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Compositional variety of soil organic matter in mollic floodplain-soil profiles - Also an indicator of pedogenesis

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ABSTRACT

Soils on riverine floodplains in Central Europe are commonly enriched in soil organic matter (SOM). We analyzed the quantity and qualitative aspects of SOM in three soil profiles with mollic horizons along the Elbe River (Germany) after physical fractionation by diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy to gain deeper insights into the composition of SOM and the formation of these soils. In all horizons, the majority of SOM was recovered in the fraction of particulate OM and in that of sand and aggregates, while SOM in the silt and clay fraction always made up < 20% of soil organic carbon. The C:N ratios of most fractions did not decrease with depth, indicating less decomposed or pyrogenic OM or both. The presence of pyrogenic OM, as a characteristic feature of floodplain soils, was indicated in almost all physical fractions. As derived from DRIFT spectroscopy, SOM was less qualitatively differentiated among the fractions in the soil with the longest duration of flooding, while qualitative differences of SOM were more pronounced in the more aerated ones. The soils have developed from stratified fluviatile sediments and fulfil the criteria of a mollic horizon, irrespective of differences in the composition of SOM. From a soil-genetic point of view, we strongly suggest to classify these soils as Mollic Fluvisols instead of Fluvic Phaeozems, which would accord to the latest WRB classification.

1. Introduction

Soils developed on riverine floodplains in the temperate zone are characterized by enhanced contents of soil organic matter (SOM) and to greater depth, relative to terrestrial soils (e.g., Graf-Rosenfellner et al., 2016; Rennert et al., 2017; Rinklebe, 2004; Szombathová et al., 2008; Zehetner et al., 2009). Several explanations may apply: i) floodplain soils receive periodical inputs of SOM including free particulate organic matter (POM), SOM-containing soil aggregates and SOM adsorbed to minerals as a consequence of flooding and subsequent sedimentation of previously eroded soil materials, ii) SOM-containing A horizons are formed and subsequently buried after longer periods of sedimentation, and iii) decomposition of SOM is decreased at water saturation during flooding or when the water table in soil is close to the surface (summarized by Graf-Rosenfellner et al., 2016 and Sutfin et al., 2016). For accumulation of SOM in floodplain soils, Graf-Rosenfellner et al. (2016) and Tobiašová et al. (2015) emphasized the importance of aggregation on SOM stabilization that proceeds preferentially in soils with fine soil texture, as stable aggregates are formed by periodical drying/re-wetting cycles that are characteristic of floodplain soils.

Periodical flooding and sedimentation events on riverine floodplains may furthermore result in stratification of the parent material of floodplain soils. Stratification of fluviatile sediments is the criterion for fluvic material that is diagnostic of the reference soil group Fluvisol according to the WRB classification (IUSS Working Group WRB, 2015). Fluvisols are widespread along the floodplains of the Elbe River, Germany (Wälder et al., 2008), and Fluvisols on the low terraces are characterized by the presence of thick dark-coloured mineral surface horizons that are well structured, mixed by bioturbation, with a high base saturation and with moderate to high contents of SOM (Du Laing et al., 2009; Rinklebe, 2004; Shaheen and Rinklebe, 2014). In that case, the criteria of a mollic horizon are fulfilled. Thus, Mollic Fluvisols represent soils that combine a certain setting in the landscape (floodplains) with a certain water budget (periodical saturation and drying), with certain geomorphologic processes (erosion/sedimentation (stratification)) and with a certain quality of SOM (mollic horizon).

The mollic horizon is by far not exclusively connected to soils on floodplains, developing from stratified fluviatile sediments. In fact, the presence of a mollic A horizon was a precondition for classifying a soil as Phaeozem and Chernozem (FAO, 1988; IUSS Working Group WRB,

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2007), and still is for Phaeozems in the recent WRB classification (IUSS Working Group WRB, 2015). Thus, SOM in Mollic Fluvisols may be designated as "chernozem-like". Soil OM in topsoils of Mollic Fluvisols has been found less labile than that in Eutric Fluvisols, Luvisols and Chernozems, as derived from oxidation with permanganate (Tobiašová et al., 2015).

The formation of soils on floodplains with chernozem-like SOM in Central Europe is not completely understood yet. Thater and Stahr (1991) suggested initial formation of chernozem-like soils from loess deposited in river valleys in Southern Germany. After ascendance of the groundwater table, previously accumulated SOM was then stabilized because of the periodical change of reducing and oxidizing conditions and the presence of dissolved $CaCO_3$ in the groundwater. In contrast, Ostendorff and Beinroth (1964) suggested that these soils may have developed from Histosols in fens that degraded after permanent lowering of the groundwater table. They also pointed out that soils may develop directly towards a chernozem-like soil or from a different soil type into it after a shift in the effects of soil-forming factors. In the German soil classification system, soils on floodplains with chernozem-like SOM are designated as "Tschernitza". This type of soil is characterized by distinct bioturbation in the A horizon that increases its thickness to > 40 cm (Ad-hoc Arbeitsgruppe Boden, 2005). Accordingly, the "Tschernitza" has been described as a floodplain soil which is similar in its morphology to a Chernozem (Altermann et al., 2005), which has usually developed from floodplain silt or loam.

However, the formation and differentiation of soil horizons in both, an original Chernozem, subsequently affected by groundwater, and in a degrading Histosol, subsequently forming a mollic horizon, is controlled by pedogenic processes, not by repeated deposition of fluviatile sediments, which is the precondition for stratification and thus the classification as Fluvisol.

The different approaches to explain the formation and the development of Mollic Fluvisols indicate that also SOM may form and process differently in Mollic Fluvisols. Assuming the formation of a Mollic Fluvisol from a Chernozem, which later became affected by ascending groundwater, the quantity of SOM and its composition along the soil profile may be similar to a terrestrial soil, having developed outside of a floodplain. In contrast, SOM in a Mollic Fluvisol, having developed from a degraded Histosol, may have depth gradients in quantity and composition that are inherited from the previous organic soil. In both cases, the input of SOM in floodplain soils by river water and the duration of water saturation, controlling the availability of O_2, have additionally to be considered.

Generally, SOM in Fluvisols in temperate climate, especially when including SOM in subsoils, has gained less scientific attention than that in terrestrial soils. Nonetheless, Wiesmeier et al. (2014) applied a physical-fractionation technique (Zimmermann et al., 2007a) to Bavarian Gleysols and Fluvisols among other soils and quantified C contents and stocks in their top- and subsoil horizons. Graf-Rosenfellner et al. (2016) similarly characterized floodplain soils of the Danube River and detected differences in SOM quantity and allocation in physical fractions as depending on hydroecomorphological site properties. Zehetner et al. (2009) studied the temporal course of SOM accumulation along a soil chronosequence in the same area. Bullinger-Weber et al. (2014) detected the dependency of SOM storage on progress in soil development and hydromorphic features in soils on floodplains of Swiss rivers. Rennert et al. (2017) reported on a large fraction of less processed SOM in subsoils of floodplain soils along the Elbe River as a result of frequent water saturation. Barančiková et al. (2016), Szombathová et al. (2008) and Tobiašová et al. (2015, 2016) quantified SOM in Slovakian Mollic Fluvisols (partially including subsoil horizons and aggregates) and characterized SOM by oxidation with permanganate and extraction of humic substances.

The allocation of SOM in physical fractions of Mollic Fluvisols and its spectroscopic characterization has, however, not been reported yet. We hypothesize that, given the different pathways of formation of Mollic Fluvisols, the composition and allocation of SOM in Mollic Fluvisols may vary accordingly. As a consequence, these properties of SOM may be an additional tool to understand the variable formation of Mollic Fluvisols. The aim of this study is to test this hypothesis by analyzing three soil profiles of Mollic Fluvisols along the Central Elbe River by physically fractionating SOM and characterizing SOM of the fractions by infrared spectroscopy.

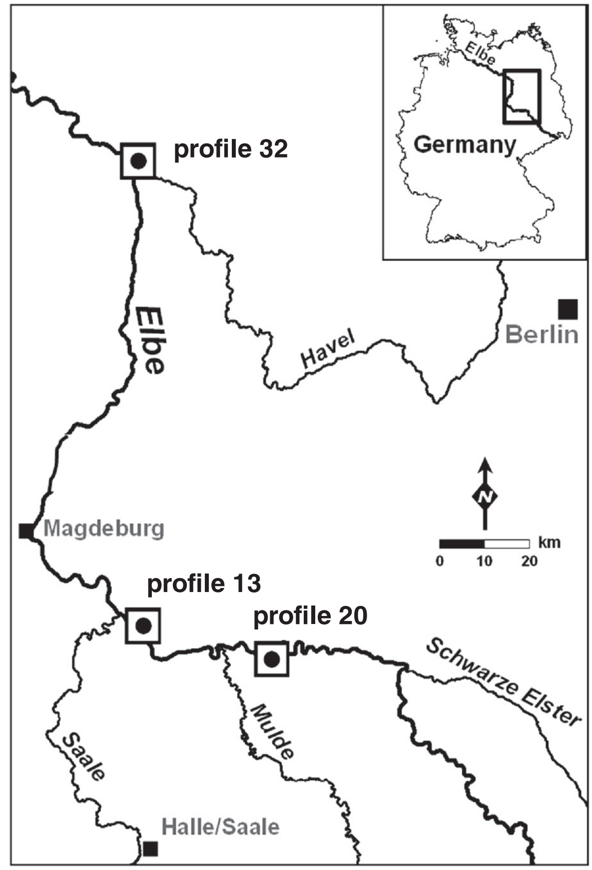

Fig. 1. Location of the soil profiles along the Elbe River, Germany.

2. Materials and methods

2.1. Study sites and soils

The three Mollic Fluvisols (FAO, 1988; IUSS Working Group WRB, 2007) under study are located on the low terraces of the Central Elbe River (Fig. 1), which are intermittently flooded (Rinklebe, 2004). The soil material we used for the analyses of this study was taken from excavated pits (several kilograms per horizon), considering genetic horizons, sieved to < 2 mm, air-dried and stored. The location of the pits was selected after detailed soil mapping of the sites (Rinklebe, 2004; Rinklebe et al., 2000, 2007; Wälder et al., 2008). The numbering of the soil profiles was taken from Rinklebe (2004), where a detailed description of the soils and of soil sampling is available (also given by Shaheen and Rinklebe, 2014). The material, from which soils have developed on the floodplains, is controlled by the petrologic conditions of the catchment area of the Elbe River. Thus, the Holocene fluvial deposits may consist of a variety of materials including sandstone, limestone, marl, calcareous and decalcified loess, and soils developed from these materials.

The study sites represent common soil units on the low terraces of the Elbe River (Rinklebe et al., 2000). The sites are used as extensive grassland, pasture or fallow. Dominant plant species are *Alopecurus*