

Organic Carbon Dynamics in a Soil Profile and an Alluvial Deposit from India

P. O. Suresh

Department of Environment and Geography, Macquarie University, Sydney, NSW 2109, Australia.

Abstract

Soil Organic Carbon (SOC) plays a major role in permanently fixing atmospheric carbon dioxide and hence influences global warming. Agricultural longevity of soil is affected by organic carbon content. This paper reports a steady state dissociation constant of SOC from soils and sediments, which represent the SOC fixing capacity of some soil and sediment samples from India. The SOC dissociation constant for the soil is about $2 \times 10^{-4} \text{ yr}^{-1}$ and for the sediment samples is about $0.2 \times 10^{-4} \text{ yr}^{-1}$. The radiocarbon ages of soil vary from 100 yr BP to 2000 yr BP with increasing soil depth, whereas for the sediments, the upper limit of deposition age is ~4800 yr BP. The steady state dissociation constants of the soil and sediments and the organic carbon content in the samples point towards an optimum capacity of soils and sediments to hold SOC for long time.

Corresponding Author:

P.O. Suresh

Email: suresh.puthiyaveetil-othayoth@mq.edu.au

Received: 13/04/2014

Revised: 04/05/2014

Accepted: 05/05/2014

Keywords: Soil organic carbon, radiocarbon dating, sedimentation rate, SOC dissociation.

1. Introduction

Atmospheric CO₂ plays a major role in global warming and hence its dynamics is a subject of research for several decades. Large uncertainty exists in the pool of carbon stored by soils in the tropical region. Atmospheric carbon reaches soil mainly through plants. Plants assimilate atmospheric CO₂ through photosynthesis, and plant materials incorporate the carbon in to the soil as organic matter. Similarly, all the living organisms when incorporated to soil deposit carbon to soil. Over a timescale expanding from centuries to millennia, most organic carbon in the soil will degrade to inorganic form (Schimel *et al.*, 1994). This form is expected to be more stable, but its variation on temporal and spatial scale is still unknown. Denudation exposes soil for chemical weathering and will enhance consumption of CO₂ in water which is dissolved from the atmosphere (Berner, 1990; France-Lanord and Derry, 1997). This enhances the removal of CO₂ from the atmosphere and reduces atmospheric temperature (Raymo *et al.*, 1988; Kump *et al.*, 2000; Jacobson and Blum, 2003). France – Lanord and Derry (1997) reported that the erosion of Himalaya has caused reduction of atmospheric CO₂ more by burial of organic material in the alluvial fans than by consumption of carbonic acid (formed by the dissolution of atmospheric CO₂ in river water) for weathering. Global scale studies showed that about 1576 Pg (Pg = 10¹⁵ g) of carbon is stored in soil, out of which 32% is stored in soils from the tropics, and a

40% of this fraction is stored by tropical forest soils (Eswaran *et al.*, 1993). Battacharyya *et al.* (2000) reported that the top 150 cm thick soils in India stores ~ 63 Pg of carbon. Erosion can cause release of ~50% of this stored carbon and hence it is important to understand the dynamics of stored carbon in the soil. This report examines the rate of cycling of organic carbon in profile of forest soil and an alluvial deposit from India.

Radiocarbon has been used as a tracer for studying storage and mobilization of organic matter in soil pool over timescales of a few hundred years up to 50000 years (Smittenberg *et al.*, 2006; Yadava *et al.*, 2007). After studying the radiocarbon amounts in organic materials from Holocene deposits from Canada, Smittenberg *et al.* (2006) reported ongoing organic matter – mineral association to permanently fix the carbon and hence claimed that equilibrium is yet to be established in this reaction. They further reported much older radiocarbon ages than the deposition ages, indicating prolonged association of organic matter with minerals without dissociation during any post depositional processes.

There are only limited studies of cycling soil organic carbon in India so far. Yadava *et al.* (2007) compared steady state decay rates of SOC from peat deposits at two locations in the western and eastern Himalayan region respectively. They reported decay rates varying from $0.2 - 13 \times 10^{-4} \text{ yr}^{-1}$. This manuscript discusses the results from a soil profile from a deep

forest area in Bastar, Chhattisgarh in Central India. Radiocarbon data of alluvial deposit samples from Parappukkara in southern India is also reported.

2. Materials and Method

Soil samples were collected from a fresh Road cut (Kotamsar Road) in the deep forest from Kanger Valley National Park (18° 54.762', 81° 53.880', elevation ~400 m). The profile is 80 cm deep above the saprolite layer, with an organic rich surface later, covered with leaf litter. The annual average rainfall at this site is ~1600 mm and the annual average temperature is ~28 °C for this area (Biswas, 2010). Details of the soil samples are given in Table 1.

Sediment samples were collected from two locations of an alluvial deposit from Parappukkara area in Thrissur district in Kerala (10° 24.499', 76° 15.193'). Average annual average rainfall and temperature are ~3000 mm and 29 °C, respectively (Magesh *et al.*, 2012). The Parappukkara River drains the Western Ghats to the Arabian Sea. Details of the samples are given in Table 2. Collection and analysis of all the samples in this study has been carried out during 2004-2006.

All the samples were double bagged and labeled and transported to the lab for further analyses. Gravels, roots and other recent organic matter from the dried samples were removed by handpicking. Inorganic carbon from the carbonate content of the samples was removed by bubbling with orthophosphoric acid. Organic carbon was then burnt in a vacuum glass line with oxygen supply, and converted into CO₂. This was then converted into benzene following the procedure described by Yadava and Ramesh (1999). An organic scintillator (butyl -PBD) was mixed with the benzene for counting the beta activity of radiocarbon on an "LKB-Quantulus" machine. Background is measured using a laboratory standardized coal sample. NBS Oxalic Acid 1 is used for modern activity measurements.

3. Results and Discussion

Soil samples from the Kotamsar Road profile contain 0.03 to 0.22 ppm of organic carbon (Table 1). The SOC content increases with decreasing depth, indicating the concentration of fresh organic materials in the top soil. This organic carbon fraction contains the two stable isotopes of carbon (¹²C and ¹³C) and the radiocarbon (¹⁴C).

Radiocarbon is produced in the upper atmosphere by bombarding of cosmic ray – produced slow neutrons to nitrogen atoms. It decays by emitting a β particle at a half – life of 5730 ± 40 years. The radiocarbon, with the two stable isotopes forms CO₂

and enters the biosphere through photosynthesis and then enters the lithosphere. Once the living organisms die, the intake of C by these organisms stops, and the ¹⁴C will continue its radioactive decay without replenishment and the time elapsed since the death (radiocarbon age) can be determined.

Radiocarbon age (t) of the sample is determined using the classical age equation:

$$t = -8268 \ln \frac{pMC}{100} \quad (1)$$

Where pMC (percentage Modern Carbon) = A_s/A_{abs} expressed in percentage. A_s is the residual radiocarbon activity of the sample and A_{abs} is the absolute radiocarbon activity, which represents the modern activity in the atmosphere, which is obtained using standard samples (Stuiver and Polach, 1977).

The radiocarbon ages of the samples from Kotamsar Road soil profile increase from 111 years to 2190 years from top soil to the bottom (Table 1). The linear increase of age from top to bottom indicates no physical mixing of soil (Fig. 1). This could imply minimal effect of bioturbation of soil on radiocarbon ages at this location.

The radiocarbon age could also represent a mean residence time of organic carbon in the soil. Soil profiles are open to ¹⁴C and hence the time evolution of ¹⁴C in the profile could be expressed as:

$$\frac{\partial C(z,t)}{\partial t} = \phi(z,t) - kC(z,t) \quad (2)$$

following Wang *et al.* (1996). Here, C(z,t) is the organic carbon content (moles/cm³) at depth z at time t. φ(z,t) (moles/cm³/yr) represents the sum of ¹⁴C in the soil at depth z at time t available due to vertical diffusion of organic matter and in situ growth of ¹⁴C due to root penetration. The term k represents a decay constant of organic matter, which includes the loss of ¹⁴C due to diffusion to other layers, decomposition of SOC and radioactive decay.

For simplification of the approach, steady state SOC content can be assumed to calculate indicative decay constant (k_s) for the soil profile (Wang *et al.*, 1996) and can be expressed as:

$$k_s = \frac{\left[\frac{pMC_{om} \times \lambda}{100} \right]}{\left[\frac{pMC_{input-om}}{100} - \frac{pMC_{om}}{100} \right]} \quad (3)$$

And

$$\phi_s = k_s \times C. \quad (4)$$

Calculated values of k_s and ϕ_s for the soil samples are shown in Table 1. These numbers have the limitation of contamination from ‘bomb carbon’ – the radiocarbon produced by atmospheric nuclear testing in the mid of 19th century (Nydal *et al.*, 1996). The then atmospheric ¹⁴C concentration and the current

concentration may be different, which could affect the accuracy of the results. However, it is reported that the ‘bomb carbon’ has not penetrated to deep soil yet (Stout and O’Brien, 1972).

Table 1: Radiocarbon data, k_s and ϕ_s of soil samples from Kotamsar Road

Sample	depth (cm)	soc (g/kg)	Age (year BP)	k_s (10^{-4} yr^{-1})	ϕ_s ($10^{-5} \text{ mol/cm}^3/\text{yr}$)
K10	2	0.22	111 ± 0.87	3.48	9.53
K11	48	0.04	1530 ± 70	1.52	0.78
K12	70	0.03	2190 ± 70	1.29	0.48

Table 2: Radiocarbon data, k_s and ϕ_s of sediment samples from Parappukkara

Sample	Site	Depth (cm)	SOC (g/kg)	Age (year BP)	k_s (10^{-4} yr^{-1})	ϕ_s ($10^{-5} \text{ mol/cm}^3/\text{yr}$)
P6	1	79	0.017	5468±89	0.21	0.043
P7	1	20	0.029	4620±126	0.36	0.131
P8	2	45	0.021	4825±107	0.25	0.647
P9	2	120	0.010	4659±186	0.12	0.155
P10	2	180	0.018	4845±182	0.22	0.503

Yadava *et al.* (2007) assumed that the ‘bomb carbon’ has contaminated only the leaf litter part of the soil profile, based on pollen studies from a soil profile in the Himalayan region. Although there is a possibility that humic acid produced from organic materials from the top penetrating through the soil profile, the influence should be negligible in the case of the soil profile from Kotamsar Road, as there is no mixing of soil observed and the radiocarbon age increases linearly with increasing depth (Fig 1).

The steady state dissociation constant decreasing with increasing depth may indicate the increasing sequestration of organic carbon by soil in that area over time. The organic carbon present in the bottom soil might have been converted into permafrost, which will be permanently stored there. The decreasing ϕ_s values with increasing depth also may indicate that the removable fractions of organic carbon from the soil are decreasing with increasing depth.

The k values for the soil samples are comparable to those reported for Himalayan soils by Yadava *et al.* (2007). Wang *et al.* (1996) also reported similar values of k for soils of similar depths in the US.

River sediments are transported soils and the radiocarbon age may represent an upper limit of the deposition age. The ages of the Parappukkara

sediments represents a faster deposition rate forming a thick layer of alluvium in a shorter period. The k value calculated for these sediments may be considered as indicative only, as these sediments are in transit for a longer period than the deposition age (Table 2). However, the lower k values than those for the soils indicate lower rate of decomposition of organic matter from these sediments. The ϕ_s values for these sediments are an order of magnitude lower than those for the soil samples from Kotamsar Road (Fig 2).

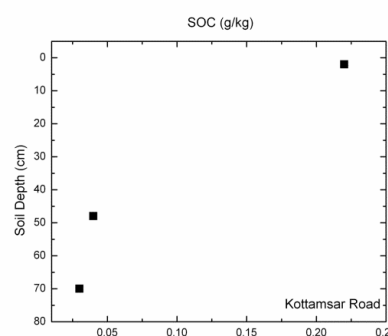


Fig 1: SOC profile of soil samples from Kotamsar Road in Bastar forest area

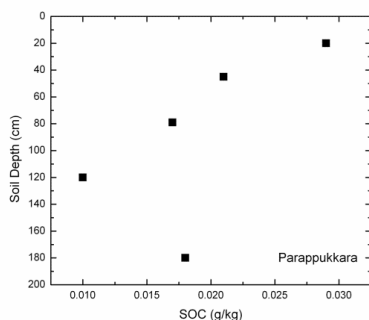


Fig 2: SOC content of river sediment samples from Parappukkara

This could indicate that the steady state calculation of k may need to be modified considering the current organic carbon content. This could further indicate the existence of an optimum organic carbon

dissociation rate in the soil which decides the organic carbon storage capacity.

4. Conclusion

The steady state dissociation constant of soil organic carbon from the tropical Indian forest soils is comparable to those reported for the Himalayan peat deposits. For the river sediments from the southern part of the Indian subcontinent, the dissociation constants are an order of magnitude lower than those reported at other locations. Organic carbon content decreases with increasing depth of the soil. There seems to have an optimum value of the SOC dissociation rate from the soil, which needs further investigation.

Acknowledgement

A Junior Research Fellowship from PRL Ahmedabad supported this project. Assistance and support provided by Mr. N. B. Vaghela, Dr. Madhu G. Yadav and Prof. Ramesh is acknowledged.

References

- Berner RA (1990). Atmospheric carbon dioxide levels over Phanerozoic time. *Science*, 249: 1382-1386.
- Bhattacharyya T, Pal DK, Mandal C and Velayutham M (2000). Organic carbon stock in Indian soils and their geographical distribution. *Current Science*, 79(5): 655-660.
- Biswas J (2010). Kotumsar cave biodiversity: a review of cavernicoles and their troglolobitic traits. *Biodiversity Conservation*, 19: 257-289.
- Cump LR, Brantley SL and Arthur ML (2000). Chemical weathering atmospheric CO₂ and climate. *Annual Review of Earth and Planetary Science*, 28: 611-667.
- Eswaran H, Van Den Berg E and Reich P (1993). Organic carbon in soils of the world. *Soil Science Society of America Journal*, 57: 192-194.
- France-Lanord C and Derry LA (1997). Organic carbon burial forcing of the carbon cycle from Himalayan erosion. *Nature*, 390: 65-67.
- Jacobson AD and Blum JD (2003). Relationship between mechanical erosion and atmospheric CO₂ consumption in New Zealand Southern Alps. *Geology*, 31: 865-868.
- Magesh NS, Jitheshlal KV, Chandrasekar N and Jini KV (2012). GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, India. *Earth Science Informatics*, 5: 111-121.
- Nydal R, Lovseth K and Boden TA (1996). Carbon-14 measurements in atmospheric CO₂ from northern and southern hemisphere sites, 1962-1993. *Global Change Research Program*, 1996.
- Raymo ME, Ruddiman WF and Froelich PN (1988). Influence of late Cenozoic mountain building on ocean geochemical cycles. *Geology*, 16: 649-653.
- Schimel DJ, Braswell BH, Holland EA, McKown R, Ojima DS, Painter TH, Parton WJ and Townsend AR (1994). Climatic, edaphic and biotic controls over storage and turnover of carbon in soils. *Global Biogeochemical Cycles*, 8(3): 279-293.
- Smittenberg RH, Eglinton TI, Schouten S and Sinningh-Damste JS (2006). Ongoing buildup of refractory organic carbon in boreal soils during the Holocene. *Science*, 314: 1283-1286.
- Stout JD and O'Brien BJ (1972). Factors affecting radiocarbon enrichment in soil and the turnover of soil organic matter. *Radiocarbon*, 1: 394-407.
- Stuiver M and Polach H (1977). Reporting of ¹⁴C data. *Radiocarbon*, 19: 355-363.
- Wang Y, Amundsen R and Trumbore S (1996). Radiocarbon dating of soil organic matter. *Quaternary Research*, 45(3): 282-288.
- Yadava MG and Ramesh R (1999). Spelothems—Useful proxies for past monsoon rainfall. *Journal of Scientific and Industrial Research*, 58: 339-348.
- Yadava MG, Gandhi N and Ramesh R (2007). Estimation of decomposition rates of peat deposits using radiocarbon. *Indian Journal of Geochemistry*, 22(1): 57-64.