Geoderma 241–242 (2015) 41–50

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Carbon dioxide and methane fluxes in variably-flooded riparian forests

P.A. Jacinthe *

Department of Earth Sciences, Indiana University Purdue University, Indianapolis, IN 46202, United States

ARTICLE INFO

Article history:
Received 24 May 2014
Received in revised form 14 October 2014
Accepted 15 October 2014
Available online 8 November 2014

Keywords:
Riparian forest
Overbank flooding
Methane uptake
Flood protected

ABSTRACT

The water quality protection function of riparian buffers is widely recognized, but much less is known regarding the dynamics of greenhouse gases in these ecosystems. Carbon dioxide (CO_2) and methane (CH_4) fluxes were monitored at 6 riparian sites along a 4th-order segment of the White River (Indiana, USA) to assess the effect of vegetation and flood frequency on gas fluxes. The study sites included shrub/grass, young (<15 years) and mature (>80 years) riparian forests that were either flood-protected (FP), occasionally flooded (OF) or frequently flooded (FF). No significant effect of vegetation type on either CO_2 or CH_4 flux was noted. While CH_4 level was sometimes high (up to 120 $\mu L\ L^{-1}$) in the deep soil layers, concentration near the soil surface (1.28 $\mu L\ L^{-1}$) was generally lower than in the litter layer (2.35 $\mu L\ L^{-1}$). In addition to this pattern, the negative relationship (r^2: 0.23, $P < 0.04$) between CH_4 flux and soil air CH_4 concentration in the 0–20 cm soil depth suggests the occurrence of a zone of active CH_4 oxidation in the upper soil layers. While CO_2 emission was significantly ($P < 0.001$) higher at the flood-impacted than at the flood-protected sites, the opposite was observed with regard to CH_4 uptake. Depending on soil temperature, flood events triggered spikes in CH_4 emission (up to +45.1 mg CH_4-C $m^{-2}\ d^{-1}$ at the FF mature forest). Among the mature forests, mean flux was +0.61, −1.57 and −3.12 mg CH_4-C $m^{-2}\ d^{-1}$ at the FF, OF and FP site, respectively. These results demonstrate that some riparian forests can act as strong terrestrial CH_4 sinks, but that potential can be easily offset with increased frequency of flooding. Thus, a characterization of flood frequency is required for large scale assessments of CH_4 fluxes in riparian ecosystems.

1. Introduction

Riparian buffers can attenuate the transfer of pollutants to adjacent surface water bodies, and thus act as natural filters in the landscape. Depending on geomorphic settings and climate, the connection between a riparian buffer and an adjacent stream channel can be variable. The nature and degree of that connectivity can influence a range of biotic and abiotic drivers, and ultimately determine the efficiency of pollutant removal in riparian buffers. Research conducted during the last several decades has provided ample documentation of the water quality protection function of riparian ecosystems (Lowrance et al., 1997; Polyakov et al., 2005), but much less is known regarding the dynamics of greenhouse gases (GHG) in riparian buffers. Groffman et al. (1998) noted the discrepancy between the large amount of research on nutrient removal and the lack of data on trace gas dynamics in riparian ecosystems.

Owing to their landscape position, riparian areas can be periodically inundated, and that can have immediate and long-term effects on biogeochemical processes in riparian soils, including the exchange of GHG with the atmosphere. Flood events can lead to O_2 exclusion from soil pore space, and ultimately result in the production of methane (CH_4) as a by-product of anaerobic metabolism. Flood events can contribute to the redistribution of nutrients and the deposition of organic debris from allochthonous sources across riparian landscapes, and such inputs can augment the supply of organic substrates available to decomposers. Flood regime can also indirectly influence soil respiration through its effect on the floristic composition of riparian vegetation communities, and the amount, distribution (shoot versus root) and chemical composition of plant tissues deposited on riparian land surface (Catford et al., 2011; Rotkin-Ellman et al., 2004; Tufekcioglu et al., 2001).

The atmospheric trace gases carbon dioxide (CO_2) and methane (CH_4) play important roles in the chemistry and thermal balance of the earth's atmosphere, and the steady growth in their atmospheric concentration during the last 150 years (CO_2: 280 in 1850s to 380 $\mu L\ L^{-1}$ in 2005; CH_4: 0.715 to 1.77 $\mu L\ L^{-1}$) has been linked to the accelerated greenhouse effect (IPCC, 2007). Terrestrial ecosystems – forest soils in particular – represent an important CH_4 sink with a global uptake capacity of 30–40 Tg $year^{-1}$ (Mosier et al., 1997). This uptake is achieved through the oxidation of CH_4 by methanotrophic bacteria in soils.

Our knowledge of CH_4 dynamics in terrestrial ecosystems is derived almost exclusively from research conducted in upland soils, and limited information currently exists with regard to CH_4 dynamics in flood-affected riparian forest soils. This question is particularly relevant to the US Midwest region where deciduous forest is the dominant land

* Department of Earth Sciences, Indiana University Purdue University Indianapolis (IUPUI), 723 W. Michigan Street, SL 118H, Indianapolis, IN 46202, United States.
E-mail address: pjacinth@iupui.edu.

http://dx.doi.org/10.1016/j.geoderma.2014.10.013
0016-7061/

cover in riparian buffers (Palik et al., 2004), some of which are variably affected by flood events. McLain and Martens (2006) reported a net CH_4 uptake in semi-arid riparian ecosystems when soil moisture was not severely limiting, whereas Ambus and Christensen (1995) recorded both emission and uptake upon flooding of riparian areas. Kim et al. (2010) reported an effect of vegetation cover on CH_4 dynamics, with forested and grass-covered buffers acting as CH_4 sinks and sources, respectively. The production of CO_2 in riparian ecosystems has been investigated through modeling and laboratory experiments (Jacinthe et al., 2003; Rotkin-Ellman et al., 2004), but only few studies have reported field-scale measurements of CO_2 in riparian areas (McLain and Martens, 2006; Oberbauer et al., 1992; Tufekcioglu et al., 2001).

The dynamics of CO_2 and CH_4 in riparian zones can be affected by bio-physical properties of soils, vegetation attributes, and hydro-climatic factors such as temperature, rainfall, and flood frequency. At the present, however, the impact of these factors on CO_2 and CH_4 fluxes in riparian buffers is not well characterized. Past studies have shown that flood history affect riparian vegetation community composition (Catford et al., 2011; Rotkin-Ellman et al., 2004), and the distribution of sediment, organic matter and nutrients across riparian landscapes (Blazejewski et al., 2009). Flood frequency was also found to have both short-term and long-term effects on the nitrous oxide-producing capacity of riparian soil (Jacinthe et al., 2012). In light of the foregoing, it is hypothesized that flood frequency determines the dynamics of trace gases in riparian buffers, with higher emission rates expected in flood-impacted than in flood-protected riparian areas. Therefore, the objective of this study was to assess the effect of vegetation type and flood frequency on CO_2 and CH_4 fluxes in riparian buffers.

2. Materials and methods

2.1. Description of study sites

The study was conducted at the Lilly Arbor restored floodplain (N 39°46′, W 86°11′), Southwestway Park (N 39°39′, W 86°14′) and McCormick's Creek State Park (N 39°17′, W 86°44′) along a fourth-order stretch (70 km) of the White River in South-Central Indiana (USA), between the city of Indianapolis to the north and the town Spencer to the south (Fig. 1).

The Lilly Arbor floodplain includes a shrub/grass vegetation community, and woodlots established during restoration of the site in 1999. At that location, mean (1970–2010) river discharge is 46.9 $m^3 s^{-1}$ and the bankfull discharge is ~270 $m^3 s^{-1}$. The site is occasionally flooded (2–3 times $year^{-1}$). The Southwestway Park includes a mature forest (>80 years) and an aggrading (~15 years) forest stand established in the mid-1990s on farmland removed from agriculture in 1984. The mature forest is occasionally flooded (2–3 times $year^{-1}$), whereas the aggrading forest is protected from flooding by a constructed levee. At the McCormick's Creek State Park, two tracts of mature forest were delineated: one tract that is flood-protected due to its position on a second terrace, and a frequently flooded (4–6 times $year^{-1}$) forest stand at the confluence of the White River and McCormick's Creek. The flow of water from McCormick's Creek (a second order stream) into the White River is sometimes impeded when water level in the White River is high, causing backwater inundation of adjacent low-lying areas (Fig. 1). River discharge and water temperature data were obtained from U.S. Geological Survey (USGS; http://waterwatch.usgs.gov) gauging station 3353000

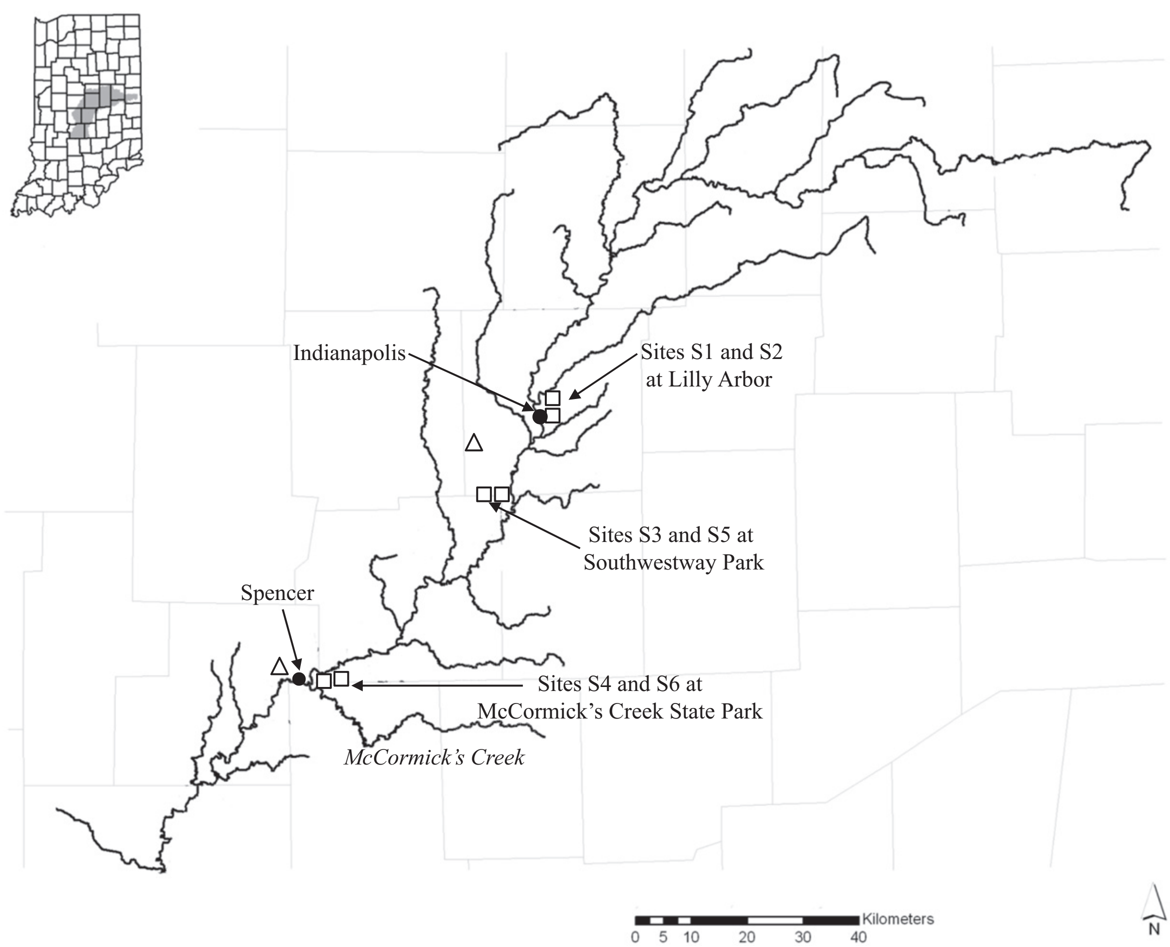

Fig. 1. Location of the study sites in the White River watershed (depicted by the gray area in the Indiana map insert). The black circles indicate locations of the study sites along the White River. The triangle symbols represent the location of the weather stations in Indianapolis and Spencer, IN.