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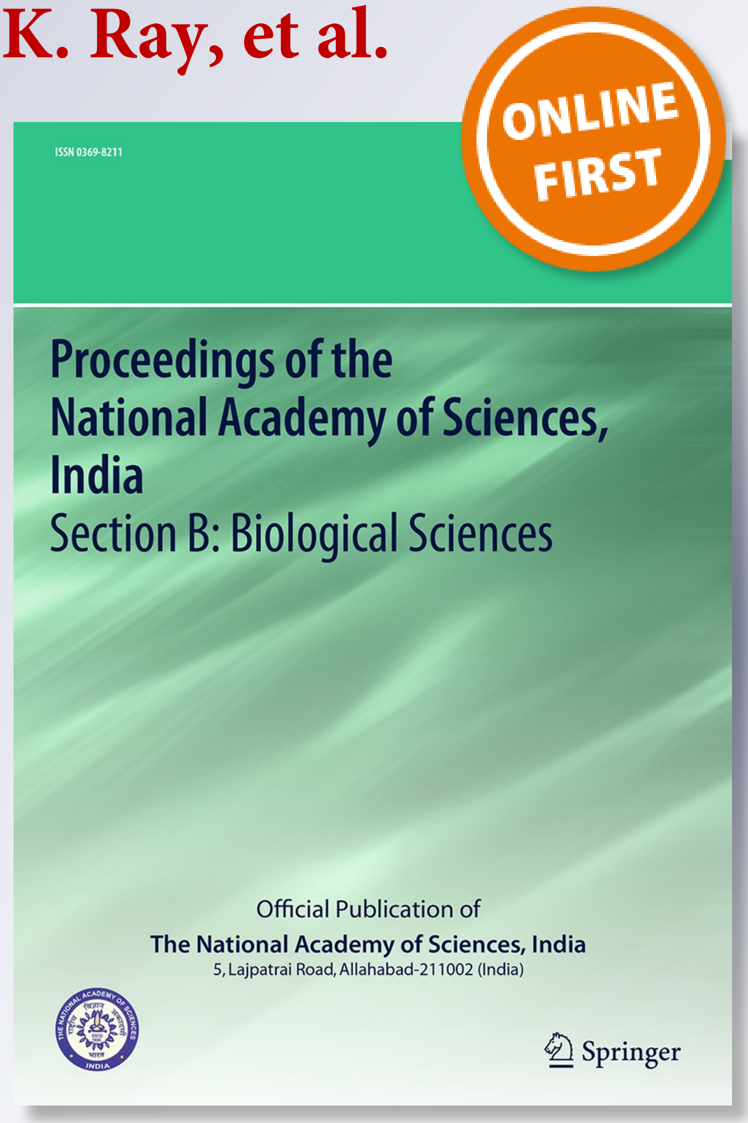

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RESEARCH ARTICLE

Microbial Biomass Carbon Status in Agro-Ecological Sub Regions of Black Soils in India

Kulandaivelu Velmourougane · M. V. Venugopalan · T. Bhattacharyya · Dipak Sarkar · D. K. Pal · Apeksha Sahu · P. Chandran · S. K. Ray · Champa Mandal · K. M. Nair · Jagdish Prasad · R. S. Singh · Pramod Tiwary

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Abstract The present study was undertaken with an objective to study the impact of pedo-edaphic environments, cropping systems, land use, and management practices on the MBC. Soil samples were collected from seventeen benchmark soils representing different agro-ecological sub regions of black soil region of India. The pooled comparisons of MBC in different bio-climates indicated significant differences ($p < 0.001$) between the bio-climates. Significantly higher ($p < 0.001$) MBC was recorded in sub-humid dry bio-climate (267 $\mu g\ g^{-1}$) followed by sub-humid moist and least in arid bio-climate (97.5 $\mu g\ g^{-1}$). In cropping systems, legume-based system (205 $\mu g\ g^{-1}$) had higher MBC. The lowest MBC was recorded in cotton-based system (128 $\mu g\ g^{-1}$). In soil sub-groups, Halic Haplusterts showed higher MBC (209 $\mu g\ g^{-1}$) followed by Typic Haplusterts (208 $\mu g\ g^{-1}$), while the lowest MBC was observed in Gypsic Haplusterts (98.5 $\mu g\ g^{-1}$). Significantly higher ($p < 0.05$) MBC was recorded in high management and irrigated agro-systems as compared with low management and rainfed agro-systems. The MBC content in the soil is significantly and positively correlated with organic carbon %, total culturable microbial population, nitrogen content, and available water content.

Keywords Microbial biomass carbon · Bio-climates · Cropping systems · Land use · Management practices

Introduction

In recent years, indicative components like soil microbial biomass carbon (MBC), community structures, functions, and enzyme activities have been used to describe soil qualities under different agricultural practices [1]. MBC generally comprises 1–4 % of soil organic matter [2] and is the most active component of soil organic carbon that regulates biogeochemical processes in terrestrial ecosystems [3]. The MBC is one of the most promising indicators of soil quality because it responds promptly to environmental changes, often much earlier than bulk soil organic matter. Soil microbial biomass is a source and sink of soil nutrients [4]. The measurement of microbial biomass is useful for describing biomass turnover in different ecosystems [5]. Microbial biomass represents the fraction of soil responsible for the energy, nutrient cycling and regulation of organic matter transformations [6]. MBC is the living portion of soil organic matter, constituted by archaea, bacteria and eukaryotes, excluding roots and smaller animals [7]. Decrease of MBC as a fraction of total organic carbon implies a reduction in microbial transformation and intensity [8].

The present study was undertaken with an objective to study the impact of bio-climates, cropping systems, land use systems, soil sub groups, and management practices on the

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K. Velmourougane (✉) · M. V. Venugopalan · A. Sahu
Central Institute for Cotton Research, Nagpur, Maharashtra, India
e-mail: velicar@gmail.com

T. Bhattacharyya · D. Sarkar · D. K. Pal · P. Chandran · S. K. Ray · C. Mandal · J. Prasad · P. Tiwary
National Bureau of Soil Survey and Land Use Planning, Nagpur, Maharashtra, India

K. M. Nair
Regional Centre, National Bureau of Soil Survey and Land Use Planning, Bangalore, Karnataka, India

R. S. Singh
Regional Centre, National Bureau of Soil Survey and Land Use Planning, Udaipur, Rajasthan, India

distribution of MBC in selected benchmark (BM) sites in black soil region (BSR) of India. This is the first extensive report on MBC status of BSR in India and the information generated through this study will be highly useful for the assessment of land quality and the changes in the soil quality indicators for sustainable land management in BSR of India.

Material and Methods

Site Description and Sampling

The soil samples (approximately 1 kg) were collected at 0–30 cm soil depth from the representative benchmark (BM) sites in black soil region (BSR) of India (Fig. 1) covering specific bio-climatic systems, based on the variations in mean annual rainfall (mm), the BSR was grouped in 6 AERs (agro climatic regions) as Arid: <550 mm, Semi-arid (dry) SAd: 550–850 mm, Semi-arid (moist) SAm: 1,000 mm to 850 mm, Sub-humid (dry) SHd: 1,100–1,000 mm, and Sub-humid (moist) SHm: >1,100 mm) [9] and 17 AESRs (agro-ecological sub regions-3.0, 5.1, 5.2, 6.1, 6.2, 6.3, 6.4, 7.1, 7.2, 7.3, 8.1, 8.2, 8.3, 10.1, 10.2, 10.3 and, 5.1) [10] accounting for 19 % (76.4 m ha) of total geographical area of the country. The soil series were selected in such a way that in any agricultural system under a particular cropping pattern, two representative pedons/soil profiles under the same soil series [11] were included. The soil series under

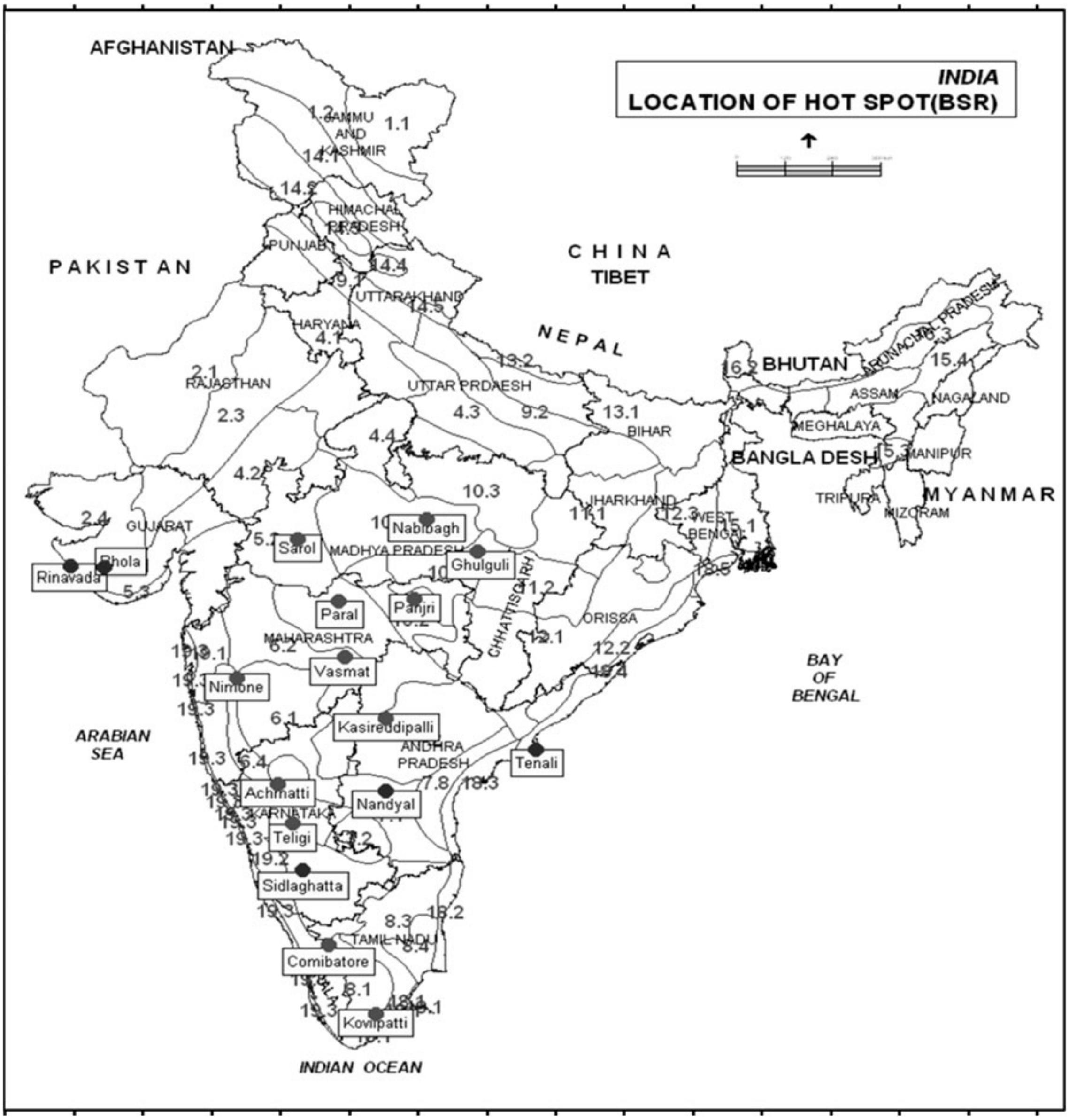

Fig. 1 Location of bench mark spots in black soil regions of India

low management (LM) were characterized by the application of low NPK, rarely applied manures, removal of residues and biomass and no soil moisture conservation practices. While, the soil series under high management (HM) were characterized by application of recommended levels of NPK, regular application of organic manures, incorporation of residues and adoption of soil moisture conservation techniques (ridge furrows, bunding, broad bed and furrow).

Soil Physico-Chemical and Microbiological Analyses

The international pipette method was used for particle-size analysis for quantifying the sand, silt and clay fractions according to the size segregation procedure of Jackson [12]. Bulk density was determined by field-moist method using core samples (diameter 50 mm) of known volume (100 ml) [13, 14]. Hydraulic conductivity (cm/h) was measured by taking 200 g of soil, uniformly tapped and saturated overnight. It was measured by taking an hourly observation until three constant observations were obtained [15]. The chemical characteristics of soils were determined by standard procedures [16]. For microbiological analysis, soil samples collected at different soil depths from different BM spots were serially diluted in 90 ml Ringers solution up to 10^{-4} dilution and 1 ml of aliquot was pour plated in selective media (Nutrient Agar for bacteria; Rose Bengal Agar for fungi; Ken Knights and Munaier's Agar for actinomycetes and Buffered Yeast Agar for yeast). The plates were incubated at optimum temperature (28 ± 1 °C for bacteria and yeast; 30 ± 1 °C for fungi and actinomycetes) in triplicates. The microbial colonies appearing after the incubation (3 days for bacteria and yeast; 5 days for fungi; 7 days for actinomycetes) were counted and expressed as total culturable colony forming units (Cfus)/g of the sample.

Table 1 Characteristics of selected bench mark spots in black soil regions of India

AESR	Bio-climates	MAR (mm)	Soil series	MSL (m)	District	State	Texture	Mineralogy	Temperature	Subgroup	Great group
6.1	Arid	520	Nimone	517	Ahmednagar	Maharashtra	Fine	Smectitic	Isohyperthermic	Sodic	Haplusterts
5.1	Arid	533	Sokdha	25	Rajkot	Gujarat	Fine	Smectitic	Hyperthermic	Calcic	Haplusterts
8.1	SAd	612	Coimbatore	421	Coimbatore	Tamil Nadu	Fine	Smectitic	Isohyperthermic	Vertic	Haplustepts
3.0	SAd	632	Teligi	379	Bellary	Karnataka	Fine	Smectitic	Isohyperthermic	Typic	Haplusterts
6.4	SAd	638	Acchamatti	573	Dharwad	Karnataka	Very fine	Smectitic	Isohyperthermic	Sodic	Haplusterts
7.1	SAd	650	Nandyal	212	Kurnool	Andhra Pradesh	Fine	Smectitic	Isohyperthermic	Chromic	Haplusterts
5.1	SAd	650	Bhola	76	Rajkot	Gujarat	Fine	Smectitic	Hyperthermic	Typic	Haplusterts
8.3	SAd	660	Kovilpatti	81	Tuticorin	Tamil Nadu	Very fine	Smectitic	Isohyperthermic	Gypsic	Haplusterts
8.2	SAd	661	Siddalaghatta	717	Kolar	Karnataka	Fine	Smectitic	Hyperthermic	Vertic	Haplustepts
7.2	SAd	764	Kasireddipalli	538	Medak	Andhra Pradesh	Fine	Smectitic	Isohyperthermic	Sodic	Haplusterts
6.2	SAd	789	Vasmat	372	Hingoli	Maharashtra	Very fine	Smectitic	Hyperthermic	Sodic	Haplusterts
6.3	SAd	794	Paral	267	Akola	Maharashtra	Very fine	Smectitic	Hyperthermic	Sodic	Haplusterts
5.2	SHd	1,053	Sarol	564	Indore	Madhya Pradesh	Fine	Smectitic	Hyperthermic	Typic	Haplusterts
10.3	SHd	1,100	Ghulguli	509	Shahdol	Madhya Pradesh	Fine	Smectitic	Hyperthermic	Typic	Haplusterts
10.2	SHm	1,127	Panjri	309	Nagpur	Maharashtra	Very fine	Smectitic	Hyperthermic	Typic	Haplusterts
10.1	SHm	1,209	Nabibagh	501	Bhopal	Madhya Pradesh	Fine	Smectitic	Hyperthermic	Typic	Haplusterts
7.3	SHm	1,250	Tenali	15	East Godavari	Andhra Pradesh	Fine	Smectitic	Isohyperthermic	Halic	Haplusterts

AESR agro-ecological sub regions, *MAR* mean annual rainfall (mm), Arid (<550 mm), *SAd* semi-arid dry (850–550 mm), *SHd* sub-humid dry (1,100–1,000 mm), *SHm* sub-humid moist (>1,100 mm), *MSL* elevation above mean sea level

Estimation of Soil Microbial Biomass Carbon

Soil microbial biomass carbon was determined using the $CHCl_3$ fumigation-extraction method [17]. Samples of moist soil (10 g) were used in duplicates, and K_2SO_4-extractable C was determined using dichromate digestion. Microbial biomass carbon was calculated using the equation Biomass C = 2.64 EC. where EC = (organic C in $K_2SO_4$from fumigated soil)—(organic C in K_2SO_4 from unfumigated soil).

Statistical Analysis

To study the impact of different factors on soil microbial biomass carbon, the data pertaining to BSR regions representing different bio-climates, cropping systems, type of agriculture, soil sub groups, and management practices were pooled together and analysed by ANOVA followed by multiple comparison test and principal component analysis using a statistical software's SAS version 9.2 and JMP-8.

Results and Discussion

Variations in Microbial Biomass Carbon in BM Spots of BSR of India

The characteristics of selected BM spots of BSR of India are summarized in Table 1 and the cropping systems and management practices adopted in the BM spots are presented in Table 2. Higher MBC was recorded in HM spots as compared to LM spots and the MBC found to differ significantly ($p < 0.001$) between the BM spots (Table 3). Among the BM spots in HM, higher MBC was observed in the Ghulguli soil series of Maharashtra (294 µg g^{-1} Pigeon pea/Mustard/Green gram system), followed by Sarol (276 µg g^{-1} Soybean–wheat system), Teligi (264 µg g^{-1} Triple cropping of rice system) and Panjari (253 µg g^{-1} Cotton/soybean system) soil series which were at par as per the Tukey HSD, while the lowest MBC was recorded in Bhola soil series (53 µg g^{-1} Cotton–wheat system). In LM, higher MBC was recorded in Coimbatore (256 µg g^{-1} Single cropping of chick pea), Sarol (251 µg g^{-1} Soybean–

Table 2 Cropping systems and management practices adopted in selected BM spots in BSR of India

BM spots	High management (HM)		Low management (LM)	
	Cropping systems[a]	Agriculture	Cropping systems[a]	Agriculture
Nimone	Soybean–wheat/chick pea	Irrigated	Soybean/pearl millet/chick pea	Irrigated
Sokdha	Cotton + green gram/pearl millet	Rainfed	Cotton + green gram/pearl millet/sorghum	Rainfed
Coimbatore	Maize–chick pea	Irrigated	Single cropping of chick pea	Rainfed
Teligi	Triple cropping of rice	Irrigated	Maize/sorghum–chick pea	Rainfed
Acchamatti	Cotton-wheat/safflower/sorghum	Irrigated	Maize–chick pea	Rainfed
Nandyal	Rice–rice	Irrigated	Cotton/sunflower	Rainfed
Bhola	Cotton–wheat	Irrigated	Cotton–wheat	Irrigated
Kovilpatti	Single cropping of sorghum	Rainfed	Single cropping of cotton/sunflower/chick pea	Rainfed
Siddalaghatta	Fruits crops + Sunflower/Sorghum	Irrigated	Rice–maize–tomato	Irrigated
Kasireddipalli	Soybean + pigeon pea/maize–sunflower	Rainfed	Chick pea/sorghum	Rainfed
Vasmat	Sugarcane	Irrigated	Rice-Fallow	Irrigated
Paral	Cotton + soybean/green gram + sorghum	Irrigated	Cotton + black gram/chick pea + sorghum	Irrigated
Sarol	Soybean–wheat	Irrigated	Soybean–chick pea	Irrigated
Ghulguli	Pigeon pea/mustard/green gram	Rainfed	Rice–wheat/chick pea	Irrigated
Panjri	Single crop of cotton/soybean	Rainfed	Soybean–wheat/soybean-chick pea	Rainfed
Nabibagh	Soybean-wheat/soybean–chick pea	Irrigated	Soybean–wheat/soybean–chick pea	Irrigated
Tenali	Rice–rice	Irrigated	Rice–rice	Irrigated

High management practices	Low management practices
Application of higher NPK	Application of low NPK
Regular application of organic manures	Manures rarely applied
Incorporation of residues	Removal of residues and biomass
Adoption of soil moisture conservation techniques (ridge furrows, bunding, broad bed and furrow)	No soil moisture conservation practices

[a] Cropping systems: '/' = or; '+' = intercropping; '–' = followed by

Table 3 Microbial biomass carbon in different AESR of black soil regions in India

AESR	Bio-climates	BM Spots (soil series)	Microbial biomass carbon (μg g^{-1})	
			High management	Low management
6.1	Arid	Nimone	79 g	66 d
5.1	Arid	Sokdha	157 def	81 d
8.1	SAd	Coimbatore	248 abc	256 a
3.0	SAd	Telgi	264 ab	248 a
6.4	SAd	Achhamatti	184 cde	170 bc
7.1	SAd	Nandyal	115 fg	84 d
5.1	SAd	Bhola	53 g	ND
8.3	SAd	Kovilpatti	109 fg	88 d
8.2	SAd	Sidalghatta	112 fg	84 d
7.2	SAd	Kasireddipalli	105 fg	92 d
6.2	SAd	Vasmat	246 abc	221 ab
6.3	SAd	Paral	145 ef	108 cd
5.2	SHd	Sarol	276 ab	251 a
10.3	SHd	Ghulghuli	294 a	248 a
10.2	SHm	Panjari	253 ab	224 ab
10.1	SHm	Nabibagh	108 fg	72 d
7.3	SHm	Tenali	221 bed	197 ab

Values with the same letter in columns are not significantly different following Tukey HSD

AESR agro-ecological sub regions, *SAd* semi-arid dry, *SHd* sub-humid dry, *SHm* sub-humid moist, *ND* not determined

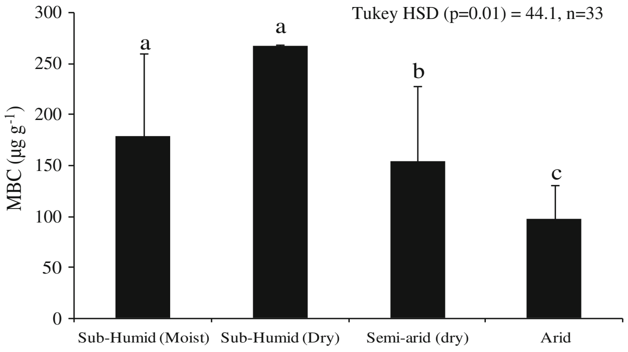

Fig. 2 Impact of bio-climates on microbial biomass carbon in BSR

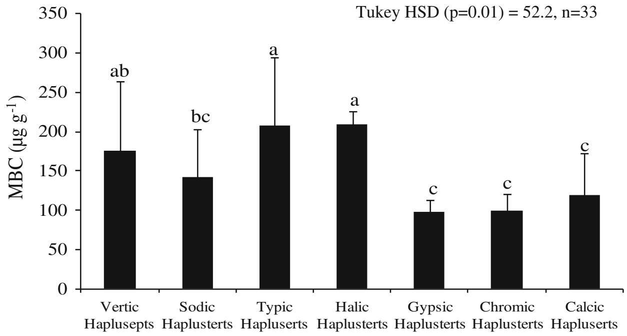

Fig. 4 Impact of soil sub-groups on microbial biomass carbon

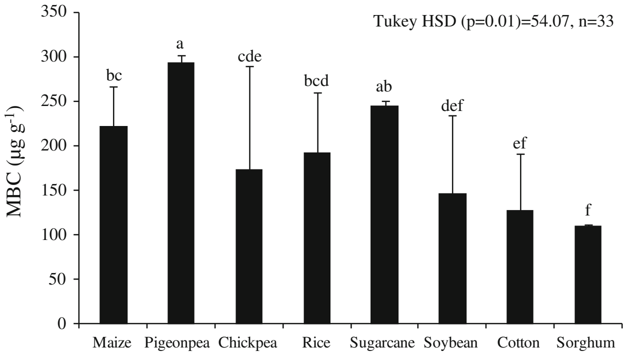

Fig. 3 Impact of cropping systems on microbial biomass carbon in BSR

chick pea system), Teligi (248 μg g^{-1} Maize/sorghum–chick pea system), and Ghulguli (248 μg g^{-1} Rice–wheat/chick pea system) soil series which were at par as per the Tukey HSD, while the lowest MBC was recorded in Nimone (66 μg g^{-1} Soybean/Pearl millet system) series.

Impact of Bio-Climates on Microbial Biomass Carbon

The pooled comparisons of MBC in different bio-climates of BM spots indicated significant differences ($p < 0.001$) between the bio-climates (Fig. 2). Higher MBC was recorded in SHd bio-climate (267 μg g^{-1}) followed by SHm (179 μg g^{-1}) and the least in arid regions

(97.5 µg g^{-1}). MBC was found to be at par in SHm and SAd BM spots as per the Tukey HSD. The average MBC in different bio-climates decreased in order of SHd > SHm > SAd > arid. Li and Sarah [18] reported significant decrease of microbial biomass with the increasing aridity along a climatic transect in Judean desert of Israel. By studying microbial biomass carbon along the climatic transect in North America, Insam [19] concluded that the ratio of precipitation and evaporation affects the soil microbial activity and microbial biomass. Microbial biomass and its associated enzymatic activities show a marked seasonal fluctuation [20].

Impact of Cropping Systems on Microbial Biomass Carbon

The pooled comparisons of MBC in different cropping systems of BM spots indicated significant differences ($p < 0.001$) between the cropping systems (Fig. 3). Legume-based system recorded higher MBC followed by sugarcane-based cropping system. In legume-based system, pigeon pea recorded higher MBC (294 µg g^{-1}) followed by chick pea (174 µg g^{-1}) and soybean (148 µg g^{-1}). In cereal-based system, maize recorded higher MBC (222 µg g^{-1}) followed by rice (193 µg g^{-1}) and sorghum (111 µg g^{-1}). The lowest MBC content was recorded in cotton-based cropping system (128 µg g^{-1}). The average MBC in different cropping systems are in decreasing order of legume > sugarcane > cereal > cotton. The higher MBC activity in legume-based system showed the contribution of legumes for organic C build-up which stimulated microbial activity.

Soils under crop rotations with a high input and diversity of organic materials are reported to contain higher concentrations of microbial biomass and enzymes as compared with mono-cropping systems [21]. Crop rotations have been reported to bring a shift in rhizodeposition of organic compounds [22] differently stimulating or suppressing microbial communities [23]. Under long-term experiment in vertisols of semi-arid tropics of India, inclusion of legume crop was reported to increase MBC [24, 25]. In semi-arid moist regions in India, higher MBC was reported under legume-based intercropping system [26]. However, long-term experiments in vertisol demonstrated that legume-based systems along with rainwater management and mineral fertilizer application sequestered higher organic carbon as compared with application of farmyard manure alone [27]. Similarly, mean bacterial count was reported to be higher under soybean-wheat system than maize-wheat or cotton–wheat systems [28]. Franchini et al. [29] observed increase in MBC in soybean field previously cultivated with legumes (lupine) in comparison with those previously cultivated with wheat. They also observed that crop rotations with higher ratios of legume to non-legume resulted in higher MBC/total soil organic carbon values.

Impact of Soil Sub-Groups on Microbial Biomass Carbon

The pooled comparisons of MBC in different soils indicated significant differences ($p < 0.001$) between the soil types (Fig. 4). Halic Haplusterts showed higher MBC (209 µg g^{-1}) followed by Typic Haplusterts (208 µg g^{-1}), while the lowest MBC was observed in Gypsic Haplusterts (98.5 µg g^{-1}). The average MBC in different soil types of BSR were in decreasing order of Halic Haplusterts/Typic Haplusterts > Vertic Haplustepts > Sodic Haplusterts > Calcic Haplusterts/Chromic Haplusterts/Gypsic Haplusterts. The variation in MBC distribution in different soil types was controlled by physical and chemical properties of the soil [25]. Soil structure and texture have been reported as key determinants of microbial ecology [30]. Soil texture is reported to affect soil properties such as water availability, nutrient supply

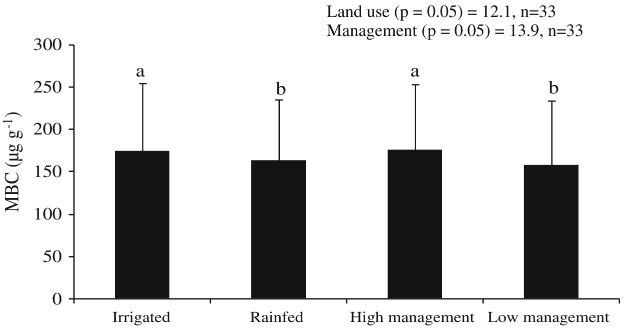

Fig. 5 Impact of land use and management practices on microbial biomass carbon

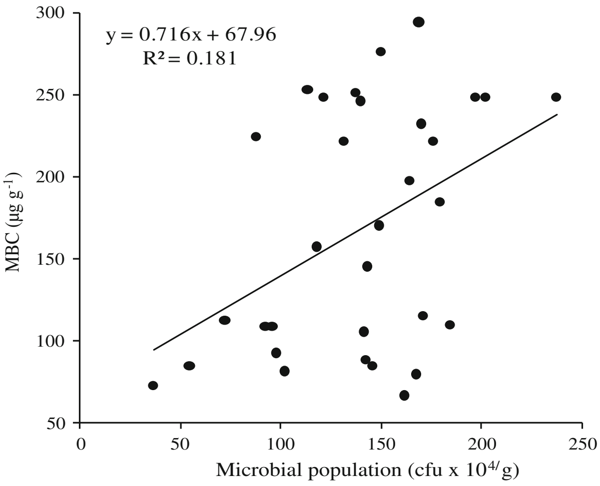

Fig. 6 Correlation between total microbial population and microbial biomass carbon

(especially cations) and to some extent pH which in turn determine microbial growth and activity [31, 32]. In vertisols, the presence of the high smectite clay is reported to enhance protection of mineralizable SOC within macroaggregates [33].

Impact of Land Use and Management Practices on Microbial Biomass Carbon

The pooled analysis of MBC data indicated significant differences ($p < 0.05$) between the irrigated and rainfed agriculture (Fig. 5). The average MBC in irrigated system is found to be 173.9 μg g^{-1}, while the rainfed agro-systems recorded 163 μg g^{-1}. Soils under HM recorded significantly ($p < 0.05$) higher MBC (175.7 μg g^{-1}) as compared to the LM (158 μg g^{-1}) (Fig. 5). Soil microbial biomass and activity were related to changes in vegetation cover [34] because they are stimulated by inputs from plants litter and rhizodeposition [35]. Types of plant cover, cropping history of soils, fertilization and manuring are also reported to influence the microbial biomass in soils [36]. Differences in soil microbial biomass are due to gradients in resource availability, in particular, soil organic matter content [37]. Long-term applications of organic and inorganic supplements are reported to help in accumulation of organic matter, which in turn had substantial incremental effect on the soil microbial biomass and its activities [38, 39].

Microbial biomass was shown to be more responsive than total organic C and N to the changes in soil management practices [40]. Goyal et al. [41] showed that application of inorganic fertilizers (N_{60} P_{30} K_{60}) increased the soil MBC over unfertilized field (N_0 P_0 K_0) in a long-term fertilizer experiments on pearl-millet-

Table 4 Effects of soil properties on microbial biomass carbon in BSR

Variable (soil parameters)	Correlation	Contributions of the variables (%) after Varimax rotation			
		F1	F2	F3	F4
Sand %	−0.270	9.526	1.290	7.695	0.051
Silt %	0.239	0.246	8.661	16.06	0.681
Clay %	0.125	12.22	1.567	0.018	1.100
Fine clay %	0.179	4.783	0.133	8.608	0.123
Bulk density (M gm^{-3})	0.088	1.238	2.691	6.752	0.237
1/3 bar	0.344	12.40	2.206	0.258	0.110
15 bar	**0.364**	12.75	1.211	0.487	0.082
1 bar	0.258	13.20	1.096	0.331	0.004
3 bar	0.300	12.82	1.366	0.938	0.002
Hydraulic conductivity (cm h^{-1})	−0.232	0.060	1.991	12.42	0.991
Water pH (1:2)	**−0.360**	0.208	16.79	0.464	0.596
KCl pH (1:2)	-0.306	0.775	9.476	0.887	0.167
Electrical conductivity (1:2) (dS m^{-1})	0.242	2.439	1.074	7.406	0.953
Organic carbon %	**0.516**	1.079	12.76	1.065	0.234
Calcium carbonate %	−0.066	0.004	5.458	1.656	0.227
Cation exchange capacity (cmol (+) kg^{-1}) (CEC)	0.189	8.293	0.740	0.002	1.386
Base saturation (BS) %	0.108	3.064	4.636	2.706	5.573
Exchangeable sodium percentage (ESP)	−0.302	0.907	1.017	3.198	18.27
Exchangeable magnesium percentage (EMP)	−0.140	0.004	0.135	0.955	0.055
Nitrogen (kg ha^{-1})	**0.390**	0.296	15.89	0.423	0.657
Phosphorus (kg ha^{-1})	0.015	0.272	1.944	0.081	7.681
Potassium (kg ha^{-1})	0.240	0.662	0.175	1.585	9.390
Microbial population (cfu × 10^4/g)	**0.392**	1.890	0.446	0.119	20.99
% Variance (after Varimax rotation)					
Eigen value		7.195	4.029	2.622	2.224
% Variance		27.67	15.49	10.08	8.555
Cumulative %		27.67	43.16	53.25	61.80

In bold, significant values at the level of significance alpha = 0.050 (two-tailed test) wheat rotation in a sandy loam soil even though organic carbon had not increased. They attributed the increase in MBC to increased root growth, root exudates, mucigel and sloughed-off cells. Nayak et al. [42] reported that microbial biomass in NPK plots were comparable to either fallow or to compost added treatments in most cases in a long term fertilizer experiment. Manna et al. [43] showed that applying only nitrogen or nitrogen + phosphorous led to a decline in MBC, which were however improved significantly on addition of NPK or NPK + organics.

Farmyard manure and inorganic fertilizers have been reported to have both positive and negative effects on the size of MBC and microbial activities [44]. Studies have shown that application of farmyard manure plus NPK fertilizer had significantly increased the SOC and microbial biomass [45]. Further the quantity and quality of organic material added to soils are the major factors in controlling the abundance of different microbial groups and the activity of microorganisms involved in nutrient cycling [46]. Higher microbial biomass in no-tillage or reduced tillage over conventional tillage is also reported [47]. Addition of biomass mulch along with no tillage operation is also reported to improve microbial biomass as compared to conventional management [48]. Studies have shown the presence of high microbial biomass, activity and diversity in organically managed soils [49]. The addition of sugarcane trash and green manure was reported to improve soil biology by increasing microbial biomass and activity irrespective of management history [50, 51]. Quality of irrigation water was also reported to influence the MBC considerably. Masto et al. [52] showed significant decrease in microbial biomass carbon in soils irrigated with sewage water.

Impact of Soil Properties on Microbial Biomass Carbon

Microbial biomass was reported to be influenced by several ecological factors, such as plant community composition [53, 54], soil organic matter level, soil moisture, and temperature [55, 56]. In the present study, MBC showed significant positive correlation with organic carbon, total microbial population (Fig. 6), available nitrogen, and available water content (Table 4 and Fig. 7). Though, sand, hydraulic conductivity, calcium carbonate, ESP, and EMP showed negative correlation for MBC, the values were found to be non-significant. Physical properties (factors), available water content followed by clay and sand proportion (negative correlation) were found to influence the MBC in BSR soils. Available nitrogen, organic carbon, pH, and ESP in soil chemical properties and microbial population in biological properties also influence MBC in BSR.

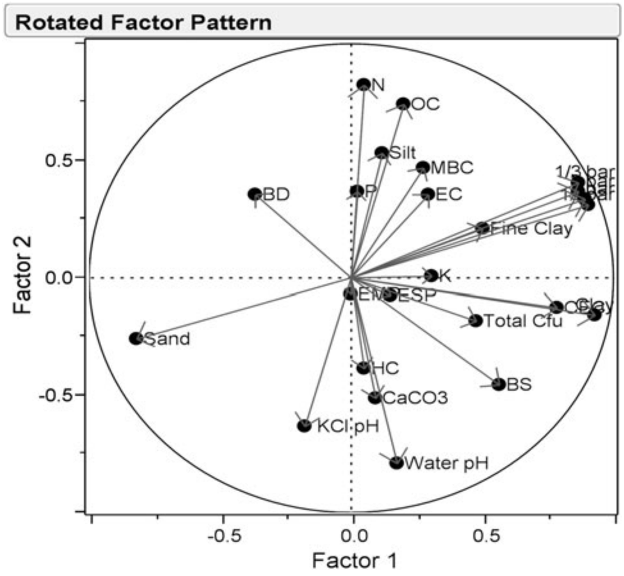

Fig. 7 Impact of soil variables on microbial biomass carbon (Principal component analysis)

Several researchers have investigated the relationship between microbial biomass carbon and soil properties like moisture [57] and texture [58]. Soil moisture, as an abiotic driver of soil organic matter dynamics [59] and as an important factor related to the soil microbial activity [60] is well studied. The positive correlation of MBC with soil moisture was reported by many researchers [61–63]. Positive correlation between biomass C and organic C [64], microbial population [65], N content [66] and CEC [67] is also reported. Higher clay and silt content of soil is reported to play a major role in determining microbial biomass and to promote soil organic matter accumulation by aggregate formation and adsorption on mineral surfaces [68–70], and greater soil extractable C, thus providing more C and N substrates for soil microbes [71]. Soils with high clay content are also reported to stabilise soil organic C [72]. Hassink [73, 74] showed that the proportions of soil C and N in the biomass were higher in fine than in coarse-textured soils. Among the different soil parameters, though sand content, hydraulic conductivity, calcium carbonate, ESP and EMP showed negative correlation with MBC, only pH was significantly and negatively correlated with MBC. Earlier, Omer and Ilyas [75] reported negative correlation between microbial biomass C and soil pH. Previous work has also shown variability in microbial biomass that can be caused by alterations in soil pH [53]. Some authors suggest that maximum activities of soil microbial biomass occur at pH values of about 6.5 [76].

Conclusion

From the present study, it is concluded that the bio-climates have significant influence on the microbial biomass carbon activity in different AESR of BSR in India. Based on the pooled comparisons between the cropping systems in BSR, it is clear that legume-based cropping systems had a significant and positive effect on MBC as compared to other cropping systems. Significant differences in MBC content were observed between the type of land use (irrigated and rainfed agro systems) and level of management (HM and LM). In soil types, Halic Haplustepts and Typic Haplusterts showed higher MBC, while the lowest MBC was observed in Gypsic Haplusterts and Chromic Haplusterts. Among the soil properties, MBC content is significantly and positively correlated with organic carbon percentage, total culturable microbial population, nitrogen content, and available water content.

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