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Dynamics of organic carbon in deep soils under rice and non-rice cropping systems

Shovik Deb [a], Somsubhra Chakraborty [b,*], David C. Weindorf [c], Arjun Murmu [a], Pabitra Banik [d], Manoj Kanti Debnath [e], Ashok Choudhury [a]

[a] Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Cooch Behar 736 165, India
[b] Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur 721 302, India
[c] Department of Plant and Soil Science, Texas Tech University, Lubbock, TX, USA
[d] Agricultural and Ecological Research Unit, Indian Statistical Institute, Kolkata 700 108, India
[e] Department of Agricultural Statistics, Uttar Banga Krishi Viswavidyalaya, Cooch Behar 736 165, India

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ABSTRACT

Subsoil might be a possible sink of stable C in some regions of India, which itself has low soil C storage. Further, knowledge of subsoil C chemistry under submerged rice ecology is required as rice is one of the major staple cereals in India and waterlogging influences SOC characteristics. This study investigated the dynamics of organic C in surface and deep subsoil layers under rice and non-rice ecology in eastern India. Outcomes revealed less organic C in deep subsoils ($\bar{x}$ 5.35 Mg ha^{-1}), but with higher residence time as evidenced by a higher mean recalcitrant index (20.2) and lower mean lability index (1.86). Further, deep rice soils exhibited higher C sequestration potential than deep non-rice soils resulting from curbed microbial biomass and their activities. Summarily, deep rice soil exhibited the potential for C sequestration, displaying a synergistic effect from deep soil and submerged rice ecology.

1. Introduction

Soil is the prime global carbon (C) sink, harbouring approximately two-thirds of the C in terrestrial ecosystems (Schimel et al., 1994). Since soil organic C (SOC) has a slow turnover rate (Trumbore, 1997), soil C sequestration can diminish CO_2 loading in the atmosphere (Paustian et al., 1997). Organic C also contributes positively to soil fertility and productivity (Lal, 2004a). For these reasons, research on soil C is being undertaken internationally to address both climate change and soil quality. Although most SOC related works thus far have focused on surface soil layers, "deep" subsoil may be an even more important C sink (Scharpenseel et al., 1989). Radiocarbon analysis shows that deep soil C is stable at longer timescales (Marin-Spiotta et al., 2014). Tillage activities do not influence this subsoil C (Blanco-Canqui and Lal, 2008). Further, the presence of an energetic barrier may lower the effect of temperature change on deep soil C (Fontaine et al., 2007). Thus, some have suggested that subsoil has the potential to sequester higher levels of organic C from roots and other inputs (Lozano-García et al., 2016).

Considering soil C pools, submerged rice ecology has also emerged as a potential C sink. Very few studies have revealed the unique soil C chemistry in lowland rice soils that differ from other upland cropping systems (Mandal et al., 2008). Under prolonged waterlogging, depletion of O_2 levels and the absence of iron oxides and hydroxides as electron acceptors have resulted in the slow decomposition of organic substances in rice soils (Sahrawat, 2004). This results in higher accumulation of C in stable fractions (Mandal et al., 2008) or SOC sequestration in rice systems.

India, being a dominantly tropical nation, has the lowest average of SOC among Asian countries (Kyuma, 1988). The majority of cultivated Indian soils contain <0.5% SOC (Lal, 2004b); much less than the world average (Wu et al., 2003). The total C stock of Indian soil is 14 Pg and 64 Pg for upper 30 cm and 150 cm respectively (1 Pg = 10^{15} g) (Bhattacharyya et al., 2000a). Any Indian soil with high organic C stabilization capacity is of great importance for soil sustainability and climate change resilience. In this study, we hypothesized that continuous rice cropping could potentially enable C sequestration in deeper soil C layers/horizons because of inherent characteristics of flooded rice production systems. Conversely, this sequestration potential can be hindered by plow layer compaction. Thus, the objective of the present study was to determine the capacity of rice subsoil to act as a niche of terrestrial C sequestration in comparison to non-rice subsoils in eastern India.

2. Materials and methods

2.1. Study locations and sample collection

Soil samples were collected from two locations of eastern India viz. Gayeshpur KVK farm, West Bengal (22°57′N, 88°29′E) managed by Bidhan Chandra Krishi Viswavidyalaya and Giridih farm, Jharkhand

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* Corresponding author.
E-mail address: somzcall@gmail.com (S. Chakraborty).

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(24°11′N, 86°18′E) managed by Indian Statistical Institute (Fig. 1, Table 1), India. Both locations were under long term field experiments, ensuring equal quality and quantity of C inputs in soils through similar management practices (Mandal et al., 2007). Soils of both farms were of moderate to high weathering stage (Alfisol or Ultisol) (Hartemink, 2003) and texturally varied from clay loam to sandy clay loam (Table 1). The Gayeshpur KVK farm occurs on the great Indian plain while the Giridih farm, Jharkhand is found on the peninsular plateau (Bhattacharyya et al., 2000b). As a whole, the great Indian plain and peninsular plateau store 10.53 and 10.11 Pg SOC, respectively, in upper 150 cm (Bhattacharyya et al., 2000b).

Within each location (Gayespur and Giridih farm), lowland rice and upland non-rice based cropping systems were selected. Under each cropping system, soil samples were collected from three sites with two field replications per site. To compare C and microbial dynamics of surface and below-ground deep subsoils, samples were collected from both surface (0–20 cm) and deeper layers (100–120, 120–140 cm) for each field replication, resulting in a total of 72 samples. Composite soil sampling (five) was performed for each depth for each field replication. Physically soils were collected using a spade, during the winter months (November 2014 to February 2015) when the lands were dry, fallow and without any fresh C addition in soils (Deb et al., 2016). Each sampling location was georeferenced using a hand-held global positioning system receiver (Garmin, Olathe, KS, USA). As SOC pools and soil microbial community composition are influenced by climate (Deb et al., 2015), mean annual precipitation and mean annual temperature were calculated using Food and Agricultural Organization (FAO) software ClimWAT (FAO, 2016).

2.2. Soil analysis

Samples were air-dried, ground and passed-through 2 mm sieve for all soil physicochemical analysis. Soil reaction (pH) was quantified using an electronic pH meter (Systronics, Model 4381) fitted with a glass electrode. Soil CEC was determined per Mandal et al. (2007) using 1.0 *N* ammonium acetate (NH_4OAc) at pH_w 7.0. Soil texture was assessed by pipette method with an error of ±1% clay (Gee and Or, 2002). Soil bulk density was estimated by sampling through 50 mm diameter core sampler and dividing soil oven dried weight (at 105 °C for 48 h) by bulk volume (Blake and Hartge, 1986).

2.2.1. Determination of soil C fractions

Soil total C was determined via Vario EL III elemental analyzer (Elementar, Germany) (Deb et al., 2016). Separately, inorganic C (C_{inorg}) was measured via a dilute HCl method (Jackson, 1967). Subsequently, the soil total organic C (C_{org}) was obtained by subtracting the C_{inorg} from total C. Following the turnover time, the C_{org} was operationally separated into four different fractions by oxidizability using a modified Walkley and Black method (Chan et al., 2001; de Assis et al., 2010; Thomazini et al., 2015). This allowed sub-division of C_{org} into the following fractions (Mandal et al., 2008):

$C_{Fraction\ 1}$, very labile (C_{VL}); organic C oxidizable with 12.0 N H_2SO_4.

$C_{Fraction\ 2}$, labile (C_L); difference between SOC extracted with 18.0 N and 12.0 N H_2SO_4.

$C_{Fraction\ 3}$, low lability (C_{LL}); difference between SOC extracted with 24.0 N and 18.0 N H_2SO_4.

$C_{Fraction\ 4}$, non−labile (C_{NL}); residual SOC after reaction with 24.0 N H_2SO_4.

Following the fractionation of C_{org}, different SOC indices were calculated. A lability index (LI) of organic C was computed following Mandal et al. (2008) (Eq. (1)):

$$LI = \frac{C_{VL}}{C_{org}} \times 3 + \frac{C_L}{C_{org}} \times 2 + \frac{C_{LL}}{C_{org}} \times 1 \qquad (1)$$

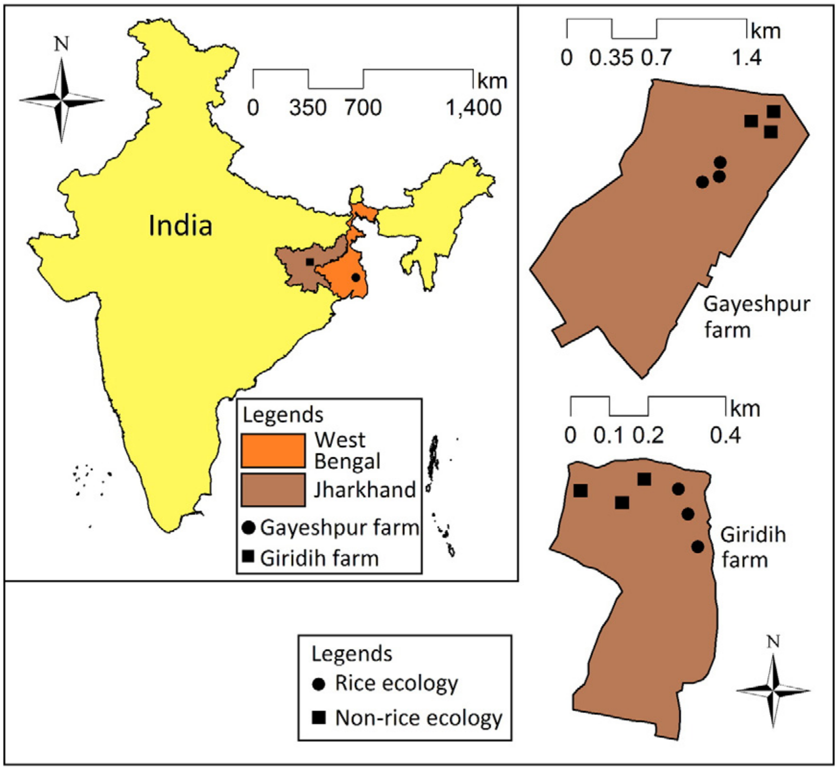

Fig. 1. Location map of soil sampling in eastern India.