



Organic Carbon Stocks in Various Land-use Types of Karst Landscape in Northeastern India

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Abstract: Although karst landscapes cover about 20 per cent of the Earth's ice-free land surface, their potential for climate change mitigation is still widely unexplored. The present study investigated the variation in organic carbon stocks under different land uses of karst landscape in Meghalaya, India. The sampled land uses of Mawsmi village karst landscape were forest land (Mawlong sacred forest and Ramjadong forest), grassland and homegarden. There was a decline in total organic carbon stocks along Mawlong sacred forest (236 Mg C ha^{-1}), Ramjadong forest (158 Mg C ha^{-1}), homegarden (116 Mg C ha^{-1}), and grassland (50 Mg C ha^{-1}). Land use history of Mawlong sacred forest represented by lower disturbance intensity as compared to that of the non-sacred Ramjadong forest had a positive impression on its total organic carbon stocks. Yet even Mawlong sacred forest had relatively low organic carbon stocks as compared to that reported for other comparable forests in literature indicating a potential negative impact of karst topography on forest carbon stock. Homegarden land use of the karst landscape was found to have the potential to store substantial amount organic carbon stock per unit area.

Keywords: Carbon stock, Karst, Meghalaya, Land use, Sacred forest, Grassland, Homegarden

Biological storage of carbon is an ecosystem service with several potential benefits; its role in climate change mitigation policies is progressively growing (Davies et al 2011). Malhi et al (2003) highlighted the important role that forests play in climate change mitigation, reasoning that this can be seen from the evident impact of forest loss on atmospheric carbon concentration. Carbon emissions from forest degradation can be investigated by comparing carbon storage under different forest conditions (Gibbs et al 2007). Not only in forest land, there is a growing interest to inspect the opportunities of storing carbon in different land use types (Murthy et al 2013). Karst is a terrain, usually underlain by limestone, in which the topography is mainly formed by the dissolving of rock, and is normally characterized by closed depressions, underground drainage, and caves (Indiana Natural Resources Commission 1999). Karst makes up about 20 percent of the ice-free continental surface (Ford and Williams 2007). From the ecological point of view, the chemical processes in karst landscape form an important CO_2 sink which may contribute in buffering climatic change phenomenon (White et al 1995). Apart from the study of Liu et al (2013) that estimated organic carbon stocks in the karst region in southwestern China for four land cover types and different pools, the focus of most other studies was on soil pool (Ahmed et al 2012, Chen et al 2014, Qi et al 2014). Within the Indian subcontinent, the Meghalaya Plateau of northeastern India is the richest location of karst features (Prokop 2014). This study aims to investigate organic carbon

stocks' potential and variability in inhabited karst landscape. Hence, the objective of the present study is to estimate total organic carbon (carbon in above-ground biomass, below-ground biomass (for trees), dead wood, litter, and soil organic matter) in different land use types of inhabited karst landscape.

MATERIALS AND METHODS

Study area: The present study was conducted in Mawsmi village, East Khasi Hills district, Meghalaya, India (Fig. 1). Mawsmi is located between $25^{\circ}14'21.86''$ and $25^{\circ}15'08.61''$ North latitudes and $91^{\circ}43'05.45''$ and $91^{\circ}43'57.02''$ East longitudes. The altitude is between 1150 and 1240 m above sea level and village is part of Cherrapunji Plateau. The climate of the area is humid subtropical, divided into three seasons: dry winter season from November to February, short spring season during March and April and rainy season from May to October. For the decade spanning from 2004 to 2013, the annual rainfall at Sohra was in the range of 7560 to 14791 mm with an average of 10953 mm. The mean monthly temperature in the year 2013 varied between a maximum of 21.8°C in June and a minimum of 11.9°C in January. The meteorological data were collected from Indian Meteorological Department office at Lower Sohra/Cherrapunjee, approximately 3 km to the north of Mawsmi village. Mawsmi forest is a relict rain forest ecosystem which contains climax vegetation found at higher elevations in Meghalaya. There is an abrupt boundary between this

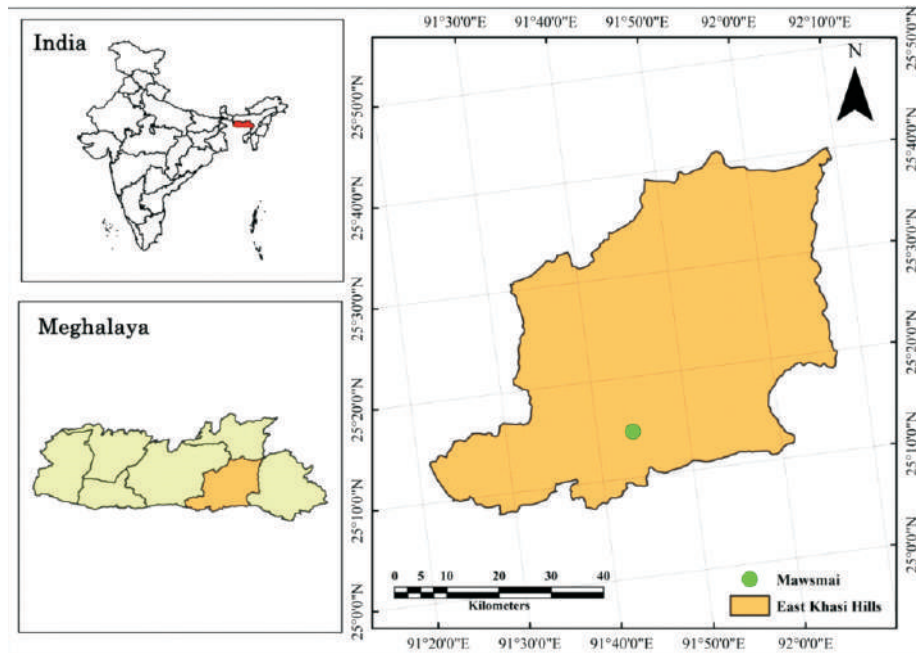


Fig. 1. Location map of the study area

subtropical forest and the surrounding landscape, which is primarily grassland. Limestone formation underlies the fragile, highly leached soil of Mawsmai forest (Ramakrishnan 1997). The soil of Sohra sacred groves is sandy loam of color gradient ranging from dark brown at the top to a yellowish colour in deeper horizons (Khiewtam and Ramakrishnan 1993). The soil is generally shallow and rock outcrops are common in the forest.

Field inventory: The sampled land uses are: 1–forest land, 2–homegarden, and 3–grassland. Mawsmai forest land was further stratified based on its historical status into 1–Mawlong Syiem sacred forest (Mawlong sacred forest) representing forest land of about 70 ha within Mawsmai village and having Mawsmai show cave. The forest is the historically sacred portion of larger forest land that extends out of Mawsmai village boundaries. 2–Ramjadong forest, representing non-sacred forest fragment with an area of about 5 ha. There are small irregular forest patches at the western part of Mawsmai village. Disturbance magnitude for Mawlong and Ramjadong forests was calculated as a ratio of the basal area of cut trees to the total basal area of all trees (intact and felled) following Kanzaki and Yoda (1986) as cited in Rao et al (1990). The disturbance was calculated for tree diameter class 10 cm. Typical homegardens were identified following the definition of Hoogerbrugge and Fresco (1993) in which a homegarden represents a small, multi-layered ecosystem with well-defined boundaries. Out of the twenty-five homestead gardens present in the village, only fourteen could be considered as typical homegardens. The houses that do not

have gardens, are surrounded by either grassland, or civil structures. Five organic carbon pools as per IPCC (2006) guidelines were estimated for each land use type during the rainy season. The pools are: above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter.

Biomass estimation: Square nested plots of 1000 m² described in the field inventory manual of Forest Survey of India, FSI (2002) were used for biomass estimation for forest and grassland. Each nested plot is composed of: one main plot of area 1000 m² for sampling trees and palms 5 cm Diameter at Breast Height (DBH) and standing dead trees pools; four sub-plots of area 9 m² for trees and palms < 5 cm, shrubs, climbers and woody litter pools; and four sub-plots with area 1 m² for herbs, leaf litter and duff. Eight 1000 m² nested plots were established for the stratified random sampling of the forest land of the village. The number of the plots met the precision level of 15% of the mean total above-ground carbon at a 95% confidence level for each forest. Seven random 1000 m² nested plots were used for sampling grassland. The study adapted the Y-shaped sampling frame of Henry et al (2009) for sampling village homegarden land use. Eventually, 6 homegardens out of the 14 typical homegardens of the village were analyzed. The sampling intensity is therefore 43%. The average area of a homegarden (excluding the house) was about 278 m². Being land use type smaller than 0.1 ha, the sampled homegardens were analyzed in totality. At each main 1000 m² sampling plot, the DBH and the height of all trees and palms having DBH 5

cm were measured. The above-ground biomass of each tree/palm tree was estimated using biomass regression equation cited in FAO (1997)-

$$\text{Biomass (tree)} = 21.297 - 6.953 \times (\text{DBH}) + 0.740 \times (\text{DBH})^2$$

Where, biomass is in kg and DBH is in cm

$$\text{Biomass (palm)} = 10.0 + 6.4 \times (\text{total height})$$

Where, biomass is in kg and total height is in m.

For sampling trees having < 5 cm DBH, shrubs, climbers and herbs, destructive harvesting techniques were used, employing the four 9 m² sub-plots of each nested plot, except for herbs where the 1 m² sub-plots were used. Oven dry weight was recorded. It should be noted that particularly in sampling homegarden land use, reference unit method described in Andrew et al (1997) was used when destructive techniques could not be used. For down dead wood, line intersect method described by Harmon and Sexton (1996) was used for determining the volume of each dead wood class (rotten, intermediate and sound). The minimum diameter considered for down dead wood was 5.0 cm diameter (FSI default). The dry mass of dead wood was measured as a product of volume and the wood density for each corresponding class. The biomass of standing dead tree having branches and twigs was estimated as for live tree by subtracting the biomass of leaves (2–3 % of above-ground biomass) as per Pearson et al (2007). For a dead tree when a tree has no branches and is only a bole, tree volume was estimated as per Walker et al (2012). Then biomass was estimated using the appropriate wood density class. Below-ground biomass was calculated based on the relation to above-ground biomass. For this calculation, above-ground biomass for standing dead trees was added to above-ground biomass for live trees for calculations of tree above-ground biomass at the plot level as per Kirby and Potvin (2007). Below-ground biomass was estimated using regression equation developed by Cairns et al (1997):

$$\text{BGBD} = \exp \{-1.059 + 0.884 \times \ln(\text{AGBD}) + 0.284\}$$

Where, BGBD = below-ground biomass density; AGBD = Above-ground biomass density.

In the four 9 m² sub-plots in each nested plot, all woody litter, i.e. all fallen branches below 5 cm diameter were collected, weighed and subsamples were collected. In the four 1 m² sub-plots of each 1000 m² nested plot, all leaf litter and duff within the sample frame were collected and all samples from the plots were pooled and weighed. Well-mixed subsamples were collected and placed in marked bags. The subsamples were used to determine oven-dry-to-wet mass ratios to convert the total wet mass to oven-dry mass. The herbaceous litter found in the grassland was included under leaf litter category. Biomass results were

expressed in Mg ha⁻¹ after plot area was corrected for slope.

Organic carbon estimation: The carbon stock (Mg C ha⁻¹) of each vegetation pool was calculated by multiplying biomass density by carbon fraction value. The IPCC (2006) default carbon fraction value of 0.37 was used for leaf litter and duff while the value of 0.5 was used for the woody litter pool. The IPCC (2006) default carbon fraction value of 0.47 was used for all other vegetation pools. Soil samples were collected to the complete profile depth available from within the four 1 m² sub-plots at the corners of each 0.1 ha nested plot using a corer. For homegardens, three soil samples from each homegarden were collected. The numbers of soil samples collected for estimating soil organic carbon were 20, 12, 18 and 28 in Mawlong sacred forest, Ramjadong forest, homegarden and grassland respectively. Similar numbers of samples were collected for soil bulk density analysis. The concentration of soil organic carbon was estimated by Walkley and Black wet digestion method as described by Okalebo et al (1993). The results were then corrected by multiplying with the commonly applied correction factor 1.32 (Skjemstad et al 2000). Soil organic carbon density was calculated by using the equation suggested in IPCC (2003). One way analysis of variance and Tukey Kramer post hoc test were used to analyse the data.

RESULTS AND DISCUSSION

The disturbance index was 8.51 and 39.45 per cent for Mawlong sacred and Ramjadong forest respectively. Hence, Mawlong sacred forest can be described as mildly disturbed while Ramjadong forest as a moderately to highly disturbed forest. Carbon density in total above-ground biomass was highest in Mawlong sacred forest (104.4 Mg C ha⁻¹). Ramjadong forest (50.9 Mg C ha⁻¹) had comparable total above-ground carbon stock values with that of homegarden (Table 1). Live trees and palms 10 cm DBH accounted for 95, 91 and 94 per cent of total above-ground biomass for Mawlong sacred forest, Ramjadong forest and homegarden respectively. In Mawlong sacred forest, trees above 60 cm DBH accounted for 25 per cent of the total above-ground carbon stocks in trees and palms 10 cm, which is the highest share among other tree classes. The same tree class accounted for 21 per cent of the total above-ground carbon stocks in trees and palms 10 cm in Ramjadong forest while the class 30–40 DBH had the highest share 24 per cent. The least disturbed Mawlong sacred forest had lower shrub contribution to total biomass as compared to the more disturbed Ramjadong forest. Herb pool in both Mawlong and Ramjadong forests represented a minor component of carbon stocks (<1 % of total organic carbon stocks). The soil bulk density in the sampled land uses of the landscape

ranged from 0.84 g cm⁻³ at the upper soil layer of homegarden to 1.61 g cm⁻³ at the deepest soil layer of the grassland. The values of soil coarse fragments (volume %) in the soil layers 0–10 cm and 10–20 cm were significantly higher in grassland than Mawlong sacred forest and Ramjadong forest (Table 2). Statistically significant differences in soil organic carbon concentrations between corresponding soil layers of the land uses were not observed. Soil organic carbon concentration (upper to deepest soil layer) ranged from 3.72 to 0.83; 3.23 to 1.12; and 2.97 to 0.92 per cent at Mawsmal forest land, homegarden and grassland respectively. Total organic carbon stocks was highest in Mawlong sacred forest followed by Ramjadong forest and homegarden; while the lowest value was reported for grassland (Table 1). With regards to the contribution of each major pool to organic carbon stocks

of the land uses, above-ground biomass stored the largest amount of organic carbon in Mawlong sacred forest (44.2%) followed by soil pool (37.1%). Soil pool was the pool of greatest share of organic carbon in Ramjadong forest (38.7%) and homegarden (59.5%). Soil pool stored most of the organic carbon (96.3%) in grassland.

Forest land: Since Mawlong and Ramjadong forests were situated in proximity to each other and have similar physiographic, climatic and edaphic features, the differences in average carbon stocks of above-ground biomass between the two forests could be attributed largely to the more disturbance imposed on the non-sacred Ramjadong forest (39.45%) as compared to Mawlong sacred forest (8.51%). The disturbance reported in Mawlong sacred forest reflects change in the social attitude toward the sacredness of the

Table 1. Organic carbon stocks (Mg C ha⁻¹) of vegetation and soil pools

Vegetation	Mawlong sacred forest	Ramjadong forest	Homegarden	Grassland
Carbon in above-ground pools				
Trees 10 cm DBH	97.47a	45.18ab	34.00b	–
Trees 5 cm to < 10 cm DBH	3.10a	2.68a	0.53b	–
Trees < 5 cm DBH	0.09a	0.63b	0.13a	0.01c
Palm trees 10 cm DBH	1.82a	0.90a	–	–
Palm trees < 10 cm DBH	0.09a	0.08a	0.27a	–
Shrubs	0.31a	0.81b	0.06c	–
Climbers and creepers	0.07a	0.09a	0.001b	0.003b
Large herbs (banana)	–	–	0.43	–
Bamboo	1.03a	–	0.03b	–
Herbs	0.38a	0.52a	0.68a	1.55b
Total above-ground carbon	104.36a	50.90b	36.12b	1.56c
Carbon in below-ground pools (for trees, palms and standing dead wood)				
Total below-ground carbon	29.03a	20.17b	9.69b	0.005c
Carbon in dead wood pools				
Downed dead wood	2.24a	1.42a	–	–
Standing dead wood	9.60a	21.49b	0.42c	–
Total Dead wood	11.84a	22.91b	0.42c	–
Carbon in litter pools				
Woody litter	0.45a	0.57b	0.01c	–
Leaf litter	0.50a	0.48ab	0.16bc	0.25c
Duff	2.20a	2.08a	0.71b	–
Total litter	3.14a	3.13a	0.88b	0.25b
Soil organic carbon (Soil layer depth)				
0–10 cm	28.17ab	35.60a	24.06b	24.33b
10–20 cm	27.94a	25.69a	19.47ab	12.59b
20–30 cm	21.17a	–	14.58ab	10.78b
30–40 cm	10.25a	–	11.02a	–
Total soil organic carbon	87.53	61.29	69.13	47.70
Total carbon stocks	235.90	158.40	116.24	49.52

Means in a row followed by different letters are significantly different ($P < 0.05$), “–” refers to the absence of a vegetation pool or soil layer

Table 2. Volumetric fraction of coarse fragments ($\text{cm}^3 \text{cm}^{-3}$) at intervals of 10 cm along soil profiles of different land use types of Mawsmmai village

Land use	0–10 cm	10–20 cm	20–30 cm	30–40 cm
Mawlong sacred forest	0.05 ^a	0.07 ^a	0.11 ^a	0.20 ^a
Ramjadong forest	0.05 ^a	0.07 ^a	–	–
Homegarden	0.11 ^{ab}	0.17 ^b	0.22 ^a	0.24 ^a
Grassland	0.17 ^b	0.22 ^b	0.27 ^a	–

Means in a column followed by different letters are significantly different ($P < 0.05$). “–” refers to the absence of soil layer

forest. The sacredness of Mawlong forest is derived from the indigenous Khasi religion that gradually vanished from Mawsmmai village with the arrival of British missionaries in the mid of the nineteenth century (Anonymous Mawsmmai village inhabitants, personal communication 2013). Tree class > 60 cm DBH was a major contributor to above-ground carbon in both Mawlong and Ramjadong forests. Similar finding was reported in Baishya et al (2009) for other Meghalayan forest. Above-ground carbon in live trees of Mawlong sacred forest is within the above-ground carbon range of 81.2–118.2 Mg C ha⁻¹ reported by *Thokchom and Yadava* (2013) for subtropical forests of Manipur, North-East India, and the range of 96.77–129.32 Mg C ha⁻¹ reported by Upadhaya et al (2015) for reserved forests in Garo hills, Meghalaya, North-East India. However, above-ground carbon densities in live trees 10 cm DBH for both forests are markedly lower than that reported in literature for subtropical and tropical forests around the world (Lewis et al 2009, Kho et al 2013, Brown et al 2014). Hence, it could be inferred that Mawlong sacred forest and, to a greater degree, Ramjadong forest have relatively low above-ground biomass. Soil organic carbon density values (full soil profile) for Mawlong sacred forest of 87.5 Mg C ha⁻¹ and Ramjadong forest of 61.3 Mg C ha⁻¹ are markedly lower than that of 19.1 kg m⁻² (190 Mg C ha⁻¹) reported in Post et al (1982) for average soil organic carbon density (1 m depth) in tropical forest wet life-zone. Soil organic carbon densities of both Mawlong and Ramjadong forests are also lower than that reported for tropical forests in Asia (Houghton 1999, Ziegler et al 2012). Soil organic carbon concentrations of Mawlong and Ramjadong forests are comparable to that reported in Sanchez (2012) for tropical soils and to that reported for other forests in India (Mishra et al 2005, Gautam et al 2011). The limited soil depth could then be a main reason behind the relatively low soil organic carbon densities reported for the forests of the Mawsmmai karst landscape. In fact, soil organic carbon density is even lower than the reported one. The equation used frequently in calculating soil organic carbon density assumes that soil layer is continuous. Not accounting for rock outcrop coverage ratio would lead to overestimating soil

organic carbon density.

Average carbon stocks in above-ground live, downed dead and standing dead vegetation reported for Mawlong sacred forest (116.2 Mg C ha⁻¹) and Ramjadong forest (73.81 Mg C ha⁻¹) are lower than that of 147.5 Mg C ha⁻¹ reported by Brakas and Aune (2011) for natural rainforest in the Philippines where illegal logging is practiced. Total organic carbon stocks in Mawlong and Ramjadong forests are markedly lower than the 305 Mg C ha⁻¹ reported by Woome et al (2000) for slightly disturbed forests in the humid tropics. Ramakrishnan (1998) considered Mawsmmai forest as stunted and attributed this state to the forest development over unbalanced soil derived from limestone. Liu et al (2013) estimated organic carbon stocks in subtropical karst landscape in southwestern China for four land cover types (i.e. secondary forest, forest shrub transition, thorn shrubbery, and shrub grassland). Their study found that karst ecosystems in southwestern China have lower organic carbon stocks (biomass carbon as well as soil organic carbon) in comparison to other non-karstic ecosystems. The present study reports similar finding for a forest land of a karst landscape in northeastern India. The similarities in the findings indicate that karst topography may have negative impacts on organic carbon stocks.

Grassland: Above-ground biomass of Mawsmmai grassland (3.3 Mg ha⁻¹) is less than the IPCC (2006) default value of 6.2 Mg ha⁻¹ for peak above-ground biomass in tropical grassland after conversion from other land use. Above-ground carbon stocks of Mawsmmai grassland (1.56 Mg C ha⁻¹) is below the range of 3–35 Mg C ha⁻¹ reported in Ziegler et al (2012) for total above-ground carbon biomass in grasslands of South-east Asia. Above-ground carbon stocks of Mawsmmai grassland is also less than that of 2.9 Mg C ha⁻¹ reported by Brakas and Aune (2011) for Claveria, the Philippines. The absence of trees and palms > 5 cm DBH contributed to the relatively low above-ground biomass in the grassland of Mawsmmai village karst landscape. The relatively high volumetric fraction of coarse fragment in grassland has played a role in the 54% decline in soil organic carbon density in full soil profile in grassland as compared to Mawlong sacred forest. It should be noted that using soil corer might not be the best method for sampling for soil bulk density in this karstic landscape. This is particularly relevant for sampling grassland where high volumetric fraction of coarse fragment is present. The soil organic carbon density value of Mawsmmai village grassland of 47.7 Mg C ha⁻¹ (0–30 cm) falls below the range of 66–198 Mg C ha⁻¹ estimated by Ziegler et al (2012) for total soil organic carbon reported in grasslands of South-east Asia. For the soil layer 0–20 cm, the grassland

of Mawsmal karst landscape had soil organic carbon density value of 36.9 Mg C ha⁻¹ that is lower than that of 60.4 Mg C ha⁻¹ reported for grassland on karstic landscape in southwest China (Zheng et al 2012). However, soil organic carbon density of Mawsmal village grassland was comparable to the 50 Mg C ha⁻¹ (1 m depth) reported by Houghton (1999) for grassland in tropical Asia. The total organic carbon stocks in Mawsmal village grassland was very close to the value 48 Mg C ha⁻¹ reported in Wooster et al (2000) for grassland in the humid tropics in which soil pool (50 cm) also stored most of the organic carbon.

Homegarden: The average above-ground carbon stock value reported for Mawsmal homegarden land use (36.1 Mg C ha⁻¹) is lower than that of 75.47 Mg C ha⁻¹ reported by Kirby and Potvin (2007) for homegardens and outfield gardens in Eastern Panama. Average carbon stocks in above-ground live, downed dead and standing dead vegetation reported for Mawsmal homegarden land use (36.5 Mg C ha⁻¹) is markedly lower than that of 159.7 Mg C ha⁻¹ reported in Brakas and Aune (2011) for Philippine homegardens. However, average above-ground carbon stocks reported for Mawsmal homegarden is higher than the two averages of 13.8 and 17.3 Mg C ha⁻¹ documented by Henry et al (2009) for homegarden systems of two districts in western Kenya. Average above-ground carbon stock for Mawsmal homegarden is at the higher end of the range of 16 to 36 Mg C ha⁻¹ reported by Kumar (2011) for above-ground carbon stocks in homegardens of central Kerala, India. Homegarden land use in Mawsmal village karst landscape stored carbon in its above-ground biomass pool comparable to that of the disturbed forest, Ramjadong. A particular homegarden was able to store substantial amount of carbon (81.86 Mg C ha⁻¹) in total above-ground biomass making the land use promising with regards to organic carbon storage per unit area.

CONCLUSION

With regards to above-ground carbon, forest land and homegardens of Mawsmal karst landscape are like oases of carbon in a desert of grassland that extends over vast areas in Sohra plateau. There is a decline in total organic carbon stocks along the historically sacred forest, non-sacred forest, homegarden and grassland of Mawsmal village karst landscape. Land use history represented by higher disturbance intensity in the non-sacred Ramjadong forest as compared to Mawlong sacred forest had negatively impacted its total organic carbon stocks. Nevertheless, even the less disturbed forest (Mawlong sacred forest) showed relatively low organic carbon stocks as compared to that reported in literature for other comparable forests. The karst topography may have a negative impact on forest organic carbon stocks.

Total collapse of the forest sacredness concept without having an alternative custom that can meet the needs of the people and the integrity of the sacred forests would negatively impact their biological carbon storage service. Homegarden stored substantial amount of organic carbon making it a valid option for storing organic carbon in this karst landscape.

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