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Original Research Article

Riparian land uses affect the dry season soil CO_2 efflux under dry tropical ecosystems

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ABSTRACT

Riparian ecosystems are amongst the most vulnerable ecosystems of the world. The natural gradients and increasing human perturbations under these ecosystems can be explored for understanding the soil carbon (C) dynamics, especially soil carbon dioxide (CO_2) efflux. However, studies on soil CO_2 efflux and its governing variables under different land uses of dry tropical riparian ecosystems are limited. Therefore, the present study aimed (1) to assess the impact of riparian land use on soil CO_2 efflux, and (2) to identify the key drivers of soil CO_2 efflux along the river Ganga, Varanasi, India. The riparian land uses taken in this study were moist sandy flat (MSF), uncultivated sandy land (USL) and cultivated sandy land (CSL) depending upon their slope and distance from river body to upland, respectively. Soil CO_2 efflux and other soil biophysical properties were measured at 54 locations distributed in six sites having these land uses, in dry season of 2014–15. Soil biophysical properties considered in this study were soil organic C, soil moisture, bulk density, porosity, fine particles, microbial biomass C and soil pH. Riparian land uses were found to have significant impact over soil CO_2 efflux with a respective increase of 222, 424 and 63%, for MSF to USL, MSF to CSL, and USL to CSL land use transitions ($P < 0.01$), respectively. Similarly, the regulators of soil CO_2 efflux varied with the land uses. It showed strong positive correlation with soil organic C ($r = 0.81$), fine particles ($r = 0.64$) and porosity ($r = 0.61$), whereas negative correlation with soil moisture ($r = 0.61$) and bulk density ($r = 0.62$) for overall dataset. However, soil organic C, fine particles, microbial biomass C and soil pH at MSF; soil organic C and microbial biomass C at USL; and soil moisture, porosity and microbial biomass C at CSL land uses were observed to regulate soil CO_2 efflux. The findings revealed that riparian land uses have significant control over soil CO_2 efflux and its biophysical regulators which have relative control over it. Soil organic C, soil moisture, fine particles, porosity and microbial biomass C were identified as prevalent regulators of soil CO_2 efflux under dry seasons. Overall, the results indicate that the biophysical variables in addition to human interferences (CSL land use) have pronounced regulation over soil CO_2 efflux in dry tropical riparian ecosystems.

1. Introduction

Soil CO_2 efflux accounts for the largest terrestrial source of atmospheric CO_2, emitting around 80 Pg C yr^{-1} (Raich et al., 2002; Curiel-Yuste et al., 2007). It attributes around ten times higher CO_2 emission than fossil fuel burning (Andrews and Schlesinger, 2001). Accordingly, minor spatial variations in it across different land uses and natural ecosystems have significant impact over global C cycle. Soil organic C (SOC) loss as soil respiration (soil CO_2 efflux) is one of the major contributor to present climate change feedback mechanism (Raich et al., 2002; Jha and Mohapatra, 2011). An increase in soil CO_2 efflux in response to global warming is proposed by several researchers due to large pool of potentially mineralizable C in soils and its high soil-atmosphere exchange (Curiel-Yuste et al., 2007). For example, the area lying between stream channel and the nearby upland vegetated land constitute the riparian ecosystems (Seibert and McGlynn, 2005), however, it differs from the uplands in soil and hydrologic characteristics. These ecosystems generally have high soil moisture and low water table (Chang et al., 2014), and contribute significantly to the primary productivity in dry environments, thus acts as a remarkable nutrient turnover zones (Schade et al., 2002). Generally, these ecosystems are consisted of flat sandy landscape, dominated by hydromorphic soils having buried labile carbon as high soil organic matter (SOM) con-

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tent (Gurwick et al., 2008; Pacific et al., 2011). These ecosystems are highly vulnerable to degradation due to their sensitivity to land use change (Jha et al., 2010; Harvolk et al., 2015; Jiang et al., 2015; Yang et al., 2015). The important land uses often visible in dry tropical riparian ecosystems include conversion of herbs vegetated landscape (sandy-loam) to agricultural landscape (Bedard-Haughn et al., 2006; Jha et al., 2010; Cui et al., 2015; Jiang et al., 2015). Thus, these are considered as one of the most important contributors to terrestrial CO_2 emission (Degryze et al., 2004).

The strong gradient in biophysical properties (such as soil moisture, organic C, labile C and porosity) across riparian ecosystem has significant impact on soil CO_2 efflux (Pacific et al., 2008, 2011; Riveros-Iregui et al., 2012). For example, soil temperature and moisture have been considered as the major determinants of soil CO_2 efflux, in addition to soil texture, bulk density, degree of saturation and microbial activities (Singh and Gupta, 1977; Curiel-Yuste et al., 2007; Batlle-Aguilar et al., 2012; Sun et al., 2013; Chang et al., 2014; Srivastava et al., 2015, 2016a, b). Further, the spatial variability in soil CO_2 efflux induced by landscape structures has been the focus of last decades to understand the physical and environmental controls over it under temperate ecosystems (Pacific et al., 2011). Therefore, understanding of the role of such ecosystems in soil C dynamics *i.e.*, net C source or sink, is of immense importance under dry tropical ecosystems (Pandey et al., 2014). Moreover, in the present changing climatic scenario, detailed characterization of biophysical-topographic interactions in addition to biophysical-climate interactions is imperative to understand the soil CO_2 efflux response (Pacific et al., 2008; Riveros-Iregui et al., 2012). Overall, variations in soil CO_2 efflux under riparian ecosystems provide a thrust to examine the effects of land uses in relation to various biophysical variables at varying spatio-temporal scales (Pacific et al., 2008; Pacific et al., 2011; Chang et al., 2014). In this regard, riparian land use gradients, having strong variability in soil CO_2 efflux determinants such as soil moisture, temperature, SOM and texture, could act as a model system for the spatial investigation of soil CO_2 efflux under climate change scenario (Pacific et al., 2009, 2011; Riveros-Iregui et al., 2012).

Recently, a few studies have focused on the soil nutrient dynamics from the dry tropical riparian ecosystems under different soil-atmosphere-water interfaces (Jha et al., 2010; Pandey et al., 2014, 2015; Xiong et al., 2015). However, studies on soil CO_2 efflux and its major drivers in dry tropical riparian land uses at spatial scales are limited (Griffiths et al., 1997; Bedard-Haughn et al., 2006; Jha and Mohapatra, 2011). Further, Yang et al. (2015) emphasized on the need of understanding of various ecological aspects of tropical riparian ecosystems under changing climate and human perturbed conditions. Overall, to shield the gap between the riparian land uses, their nutrient dynamics and its role in present climate change- and human-related processes, studies on spatial variability of soil CO_2 efflux and identification of its key determinants is necessitated. Therefore, a study was designed to understand the spatial pattern of soil CO_2 efflux along with its governing variable across a riparian section of the river Ganga (Varanasi stretch), India. The Ganga river basin constitutes a major part of dry tropics and considered as the lifeline of the country, India. Presently, it is under immense anthropogenic pressure and needs its basin management. This study would provide a thrust to the ecological engineers to understand the mechanism governing soil CO_2 efflux and the role of the river basin under present climate change scenario. Thus, we aimed to study the soil CO_2 efflux across various riparian land uses (*viz.,* moist sandy flat, uncultivated sandy land, and cultivated sandy land) to address the following objectives: (1) to observe the spatial variation in soil CO_2 efflux across the riparian land uses, and (2) to identify the key biophysical determinants of soil CO_2 efflux under different riparian land uses.

2. Material and methods

2.1. Site description

The study was conducted along the bank of the river Ganga across Varanasi stretch, Uttar Pradesh, India. The study sites represent a typical semi-arid dry tropical riparian landscape. Six representative sites, distributed from 25°12′43.1″N to 25°18′08.5″N and 82°57′13.6″E to 83°01′12.1″E (Fig. 1), were chosen along the river on the basis of available aerial map and on-site survey relevant for this study. The sites were Shultankeshwar (ST), Narottampur Khurd (NK), Mirzapur Khurd (MK), Garhwa Ghat (GG), Ramnagar Bridge (RB) and Katesar (KT) situated along the river Ganga (Fig. 1, Supplementary Table 1). Of these, three sites (*viz.,* ST, NK and GG) were situated along Varanasi river bank, whereas, other three sites (*viz.,* MK, RB and KT) were situated opposite to the Varanasi river bank (Fig. 1). The sites are located in flood plain of the river Ganga and generally remain inundated during the months of August to mid-October. The study area is characterized by a typical dry tropical monsoonal climate, predominated by three distinct seasons, *viz.,* summer (April to mid-June), rainy (mid-June to September) and winter (November to February). October and March constitute the transitional months between the rainy and winter seasons and between the winter and summer seasons, respectively (Singh et al., 2008; Srivastava et al., 2016b; Chaturvedi et al., 2017). Average annual rainfall is 1100 mm, of which 85% rainfall occur during the rainy season. Monthly minimum and maximum temperatures varied between 7.3–25.4 °C and 25.6–35.6 °C, respectively (Singh et al., 2008). During the study period (winter peak), no rainfall was recorded and the temperature ranged from 13 to 16 °C with an average of 14 °C, however, occasional overcast conditions were observed.

2.2. Landscape description

The river Ganga is perennial in nature originating from Gomukh in the Western Himalayan region and enters the plain in Uttarakhand. The river flow is fast up to Haridwar and gets slower after entering the flat plains in Uttar Pradesh, where the study was conducted. Comparatively slower flow has been responsible for the deposition and formation of flat alluvial plain of Indo-Gangetic Plains (IGP) from Western Uttar Pradesh to West Bengal, considered as the most productive region of the world. Therefore, it is considered as the lifeline of the country, India, with its flow length of around 2525 km passing through the major cities of the country. The soils and sediments are typically made by the regular alluvial depositions differing in percentage of fine soil fractions (silt and clay components) and were characterized as alluvial fluvisols (with SOC range of 1–2%) as per the World Reference Base (Nachtergaele et al., 2000; Pandey et al., 2014).

Generally, the riparian zones of the semi-arid regions of India comprises of xerophytic shrubs, bushes and trees between terraced table land at the top and ravenous land at the bottom (Jha and Mohapatra, 2011). Thus, the sides of the river Ganga are distinctly comprise of moist sandy river front zone close to the river water flow, followed by sandy-loam moist bed dominated by herbaceous vegetation, followed by comparatively drier loamy cultivated landscapes (Supplementary Table 1). These landscapes are further characterized here as the land uses due to human interferences along the river body as Moist Sandy Flat (MSF), Uncultivated Sandy Land (USL), and Cultivated Sandy Land (CSL) representing the sandy bed, grassy patch and agricultural land, respectively (Fig. 2). The MSF, which was in immediate proximity with the river water (upto 5 m from the river body), was characterized with water-logged condition with zero herbaceous vegetation. The USL was characterized by the soil moisture level below MSF and dominated by herbaceous