Soil Biology & Biochemistry 69 (2014) 382–392

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

Erosion-induced changes in soil biogeochemical and microbiological properties in Swiss Alpine grasslands

Ji-Hyung Park [a],*, Katrin Meusburger [b], Inyoung Jang [c], Hojeong Kang [c], Christine Alewell [b]

[a] Department of Environmental Science & Engineering, Ewha Womans University, Seoul 120-750, Republic of Korea
[b] Environmental Geosciences, Department Environmental Sciences, University of Basel, 4056 Basel, Switzerland
[c] School of Civil and Environmental Engineering, Yonsei University, Seoul 120-749, Republic of Korea

A R T I C L E I N F O

Article history:
Received 10 July 2013
Received in revised form
18 November 2013
Accepted 24 November 2013
Available online 7 December 2013

Keywords:
Alpine grassland
Bacterial abundance
Soil carbon sequestration
Dissolved organic carbon
Fluorescence EEMs
Soil enzymes
Soil erosion
Wetland soil

A B S T R A C T

Soil erosion can alter the storage of carbon (C) and other biogeochemical properties in both eroding and depositional soils. Little is yet known about soil microbial responses to erosion-induced changes in the quantity and quality of organic matter in mountain grasslands. To examine biogeochemical and microbiological responses to soil erosion, we compared the concentrations and stable isotope ratios of C and N, and microbial properties in eroding upslope (oxic), and depositional downslope (oxic) and wetland soils among three grasslands in the Swiss Alps. Compared to the reference site (Moos), the eroding upslope soils (Laui and Bielen) tended to have lower N concentrations and δ^{15}N. The depositional wetland soils had higher δ^{13}C and lower δ^{15}N and C and N concentrations compared to the reference wetland, reflecting the influence of dry, oxic soils from eroding slopes. The depositional wetland soils had lower water-extractable organic C (WEOC) concentrations and optical intensities (UV absorbance and humic- and protein-like fluorescence) compared to the reference wetland. The activity of soil enzymes was positively related to most of the measured parameters indicative of organic matter quantity (e.g., %C and %N) and quality (e.g., WEOC and protein-like fluorescence), exhibiting significantly lower values in the sheet erosion-affected wetland (Bielen) than at the other sites. 16S rRNA gene copy numbers in the wetland were smaller than in the upland soil at all sites and greatest at Laui among three sites, indicating a potential alteration of the microbial community by the deposited oxic soils and attached microbial cells. The results suggest that soils deposited from the eroding slopes can slow down organic matter decomposition in the depositional wetland soils through decreases in the availability of labile organic matter and enzyme activity. Further research is required to elucidate erosion-induced changes in the activity and abundance of wetland microbial communities.

1. Introduction

Soil erosion represents one of the most important, but poorly quantified environmental problems, particularly in mountain regions (Pimentel et al., 1995; Gobin et al., 2004; Montgomery, 2007). There have been rare attempts to quantify soil erosion in mountainous regions under natural precipitation regimes (Felix and Johannes, 1995; Descroix and Mathys, 2003; Isselin-Nondedeu and Bedecarrats, 2007). On-site measurements of soil erosion are particularly challenging in mountainous regions where low accessibility often makes it difficult to employ research methods developed for the lowlands and harsh climatic conditions such as heavy snow and frost events may destroy measurement devices (Konz et al., 2009). Time integrating approaches based on the radionuclide Caesium-137 (Cs-137) and geochemical tracers such as stable isotopes are promising for soil erosion detection (Alewell et al., 2008; Schaub and Alewell, 2009; Schaub et al., 2010; Meusburger et al., 2013). However, these recent methodological developments have rarely been linked with soil microbiological measurements to examine the response of soil microbial communities to erosion-induced physical disruptions or soil biogeochemical alterations in mountain grassland ecosystems (Hiltbrunner et al., 2012).

The deposition of eroded soils at various depositional settings has recently been implicated as a sink of atmospheric CO_2 (Berhe et al., 2007; Galy et al., 2007; Van Oost et al., 2007, 2012; Zehetner et al., 2009), although erosion has traditionally been considered a major source of CO_2 in agricultural soils (e.g., Lal and Pimentel, 2008). Most of recent studies on erosion-induced C sinks have focused on erodible agricultural fields or grasslands in lowland

---

* Corresponding author. Tel.: +82 2 3277 2833; fax: +82 02 3277 3275.
E-mail address: jhp@ewha.ac.kr (J.-H. Park).

0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.11.021

areas in which increased stabilization of C buried in depositional landscape positions has been associated with physical protection of organic matter within the soil aggregates or organic matter complexation with soil minerals (Berhe et al., 2012; Doetterl et al., 2012). There have been only a few attempts to study the erosion-induced alterations of C storage and other biogeochemical properties in degraded Swiss Alpine soils under a strong influence of agricultural activities (Alewell et al., 2009). Grazing and cattle trampling have been suggested as major controls on the morphology and chemistry of degraded soils over decades (Trimble and Mendel, 1995; Hiltbrunner et al., 2012). In a Swiss sub-alpine pasture, for example, Hiltbrunner et al. (2012) found lower C contents in the bare surface soils than in the vegetated areas and ascribed this to an enhanced erosion rather than to the soil compaction caused by cattle trampling. Altered C storage in erosion-impacted soils has been associated with changes in the composition and activity of microbial communities in Swiss and other grassland systems (McKinley et al., 2005; Hiltbrunner et al., 2012). It remains unexplored whether C dynamics and microbial activity differ along erosion-deposition gradients in the mountain grassland ecosystems and how their changes affect the capacity of C source or sink in depositional downslope soils including wetland soils.

Properties of microorganisms in soils can be assessed in several ways. Firstly, soil biogeochemical processes mediated by microorganisms provide valuable information about ecosystem functioning. For example, enzyme activities in soils have widely been studied in relation to decomposition rates of organic matter (Sinsabaugh and Findlay, 1995; Carreiro et al., 2000; Sinsabaugh et al., 2002; Freeman et al., 2004). In addition, enzyme activities have been used as an indicator for various microbial properties and environmental influences on ecosystems. For example, enzyme activities were determined to assess the abundance of microorganisms (DeForest et al., 2004), microbial community composition (Sinsabaugh, 1994; Waldrop et al., 2000), microbial diversity (Caldwell, 2005), influences of soil physico-chemical properties (Amador et al., 1997; Kang and Freeman, 1999) or vegetation (Kang and Freeman, 2007), and impacts of disturbance (Saiya-Cork et al., 2002). It is anticipated that soil erosion would change not only soil physico-chemical properties but also microbial properties such as composition, abundance, and activity (Xu et al., 2010; Hiltbrunner et al., 2012). Impacts of soil erosion on enzyme activities have been addressed in some highly degraded soils (Garcia and Hernández, 1997; Moreno-de las Heras, 2009), but not at all in mountain grassland ecosystems. Information of soil enzyme activities, in combination with the structure and abundance of soil microbial communities, would help to evaluate the long-term effects of soil erosion on organic matter decomposition and long-term stability in both eroding and depositional positions of grassland ecosystems. Culture-based bacterial analysis can usually detect a small fraction of the total microorganisms in soils. Various molecular approaches have recently been developed and applied to investigate the microbial community structure and abundance in soils. In particular, 16S rRNA and its genes have proven to be powerful markers for the presence of bacteria in soil samples (Janssen, 2006). Real-time quantitative polymerase chain reaction (PCR) targeting 16S rRNA genes can provide information about the abundance of copy numbers of those genes and hence of bacterial community (Kim et al., 2008).

Previous studies of soil erosion in the grasslands of the Urseren Valley in the southern part of Central Switzerland have focused on erosion-induced changes in soil chemical characteristics (Alewell et al., 2008, 2009; Schaub et al., 2010). The primary objective of this study was to examine concurrent changes in biogeochemical and microbial properties in eroding upslope and depositional downslope soils. Specifically, the distribution of the concentrations and stable isotopes of C and N and microbial properties along the erosion-deposition transect was compared among three grasslands with different degrees of erosion as well as two encroaching upslope shrubs to examine whether erosion can affect organic matter decomposition and hence the storage of soil C in depositional wetland soils.

2. Methods

2.1. *Study site and sampling*

The study area is located in the Urseren Valley in the southern part of Central Switzerland (Fig. 1). The elevation of the W-E extended mountain valley ranges from approximately 1450 m above sea level to mountain ranges of altitudes up to 3200 m above sea level. The mean annual rainfall is 1400 mm (1986–2007; MeteoSwiss) and the mean annual air temperature is 4.3 °C (1986–2007; MeteoSwiss). The valley is snow covered from November to April with a maximum snow height in March. The rainfall maximum usually occurs in October, and the minimum in February. Runoff is dominated by snowmelt in May and June. Nevertheless, summer and early autumn floods represent an important contribution to the flow regime. The land cover of the valley mainly consists of grasslands that are grazed and also used for hay harvesting in the lower reaches. Avalanches are frequent in many areas with the scarce forest cover and steep topography. Small forested patches are scattered upslope the villages for avalanche protection.

Samples were collected at two eroding grassland sites (Laui and Bielen) on the lower southern slopes (between 1500 and 1600 m a.s.l.) adjacent to the villages of Hospental and Realp in July, 2010 (Fig. 1; Table 1). At the Bielen grassland site intense sheet erosion has resulted in apparent erosion features throughout the year. The erosion rate of an adjacent grassland site was estimated to amount to 11 t ha^{-1} yr^{-1} for the period 1986–2007 (Konz et al., 2009). At the Laui site sheet erosion is less apparent in the summer compared to the Bielen grassland, but noticeable erosion features usually appear during the snowmelt period. High erosion rates during the snowmelt period could result in unusually high annual rates (up to $>$ 30 t ha^{-1} yr^{-1} ha) of soil erosion in the Laui area, particularly when severe snow gliding and avalanches occurred during the snowmelt period (Konz et al., 2009). The depositional oxic and depositional wetland locations of both sites are located next to each other with less than 25 m distance. However, the two depositional locations are distinguished from each other, because wetlands have characteristic strips of vegetation and high soil moisture (mean gravimetric soil water content: 294% at the wetland soils vs. 58% at the depositional oxic soils). We assume a similar deposition rate in both locations because these neighboring depositional locations have similar topographic attributes such as slope aspect and angle (Table 1).

To compare the magnitude of erosion or deposition in surface soils that would indicate any erosion-induced changes sensitively, surface soil cores (depth: 5 cm; ID: 5 cm) were taken from an oxic, eroding upslope transect (hereafter termed ‘Up’) as the source of erosion, an oxic, depositional downslope transect (termed ‘Down’), and a depositional wetland transect (termed ‘Wet’) at each of the Laui and Bielen sites, with four replicates per each transect (Fig. 1). An additional grassland site in Oberes Moos (hereafter termed “Moos”) without showing noticeable symptoms of erosion and deposition was sampled as a reference site, in which soil cores were collected only from an oxic upslope and a wetland transect (Fig. 1). The reference wetland at the Moos site is separated from the depositional slopes under the influence of any upslope erosion sources, so we assume that the rate of soil deposition at this