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RADIOCARBON AND STABLE CARBON ISOTOPES IN TWO SOIL PROFILES FROM NORTHEAST INDIA

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ABSTRACT. Two soil profiles from northeast India, one from Bakrihawar, an agricultural land, and the other from Chandipur, a virgin hilly area from Assam, are investigated to understand the organic carbon dynamics of the area. Due to frequent flooding, the Bakrihawar soil has accumulated a higher clay content than that of Chandipur. The carbon content is less than 1% by weight in both the sites. The higher clay content is responsible for relatively more soil organic carbon at Bakrihawar. The mean $\delta^{13}C$ values at both sites reflect the values of the overlying vegetation. At Bakrihawar, both rice cultivation (C_3) and natural C_4 grasses contribute to higher mean enriched values of ^{13}C relative to Chandipur, where the surface vegetation is mostly of C_3 type. The turnover time of organic carbon, estimated using the residual radiocarbon content, depends strongly on the soil particle size distribution, especially the clay content (i.e. it increases with clay content). To the best of our knowledge, this is the first soil carbon dynamics study of its kind from northeast India.

INTRODUCTION

Understanding the mechanistic controls over the fate, transport, and turnover times of organic carbon in soils is important because it is a significant carbon reservoir with a potential role in the global climate. The dynamics of soil organic carbon (SOC), factors governing the turnover time of SOC, and variation with depth in many tropical regions are not clearly understood. It is believed that the turnover time of the organic carbon in tropical soils is less than that of boreal and temperate soils (Raich and Schlesinger 1992; Schimel et al. 1994; Thompson et al. 1996; Torn et al. 2009).

Stable carbon isotopic composition ($\delta^{13}C$) of soil and sedimentary organic matter has been widely used in paleoclimatic studies (Sukumar et al. 1993; Biedenbender et al. 2004; Leavitt et al. 2007; Wynn and Bird 2008; Laskar et al. 2010; Zhong et al. 2010). In an undisturbed site, under humid and low temperature conditions, C_3 vegetation dominates, with $\delta^{13}C$ values between –19‰ and –32‰ and a mean of –27‰. While in a warm/arid climate, C_4 plants are abundant, with $\delta^{13}C$ values from –9‰ to –19‰ and a mean of –13‰ (Deines 1980). Kohn (2010) showed that the $\delta^{13}C$ of C_3 vegetation increases with the decrease in mean annual precipitation. The average $\delta^{13}C$ value of C_3 vegetation estimated by Kohn (2010) is –28.5‰ considering the Northern Hemisphere tropical and mid-latitude biomass. At any place, SOC carries the $\delta^{13}C$ signature of the mixed vegetation, which is present at the time of pedogenesis (Balesdent et al. 1993; McPhearson et al. 1993), although percolation of fresh material cannot be ruled out totally. A carbon isotopic fractionation of up to 2–4‰ during humification and microbial decomposition has been reported, mainly in the upper soil layers (Quade and Cerling 1995; Accoe et al. 2002; Wynn et al. 2006; Bostörm et al. 2007), but this is small compared to the difference between the mean $\delta^{13}C$ values of the 2 major plant types (C_3 and C_4). Radiocarbon and stable carbon isotopes are very good tools to study the soil carbon dynamics and their driving mechanisms (Torn et al. 2009; Trumbore 2009).

Detailed quantitative studies of carbon dynamics in the tropical soils from India are very limited (Becker-Heidmann and Scharpenseel 1989; Caner et al. 2007). Therefore, this paper presents the results of concentration, ^{14}C, and $\delta^{13}C$ measurements made on the SOC of 2 soil sections from an unexamined region in northeast India. The aims of the present study are (i) to determine the difference between the organic carbon content in the tropical agricultural and undisturbed soils; (ii) to use soil $\delta^{13}C$ and ^{14}C variations to understand SOC dynamics, especially its turnover time; and (iii) to better understand the factors influencing the variability of $\delta^{13}C$ in a soil profile.

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STUDY AREA AND SAMPLING

Soil samples were collected in May 2009 from 2 sites ~5 km apart: (1) an agricultural land at Bakrihawar (henceforth referred to as BR) and (2) Chandipur, an undisturbed hilly region (henceforth referred to as CH). Both are located in the Hailakandi district (Figure 1; 24°41′N, 92°34′E; 21 m asl) of Assam, northeast India. The long-term mean annual precipitation and temperature in the sampled area are ~3200 mm/yr and ~20 °C, respectively, obtained from the nearest meteorological station, Silchar (India Meteorology Department 1999). The district is located ~200 km south of the world's heaviest rainfall regions, Cherrapunji and Mawsynram. It receives most of its annual precipitation (~80%) during the southwest monsoon (June to September). Soils at both the sites are free of carbonates, confirmed using 10% HCl. Individual descriptions of the 2 sites are given below.

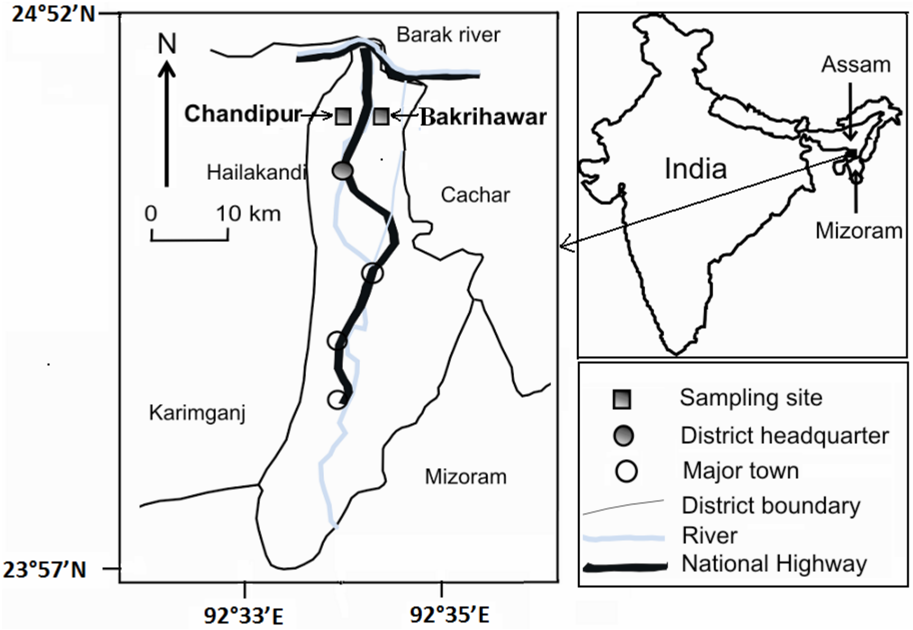

Figure 1 Map showing the Hailakandi district and the locations of the study sites

Bakrihawar (BR)

This is a flat agricultural land a few tens of km^2 wide and is locally known as *hawar* (open land). It is well drained through small water channels and is at present being used for cultivating paddy, from July to December. The rest of the year, the land remains a grazing field. Almost every year, during heavy rains, the site is flooded. Occasional large-scale flooding is also observed (about once every ~5 yr). The soil is very rich in clay, gray in color with no distinct lamination (Figure 2). The soils are Entisols, alluvial in nature and classified as silty clay. During heavy floods, sediments from higher elevation (the southern part of Hailakandi and Mizoram state) are brought and deposited in this region.

Chandipur (CH)

This site is a hilly region with insignificant anthropogenic activity. The present vegetation is dominated mainly by shrubs and bamboo trees, however, with a very low spatial density. The site is well

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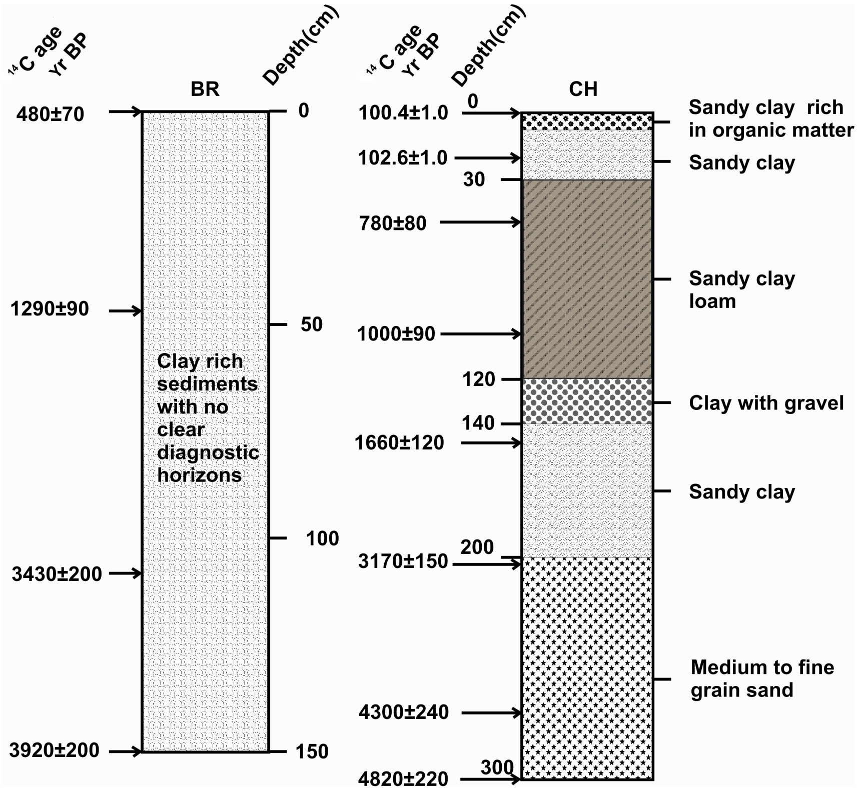

Figure 2 Lithologs of the 2 soil profiles. ^{14}C ages at various depths are shown on the left (BR = Bakrihawar; CH = Chandipur).

drained by a small stream flowing down to the foothills. The soils are Spodosols, appearing reddish-brown with well-developed distinct laminations (Figure 2) and are classified as sandy loam. The samples were collected from the whole profile covering the 3 soil horizons: A (depth 0–50 cm); B (50–200 cm); and C (200–300 cm). The O horizon is absent in the site.

METHODS

Samples from BR were collected by digging a ~1.5-m-deep pit and those of CH, from a ~3-m-high cliff section. A ~300-g sample was recovered from a ~2-cm-thick layer along the profile at several depths (Table 1). These were brought to the laboratory in sealed plastic bags, and later dried at 70 °C for ~24 hr. Before analyses, rootlets and their fragments, which could be relatively modern, were removed manually. The remaining samples were thoroughly homogenized and filtered through a 2-mm sieve. Samples of modern vegetation and grasses present were also collected from the 2 sites for determining their δ^{13}C (Table 1).

All samples were washed with 10% HCl to remove the carbonate fraction if present in trace amount. The samples were neutralized with distilled water and dried. Weighed amounts of dried samples were combusted in excess oxygen at 900 °C to convert SOC to CO_2. Manometric pressure measurements of CO_2 in a precalibrated volume were used to determine the organic carbon concentrations. The ^{14}C dates of the soils were measured by liquid scintillation spectrometry at the Physical Research Laboratory (PRL), Ahmedabad (for details, see Yadava and Ramesh 1999). We assume

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that the soils are under a steady-state with respect to carbon cycling and, therefore, ^{14}C dates are assumed to represent the turnover times of SOC.

For stable isotope analysis of SOC, ~1 g of dry soil sample was taken in a small quartz tube (outer diameter 9 mm) along with pure CuO powder, sealed with quartz wool, evacuated, and heated at ~900 °C for ~1 hr to produce CO_2, which was purified cryogenically in several steps and its carbon isotopic composition (δ^{13}C) was measured using a stable isotope ratio mass spectrometer (GEO 20-20, Europa Scientific, UK) at PRL, Ahmedabad. The external precision for the δ^{13}C measurements for the procedure followed is better than ±0.2‰ (Laskar 2011). The accuracy of the measurements was checked by running an international standard (oxalic acid II supplied by the National Bureau of Standards, used as a modern reference for ^{14}C dating). The average δ^{13}C (with respect to PDB) obtained is –17.7 ± 0.1‰, close to the internationally accepted value of –17.8‰ (Laskar 2011).

For the soil texture study, about 30 g of sample was decarbonated by reacting with 10% HCl for ~8 hr, neutralized with distilled water to obtain pH = 7, dispersed with sodium hexametaphosphate to separate the clay coatings on sand grains, and sieved with a 2-mm mesh to remove gravels. Sands are separated with a mesh of size 63 µm. For grain-size distribution of clay and silt, the pipette method is used, where settling velocities of the components are calculated using Stokes' law (see Carver 1971 for further details).

RESULTS AND DISCUSSION

The alluvial sediment profile at BR has no clear horizons (Figure 2) and a fairly high clay content (30–70%) (Figure 3). During flooding years, large amounts of fine particles are brought and deposited in the alluvial plain; therefore, this site has a large clay %. In contrast to this, soil samples at CH show distinct layers with varying proportions of clay from 20–30% only (Figure 3). The bulk densities in both profiles are comparable, varying from 1.1 to 1.4 g/cc and 1.2 to 1.5 g/cc for BR and CH, respectively. Usually, it is observed that SOC tends to increase with an increase in clay % (Schimel et al. 1994; Rice 2002; Telles et al. 2003; Plante et al. 2006), which is clearly seen in the observed values, with the average SOC at BR being higher than CH (Figure 4). In BR, at ~50 cm depth where the clay content is the highest, SOC also has the highest value. The absence of the organic layer and modern carbon at the surface (Table 1) of BR is probably due to the frequent flooding in the region.

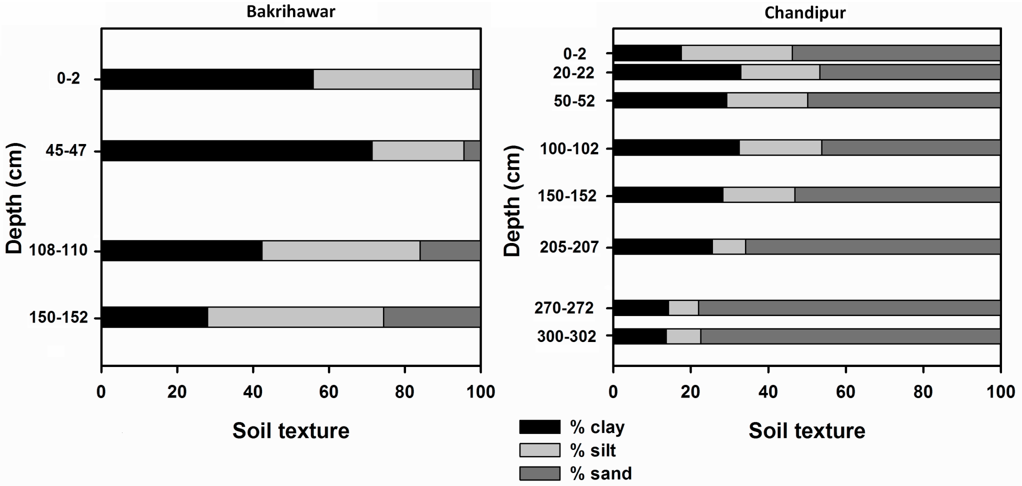

Figure 3 Distribution of clay, silt, and sand at different depths in the 2 soil profiles

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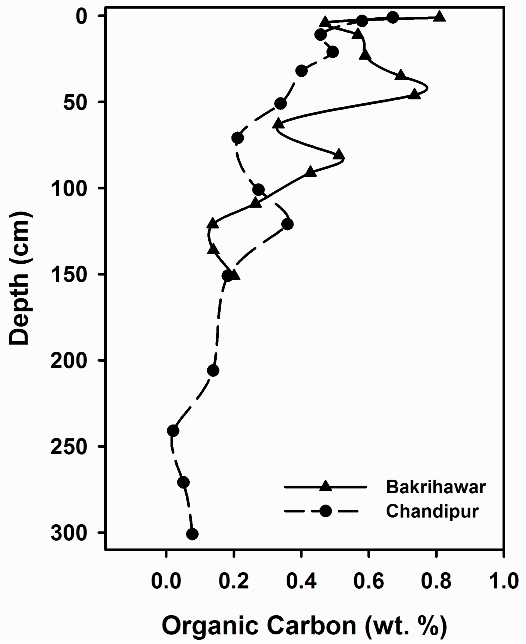

Figure 4 Variation of organic carbon contents with depth in the 2 soil profiles.

The δ^{13}C values at BR are relatively enriched compared to CH (Figure 5). This can be explained as follows: the average δ^{13}C of SOC at the surface in BR is contributed from 2 sources, 1) rice cultivation (C$_3$ type, δ^{13}C ~ –27‰) and 2) from grasses (C$_4$, measured δ^{13}C = –11.4‰, Table 1). Whereas at CH, the surface vegetation is dominantly of C$_3$ type (measured δ^{13}C about –28.6‰, Table 1). Therefore, the SOC percolating from the surface at BR should be enriched in ^{13}C relative to that of CH. Another observation is that the highest δ^{13}C value in BR (at ~50 cm depth, Figure 5) coincides with the highest clay content. A similar signature was also observed by Becker-Heidmann and Scharpenseel (1989). This is thought to be due to the "chromatographic"-like effect in the soils; i.e. the clay with a complex binding with the old metabolized organic matter (due to microbial decomposition it has higher δ^{13}C values relative to surface vegetation) does not get rejuvenated with the fresh organic matter (from the surface, having a δ^{13}C value of the contemporary vegetation). This eventually percolates further into deeper layers with lesser clay content. Clay binds organic matter strongly and also favors the formation of aggregates, which protect against microbial decomposition (Feller and Beare 1997; Balesdent et al. 2000; Giardina and Ryan 2000; Rice 2002; Bradford et al. 2008; Manjaiah et al. 2010). This acts in 2 ways, first, the clay rich soil has higher SOC and second, it has less affinity for binding additional fresh organic matter. There is an enrichment of >2‰ in δ^{13}C with depth in both profiles in the upper soil layers (0–50 cm; Figure 5). The probable reasons are (a) preferential decomposition of isotopically lighter molecules during microbial respiration (Ehleringer et al. 2000; Accoe et al. 2002) and/or (b) progressive δ^{13}C decrease in the atmosphere during the industrial era due to emission of ^{13}C-depleted CO$_2$ from fossil fuel burning (Ehleringer et al. 2000).

The turnover time (or the mean residence time) of the soil carbon is defined as the average time spent by a carbon atom in the soil, from the time of its incorporation via photosynthesis and release back to the atmosphere by respiration/decomposition. ^{14}C ages of the bulk SOC, which accumulates

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Table 1 Organic carbon content, $\delta^{13}C$ of soil organic carbon with respect to VPDB and ^{14}C dates of the samples from the 2 studied soil profiles.

Sample	Depth (cm)	Carbon content (wt%)	$\delta^{13}C$ (‰)	^{14}C age (yr BP)
Chandipur (CH)				
Vegetation			–28.57	
CH 1	0–2	0.67	–27.95	Modern (100.4 pMC)[a]
CH 2	2–4	0.58	–26.66	
CH 3	10–12	0.46	–25.93	
CH 4	20–22	0.49	na	Modern (102.6 pMC)[a]
CH 5	30–34	0.49	–24.41	
CH 6	50–52	0.40	–24.02	780 ± 80
CH 7	70–72	0.34	–24.75	
CH 8	100–102	0.21	–24.91	1000 ± 90
CH 9	120–122	0.27	–22.95	
CH 10	150–152	0.36	–25.04	1660 ± 120
CH 11	170–172	0.18	–24.15	
CH 12	205–207	0.14	–25.55	3170 ± 150
CH 13	240–242	0.02	–26.25	
CH 14	270–272	0.05	–25.27	4300 ± 240
CH 15	300–302	0.08	–25.39	4820 ± 220
Bakrihawar (BR)				
Grass			–11.38	
BR 1	0–2	0.81	–22.29	480 ± 70
BR 2	2–5	0.47	–22.26	
BR 3	10–12	0.57	–20.08	
BR 4	22–24	0.59	–19.57	
BR 5	34–36	0.69	–18.09	
BR 6	45–47	0.74	–18.12	1290 ± 90
BR 7	62–64	0.33	–24.45	
BR 8	80–82	0.51	–21.09	
BR 9	90–92	0.43	–23.03	
BR 10	108–110	0.26	–22.70	3430 ± 200
BR 11	120–122	0.14	–22.35	
BR 12	135–138	0.14	–20.81	
BR 13	150–152	0.20	–22.71	3920 ± 200

[a] pMC = percent modern carbon (±1σ error).

over a long period of time, do not represent the “true age” of the soil layer. In most cases, as it is an open system with a continuous supply of fresh organic matter, the estimated age is different from the true age. Therefore, at the most, ^{14}C ages of the SOC can be considered as minimum ages of the soil formation (Wang et al. 1996) and can be used to investigate the turnover time of SOC. Figure 6 shows the down-profile variation of ^{14}C ages at the 2 sites. At any depth, turnover time at BR is higher compared with CH. This could be due to the relatively higher clay content at BR. At CH, the top soil layers up to a depth of ~20 cm contain bomb carbon, indicating that a significant fraction of the organic carbon, added post-1950s, is still preserved in the upper soil layers. At BR, being an alluvial deposit, we do not see any reversal in the age stratigraphy (Table 1). As in flood years, BR is inundated and material from higher elevation is deposited, and old clay-rich organic materials from catchment mix with modern surface SOC, resulting in the finite non-zero age at 0–2 cm depth, about 500 yr BP (Table 1).

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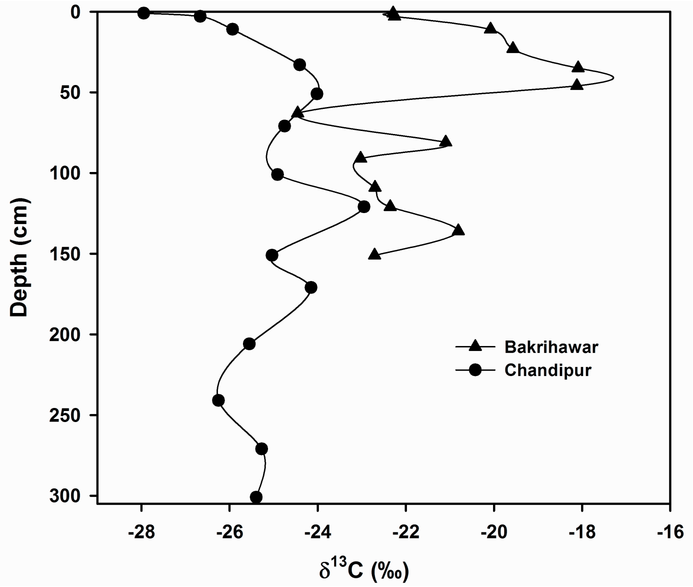

Figure 5 Depth profile δ^{13}C of soil organic matter

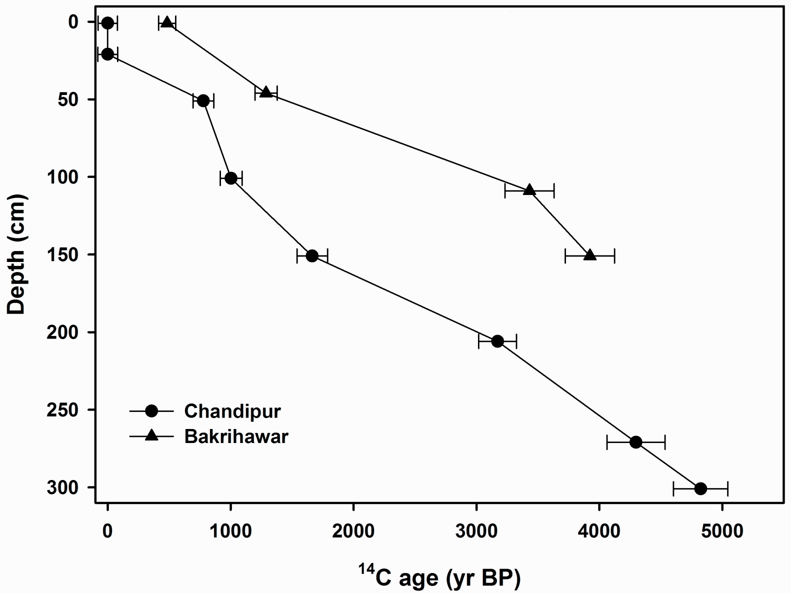

Figure 6 Variation of ^{14}C ages with depth. For pMC 100 or more, the ^{14}C age is taken as modern. Errors are at 1σ levels.

Intense farming at BR started possibly in recent years. The effect of agricultural activity is prominently seen in the concentration profile of the SOC, as lower carbon contents in the top 2 to 50 cm layers due to the regular tillage, which brings up carbon to the surface and leads to erosional loss (Figure 4).

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CONCLUSIONS

Two soil sections from northeast India, an unexplored region from the soil carbon point of view, have been studied for their SOC, ^{14}C, and ^{13}C inventories. The agricultural site has higher clay content and SOC due to the fluvial nature of its sediments. The highest clay layer in the agricultural site is associated with the highest SOC content and the most enriched ^{13}C of SOC. Here, due to the mixed contribution from rice cultivation and C_4 grasses, δ^{13}C values are found to be higher than that of the virgin soil. The turnover time of SOC in the subsoil is higher for the clayey alluvial sediments (Bakrihawar, BR) compared to the sandy soil of the hills (Chandipur, CH), indicating that organic carbon associated with clay minerals are much more resistant to degradation.

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