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The structure of bacterial communities along two vertical profiles of a deep colluvial soil

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ABSTRACT

The redistribution of soil and associated organic matter across landscape represents a major perturbation to the carbon cycle because the established colluvial soils change the levels of C mineralization and sequestration. In this study, two profiles of a colluvial soil 4 m deep were analyzed to test whether its two layers produced by erosion differ from the organic layer of the original soil and if the microbial characteristics correspond to the soil properties. The structure of microbial communities was assessed by both quantitative PCR and Illumina amplicon sequencing. Microbial activities were determined by hydrolytical enzymes. The bacterial community structure was correlated with vertical gradients of soil chemical properties. The dominating bacterial phyla were the same along the whole profile but their relative abundance changed. The upper horizon determined by tillage and reaching to approx. 75 cm had highest values of dissolved organic carbon, P and K and was characterized by *Proteobacteria* and *Bacteroidetes*. Also, the activities of hydrolytical enzymes occurred mostly there. The second horizon of deposited soil reaching to approx. 250 cm was characterized by *Acidobacteria* and *Gemmatimonadetes*. The lowest horizon of buried Chernozem was characterized by increased soil organic carbon, manganese, iron and sulfate and characterized by *Nitrospirae* and *Rubrobacteria*. The community analysis indicated that chemolithotrophic processes might be important in these buried horizons so the decomposition may be slower and residence times for these deep carbon pools longer than in the original upper horizons. In these colluvial systems, erosion could lead to soil organic C stabilization.

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1. Introduction

The movement of soil and associated organic carbon across landscape, often greatly accelerated in agricultural settings, represents a major perturbation to the carbon cycle at local, regional and global scales (Sanderman and Chappell, 2013). Erosion causes a depletion of soil organic carbon (SOC) on eroded sites and enrichment in deposition sites, which leads to changes of C mineralization and sequestration rates. Those changes are widely unrecognized particularly with respect to greenhouse gases, which may be produced differently under anaerobic conditions in depression sites. Consequently, identification of unknown organic carbon sinks is important in developing strategies for mitigating potential climate change (Lal, 2003).

Deep, SOC rich colluvial soils are reported from the loess Chernozem and Luvisols regions in Central and Western Europe, North America and China (Kadereit et al., 2010; Poreba et al., 2011; Dotterweich et al., 2012; VandenBygaart et al., 2015; Zádorová et al., 2013; Wang et al., 2015). These Holocene soils developed by subsequent accumulation of eroded topsoil in concave relief positions. Colluvial soil material is transported from eroding topsoil due to past and present human activities such as deforestation or

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tillage. Generally, colluvial soil can develop on any parent material or former soil that is often recognizable in the soil profile as a buried soil to a certain depth. Depth, profile stratigraphy and features of colluvial soils are primarily derived from the character of source material, character of erosion process, terrain configuration and land use (Zádorová et al., 2013). In Central Europe, the accumulation rate of recent colluvium is evaluated from 2 to 6 mm per year (Zgłobicki, 2002; Smolska, 2007) to 3 cm per year (Zádorová et al., 2013), depending on soil properties and land management.

The current understanding is that mineralization of soil organic carbon is governed partially by oxidation/hydrolysis, desorption and diffusion as well as by the size, structure and metabolic activity of microbial communities (Ekschmitt et al., 2005). The microbial contribution to soil C dynamics is directly related to soil properties such as texture, clay mineralogy, pore-size distribution, and aggregate dynamics but it is also influenced by soil physico-chemical properties and climate. Most studies on SOC decomposition by microorganisms focus on topsoil or shallow subsoil (Kramer and Gleixner, 2008; Kramer et al., 2013) as it is generally thought that substrate pools and microbial biomass and activity decline with soil depth, yet relatively shallow soils only down to 1.7 m were analyzed (e.g. Blume et al., 2002), in colluvial soils even only to 0.8 m (Helgason et al., 2014). However, despite their low carbon content, subsoil horizons contribute to more than half of the total soil C stocks, and therefore need to be considered in the global C cycle (Rumpel and Kögel-Knabner, 2011). The burried C-rich soil material enhances microbial activity in deep soil horizons (Lal, 2003; Helgason et al., 2014). Above that this activity is supported by mineral nutrients sourced from parent material, such as inorganic phosphorus, calcium, magnesium, iron and aluminum available in deep soils and by relatively high temperature and soil moisture over winter season (Allison et al., 2007; Kramer et al., 2013).

Soil microorganisms influence biogeochemical processes throughout the soil profile, but our understanding of the structure and diversity of soil microbial communities depends predominantly on horizontal distribution because the vast majority of studies focused solely on the top 15 cm–30 cm (frequent tillage depth) (Eilers et al., 2012) with a few exceptions (Fierer et al., 2003). This limits not only our understanding of element cycling but also more precise understanding of niche partitioning between different taxonomic groups. The chemical gradients occurring in soil vertical profiles represent a unique environment, in which relatively steep changes of physico-chemical characteristics occur in short distances and are therefore a suitable environment for comparison of chemical properties with microbial structure and functioning. Indeed, microbial communities within the same profile, even communities separated by as little as 10–20 cm in depth, can be as distinct from one another as soil communities from completely different biomes separated by thousands of kilometers (Eilers et al., 2012).

The present study aimed in determining differences in chemical and microbial characteristics between the three distinct soil layers corresponding to sedimentation history. We hypothesized that (1) microbial community structure and activity in soil layers should reflect the respective soil layer properties and in particular its organic C content and that (2) deposited organic soil layers would exhibit different soil microbial community structure from that of the organic layer of the original soil. To test these hypotheses we analyzed two profiles of a colluvial soil with respect to bacterial community structure. This soil is particularly deep with the buried SOC rich horizon occurring to the depth of 370 cm, resulting from strong material redistribution at the study plot. We measured the structure of microbial communities by both quantitative PCR and Illumina amplicon sequencing. Microbial activities were assessed by quantification of hydrolytic enzymes involved in organic matter decomposition. As a result of the combined methods, some of the functional groups of bacteria typical for each of the three horizons were identified.

2. Material and methods

2.1. Site description

The study was conducted in a loess region in South Moravia in the Czech Republic. The region ranks among the earliest human settlements in Central Europe and has been under uninterrupted agricultural use since the middle of the Holocene. Brief description of the land cover history of the region is given in Zádorová et al. (2013). The area is formed by Oligocene sandstones covered by a Pleistocene loess layer with variable depth ranging from several meters up to several tens of meters (Chlupáč et al., 2002). Climate is characterized by a mean annual precipitation of 542 mm and a mean annual temperature of 8.4 °C.

Calcic Chernozem is the original dominant soil unit in the region, nowadays progressively transformed into different soil units along with intensive soil erosion and deposition. The research was carried out on an agricultural parcel (6 ha) that comprises a complex slope system with different terrain units: a plateau (slope 0–0.5°), a steep middle part (up to 19°) formed by a back-slope and a side valley, and a toe-slope. The mean slope of the plot is 7°. The side valley represents a major line of concentrated runoff emptying into a colluvial fan at the toe-slope. The back-slope is interrupted by a road that separates it from the flood plain. Plateau areas with no erosion are covered by Calcic Chernozem. Chernozems with a truncated mollic horizon cover areas with increasing slope (2–8°). Regosols (ploughed exposed loess material) cover the steepest parts of the slopes. Colluvial Chernozems and colluvial soils with deep A horizons are formed in concave parts of the landscape (Zádorová et al., 2011). Colluvial soils with a 100–250 cm thick A horizon rich in organic matter have developed in the side valley, whereas the deepest colluvial profiles are formed by a mixture of loess and humus-rich material in the top 300 cm, and humus-rich material at 300–400 cm depth was found in the toe-slope (Zádorová et al., 2013, 2015). The plot has been under organic farming for the last 15 years.

2.2. Soil sampling

Two soil cores (A, B) were taken on September 15, 2014 in toe-slope (Fig. 1) where the deepest soil profiles were described in previous research (Zádorová et al., 2015). Profiles were cored down with a percussion drilling set (gouges diameters of 100 and 75 mm) from the surface to the substrate (profile A 400 cm, profile B 425 cm). Samples for soil and microbial properties analysis were taken every 25 cm. The soil was homogenized within the 25 cm increments and microbial subsamples were immediately frozen in −20 °C, in one day in −80 °C.

2.3. Soil analyses

Elemental analysis of N and C was realized using a Thermo Scientific Flash 2000 NCS Analyser. Soil pH was measured using a 1:5 (w/v) ratio of soil and water or 1 M KCl solution (ISO 10390:1994) using an inoLab Level 1 pH-meter. Carbonate content was measured using the volumetric calcimeter method described by Looppert and Suarez (1996). Soil nutrients (phosphorus — P, potassium — K, calcium — Ca, magnesium — Mg) were measured by Mehlich 3 method (Mehlich, 1984).

Different Fe forms (amorphous together with organically

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