.099	0.200	0.799**	1											
TOC	0.042	0.020	0.839**	0.886**	1										
TN	0.077	0.726**	0.599*	0.747**	0.557*	1									
P	–0.133	0.047	0.569*	0.491	0.560*	0.349	1								
pH	–0.599*	0.088	–0.338	–0.006	0.019	0.201	0.100	1							
ST	–0.003	–0.937**	–0.383	–0.444	–0.207	–0.826**	–0.102	–0.074	1						
SM	–0.046	0.315	0.552*	0.765**	0.602*	0.624*	0.128	–0.012	–0.585*	1					
BD	–0.692**	0.226	0.181	0.264	0.279	0.380	0.489	0.590*	–0.317	0.200	1				
Sa	0.287	0.000	–0.745**	–0.592*	–0.799**	–0.350	–0.741**	–0.099	0.086	–0.236	–0.435	1			
Si	0.519*	0.000	–0.150	0.020	0.004	0.166	0.009	0.210	0.013	–0.149	0.060	0.263	1		
Cl	–0.541*	0.000	0.389	0.191	0.277	–0.018	0.253	–0.143	–0.041	0.210	0.102	–0.575*	–0.941**	1	
WHC	0.022	0.074	0.828**	0.532	0.667**	0.286	0.546*	–0.339	–0.144	0.236	0.170	–0.851**	–0.617**	0.736**	1

Correlation is significant at the *0.05 level and at **0.01 level; S, Systems; Se, Seasons; C_{mic}, Soil microbial biomass carbon; N_{mic}, Soil microbial biomass nitrogen; TOC, Total organic carbon; TSN, Total soil nitrogen; P, Phosphorus; ST, Soil temperature; SM, Soil moisture; BD, Bulk density; Sa, Sand; Si, Silt; Cl, Clay; WHC, Water holding capacity.

Relationship between physicochemical characteristics and microbial biomass

Pearson's correlation between physicochemical characteristics and microbial biomass is given in Table 6. The C_{mic} values showed significant positive correlation with N_{mic} ($r = 0.79$), total organic carbon ($r = 0.84$), total soil nitrogen ($r = 0.60$), soil moisture ($r = 0.55$) and water holding capacity ($r = 0.82$). Significant positive correlations have also been recorded between N_{mic} and total carbon ($r = 0.88$), total nitrogen ($r = 0.74$) and soil moisture ($r = 0.76$). Both C_{mic} and N_{mic} were negatively correlated with sand content.

Discussion

Effects of cropping system on soil characteristics

The higher proportion of silt and lower proportion of sand in ADL were observed as compared to cultivated lands. Abad *et al.*[15] also observed increased sand content with changing forest to cultivated land, most likely as a result of removal of silt and adding sand in soil surface by accelerated soil erosion. The soil of cultivated land had the highest bulk density compared to uncultivated land. These results are consistent with earlier findings[16,17], where cultivation increased the bulk density considerably. Low soil moisture (4.8%) and high soil temperature (25.1°C) in OC system indicated that the absence of tree canopy exposed the crop fields to direct sunlight which resulted in decreased moisture and increased temperature.

The cultivated lands showed higher soil pH than uncultivated land probably due to the use of chemical fertilizers in cultivated lands. Soil organic matter (SOM) showed a significant difference between different cropping systems and the values vary from 1.61% (OC) to 2.75% (C + mT). SOM is the most important indicator for the assessment of productivity in different cropping systems and management practices[18]. The cultivation promotes soil ventilation which exchange decomposition by SOM[6], thus resulting in low soil carbon content. In this study, loss of soil C and N owing to continuous farming was 14% and 5% respectively, compared to uncultivated land. Wakene[7] also reported about 30% and 76% reduction in soil N under 40 years old cultivated farm and deserted land respectively, in contrast to virgin land. The physicochemical properties of the soils vary in space and time because of variation in topography, climate, weathering process, vegetation cover and microbial activities[19–21] and several other biotic and abiotic factors[22,23].

The results of PCA supported the analysed soil factors as predictors of quality of cropping systems. PCA was carried out with six biological soil quality indicators and it was then reduced to few indicators, which explains minimum relation using eigen value (Figure 2). The component contributing to maximum variance always become the first PC and hence, more quality indicators were selected from this component. The coordination of five cropping systems on the basis of soil biological quality is presented in Figure 3. There were two principal components (PCs) which have the eigen value more than one and therefore, were responsible for 90.56% of the total variation. The first component, most reliable (Y_{pc1}), reported for 74.91% of the total variations in which the highest loading value were found with soil C_{mic} ($P \leq 0.01$), N_{mic} ($P \leq 0.01$), $C_{mic} : N_{mic}$ ($P \leq 0.01$), N in biomass ($P \leq 0.01$) and N_{mic}/N (%) ($P \leq 0.05$) (Tables 7 and 8).

$$Y_{pc1} = 0.984\ (N_{mic}) + 0.969\ (\text{N in biomass}) + 0.901\ (N_{mic}/N) + 0.861\ (C_{mic}) + \ldots .$$

The second component (Y_{pc2}) contributed 15.64% of the total relationship and the highest loading was found with microbial biomass carbon in total soil carbon.

$$Y_{pc2} = 0.870\ (C_{mic}/C) + 0.132\ (C_{mic}) + \dots .$$

The OC system during summer season showed no relation with other parameters of F1 and F2 factors and therefore, represented as supplementary variable. The absence of tree fostering and the reimbursement of crop residual by burning after harvesting resulted in comparatively less soil nutrients in OC system.

Effects of cropping system on microbial biomass

The microbial biomass varied significantly with respect to different cropping systems. Due to its high turnover rate, microbial biomass could counter more quickly, the changes in soil environment[24]. Across the systems, C_{mic} ranged from 178 μg g^{-1} (OC) to 255 μg g^{-1} (C + mT) and N_{mic} from 15 μg g^{-1} (OC) to 40 μg g^{-1} (C + mT). These results suggested that variation in accumulated plant debris and fine roots in the cultivated land with multiple tree species favour the intensification of microbes and hence more C and N are accumulated in the microbial biomass[1]. The significant positive relationship ($P < 0.001$) between C_{mic} and soil carbon also indicated that soils rich in organic matter contain comparatively good amount of microbial biomass[25]. N_{mic} also follow the same trend indicating that the dynamics of N in mineral soil are closely linked to C, because most of the N exists in organic compounds and heterotrophic microbial biomass which utilize organic C for energy. Nutrient availability such as P, greatly influences soil microbial activity and function[26]. However, in this study, microbial biomass showed insignificant correlation with available P and soil pH.

The positive effect of C + mT system on microbial biomass compared to other cropping systems may be attributed to better soil properties, quantity and diversity of plant litter. The multiple tree species residue invite different type of microbes, which in turn release the nutrients more efficiently[27], resulting in increased microbial biomass.

Our results indicated that significant positive correlations occurred between C_{mic} and soil C ($P < 0.001$) and N_{mic} and soil N ($P < 0.001$) (Figure 4 *a* and *b*). The main reason for reduction in C_{mic} was lower input of soil organic carbon[6,25]. The accumulation of litter, dead and decayed part of plants and fine roots may support the expansion of microbial populations and resulted in deposition of C in microorganisms. The significant positive correlation between soil C and N (Figure 4 *c*) indicated that total N increased with increase in organic C[28]. Kara and Bolat[1] also suggested that nitrogen dynamics of the soil are intimately associated with carbon; as a result, N_{mic} showed a significant correlation ($P < 0.001$) with C_{mic} (Figure 4 *d*).

Values of C_{mic} obtained in the present study (178–253 μg g^{-1}) (ref. 4) are lower than forest soils (1326 μg g^{-1}) (ref. 29), higher than agricultural lands (116–184 μg g^{-1})

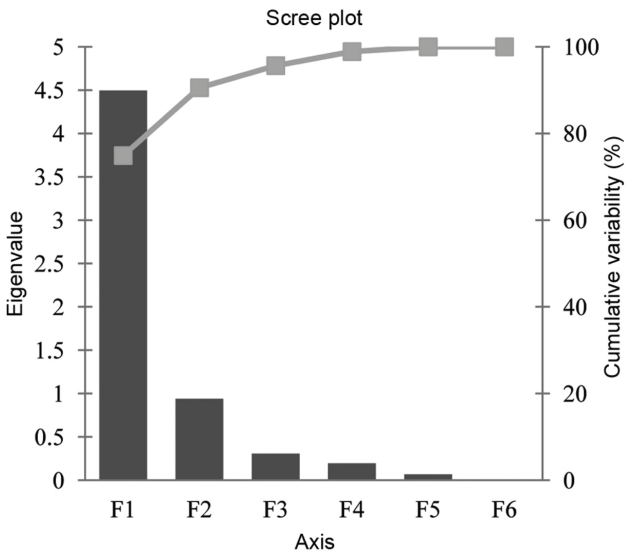

Figure 2. Screen plot for eigen values, variability and cumulative variability for various factors.

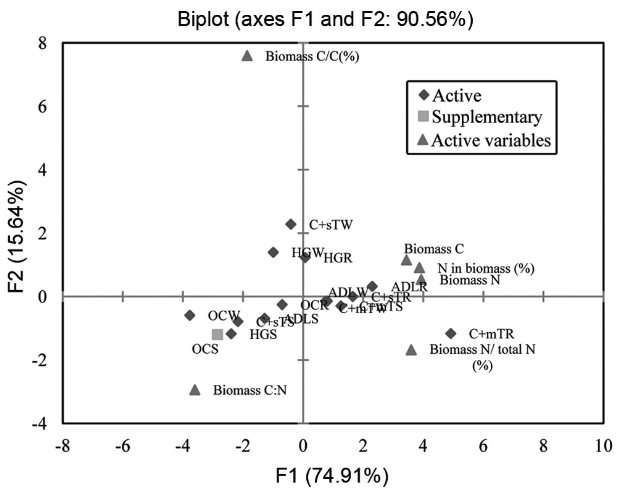

Figure 3. Principal component analysis (PCA) of microbial biomass properties of soil in different cropping systems. PCA axis 1 and 2 represent first and second coordinates (scores) of systems respectively.

Table 7. Rotated principal components of soil quality indicators

Parameters	Principal components	
	F1	F2
C_{mic}	**0.861**	0.132
N_{mic}	**0.984**	0.062
$C_{mic} : N_{mic}$	**–0.903**	–0.336
N in biomass (%)	**0.969**	0.104
C_{mic}/C (%)	–0.467	**0.870**
N_{mic}/total N (%)	**0.901**	–0.192

Values in bold correspond for each variable to the factor for which the factor loading is the highest.

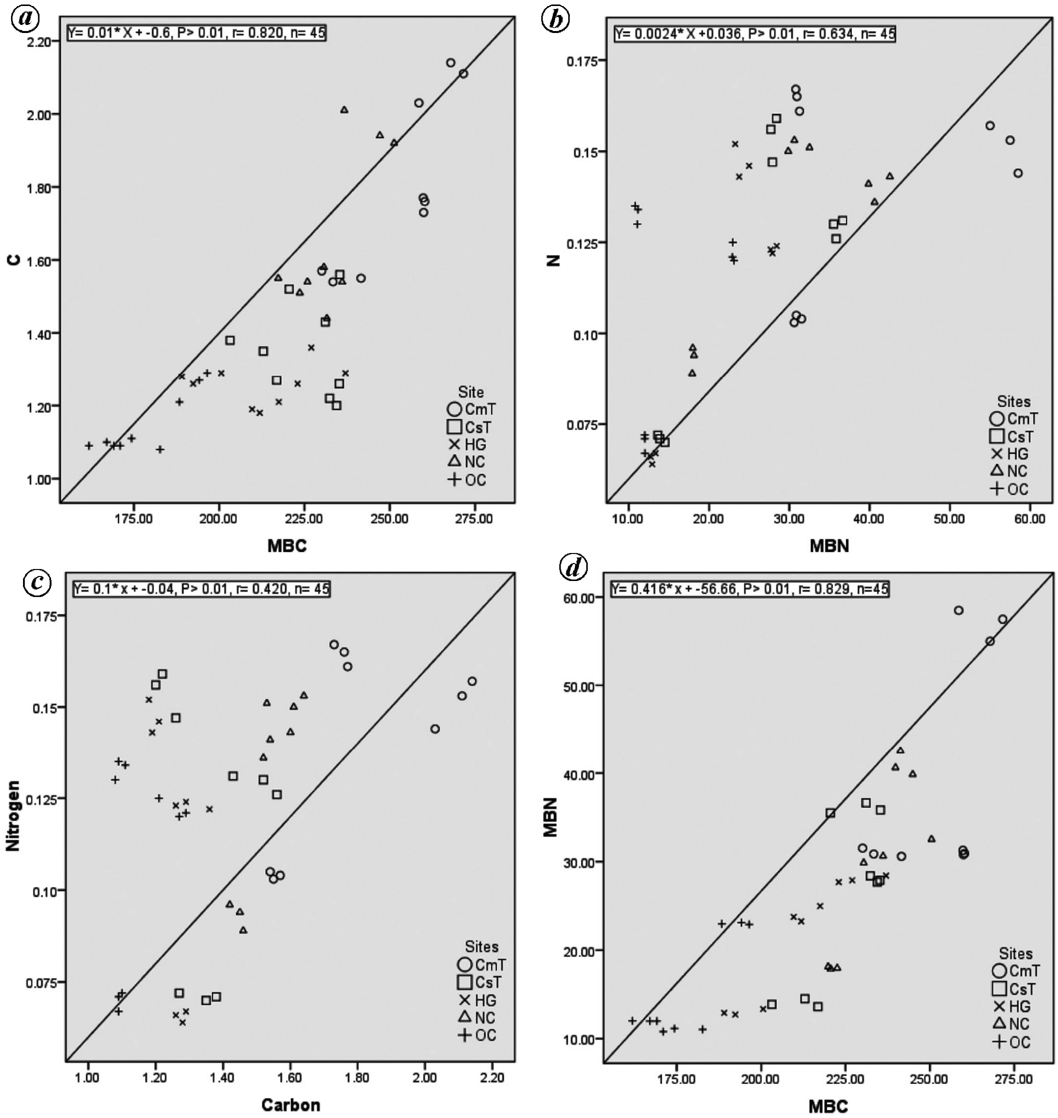

Figure 4. Relationship between (***a***) the microbial biomass C (μg g^{-1}) and soil organic C (%), (***b***) the microbial biomass N (μg g^{-1}) and total soil N (%), (***c***) the soil organic C (%) and total N (%) and (***d***) the microbial biomass C (μg g^{-1}) and N (μg g^{-1}) in soil.

and tea gardens (121–188 μg g^{-1}) (ref. 30). The N_{mic} values are comparatively low (15–40 μg g^{-1}) compared to different land-use patterns (30–142 μg g^{-1}) (ref. 4) of agricultural, postural and forest soils (42–130 μg g^{-1}) (ref. 1), agricultural lands (42–51 μg g^{-1}) and tea gardens (26–41 μg g^{-1}) (ref. 30).

Microbial biomass is often restricted by the accessibility of organic carbon instead of nitrogen[31], although the role of nitrogen may be influenced by soil C : N ratio in certain circumstances. The values of microbial biomass nitrogen showed more chronological fluctuation than those of biomass carbon[32]. The significant positive correlations between C_{mic} and SOC and N_{mic} and TSN agreed with earlier reports[1,33]. A good fit correlation was found between microbial biomass carbon and organic carbon, which suggests that microbial biomass concentration depends mainly on the organic matter availability, which was also reported in several studies[6,32,33].

The $C_{mic} : N_{mic}$ ratio is frequently used to describe the organization of the microbial community[34]. Low ratio predicts the higher concentration of bacterial population, whereas high ratio proposed fungal dominancy in microbial population[35]. Jenkinson and Ladd[2] provided the range of microbial C : N ratio between 10 and 12 for fungal hyphae and between 3 and 5 for bacterial communities. The $C_{mic} : N_{mic}$ attained in this study was moderately higher (7–13), indicating the predominance of fungi in soils, consistent with values reported for most tropical soils (10–12) (ref. 3). The cultivated land planted with trees and uncultivated land had higher C_{mic} and N_{mic} than OC system with lower C : N ratio, which is an indication of higher degree of humification and easy

Table 8. Pearson's correlation matrix of the soil biological quality indicators

Parameters	C_{mic}	N_{mic}	C_{mic} : N_{mic}	N in biomass (%)	C_{mic}/C (%)	N_{mic}/N (%)
C_{mic}	1					
N_{mic}	0.840**	1				
C_{mic} : N_{mic}	–0.777**	–0.908**	1			
N in biomass (%)	0.765**	0.987**	–0.936**	1		
C_{mic}/C (%)	–0.196	–0.350	0.115	–0.319	1	
N_{mic}/total N (%)	0.682**	0.849**	–0.725**	0.841**	–0.500	1

Correlation is significant at **0.01 and *0.05 level (2-tailed).

mineralization of organic N (ref. 36). The present values are lower than early reports (5.2–20.80) but higher than those reported for forest stands (5.0) (ref. 5) and agricultural fields (8.76) (ref. 25).

The C_{mic} and N_{mic} when articulated as SOC (%) and STN (%), respectively provide an assessment of the organic matter dynamics, magnitude of nutrients and substrate accessibility in soils[34]. The C_{mic}/C(%) ratios in the present study were 1.25–1.90%. The values fell within the range (1.2–2.7%) reported for forest[5]. Values of N_{mic}/N(%) reported in the present study (0.83–3.77%) were in the lower range compared to estimated value for agricultural soils (2–6%) (ref. 14) and for temperate forest soils (1.6–3.0%) (ref. 8); however, these values were higher than that reported for forest soils (0.96–1.11%) (ref. 3).

Effect of seasons on microbial biomass

In all the cropping systems, the values of C_{mic} and N_{mic} were reported highest during rainy and lowest during summer season (Figure 1 *a*). These findings are in conformity to previous studies[5,19,37]. The lowest values of microbial biomass were caused by slow microbial activities in extreme hot and dry period. Low soil moisture limits the microbial biomass content, which is strengthened by the positive correlation between C_{mic} and soil moisture[38]. The temporal variation in microbial biomass may be due to change in soil moisture, temperature, rainfall land use pattern etc. In the present study, uncultivated land showed least variation across the seasons while multiple tree species system showed the maximum variation (Figure 1 *b*).

Conclusion

In conclusion, continuous cultivation resulted in decreased soil fertility but incorporation of tree plantation in crop fields led to increased soil fertility by shifting natural soil properties under the similar environmental circumstances. Higher plant diversity via higher root inputs and some other unidentified mechanism increase metabolic activities of soil microorganisms, which govern the storage of carbon in the soil as indicated by strong positive relationship between soil C content and microbial biomass. Higher amount of soil organic carbon and more favourable microclimatic conditions linked to more diverse plant communities resulted in more active, abundant and more diverse microbial communities as indicated by higher microbial biomass carbon and nitrogen. Therefore, incorporation of multiple tree species in crop fields can significantly contribute to soil carbon and nitrogen stock by increasing microorganism mediated turnover rates of litter.

1. Kara, O. and Bolat, I., The effect of different land uses on soil microbial biomass carbon and nitrogen in Bartin province. *Turk. J. Agric. For.*, 2008, **32**, 281–288.
2. Jenkinson, D. S. and Lass, J. N., Microbial biomass in soil: measurement and turnover. In *Soil Biochemistry* (eds Paul, E. A. and Ladd, J. N.), New York, 1981, pp. 415–471.
3. Zaia, F. C., Gama-Rodrigues, A. C., Gama-Rodrigues, E. F., Moc, M. K. S., Fontes, A. G., Machado, R. C. R. and Baligar, V. C., Carbon, nitrogen, organic phosphorus, microbial biomass and N mineralization in soils under cacao agroforestry systems in Bahia, Brazil. *Agroforest. Syst.*, 2012, **86**(2), 197–212.
4. Sharma, P., Rai, S. C., Sharma, R. and Sharma, E., Effects of land-use change on soil microbial C, N and P in a Himalayan watershed. *Pedobiologia*, 2004, **48**, 83–92.
5. Yadava, P. S. and Devi, N. B., Seasonal dynamics in soil microbial biomass C, N and P in a mixed-oak forest ecosystem of Manipur, North-East India. *Appl. Soil Ecol.*, 2006, **31**, 220–227.
6. Srivastava, S. C. and Singh, J. S., Effect of cultivation on microbial carbon and nitrogen in dry tropical forest soil. *Biol. Fertil. Soils*, 1989, **8**, 343–348.
7. Wakene, N., Assessment of important physicochemical properties of Nitisols under different management systems in Bako area, Western Ethiopia. M Sc thesis, School of Graduate Studies, Alemeya University, Ethiopia, 2001.
8. Zhong, Z. K. and Makeschin, F., Differences of soil microbial biomass and nitrogen transformation under two forest types in central Germany. *Plant. Soil*, 2006, **283**, 287–297.
9. Misra, R., *Ecology Workbook*, Oxford and IBH Publishing Company, Calcutta, 1968.
10. Walkley, A. and Black, C. A., An experiment of Degtjareff methods for determining soil organic matter and a proposed modification of the chronic acid titration methods. *Soil Sci.*, 1934, **37**, 29–38.
11. Peach, K. and Tracy, M. V., *Modern Methods of Plant Analysis*, Springer Verlag, Adelaide, Australia, 1956.
12. Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A., Estimation of available phosphorus in soils by extraction with sodium

bicarbonate, Department of Agriculture Circular, USA, 1954, p. 939.
13. Vance, E. D., Brookes, P. C. and Jenkinson, D. S., Microbial biomass measurements in forest soils: the use of the chloroform fumigation incubation method for strongly acid soils. *Soil Biol. Biochem*., 1987, **19**, 697–702.
14. Brookes, P. C., Kragt, J. F., Powlson, D. S. and Jenkinson, D. S., Chloroform fumigation and release of soil nitrogen: the effect of fumigation time and temperature. *Soil Biol. Biochem.*, 1985, **17**, 831–835.
15. Abad, J. R. S., Khosravi, H. and Alamdarlou, E. H., Assessment the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan province, Iran. *Bull. Env. Pharmacol. Life. Sci*., 2014, **3**(3), 296–300.
16. Mulugeta, L., Effects of land use changes on soil quality and native flora degradation and restoration in the highlands of Ethiopia: Implication for sustainable land management. Ph D thesis, Swedish University of Agricultural Sciences, Uppsala, 2004.
17. Kizilkaya, R. and Dengiz, O., Variation of land use and land cover effects on some soil physico-chemical characteristics and soil enzyme activity. *Zemdirbyste*, 2010, **97**(2), 15–24.
18. Shukla, M. K., Lal, R. and Ebinger, M., Determining soil quality indicators by factor analysis. *Soil Till. Res*., 2006, **87**, 194–204.
19. Bargali, K., Manral, V., Padalia, K., Bargali, S. S. and Upadhayay, V. P., Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. *Catena*, 2018; https://doi.org/10.1016/j.catena.1018.07.001.
20. Baumler, R., *Soils*. In *Nepal: An Introduction to the Natural History, Ecology and Human Environment in the Himalayas – A Comparison to the Flora of Nepal* (eds Miehe, Pendry, C. A.), The Royal Botanical Garden, Edinburgh, 2015, pp. 125–134.
21. Paudel, S. and Sah, J. P., Physico chemical characters of soil in tropical soil (*Shorea robusta* Gaertn.) forests in eastern Nepal. *Himal. J. Sci*,, 2003, **1**(2), 107–110.
22. Bargali, S. S., Joshi, M. and Bargali, K, Seasonal pattern of total soil respiration in age series of eucalyptus plantation and mixed board-leaved forest in Tarai belt of Kumaun Himalaya. *Oecol. Mont*., 1992, **2**, 7–11.
23. Bargali, S. S., Singh, S. P. and Singh, R. P., Pattern of weight loss and nutrient release in decomposing leaf litter in age series of eucalyptus plantation. *Soil Biol. Biochem*., 1993, **25**, 1731–1738.
24. Powlson, D. S., Brooks, P. C. and Christensen, B. T., Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol. Biochem*., 1987, **19**, 159–164.
25. Kujur, M. and Patel, A. M., Quantifying the contribution of different soil properties on microbial biomass carbon, nitrogen and phosphorous in dry tropical ecosystem. *Int. J. Environ. Sci*., 2012, **2**, 2272–2284.
26. Wright, A. L. and Reddy, K. R., Phosphorus loading effects on extracellular enzyme activity in Everglades wetland soil. *Soil. Sci. Soc. Am. J*., 2001, **65**, 588–595.
27. Bargali, S. S., Shukla, K., Singh, L., Ghosh, L. and Lakhera, M. L., Leaf litter decomposition and nutrient dynamics in four tree species of dry tropical forest. *Trop. Ecol.*, 2015, **56**, 191–200.
28. Li, X., Li, F., Singh, B., Rengelc, Z. and Zhan, Z., Soil management changes organic carbon pools in alpine pastureland soils. *Soil Till. Res*., 2007, **93**, 186–196.
29. Hu, S., Coleman, D. C., Carroll, C. R., Hendrix, P. P. and Beare, M. H., Labile soil carbon pools in subtropical forest and agricultural ecosystems as influenced by management practices and vegetation types. *Agric. Ecosyst. Environ*., 1997, **65**, 69–78.
30. Chattopadhyay, T., Reza, S. K., Nath, D. J., Baruah, U. and Sarkar, D., Effect of land use on soil microbial biomass carbon and nitrogen content in the soils of Jorhat district, Assam. *Agropedology*, 2012, **22**(2), 119–122.
31. Ekblad, A. and Nordgren, A., Is growth of soil microorganisms in boreal forests limited by carbon or nitrogen availability? *Plant Soil*, 2002, **242**, 115–122.
32. Logah, V., Safo, E. Y., Quansah, C. and Danso, I., Soil microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in the semi-deciduous forest zone of Ghana. *West Afr. J. Appl. Ecol*., 2010, **17**, 121–133.
33. Oyedele, A. O., Olayungbo, A. A., Denton, O. A., Ogunrewo, O. M. and Momodu, F. O., Assessment of the microbial biomass carbon, nitrogen and phosphorus in relation to physico-chemical properties of Acric Luvisols in Ibadan South West, Nigeria. *J. Agric. Environ. Int. Develop*., 2015, **109**(2), 179–187.
34. Moore, J. M., Klose, S. and Tabatabai, M. A., Soil microbial biomass carbon and nitrogen as affected by cropping systems. *Biol. Fertil. Soils,* 2000, **31**(3), 200–210.
35. Campbell, C. A., Biederbeck, V. O., Zentner, R. P. and Lafond, G. P., Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin black Chernozem. *Can. J. Soil. Sci*., 1991, **71**, 363–376.
36. Bai, J. H., Ouyang, H., Deng, W., Zhu, Y. M., Zhang, X. L. and Wang, Q. G., Spatial distribution characteristics of organic matter and total nitrogen of marsh soils in river marginal wetlands. *Geoderma*, 2005, **124**, 181–192.
37. Patel, K., Kumar, J., Kumar, R. N. and Kumar, B., Seasonal and temporal variation in soil microbial biomass C, N and P indifferent types land uses of dry deciduous forest ecosystem of Udaipur, Rajasthan, Western India. *Appl. Ecol. Environ. Res*., 2010, **8**, 377–390.
38. Diaz-Ravina, M., Acea, M. J. and Carballas, T., Seasonal changes in microbial biomass and nutrient flush in forest soils. *Biol. Fertil. Soils*, 1995, **19**, 220–226.

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