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Effect of Topographical Settings on Distribution of Soil Organic Carbon Fractions in Rice Ecosystem of North East India

LARIKA L. CHALLAM[1], NAOREM JANAKI SINGH*, KABIR DEBBARMA[2], LALA I. P. RAY[3], SANJAY SWAMI[4]

School of Natural Resource Management, College of Post Graduate Studies, Central Agricultural University, Imphal-, Umroi Road, Umiam 793103, Meghalaya, India
Emails: [1] l.challam@gmail.com; [2] kabirdb90@gmail.com; [3] lalaipray@rediffmail.com;
[4] sanjayswamionline@yahoo.com;
* Corresponding author; Email: naorem2005@gmail.com;

ABSTRACT

Understanding the effect of different topographical settings on soil organic carbon (SOC) fractions could help better soil carbon management under hill rice ecosystems. In our study the SOC and its fractions of particulate organic matter (POM), light fraction of organic matter (LFOM), dissolve organic matter (DOC), microbial biomass carbon (MBC) and hot water-soluble carbon (HWC) were investigated for different topological settings under hill rice ecosystems of Ri-Bhoi district, Meghalaya. It was not found specific distribution pattern of SOC and its fractions at different topological settings. However, there was a variation ($P < 0.05$) of SOC and its fraction content at different topological settings. The highest POM content was noticed at 32% slope of Pyllun and lowest at Paham (32% slope) following with intermountain valley (Boirymbong). The highest content of LFOM and DOC, MBC, HWC were recorded at 6% slope topography and lowest at 32% slope of Paham. The SOC fractions (POM, LFOM, MBC and HWC) were more at the surface soil whereas DOC was found more the subsurface soil. There were significant positive relationships ($P <0.01$) between SOC and its corresponding fractions including DOC, POM, LFOM and HWC, a negative relationships ($P <0.05$) were observed between SOC and DOC and MBC in subsurface soil (15-30 cm). The correlation coefficients with SOC decreased in the order of LFOM > POM > HWC > DOC at surface soil and POM > LFOM > HWC at subsurface soil. It is concluded that further study on soil pedogenic properties influenced on SOC distribution is needed to confirm the SOC controlling variables including slope for better SOC management.

Key Words: Particulate Organic Matter; Light Fraction Organic Matter; Dissolved Organic Carbon; Microbial Biomass Carbon; Hot Water Soluble Carbon; Ri-Bhoi District; Meghalaya.

INTRODUCTION

Rice is one of the most important major staple food of the North-Eastern (NE) India and its production is fully depending on the inherent nutrient supplying power of soil without using chemical ferlitilisers, pesticides and herbicides. The inherent nutrient supplying power of soil depends upon the interaction between the topographical settings and climate, vegetation, soil texture, and management practices and also positions of SOC in pore spaces (Debasish-Saha et al. 2014, Jaiarree et al. 2014). Hence, maintaining and improving of SOC level is a pre-requisite to enhance the soil health for sustainable agricultural ecosystems (Wang et al. 2010). The carbon addition through above and below ground biomass varies with topographical settings (Fellycia et al. 2015) since the topographical settings creates different microclimates and strongly influence plant residues (Ruiz-Sinoga et al. 2012) and soil water availability (Ruiz-Sinoga and Martínez-Murillo 2009). Soil water availability reduces with shifting of climatic gradients in the hill slopes and decline organic matter content (Ruiz-Sinoga and Martínez-Murillo 2009). However, there was no found the obvious altitudinal pattern in the SOC (Zhang et al. 2011). The SOC is generally consisting of labile and recalcitrant pools (Cheng et al. 2008). The labile organic carbon fraction is important for nutrient cycling and maintaining soil quality and productivity and also sensitive to changes with disturbance and management (Mandal et al. 2007, Cheng et al. 2008, Melero et al. 2009). The labile fractions includes the particulate organic carbon (POC), light fraction organic carbon (LFOC), microbial biomass carbon (MBC), dissolved organic carbon (DOC), and water-soluble organic carbon (WSOC) (Xu et al. 2010). The MBC, DOC and WSOC are the source of soil microorganisms (Huang and Song 2010) and helped aggregate formation and nutrient conservation (Watts et al. 2005). The POC is important for SOC distribution in aggregates, and index of SOC dynamics (Lützow et al. 2007). The DOC released from dissolution of soil by root exudates are influenced by SOC content, soil pH, CO_2 concentration, Fe or A1 ions and soil texture, and the released DOC was consumed by microorganisms or loss through leaching (Dalva and Moore 1992). DOC is of two types hydrophobic (larger molecules and complex phenolic and aliphatic structure) and hydrophilic (smaller aliphatic and aromatic acids) humic matter (Leenheer and Huffman 1979). The more hydrophobic humic acids protonize first with decreased pH, and become less soluble in the soil solution. There was no study on the distribution of labile SOC fractions in rice ecosystem of highly fragile North Eastern hilly regions of India. The comparison between total SOC and labile SOC fractions of rice ecosystem of highly fragile topography are more indicative of SOC management and mitigation strategies. Therefore, a study was attempted to investigate the topological effect on distributional patterns of SOC and its fractions in rice ecosystem.

STUDY SITE

The study sites are located in Ri-Bhoi district of Meghalaya (25°40′ to 26°20′ N latitude and 91°20'30" to 92°17′00" E longitude) covering 2448 km^2 geographical area with an elevation of 620-1188 m above mean sea level (MSL), 2935 mm mean annual rainfall and 10-30°C average temperature. Forest area was covered about 869.07 km^2 (36% of geographical area). The net sown area was 222.59 km^2 (9% of geographical area) out of the total gross cropped area (251.69 km^2) (10% of geographical area), the fallow land (6% of geographical area). During kharif, Rice, Maize, and Oilseeds cover 94.04, 15.18, and 1.52 km^2, respectively. During rabi, Rice, Millets, Pulses and Oilseeds covered 1.98, 0.13, 0.28, and 1.48 km^2, respectively.

The major soil type are red loamy, laterite, and alluvial. Major physiographic units are denudational high hills with deep, narrow intermontane valleys covered with or without colluvium. The predominant geological formations are archean gneissic complex rocks, Shillong group of rocks–quartzites, granites, and alluvium. Such rocks also form highly dissected plateau with steep slopes and deep, narrow valleys exposed. Large numbers of narrow intermontane valley are good recharge areas and have highly productive shallow aquifer zone (Anonymous 2014).

METHODOLOGY

Field work and soil sampling for the research work was carried out in the month of February, 2012. The study sites were divided into three parts: upper most part of slope land (L1), middle part of slope (L2) and lower most part of slope (saturated zone) (L3). In February 2012, after kharif rice was harvested, the aboveground plant debris was removed and three composite soil samples were collected from each part of the slope at a depth of 0-15 and 15-30 cm (Table 1). The samples were brought to the laboratory within 8 hr after collection and one half of each of the soil sample was immediately stored at 2°C for analyzing MBC and the other half was kept for air drying and visible roots and residues were removed from the samples. The air dried soil samples were ground and passed through 2 mm sieve. The SOC was determined by dichromate oxidation and titration with ferrous ammonium sulphate (Walkley and Black 1934). POM is measured with size-based procedure using sodium hexametaphosphate (Gregorich and Beare 2008), LFOM is analyzed with density fractionation method (Marriott and Wander 2006). DOC was extracted with 1M KCl solution of a ratio of 5:1 (v/w) in an overhead shaker for 30 min and filtered through 0.45 µm Whatman nylon membrane (Zsolinay 1996), determine carbon content (µg g^{-1} (dw) soil) in 10 mL aliquot of filtered solution by wet oxidation method. MBC was analyzed by using the chloroform fumigation and K_2SO_4 extraction method (Brookes et al. 1985), and the result was calculated using *K*c of 0.38 (Vance et al. 1987). HWC was extracted using Phenol method (Safarik and Santruckova 1992).

Table1. Different topological settings of study sites.

Study site	Topographical settings	Land use	Location	Code Name
Pyllun	32% slope ; 1188m MSL	Rice-Fellow	L1 (upper most part of slope)	Py_L1
			L2 (middle part of slope)	Py_L2
			L3 (lower most part of slope)	Py_L3
Paham, Nongpoh	32% slope ; 620 m MSL	Rice-Fellow	L1 (upper most part of slope)	Pa_L1
			L2 (middle part of slope)	Pa_L2
			L3(Lowland)	Pa_L3
Mawpun	6% slope; 947m MSL	Rice-Fellow	L1 (upper most part of slope)	Ma_L1
			L2 (middle part of slope)	Ma_L2
			L3 (Low land)	Ma_L3
Umaite	6% slope; 903m MSL	Rice-vegetables	L1 (upper most part of slope)	Um_L1
			L2 (middle part of slope)	Um_L2
			L3 (Low land)	Um_L3
Bhoirymbong	Intermountain valley land; 883m MSL	Rice-Fellow	L1 (Gentle slope between hills)	Bh_L1
			L2 (Low land)	Bh_L2
			L3 (Lowland near drainage channel)	Bh_L3

MSL- above Mean Sea Level

Statistical Analyses

Statistical analyses were performed using SPSS statistical software (SPSS Inc., Chicago, IL). One-way analysis of variance (ANOVA) was carried out to evaluate the statistical significance of topographical settings effect on SOC fractions. Mean was tested at a significant level of P<0.05 using Duncan's Multiple Range Test (DMRT). Pearson correlation coefficient was used to evaluate the relationships between the SOC fractions.

RESULTS

Soil Organic Carbon (SOC) Concentration

It was cleared that there was no obvious SOC distribution pattern at different topological settings (Table 2). The SOC content in topography of 32% slope was found a decreasing trend from upper most part of slope (L1) to lowest part of the slope (L3). However, topography of 6% slope and intermountain valley land were shown the increasing trend of SOC from L1 to L3. The SOC varied significantly ($P < 0.05$) with topography Um_L3 (2.75 and 2.61% at 0-15 and 15-30cm). The lowest SOC content was found under topography of 32% slope for both soil depths. There was a similar effect of topological settings of 6% slope and intermountain valley land in SOC.

Table 2. Topographical effect on SOC Concentration.

Topographic location	Soil Organic Carbon (%) 0-15 cm	15-30 cm
Py_L1	2.48abc	2.42ab
Py_L2	2.38bcd	2.31ab
Py_L3	2.23cde	2.15bcd
Pa_L1	1.99ef	1.45f
Pa_L2	1.83f	1.53ef
Pa_L3	1.90f	1.85de
Ma_L1	2.41bcd	2.32ab
Ma_L2	2.54abc	2.44ab
Ma_L3	2.61ab	2.50ab
Um_L1	2.61ab	2.42ab
Um_L2	2.70ab	2.44ab
Um_L3	2.75a	2.61a
Bh_L1	2.13def	1.93cd
Bh_L2	2.62ab	2.30abc
Bh_L3	2.54abc	2.21abcd

Means followed the same letter (s) within each column are not significantly different amoung topographical settings at $P < 0.05$.

Soil Organic Carbon (SOC) Fractions

Significant differences (P <0.05) in the contents of POM, LFOM, DOC, MBC and HWC were observed between topographical settings (Table 3). The distribution of POM with respect to the topographical settings followed a pattern of increasing from L1 to L3, however, Pyllun was shown a reversed trend from L3 to L1 (2.18% at L3 and 2.37% at L1 of surface soil and 2.12% at L3 and 2.32% at L1 of subsurface soil respectively). Among different topographical settings, Pyllun was found highest POM content and lowest at Paham (32% slope) following with intermountain valley (Boirymbong). The contents of LFOM were followed similar pattern of POM among different topographical settings, highest at 6% slope (Mawpun) and lowest at 32% slope (Paham). No obvious pattern of DOC distribution with topographical settings was found. The DOC of L2 and L3 of 6% slope Umaite was significantly different from DOC of other topographical settings. The DOC content at L2 of 6% slope (Mawpun) was statisti-cally at par with L1 of intermountain valley (Boirym-bong) and L1 of 32% slope (Pyllun). MBC of surface soil was found lowest at 32% slope topography (Pyllun) as compared to other topographical settings. HWC was also not followed a pattern with topographical settings, however, higher content was noted at L2 of 6% slope (Mawpun) and intermountain valley land. The SOC fractions (POM, LEOM, MBC and HWC) were more at the surface soil and DOC was more the subsurface soil.

Relationships Between SOC Fractions

There were significant positive relationships (P <0.01) between SOC and its corresponding fractions including DOC, POM, LEFOM and HWC, however, a negative relationships (P <0.05) between SOC and DOC and MBC was shown in subsurface soil (15-30 cm) (Table 4 and 5). In surface soil (0-15cm), DOC was positive relationship (P <0.05) with HWC, POM with (P <0.01) LEOM and HWC and LEOM (P <0.01) with HWC. The correlation coefficients with SOC decreased in the order of LFOM > POM > HWC > DOC. In subsurface soil, there were significantly positive relationships (P <0.01) between SOC and POM, LEFOM and HWC, a negative relationships (P <0.05) between SOC and DOC and MBC. DOC was negative relationship (P <0.05) with MBC, a positive relationship between POM with (P <0.01) LEOM and HWC and LEOM (P <0.01) with HWC. The correlation coefficients of SOC decreased in the order of POM > LFOM > HWC in subsurface soil.

DISCUSSION

Increasing SOC content and its fractions from upper most part of slope (L1) to the lower most part of the slope (L3) in different topographical settings might be due to accumulation of water soluble nutrients, SOC and its fractions carried with rain water along the slope; however, the topographical settings of 32% slope of Pyllun

Table 3. Topological effect on soil organic carbon (SOC) fractions.

Topographic	POM (%)		LFOM (%)		DOC (μg g^{-1} soil)		MBC (μg g^{-1} soil)		HWC (μg g^{-1} soil)	
Location	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Py_L1	2.37a	2.32a	1.93ab	1.76a	902.00abc	1039.50abc	225.80d	345.35e	106.14d	64.35d
Py_L2	2.26ab	2.25a	1.86abc	1.69a	876.21bc	1045.80abc	284.45cd	350.49de	120.78abcd	82.86bcd
Py_L3	2.18abcde	2.12ab	1.57cd	1.36bc	805.47cd	1046.70abc	289.88cd	382.41cde	119.47abcd	96.57ab
Pa_L1	1.10f	0.97e	1.16e	0.94d	634.69de	1098.60ab	459.50ab	431.84abcde	86.2433e	36.63e
Pa_L2	1.15f	0.99e	1.22e	1.04d	787.70cd	1156.80a	410.27bc	378.44cde	84.4200e	70.85cd
Pa_L3	1.88de	1.81abc	1.51d	1.11cd	656.61de	971.76bc	548.06ab	505.95ab	110.65cd	71.93bcd
Ma_L1	2.23abcd	2.07abc	1.90ab	1.78a	804.93cd	955.68c	469.16ab	477.19abc	113.43bcd	72.25bcd
Ma_L2	1.97bcde	1.83abc	1.94a	1.76a	921.57abc	1010.00bc	491.18ab	439.42abcde	133.70a	93.69abc
Ma_L3	2.24abc	2.08abc	1.95a	1.79a	599.58e	927.03c	504.83ab	461.80abcde	106.64cd	76.98bcd
Um_L1	1.94bcde	1.78cd	1.62bcd	1.22cd	869.38c	947.00c	467.09ab	390.76bcde	120.69abcd	74.41bcd
Um_L2	1.97bcde	1.76cd	1.63abcd	1.37bc	1063.7a	955.03c	557.53ab	394.64bcde	114.69bcd	84.52bcd
Um_L3	2.22abcd	2.21a	1.89ab	1.59ab	1047.6ab	1062.10abc	605.52a	393.36bcde	118.28abcd	96.19ab
Bh_L1	1.98bcde	1.76cd	1.64abcd	1.16cd	931.37abc	989.24bc	536.51ab	522.89a	117.68abcd	73.56bcd
Bh_L2	1.84e	1.72d	1.93ab	1.60ab	797.39cd	941.40c	488.67ab	469.58abcd	122.87abc	110.63a
Bh_L3	1.89cde	1.81abc	1.37abcd	1.66ab	855.54c	975.86bc	479.85ab	432.74abcde	127.43ab	89.29abc

Means followed the same letter (s) within each column are not significantly different among topographical settings at P <0.05.

Table 4. The correlation between SOC and its fractions of surface soil (0-15 cm).

Parameter	SOC	DOC	MBC	POM	LFOM	HWC
SOC	1.00					
DOC	0.387**	1.00				
MBC	0.134	0.221	1.00			
POM	0.542**	0.270	-0.126	1.00		
LFOM	0.597**	0.278	0.010	0.724**	1.00	
HWC	0.496**	0.356*	0.119	0.511**	0.539**	1.00

* Significant at $P < 0.05$ and ** Significant at $P < 0.01$.

Table 5. The correlation between SOC and its fractions of subsurface soil (15-30 cm).

Parameter	SOC	DOC	MBC	POM	LFOM	HWC
SOC	1.00					
DOC	-0.310*	1.00				
MBC	-0.091*	-0.323*	1.00			
POM	0.698**	-0.223	-0.161	1.00		
LFOM	0.643**	-0.196	-0.079	0.685**	1.00	
HWC	0.528**	-0.114	-0.031	0.417**	0.401**	1.00

* Significant at $P < 0.05$ and ** Significant at $P < 0.01$.

was following a reversed trend due to accumu-lation of litter falls from surrounding forest. The POM and LFOM were following similar trend of SOC distribution pattern. This might be due to consist of partially decomposed plant debris (Crow et al. 2007) and large size of POM (more than 53μm) and LFOM (more than 20μm). The DOC content at L2 (middle part slope) was more than the L1 and L3 part of the slope. The lowest MBC was noted at 32% slope of Pyllun as compare to the MBC of other topographical settings. The reason was not much cleared. However, Xu et al. (2006) were found significantly low MBC in soils due to utilized carbon source by microorganisms. The HWC content at 32% slope topography was comparatively less than the other topographies and its content was related with SOC content. Similarly, Xu and Jiang (2004) also found the relatively high WSC content in the soils with high SOC content. The finding of Xu et al. (2010) was supported with the result that the SOC and its fractions were more in the surface soil than those of subsurface soil. The activity of microbial and fungal was declined with increasing soil depth (Ralte et al. 2005) and the degree of carbon and nitrogen limitation to C mineralization increased with soil depth (Fierer et al. 2003). However, DOC was more at the subsurface soil. In this study the significant correlation between SOC and its four main fractions (i.e. DOC, POM, LFOM and HWC) showed that the variation of carbon fractions with the change of SOC in different topographical settings. The positive correlation between HWC and POM and LFOM was clearly indicated the main source of HWC was POM and LFOM. The negative relationship between POM and MBC was shown that the amount of POM was consumed by soil microorganisms.

CONCLUSION

It is concluded that distribution of SOC and its fractions at different topographical settings was strongly influenced by slope and other unknown soil pedogenic parameters. Further study is needed on soil pedogenic influences on SOC distribution. Understanding of these soil parameters might help in better soil carbon management.

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