Catena 149 (2017) 140–149

Contents lists available at ScienceDirect

Catena

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

Influence of topography on soil organic carbon dynamics in a Southern California grassland

FissoreC. [a,*], DalzellB.J. [b], BerheA.A. [c], VoegtleM. [a], EvansM. [a], WuA. [b]

[a] Whittier College, Department of Biology and Environmental Science, United States
[b] University of Minnesota, Department of Soil, Water and Climate, United States
[c] University of California-Merced, Life and Environmental Sciences Unit, United States

ARTICLE INFO

Article history:
Received 8 March 2016
Received in revised form 15 September 2016
Accepted 18 September 2016
Available online xxxx

Keywords:
Erosion
Soil organic carbon (SOC)
^{137}Cs
FTIR
Topography

ABSTRACT

Soil erosion and deposition processes play an important role influencing accumulation and long-term stability of soil organic carbon (SOC). Therefore, evaluations of landscape-scale magnitude and variability of SOC across topographically active landscapes will improve understanding about important drivers of SOC dynamics. In this study, we investigated the relationship between terrain attributes and quantity and spectroscopic characteristics of SOC for a hillslope system in Southern California. Thirteen soil cores were sampled at representative landscape positions with a history of intense erosion. We observed a strong relationship between slope, plan and profile curvature, and quantity and quality of SOC accumulation along the hillslope systems. Specifically, moderate slopes (<15%) combined with concave profile and plan curvature led to greater SOC accumulation. Spectroscopic analysis of water extractable organic carbon (WEOC) and bulk SOC shows greater presence of aromatics at eroding sites than at depositional sites, likely due to the contribution of eroded upslope materials. These differences in SOC and WEOC are the result of landscape-scale processes of SOC respiration by soil microflora. They likely reflect the potential for SOC stabilization via interaction with soil mineral surfaces. Our findings emphasize the role of specific terrain attributes rather than hillslope position alone in influencing the dynamics of SOC and its quality, information that can be also relevant in informing management and restoration practices.

1. Introduction

Topographic features, such as slope, curvature, and catchment area, control rates of redistribution of soil across hillslope locations and have an effect on the amount and quality of soil organic carbon (SOC) that is found across the landscape (Yoo et al., 2005). Even though there have been a considerable number of studies that have addressed the issues of SOC accumulation and stabilization in sloping landscapes, uncertainties persist concerning the mechanisms controlling SOC stabilization in eroding landscapes and lack of predictability of SOC stability and stabilization mechanisms at the landscape scale. At eroding portions of the landscape, soil erosion represents a widespread cause of soil quality loss and a threat to critical soil ecosystem services (Dominati et al., 2010) due to redistribution of soil particles and SOC across the landscape. High rates of erosion diminish soil productivity, can influence soil carbon (C) sequestration potential, and alter soil hydrological properties (Gessler et al., 2000). Recent work has emphasized the role of the physical environment, together with biotic and abiotic conditions, in affecting SOC's persistence in dynamic landscapes that experience erosion and terrestrial sedimentation or deposition (Berhe et al., 2012; Van den Bygaart et al., 2012). At erosional positions along the hillslope, SOC and nutrient content are typically lower and soil thickness is reduced compared to depositional positions (Berhe et al., 2008). At eroding landscape positions, less-weathered soil parent material is present at the surface, potentially enhancing C stabilization. In contrast, however, others have hypothesized that erosion leads to exposure of protected SOC to decomposition (Fierer et al., 2003). At depositional landscape positions, SOC accumulation and burial result in greater SOC content and protection from further decomposition (Smith et al., 2001; Fontaine et al., 2007; Berhe and Kleber, 2013; Doetterl et al., 2016).

Because soils located in areas with intense erosion and deposition are continuously evolving (Van Oost et al., 2006; Quinton et al., 2010), it is necessary to rely on sampling stratification that captures landscape features (curvature, slope gradient, etc.) that are most closely associated with erosional and depositional processes (Amundson et al., 2006). This is conceptually similar to the idea of sampling along a hillslope gradient (with its related topographic attributes) but more comprehensive because slope and curvature are computed from a three-dimensional landscape, rather than a two-dimensional hillslope profile. Explicit relationships and models that link landscape and topographic characteristics with SOC processes are needed (Fiener et al., 2015). In recent

---

[*] Corresponding author at: Department of Biology and Environmental Science, Whittier College, 13406 E. Philadelphia Street, Whittier, CA 90608, United States.
E-mail address: cfissore@whittier.edu (C. Fissore).

http://dx.doi.org/10.1016/j.catena.2016.09.016
0341-8162/© 2016 Elsevier B.V. All rights reserved.

times, Light Detection and Ranging (LiDAR) technology has allowed researchers to obtain fine-resolution (typically in the range of 1 m to 3 m) digital elevation models (DEMs; Thoma et al., 2005; Zhang et al., 2008), which have the potential to inform more accurate empirical and process-based models of landscape processes, including C dynamics, in more dynamic parts of the landscape. Improved understanding of C dynamics in landscapes with intense erosional and depositional processes will contribute to the ongoing debate surrounding the impact of topography on SOC accumulation in the landscape (e.g., Gessler et al., 2000; Lal, 2003; Van Oost et al., 2007). Such improved understanding should also figure heavily into the proposed "Carbon Farming" to mitigate climate change discussed at the International Climate Talks in Paris in December 2015.

In Mediterranean and semiarid regions worldwide, projections point to the worsening in soil quality in response to global warming, reduced precipitation, and perturbation at erosion-prone hillslopes (Borrelli et al., 2014). Additionally, an increase in fire frequency in Mediterranean climates, including Southern California, is expected as a consequence of increased temperatures and decline in precipitation (IPCC Fourth Assessment Report, 2007), potentially exacerbating erosion (Shakesby, 2001), mainly due to the role of hydrophobicity in increasing erosion, restricting water infiltration into the soil profile, and increasing rates of runoff (Carroll et al., 2007). Considering that the effect of topography can manifest in both the quantity and quality of SOC along hillslopes, it is evident that restoration efforts, land management, and other interventions aimed at conserving and protecting the land will largely depend on our understanding of the relationship between topographic features and SOC dynamics. However, despite the relevance and large interest surrounding this topic, the relationship between landscape-scale erosion and deposition and SOC dynamics still has to be clearly described (Jacinthe and Lal, 2001; McCarthy and Ritchie, 2002; Lal, 2003; Van Oost et al., 2007; Berhe et al., 2008), and much remains unresolved about how SOC quantity and quality can vary among landscapes with differing topography and disturbance histories.

Inherent soil characteristics, as well as soil processes, can affect the quality of SOC (West and Post, 2012). Indication of SOC quality can be obtained, for example, through the identification of different chemical moieties and level of aromaticity of the substrate. At least in the short-term, such characteristics can affect microbial decomposition and mineralization rates of the substrate. The redistribution of soil particles and SOC across dynamic areas of the landscape can not only cause the selective removal and consequent accumulation of topsoil C, but can also lead to the accumulation of SOC that has different chemical composition and different level of mineral association, depending on its location within the landscape (Berhe and Kleber, 2013). Erosion can expose more fresh mineral surfaces, which can incorporate fresh and more labile C that will become part of the 'new' topsoil. Conversely, more labile forms of C will accumulate, and potentially be buried and protected from decomposition at depositional positions, likely altering SOC stabilization processes and mineralization across erosional and depositional landscapes. An example of varying SOC quality along hillslopes is that of an eroding landscape from Belgium, where redistribution of SOC along the landscape resulted in presence of SOC with limited physical protection at erosion positions, which resulted in greater respiration rates, whereas C that was buried at depositional sites was protected and resulted in longer mean residence time (Doetterl et al., 2012). At a mountain area in Japan, Hishi et al. (2004) observed how water extractable organic C, which is a free form of C that constitutes a major source of C to microbes, was affected by slope grade. Similarly, Wang et al. (2013) observed greater aromaticity of the water extractable fraction of soil C at depositional than eroding locations, further emphasizing the potentially large role played by terrain attributes in affecting the quality of SOC.

The scope of this work was to investigate the distribution and characteristics of SOC associated with an area in Southern California characterized by dynamic landscape features and past fire history that may have contributed to erosional processes. It has become increasingly evident that our understanding of the relationships between landscape and SOC dynamics can be improved by including terrain analysis (Berhe and Kleber, 2013). For this reason, we used a series of analytical approaches, including assessment of SOC and water extractable C fractions, ultraviolet absorbance, infrared spectroscopy and radioisotope tracing (^{137}Cs) in combination with terrain analysis to investigate the quality and distribution of SOC along the sloping landscape of Puente Hills Preserve in Whittier, CA. Our results improve our understanding of the relationships linking terrain attributes and SOC dynamics, and could prove relevant to make predictions on future changes in SOC distribution in areas with increasingly severe droughts and intense erosion in the context of a changing climate.

2. Methods

2.1. Study area and sampling

The study area is located within the Puente Hills Nature Preserve, in Whittier, California, and is part of the Turnbull Canyon hill system (33.9940° N, 118.0108° W; Fig. 1). The area has a Mediterranean climate, with mean annual temperature of 19.7 °C and mean annual precipitation of 367 mm year^{-1}. The parent material derives from sedimentary rocks. The Puente Hills region is characterized by deeply cut canyons and steep hills often rounded by erosion and weathering, and the entire region has a past history of oil drilling activities. Additionally, the region has been occasionally affected by fire, with a recent episode in the Turnbull Canyon region in 2007. The Turnbull Canyon fire spread over approximately 80 acres (0.4 km^2) of a mix chaparral, woodland and grassland vegetated area and was considered a low intensity fire (Habitat Authority, pers. comm.). The Habitat Authority, responsible for the Preserve, did not restore the fire-affected area in the subsequent years, therefore allowing vegetation to repopulate the area naturally. The vegetation is primarily sagebrush mixed with native and non-native grasses with occasional presence of oak trees (Habitat Authority, pers. comm.).

In the summer of 2014, we collected soil samples from thirteen sites (Table 1) located within the Turnbull Canyon fire perimeter. Samples were collected within three distinct clusters (namely, Western, Northeastern, and Southeastern clusters) in close proximity from each other (Fig. 1), each representing relevant topographic and soil type features specific of hillslope systems within Turnbull Canyon. At each of the thirteen sites, sampling took place by opening a pit of approximately 20 cm by 20 cm, and soil samples were collected from the exposed face at 5 cm increments to a depth of 30 cm and at 10 cm increments thereafter to a depth of 50 cm. Samples were then transported to the Environmental Science Laboratory at Whittier College, where they were processed and analyzed.

2.2. Terrain attributes

Site selection was conducted based on field observations to represent the range of topography present in this region, and particular attention was given to erosional and depositional features along the hillslopes system. The Western cluster belongs to the Zaca-Apollo complex, described as fine-loamy, mixed, superactive, thermic Calcic Haploxerolls. The Northeastern cluster and the Southeastern cluster belong to Soper-Buzzpeak complex, described as sandy, mixed, thermic Typic Haploxerepts (NRCS, preliminary unpublished data). All sampling sites face West-Northwest and are located at a relatively narrow range of elevation, from 284 m asl to 403 m asl (Table 1). Following sites selection, specific terrain attributes (slope, plan curvature, profile curvature) were derived, for each site, from a 10-m digital elevation model (DEM) obtained from U.S. Geological Survey's 3D Elevation Program (3DEP), which is sourced by LiDAR in the conterminous U.S., using ESRI ArcGIS program version 10.0. Specific terrain attributes considered here