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Microbial distribution in an eroded landscape: Buried A horizons support abundant and unique communities

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ABSTRACT

Hummocky landscapes are naturally susceptible to erosion by water and tillage. Downslope movement of material results in the accumulation of soil in depositional positions and exposed sub-soils at the surface of eroded positions, affecting landscape-scale C cycling and productivity. Prolonged or extreme erosion can create inverted soil profiles with deeply buried C-rich surface material. The susceptibility of this C to decomposition is largely controlled by the potential of microorganisms to degrade it with long-term implications for C dynamics in agroecosystems. Our objective in this study was to evaluate whether the redistribution of soil along eroded hill slopes creates differences in the structure of the soil microbial community, both laterally across the landscape and vertically through the soil profile. Using phospholipid fatty acid analysis (PLFA) and high-throughput DNA sequencing, we investigated the abundance, diversity and community structure of microbial communities along an eroded landscape. Microbial abundance and community structure were found to be strongly influenced by a depth gradient at the near-surface (0–20 cm). In a depositional backslope position, viable microbial biomass was detected to the depth of the A horizon (85 cm), with a C-rich buried layer that contained substantial viable biomass (10.1 –18.8 μg PLFA g^{-1} soil). Soil organic carbon (SOC) concentration was significantly correlated ($r = 0.40$; $p < 0.001$) with PLFA concentration at all positions, indicating microbial abundance is determined by C availability. In contrast, community structure was related to the origin of the soil in the landscape, and may be regulated more strongly by SOC composition. Pyrosequencing of bacterial and fungal DNA showed that genetic diversity was largely maintained in former surface soils. Our work demonstrates that abundant microbial biomass is supported in C-rich buried soils while SOC is largely preserved for decades. The presence of an abundant and diverse community suggests that there is potential for enhanced C loss under changing conditions such as climate change or modified land-use.

1. Introduction

Erosion results in the significant redistribution of soil in agricultural landscapes affecting soil productivity and agro-ecosystem functioning. Specifically, hill slope erosion involves the detachment, transport and deposition of material from upper to lower slope positions (Berhe et al., 2007), and can result in the preferential transport of fine particles and associated soil organic carbon (SOC) (Gregorich et al., 1998). Such erosion events can be particularly prominent in hummocky landscapes where agricultural activities, particularly tillage, can exacerbate soil detachment.

The transport of soil from upper to lower slope positions during prolonged periods of erosion alters the vertical distribution of C in the soil profile at different positions along the hill slope. Soil profile inversion occurs when continued erosion of an upslope position transports material that originates from progressively deeper in the profile and layers it on top of previously deposited soils downslope. In this way, extensive erosion can result in the burial of C-rich surface soils and lead to the formation of inverted soil profiles in depositional positions (Berhe et al., 2007). Ultimately, sub-soils are left exposed at the surface in both eroded and depositional positions. The net effect on SOC storage within the

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landscapes is debated and depends on the extent of replacement of SOC at eroded positions (Lal, 2003; Van Oost et al., 2007) and the dynamics of SOM stabilization and destabilization in depositional locations.

In a study of Canadian soils, VandenBygaart et al. (2012) found that hill slope erosion resulted in the burial of surface soils and concentration and preservation of substantial SOC for decades at six diverse agricultural sites. Although the ultimate fate of C in buried A horizon soils is unknown, VandenBygaart et al. (2012) estimated an average accumulation of 2–4 Mg C ha^{-1} y^{-1} in depositional positions across all six study sites; this demonstrated that the initial redistribution and preservation of SOC in eroded soils constitutes a substantial change in the spatial allocation of SOC within landscapes. Given the potential magnitude of soil transport and C burial due to hill slope erosion it is important to understand the capacity of these former surface soils to support microbial populations that drive decomposition and nutrient turnover of C-rich material in sub-surface environments.

Microbial abundance in soil is primarily driven by the spatial distribution of available resources, and therefore microbial abundance with depth typically decreases with declining soil C concentration. Near the soil surface, supply of fresh C by above- and below-ground plant biomass provides substrate for an abundant and active microbial community. As C inputs decline with depth, the resources available to support microbial growth and activity similarly decline and change in composition. Despite the decline in microbial abundance with depth, it is estimated that 35% of total biomass in the top 2 m is present below 25 cm (Fierer et al., 2003b). Similarly, substantial SOC (27–77% of total SOC) can exist at depths greater than 20 cm (Harrison et al., 2011). Although microbial abundance generally declines with depth in a typical profile, the specific activity (activity per unit biomass) can increase with depth; interactions between population density and spatial distribution of resources or the interaction of enzymes with mineral components may be responsible (Kramer et al., 2013). Zhuravleva et al. (2012) similarly found that the intensity of the glucose-induced priming effect in forest soils from different depths depended on the SOC content, the initial size of the microbial biomass and the enzyme activity. While microbial abundance and function in sub-soils are receiving increased attention, the principles that govern microbial distribution with depth in a typical profile may not apply to inverted soil profiles found in depositional positions of eroded landscapes. The atypical vertical distribution of resources and the fact that C-rich soils and their indigenous microorganisms are transported together create unique soil profiles along eroded landscapes. Determining the abundance and community structure in eroded landscapes is important for understanding agroecosystem nutrient cycling and storage in hummocky landscapes.

Reduced decomposition and preservation of C at depth are generally attributed to low microbial biomass and sub-optimal conditions for decomposer activity (Salomé et al., 2010). Environmental factors such as reduced oxygen availability and low temperature inhibit decomposition by slowing microbial metabolism and reducing the activity of extracellular enzymes. Therefore, sub-surface C may be preserved in part due to the constrained activity of broad decomposer communities or specific functional groups. Some research suggests that topsoil and subsoil C dynamics may respond differently to changes in conditions (Fierer et al., 2003a; Salomé et al., 2010). For example, the diversity of bacteria has been shown to decline with depth by up to 40% compared to surface horizons (Eilers et al., 2012) which may alter the C mineralization in surface and sub-soils (Zhuravleva et al., 2012). Changes in the chemical composition of SOM during decomposition may be dependent on horizon-specific conditions (Baumann et al., 2013) potentially contributing to greater recalcitrance of C in sub-soils. Doetterl et al. (2012) found longer residence times for fast and intermediate SOC pools in depositional landscape positions in Belgium, which they attributed to physical protection of C within microaggregates. The susceptibility of sub-soil C to decomposition exposed to different and more amenable conditions has been highly variable (Harrison et al., 2011) indicating that the interaction between SOM composition, decomposer community composition and chemical, physical and environmental conditions at depth is complex (Fierer et al., 2003).

Burial of C-rich A horizon materials is a significant process in hummocky landscapes (Berhe et al., 2007; Doetterl et al., 2012; VandenBygaart et al., 2012). However, to our knowledge there has been no previous investigation of microbial populations in these soil profiles. Work by VandenBygaart et al. (2012) documented soil erosion and burial of A horizon materials up to 85 cm deep in an agricultural field at St. Denis Wildlife Area in Saskatchewan, Canada. ^{137}Cs dating showed that approximately 40 cm of soil has been deposited since 1955. Combined with SOC concentration data this indicates that in some landscape positions significant soil erosion had occurred prior to 1955 resulting in C-rich A horizon material that has been buried for at least 50 years. Our objective was to examine microbial abundance and community composition with depth following erosion-induced changes in the vertical distribution of SOM to better understand how microbial communities adapt to new conditions following transport and burial. We chose the St. Denis site to perform an intensive microbial examination since this landscape is typical of the Prairie Pothole Region of the North American Great Plains and represents moderate characteristics of slope and climate.

2. Materials and methods

2.1. Site description

The study site is located north of St. Denis, Saskatchewan, approximately 40 km east of Saskatoon, within the St. Denis National Wildlife Area (SDNWA). The SDNWA is in the aspen parkland ecoregion and is characterized by undulating to hummocky landscapes dominated by Haplic Kastanozem soils (Hogan and Conley, 2002). There are approximately 200 wetland areas scattered throughout restored grasslands, native grasslands, and cultivated lands. Agricultural lands are usually leased for 1–3 years to local farmers (Hogan and Conley, 2002). The selected site location was under annual crop production using direct seeding, rotating oats (*Avena sativa*), barley (*Hordeum vulgare*), and canola (*Brassica napus*) (Environment Canada, 2013).

2.2. Sampling methodology

Samples were collected after harvest, on October 29 and 30, 2010. To characterize SOC redistribution and examine microbial community dynamics, three positions within the landscape were chosen, and numbered from upper to lower slope. Profile 1 was identified as an eroded shoulder, profile 2 as an intermediate backslope (with evidence of deposition and erosion; 22.1 m downslope from profile 1), and profile 3 as a depositional backslope (30.4 m downslope from profile 2). At each position, a large pit was excavated and a pit face cleared. In each excavated pit, four replicate samples were removed in 5 cm increments, from the soil surface to the depth of the A horizon. Each sample was homogenized and sub-sampled (100 g) in the field. Sub-samples were transported back to the laboratory on ice and frozen at −80 °C.