

Soil Microbial Biomass Carbon in Natural and Degraded Soil-A Review

SANJOY KUMAR¹, S. CHAUDHURI² AND S. K. MAITI^{1*}

¹Indian Schools of Mines, Department of Environment Science and Engineering

²Department of Mining Engineering
 Dhanbad 826004, India

E-mail : subodh_maiti@yahoo.com

*Correspondence

Abstract

Microorganisms are generally considered as the driving force or catalyst behind the decomposition process. They have played an important role in element and energy flows in soil ecosystem as the driving forces for transformation of plant residues in soil. Soil microbial biomass (SMB) is the key biological component of soil that affects decomposition, nutrient cycling, and aggregation. The size of the SMB pool is routinely measured and expressed as carbon contained in the SMB called as soil microbial biomass carbon. In general, soil microbial biomass carbon is highly related with, but constitutes only a small fraction of the soil organic carbon content. Soil microbial biomass carbon, especially the microbial C-to-organic C ratio may reflect the role of microorganisms in the C availability of soils. Soil microbial biomass carbon was significantly greater in the top 0—50 mm soil depth when compared to the lower depths. Soil microbial biomass carbon used as indicative of an adverse effect of a contaminant in soil. Soil microbial biomass carbon is also varied with different seasons such as spring, summer, and fall in different treatment of terraces and stripes. Soil microbial biomass carbon had similar significant correlations with organic C, total N and NO₃-N. The different tree species have variation in soil microbial biomass carbon. Soil microbial biomass carbon depends on soil pH, moisture content, temperature and presence of heavy metals in soil.

Key words : Soil microbial biomass carbon, Natural and mine soils.

Recent interest in evaluating the quality of our soil resources has been stimulated by increasing awareness that soil is a critically important component of the biosphere, functioning not only in the production of food but also in the maintenance of environmental quality. Soil quality conservation is, therefore, particularly important when dealing with marginal, fragile and ecologically sensitive ecosystems where excessive human pressure has led to irreversible soil degradation and desertification (1). Among the many factors which are important for judging a soil's quality are its biological and biochemical properties, which are of paramount importance, because the degradation of the plant cover has a direct bearing on the scarcity of organic matter (2). Microorganisms are generally considered as the driving force or catalyst behind the decomposition process (3). They have played an important role in element and energy flows in soil ecosystem as the driving forces for transformation of plant residues in soil. Because of the importance of biological activity as an attribute for

soil sustainability, Srivastava and Singh (4) proposed the use of soil microbial biomass (SMB) and composition as indicators. Therefore, soil microbial biomass is used as an important index to evaluate the effects of different development and management on quality and function of soil ecosystem.

Soil microbial biomass is the key biological component of soil that affects decomposition, nutrient cycling, and aggregation. The size of the SMB pool is routinely measured and expressed as carbon contained in the SMB called as soil microbial biomass carbon (SMBC). In general, soil microbial biomass carbon (SMBC) is highly related with, but constitutes only a small fraction of the soil organic carbon content. The measurement of soil microbial biomass C was one method of providing a more sensitive indicator of change than soil chemistry alone and addressing the gap in monitoring, between the soil chemistry and the vegetation covers. Soil microbial C, especially the microbial C-to-organic C ratio may reflect the role of microorganisms in the C availability of soils. In this

sense, the magnitude microbial biomass C (MBC) may indicate potential rate of C flux. Indeed, MBC is commonly described as a living or active pool in models that simulate organic C turnover in soils, and the size of this pool directly affects the model outputs. Several techniques are now available to measure MBC, including chloroform fumigation-incubation (CFI), chloroform fumigation-extraction (CFE) and substrate-induced respiration (SIR) methods (5). Nevertheless, relationships of soil respiration and organic C turnover to the size of MBC as estimated with these techniques remain unclear (6).

Soil microbial biomass carbon have shown to be sensitive indicators of soil erosion, pollution by pesticides and heavy metals, salinization, burning, CO₂ enrichment, devegetation, land abandonment, and agricultural and livestock practices. The dynamics of soil microbial C is associated with varying environmental factors including temperature, soil moisture and rainfall. The microbial biomass carbon can also provide one of the most satisfactory estimates of the restoration of soil microbial populations (7). One of the general criteria used to determine microbial activity and biomass in soil is soil microbial biomass carbon. Therefore, in this review paper the measurement of microbial biomass carbon (MBC) is useful for evaluating microbial population size and this parameter has been considered in the evaluation of natural and degraded systems (8).

Measurement of Soil Microbial Biomass Carbon

Fumigation-Extraction (FE). Microbial biomass carbon in soil was estimated by fumigation extraction (9, 10). Six portions equivalent to 25 g of dry weight soil were taken from each soil sample. Three portions were fumigated for 24 h at 25 °C with CHCl₃ (ethanol-free). Following fumigant removal, the soil was treated with 100 ml of 0.5 M K₂SO₄ by horizontal shaking for 1 h at 200 rpm and then filtered. The other three non-fumigated portions were extracted simultaneously at the time fumigation commenced. Organic carbon in the extracts was measured using dichromate oxidation method (10). Microbial biomass C was calculated as follows :

$$\text{Microbial biomass carbon} = \frac{\text{Corg (fum)} - \text{Corg (non-fum)}}{0.38}$$

Soil Microbial Biomass Carbon (SMBC) in Natural Soils

Nyamadzawo et al. (11) studied the soil microbial biomass and mineralization of aggregate protected carbon in fallow-maize systems under conventional and no-tillage in Central Zimbabwe. They have found that soil microbial biomass carbon for the 0–50 mm depth was 802 mg/kg, 740 mg/kg, 563 mg/kg, and 534 mg/kg under non-tillage compared to 667 mg/kg, 490 mg/kg, 452 mg/kg and 456 mg/kg under conventional tillage for *A. angustissima*, *S. sesbania*, natural fallow and continuous maize, respectively. Improved fallows had significantly greater ($P < 0.05$) SMBC than the natural fallow and continuous maize treatments. Soil microbial biomass carbon declined as follows *A. angustissima* > *S. sesbania* > natural fallow > continuous maize. Among the fallow species, SMBC was significantly greater in the top 0–50 mm soil depth when compared to the other two lower depths. Highest microbial biomass carbon in the top 50 mm was attributed to high SOC stocks in this layer.

The limitations of soil microbial biomass carbon as an indicator of soil pollution in the field of Australian agricultural systems were studied by Broos (12). The average size of the SMBC pool across field trials varied from 216 to 557 mg/kg dry soil. Within field trials, the SMBC of uncontaminated soils varied up to 4-fold (e.g. 162–659 mg C/g dry soil at the Avon site) leading to large standard deviations around the average SMBC of control plots. The SMBC varied up to 4-fold across control samples collected from a single field site, due to small-scale spatial heterogeneity in the soil physico-chemical environment. However, decrease in SMBC relative to a control soil is taken to indicate an adverse effect of a contaminant. Further, a studied were conducted by Xu et al. (13) to observed the effect of vegetations and temperature on microbial biomass carbon and metabolic quotients of temperate volcanic forest soils of temperate volcanic forest soils in central Japan : a Japanese cedar coniferous forest (CI), a pine coniferous forest (CII), and an oak-dominated hardwood on a grading and steep slope (DI and DII). Comparing different forest stands, it was indicated that the pine forest soil always showed the lowest MBC concentration relative to soil total carbon, and the largest qCO₂ (Pb0.05), suggesting that microbial communities in the soil were

Table 1. Status of soil microbial biomass carbon in different types of land use.

Site description	Types of soil	Soil microbial biomass carbon (mg/kg of soil)	References
Agricultural field, (Central Zimbabwe)	Non-tillage soils	534—802	Nyamadzawo et al. (11)
	Conventional tillage soils	452—667	
Agricultural systems, under polluted field trial (Australia)	Across field trials soils	216 to 557	Broos (12)
	Uncontaminated soils	162—659	
Greenhouse soil (China)	Under furrow treatments	126—356	Lin (14)
	Subsurface treatments	305—122	
	Drip irrigation treatments	143—385	
Subtropical monsoon forest (Southwest China)	Forest soils	118—447	Feng et al. (15)
Reforestation practice site (South-eastern Spain)	Natural soil without any amendments :	560.4 ± 62.9; 161.3 ± 13.8 and 145.1 ± 6.9	Bastida et al. (16)
	Spring, Summer and Winter		
	Natural soil with organic matter amendments :	577.4 ± 41.8; 166.0 ± 2.8; and 251.5 ± 14.6	
	Spring, Summer and Winter		
	Stripe management soil :		
	Spring, Summer and Winter	674.2 ± 3.21; 186.4 ± 8.03 and 311.6 ± 7.7	
	Terraces soils with organic residue amendment :	729.5 ± 12.6; 479.3 ± 14.6 and	
	Spring, Summer and Winter	535.1 ± 3.7	
	0—5 cm soils	102 to 378	
	5—10 cm soils	49 to 196	
Revegetated quarries (Southern China)	Under plantation :		Zhang and Chu (17)
	<i>A. lebbeck</i>	301.5	
	<i>A. procera</i>	241.7	
	<i>T. grandis</i>	179.1	
Restored mine spoil (India)	Under plantation :		Singh et al. (18)
	<i>M. oleifera</i>	600.0	
	<i>A. marmelos</i>	590.0	
	<i>T. grandis</i>	50.7	
Coal mining ecosystem (India)	Under plantation :		Sinha et al. (19)
	<i>M. oleifera</i>	600.0	
	<i>A. marmelos</i>	590.0	
	<i>T. grandis</i>	50.7	
	Alder sites :		
	0—5 cm layer	200—600	
	5—10 cm layer	50—300	
	Oak plus geogenic carbon addition site :		
	0—5 cm layer	250—1100	
	5—10 cm layer	150.0	
Pine minus geogenic carbon site :			
0—5 cm layer	50—250		
5—10 cm layer	150—350		

less efficient in carbon use than communities in the other forest soils. The MBC concentration in the soils beneath each forest stand mostly had no differences during two sampling periods. The low-temperature storage induced an increase in soil MBC and a reduction of CO₂ production, reducing the qCO₂. There was a smaller MBC concentration in the CII soil than in

the CI and DII soil within the range of 5 to 35°C; the MBC concentration and qCO₂ in the DI and CII soil appeared more sensitive at increasing temperature than those in the DII and CI soil.

Different irrigation methods have varied effect on dissolved organic carbon and microbial biomass carbon in the greenhouse soil (14). The MBC con-

tents were varied in the range of 126—356 mg/kg, 305—122 mg/kg and 143—385 mg/kg in furrow, subsurface and drip irrigation treatments, respectively. The MBC contents were decreased with the increase of soil depth, and followed the order of drip irrigation > furrow irrigation > subsurface irrigation at each soil depth. Further, MBC contents were also affected by soil moisture, temperature, aeration, and pH. The experimental studies were conducted by Feng et al. (15) to observe the above and belowground carbon inputs affect seasonal variations of soil microbial biomass in a subtropical monsoon forest of southwest China. They have been found that microbial biomass C of humus layer varied between 1.18 mg C/g and 4.74 mg C/g. Two years after initiation of the treatments, microbial biomass C in the humus layer did not vary with seasonal changes in soil temperature or water content. The absence of correlations between microbial biomass C and soil temperature and water content indicates that environmental factors did not influence the seasonal variation of microbial biomass C in humus layer.

Bastida et al. (16) studied the long-term effects of the management of a forest soil on its carbon content, microbial biomass and activity under a semi-arid climate. They have reported varied range of MBC in spring, MBC in spring, summer, and fall in different treatment of terraces and stripes. The MBC reported in the natural soil with no intervention as 560.4 ± 62.9 mg/kg in spring, 161.3 ± 13.8 mg/kg in summer and 145.1 ± 6.9 mg/kg in fall seasons. In stripes soil without organic matter amendment they have reported that the MBC in spring soil is 577.4 ± 41.8 mg/kg, in summer is 166.0 ± 2.8 mg/kg and for fall is 251.5 ± 14.6 mg/kg reported, respectively. For the unamended terraces soil, in spring seasons they have reported MBC as 554.2 ± 2.3 mg/kg, in summer seasons is 178.8 ± 8.0 mg/kg and in fall seasons is 142.4 ± 8.2 mg/kg. They have also reported different range of MBC in stripe management soil one with organic residue amendment as for different seasons. In spring seasons the MBC is 674.2 ± 3.21 mg/kg, for summer season 186.4 ± 8.03 mg/kg and for fall season 311.6 ± 7.7 mg/kg. For the terraces with organic residue amendment, the MBC ranges as for spring seasons is 729.5 ± 12.6 mg/kg, for summer season 479.3 ± 14.6 mg/kg, and for fall season 535.1 ± 3.7 mg/kg. MBC was significantly lower in summer and fall comparing with spring. Microbial

biomass C showed higher values in amendment treatments than in unamended treatments.

Soil Microbial Biomass Carbon in Mine Degraded Soil

Studies conducted at Department of Biology, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR, China, on the plant community structure, soil properties and microbial characteristics in revegetated quarries of Southern China. The studies indicate soil that microbial biomass carbon (SBMC) ranged from 102 to 378 mg/kg in 0—5 cm soil and 49 to 196 mg/kg in 5—10 cm soils at the different phases of the three quarries. They have reported that microbial biomass C and had similar significant correlations with organic C, total N and $\text{NO}_3\text{-N}$ (17). The different restoration successions by plants species on mine spoil have been worked out by Singh et al. (18) to observe the impact of young high-density plantations of two native leguminous *Albizia procera* and *A. lebbeck* and one non-leguminous timber tree *Tectona grandis* species on the soil redevelopment process during the early phase of mine restoration in a dry tropical environment. They have reported that soil microbial biomass carbon increased from 129.4 to 363.2 mg/kg of soil as the plantation age increased from 4 to 6 years. A continuous increase in microbial biomass with age in our study indicates continuous soil redevelopment on mine spoils. The effect of different tree species on soil microbial biomass carbon contents were showed varied results in mine soil. They have reported MBC in *A. lebbeck* as 301.5 mg/kg, *A. procera* is 241.7 mg/kg and in *T. grandis* is 179.1 mg/kg. Compared to *A. procera* plantation, microbial biomass C were significantly lower in *T. grandis* and higher in *A. lebbeck* plantations. The highest values of soil microbial biomass were found for plantations of N-fixers, *A. lebbeck* and *A. procera*.

A study was conducted by Sinha et al. (19), to examine the rhizosphere soil microbial index of tree species growing in a coal mining ecosystem, (India). They have reported highest microbial biomass carbon under *M. oleifera* is 600 mg/kg, followed by *A. marmelos* is 590 mg/kg and lowest under *T. grandis* is 50.7 mg/kg. The MBC seems to be strongly influenced by the nature of the tree species. The colonization and establishment of microorganism in the tree rhizo-

sphere is affected by many factors, such as the quantity and quality of root exudates secreted by a particular tree species, in addition to prevailing edaphic and climatic conditions. This means that a tree rhizosphere is likely to develop a microenvironment continuously under the effect of the root exudates, soil characteristics and climatic factors, giving an opportunity for development of a specialized rhizoflora. The inhibitory effect on microbial biomass observed with respect to *Eucalyptus*, *T. grandis*, *M. alba* and *F. religiosa* may be due either to a decrease in the pH of rhizosphere soil (*Eucalyptus*), or to salinity (*M. alba*), or to the release of metabolites through root exudates that might have suppressed the microbial population. Bastida et al. (20) studied the microbiological activity in a soil 15 years after its revegetation. They have reported that the undisturbed plot also maintained a higher microbial biomass carbon level than the disturbed plot, although the seasonal variations are similar in both plots. The microbial biomass carbon (MBC) in disturbed soil during the spring seasons is 720 mg/kg soil and in undisturbed soil is around 1432 mg/kg soil, during the summer it were reported as 921 mg/kg soil in disturbed soil and 1603 mg/kg soil in undisturbed soil. The MBC value during the autumn seasons was 652 mg/kg soil in disturbed soil and 1182 mg/kg soil in undisturbed soil.

Sourkova (21) studied the soil development and properties of microbial biomass succession in reclaimed post mining sites near Sokolov (Czech Republic) and near Cottbus (Germany). They have reported that soil microbial biomass carbon (MBC) was significantly higher in the 0–5 cm layer reported as 200 mg/kg to 600 mg/kg than in the 5–10 cm layer as 50 mg/kg to 300 mg/kg only in the Alder sites. The highest MBC was in the Oak plus geogenic carbon addition chronosequences which is reported as 250 mg/kg to 1100 mg/kg from the reference site of Oak tree soil which was reported as 150 mg/kg in the upper soil profile of 0–5 cm. Higher amounts of microbial biomass carbon in the 0–5 cm layer were found in the broad-leave Alder chronosequences in comparison with the coniferous chronosequences. The lowest value of soil microbial biomass carbon were recorded in Pine minus geogenic carbon ranged from 50 mg/kg to 250 mg/kg in comparison to Pine plus geogenic carbon as value ranged from 150 mg/kg to 350 mg/kg.

Effect of Different Biotic and Abiotic Factors on MBC

pH. Soil pH is widely accepted as a dominant factor that regulates soil nutrient bioavailability, vegetation community structure, plant primary productivity and a range of soil processes including soil microbial community structure and activity (22). Kemmitt et al. (23) studied the effect of pH regulation on carbon and nitrogen dynamics in two agricultural soils. They have found that the soil microbial carbon (SMB-C) increased linearly with increasing pH. This contrasts with Meharg and Killham (1990) who showed that long-term pH manipulation of an agricultural soil generally had no major effect on SMB-C determined with the fumigation-incubation method.

Soil Moisture Content. Seasonal changes in soil moisture content were frequently reported to affect microbial populations and their activities in soil. In dry periods, forest soils contained less microbial biomass and exhibited reduced enzyme activities (24) and moisture content was also found to positively correlate with microbial biomass and respiration in forest litter (25). However, Singh et al. (26) found that the soil microbial biomass carbon is negatively correlated with soil moisture contents. Microbial biomass carbon increases with soil moisture content, although the effect varies among seasons and is specific for the L and H horizons.

Heavy Metals. The microbial biomass carbon as a percentage of soil organic C may provide a sensitive indicator of the effects of heavy-metal on microbial biomass in the soil ecosystem. Wang et al. (27) studied the Indication of soil heavy metal pollution with earthworms and soil microbial biomass carbon in the vicinity of an abandoned copper mine in Eastern Nanjing, China. They have found that the SMBCs did not have significant relationships with soil heavy metal concentrations. The negative correlation is also found between heavy metals and MBC (28). Soil microbial biomass carbon (MBC) and its activity were measured in soil from Gabuzkoa (Spain) contaminated with heavy metals from a mine spoil tip by Aceves et al. (29). They have also found that soil microbial biomass was negatively correlated to heavy metals.

Temperature. Contin et al. (30) studied the temperature changes and the ATP concentration of the

soil microbial biomass from arable and grassland (UK). The microbial biomass carbon did not change significantly in either soil at any temperature throughout, except during days 0 to 1 in the grassland soil. The low-temperature storage induced an increase in soil microbial biomass carbon (13). A study were conducted to investigate whether soils developed under tropical conditions had different organic matter and microbial biomass dynamics than soils developed under temperate ones. Overall, the temperate soils had larger initial biomasses ranged from 177 ± 1285 mg/kg than the tropical ones ranged from 161 ± 599 mg/kg. Over the first 50 d at 15°C, although the decline in biomass was slow for both sets of soils. There were steep declines in the biomasses of all soils at 35°C by 50 d (31).

Conclusion

The assessment of Soil Microbial Biomass Carbon (SMBC) is essential to measure total mass of microorganisms present in a soil. The soil microbial biomass carbon is the key biological component of soil that affects decomposition, nutrient cycling, and aggregation. SMBC is a sensitive indicators of soil erosion, pollution by pesticides and heavy metals, salinization, burning, CO₂ enrichment, devegetation, land abandonment, and agricultural and livestock practices. In undisturbed soils, SMBC was significantly greater in the top 0–50 mm soil depth when compared to the other two lower depths. The SMBC contents were significantly decreased with the increase of soil depth. SMBC was significantly lower in summer and fall comparing with spring. SMBC showed higher values in amendment treatments than in unamended treatments. Environmental factors did not influence the seasonal variation of soil microbial biomass C. Contaminant soils showed decrease in SMBC relative to a control soil. In mining spoils dump the SMBC showed a continuous increase with successional age. The highest values of soil microbial biomass were found for plantations of N-fixers, *A. lebeck* and *A. procera* which have been useful for plantation work in mining reclamation. The different biotic and abiotic factors such as soil pH, moisture contents, and temperature and heavy metals contents significantly affect on soil microbial biomass carbon (Table 1).

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