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Relative availability of inorganic N-pools shifts under land use change: An unexplored variable in soil carbon dynamics

Pratap Srivastava[a,*], Praveen Kumar Singh[a], Rishikesh Singh[b], Rahul Bhadouria[a], Dharmendra Kumar Singh[a], Shivam Singh[a], Talat Afreen[a], Sachchidanand Tripathi[c], Pardeep Singh[d], Hema Singh[a], Akhilesh Singh Raghubanshi[b,**]

[a] Ecosystems Analysis Laboratory, Department of Botany, Institute of Science, Banaras Hindu University, Varanasi 221005, India
[b] Institute of Environment & Sustainable Development (IESD), Banaras Hindu University, Varanasi 221005, India
[c] Department of Botany, Deen Dayal Upadhyaya College, University of Delhi, New Delhi 110015, India
[d] Department of Chemistry, Indian Institute of Technology (IIT-BHU), Varanasi 221005, India

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ABSTRACT

Land use change (LUC) may detrimentally affect the soil organic carbon (SOC) within different soil fractions; directly supplemented by significant contribution to soil CO_2 efflux (SCE). To understand the governing mechanism, experimental data were collected for SOC and SCE along with soil physico-chemical, microbial and aggregate characteristics across adjacent secondary forest (SF)-grassland (GL)-cropland (CL) sequence in dry tropical ecosystems. A significant change in SOC and SCE was observed from SF to GL and CL systems, respectively; though moderately from GL to CL system. Respective decrease in SOC (31 and 42%); soil ammonium-N to nitrate-N ratio (ANR; 96 and 86%), microbial biomass C (MBC; 30 and 50%), nitrogen (MBN; 6 and 33%) and MBC/MBN ratio (25 and 24%); whereas increase in SCE (43 and 57%) and soil nitrate-N availability (340 and 592%) was observed from SF to GL and CL systems. Moreover, aggregate physical distribution shifted toward smaller size fractions; whereas aggregate-associated total C and $KMnO_4$-labile-C concentration and carbon management index (CMI) across aggregate-size fractions decreased linearly with the land use sequence. SOC was majorly governed by macro-aggregate water stability (WAS_{macro}) and MBC; whereas SCE by CMI of macro-aggregate (CMI_{macro}) fraction. Furthermore, the ANR showed positive correlation with microbial (i.e. MBC and MBC/MBN ratio) and macro-aggregate physical (i.e. WAS_{macro}) and chemical stability (i.e. CMI_{macro}). It indicates that a shift in the microbial community with the land use may affect the relative availability of inorganic N pools and associated aggregate characteristics. Thus, our results indicate that a shift in ANR with LUC may be an unexplored and crucial indicator of soil C dynamics mediating quantitative and qualitative changes in microbial and aggregate characteristics in dry tropical ecosystems. Further, a critical emphasis is needed on the relationship of SOC dynamics with ANR for future studies at various spatiotemporal scales worldwide to recognize its potential role as ecological indicator of SOC dynamics. Also, its inclusion under climatic models may help to better predict the future climate.

1. Introduction

Soil organic carbon (SOC) and its fractions are considered as good indicators of soil quality and environmental stability (Saha et al., 2011), therefore their monitoring and management in human-induced land use change (LUC) is important for global C cycle (Wei et al., 2013). Globally, soil holds around 1500 Pg of soil organic C representing twice and thrice as much C as in atmosphere and aboveground biomass, respectively (Batjes, 1996; Lal, 2008; Schmidt et al., 2011). LUC in the form of conversion of forest to grassland and/or cropland induces heavy changes in SOC dynamics (Helfrich et al., 2006), leading to C losses in the order of 10–55% (Helfrich et al., 2006; Perrin et al., 2014), however its mechanistic understanding is still limited in tropics (Lal, 2012; Perrin et al., 2014). LUC enhances the soil greenhouse gaseous emissions by releasing stored soil C to the atmosphere, particularly in tropics,

* Corresponding author at: G-18 Ecosystems Analysis Laboratory, Department of Botany, Institute of Science, Banaras Hindu University, Varanasi 221005, India. Tel.: +91 09305174058; mobile: +91 09451845309.
** Corresponding author.
E-mail addresses: prataps103@gmail.com (P. Srivastava), raghubansh@gmail.com (A.S. Raghubanshi).

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thus impacts global climate change and food security (Lal, 2004; IPCC, 2007; Don et al., 2011). Globally, tropics shares 32% of C present in the world soil, of which around 40% is present in the forest soils (Eswaran et al., 1993) where the current rate of C loss due to LUC is about 1.6 ± 0.8 Pg C y^{-1} (Smith, 2008). Scientists working on global warming and climate change have identified soil as a major source and sink for atmospheric CO_2 (Schmidt et al., 2011; USEPA, 2011; Sanford et al., 2012). Therefore, the quantification of different SOC pools and soil CO_2 emissions and its governing factors are necessary for the mechanistic understanding of how LUC affects the SOC dynamics for the management implications.

Land use change plays a regulatory role in SOC dynamics affecting microbial composition and activity in bulk soil as well as within aggregates (Wagai et al., 1998; Helgason et al., 2010; Wallenius et al., 2011; Cui et al., 2014). Land use majorly predicts the short term soil CO_2 flux (SCE) affecting soil microbial properties (Iqbal et al., 2009). However, microbial attributes have not been found to be related with C mineralization in most of the studies (Strickland et al., 2010). Soil microbial biomass (SMB) act as a source and sink of available nutrients, thus defines nutrient transformation in terrestrial ecosystems (Singh et al., 1989). Any changes in it may also affect the cycling of SOC. It is highly responsive to changes in land use and management than SOC (Henneron et al., 2015). Generally, it tends to decline with LUC from forest to grassland and/or cropland and offers a method in assessing the soil quality in different vegetation types (Groffman et al., 2001).

Land use change causes a loss of soil structure, but limited studies have focused on the effect of changes in aggregate size distribution and characteristics on soil physical, chemical and biological properties (Conant et al., 2004; Cui et al., 2014). Land use with minimum disturbance favors a better soil aggregation/structure (Liu et al., 2010) and conversion to appropriate land uses may recover the soil structure and quality (Li and Pang, 2010; Sanford et al., 2012). Soil aggregation is intrinsically linked with C accumulation (Six et al., 2000a,b). Further, the soil aggregation is reported to have dominance over microbial-mediated decomposition processes in terrestrial ecosystems (Six et al., 2004). Moreover, soil aggregation not only physically protects soil organic matter (SOM), but influences microbial community structure, limits oxygen diffusion, regulates water flow, determines nutrient adsorption and desorption, and reduces run-off and erosion (Six et al., 2004). Under LUC, the architecture of the pore network is much affected (Ruamps et al., 2011). The localization and accessibility of the organics stored in soil micropores inside aggregates has been found to be a function of complex biophysical interactions under changing microclimatic conditions during soil development (Simpson et al., 2004). All of these processes have profound cumulative effects on SOM dynamics and nutrient cycling. Further, Six et al. (1998) reported that soil management systems that promote aggregate destruction, principally of macro-aggregates, increase SOM decomposition rates due to the exposure of previously protected organic matter in the aggregates. The turnover of macro-aggregate, which contains greater amount of C than micro-aggregate, is fast under human management (Smith et al., 2015). The faster turnover greatly affects the C and N distribution across aggregate-size fractions (Li and Pang, 2010). The stability and turnover of macro-aggregate has been reported to define the characteristics of micro-aggregates as well (Elliott and Coleman, 1988). Therefore, LUC probably influence SOM decomposition rates affecting aggregate turnover, probably by affecting the architecture of aggregates (Cui et al., 2014; Rabbi et al., 2014a,b). Further, the identification of major driver of aggregate dynamics and C distribution within aggregate fractions with LUC would be pivotal as an indicator variable for the shift in SOC dynamics.

Pools and turnover of SOC are highly sensitive to LUC. LUC defines soil structural dynamics by affecting the qualitative and quantitative distribution of input C across aggregate size fractions. However, investigation of qualitative and quantitative effects of LUC on SOC is limited (Poeplau and Don, 2013). Attempts have been made to identify SOC fractions highly sensitive to LUC than bulk SOC, for an early detection of overall stock change (Lobe et al., 2011). Therefore, the process of C dynamics can be better understood by the differences in SOC and its fractions among different land uses (Saha et al., 2011). Soil C loss is decomposition-dependent, affected chiefly by quality of the substrate and microbial communities (Chapela et al., 2001). Recent researches have shown that molecular structure alone does not control SOM stability but environmental and biological control predominates (Schmidt et al., 2011). It is hypothesized that the turnover of aggregate-associated C is dependent on soil structural development and its dynamics would be mediated by the availability of soil nutrient pool. In addition, relative availability of soil inorganic N-species (i.e. soil nitrate-N and ammonium-N) on SOC dynamics has not been performed. Therefore, the present study investigates that how the changes in soil physicochemical, microbial and aggregate attributes with LUC affect SOC dynamics to find out a possible ecological indicator of change in the soil processes. Therefore, the objectives of present study were: (1) to study the quantitative and qualitative shift in nutrient, microbial and aggregate characteristics with LUC and (2) how these changes mechanistically govern SOC dynamics with special reference to relative availability of inorganic N pools.

2. Materials and methods

2.1. Description of experimental sites

The study was conducted at the experimental plots in the Banaras Hindu University campus, Varanasi, India during the peak of winter season of 2011–2012. The study sites comprise three separate patches of secondary forest (SF), grassland (GL) and agricultural plots (CL) each. These adjacent land uses were selected in this study as they represent the major land use types in recent times. These land use types have been created due to conversion of native forest vegetation during the year 1992–1995. The SF represents monoculture of *Cassia siamea* planted after several year of fallow, following denudation of existing native forest. Some unplanted sites, however, led to the development of the GL primarily dominated by *Cyperus rotundus*, *Cynodon dactylon*, *Desmodium trifolium*, etc., having moderate anthropogenic disturbance. Moreover, some sites were tilled for agriculture having rice-wheat fallow system, which was under chemical fertilizer-based nutrient management. The cropland sites were under wheat cultivation during the sampling. The textural composition across all the three land use systems was similar. These sites comprise a part of Indo-Gangetic Plain located at 25°18′ N latitude and 80°01′ E longitudes with 76 m above the mean sea level. The soil is Inceptisol with silty-loam texture having neutral pH. The climate is tropical monsoonal with a hot and dry summer (April–June), a cold winter (November–February) and a warm rainy season (July–September). The highest temperature is found in summer (range, 30–45 °C) and lowest in winter season (range, 10–25 °C). Highest and coldest months across the respective seasons are reported in May and January. The annual rainfall averages from 1100 mm of which 85% falls during the rainy season. There is an extended dry period of about nine months and rainfall occurs on about 55 days in an annual cycle. Moreover, occasional light rains are experienced during the winter season from retreating western monsoon.

2.2. Soil sampling

Soil sampling was done at the peak of winter season in 2011–12 from each of the three patches of secondary forest (SF), grassland