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Stability and composition of different soluble soil organic matter fractions–evidence from δ^{13}C and FTIR signatures

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Abstract

Carbon turnover models are used to estimate changes in soil organic matter (SOM) content caused by management or land use. A limitation of most of these models is that their conceptual C-pools generally do not correspond to experimentally verifiable organic matter (OM) fractions. Our intention was to isolate OM fractions different in solubility and to identify their composition and their stability. The latter was done to find out if they could be used to evaluate the conceptual C-pools. NPK fertilized soils with maize and wheat cropping from two long-term field experiments (Halle and Rotthalmünster) were selected. Water (W) and sodium-pyrophosphate soluble ($\mathrm{PY_P}$) OM fractions were extracted sequentially from the soils using water in the first and 0.1 M sodium-pyrophosphate solution (pH=10) in the second step. The amounts of W and $\mathrm{PY_P}$ fractions isolated from Rotthalmünster soils are somewhat lower than those obtained from Halle soils caused by higher Fe and Mn content in Rotthalmünster soil, which hinder the OM extraction. However, based on the natural abundance trace technique, for both sites, the $\mathrm{PY_P}$ fraction was found to be older than the W fraction and hence to be more stable than W. Therefore, it could be assumed that sequential extraction seems to be useful to isolate OM fraction different in stability. $\mathrm{PY_p}$ represents up to 40% of total soil organic matter; therefore, it may be a useful tool to evaluate a stable C-pool in C turnover models. According to FTIR spectra of the isolated OM fractions (especially $\mathrm{PY_p}$), their composition was influenced by growing crop and site conditions. This is of importance as composition of OM is related to its sorption properties, which may be relevant for transport processes.

Keywords: Soil organic matter fractions; Sequential extraction; δ^{13}C-measurements; FTIR spectroscopy; Long-term field experiments

1. Introduction

Soil organic matter (SOM) is an important part in the global terrestrial carbon cycle because about 81% of the active organic carbon is stored in soils (Paustian et al., 2000; Wattel-Koekkoek et al., 2001). Carbon turnover models are generally used to evaluate differences in SOM content caused by changes in management (Smith et al., 1997; Gabrielle et al., 2002). Such models are usually based on the assumption that SOM could be differentiated into at least two pools, a labile and a stable pool (e.g. Powlson et al., 1996; Stevenson, 1994; Wattel-Koekkoek et al., 2003). A major

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limitation of current compartment models of SOM turnover is that most of the conceptual pools they contain do not correspond to experimentally verifiable OM fractions (Powlson et al., 1996; Pennock and Frick, 2001; Wattel-Koekkoek et al., 2003). Some attempts are made by Sohi et al. (2001) who suggest that SOM fractions obtained by density separation provide a basis for models of SOM turnover based on measurable pools. However, the amounts of SOM isolated by this procedure are relatively low (1–5% of total organic C). Other methods are based on the principle of minimum entropy production for example (Bosatta and Ågren, 2002).

However, there is a lack in understanding the basic mechanisms of soil organic matter stabilization and consequently, in our knowledge of factors regulating the SOM stabilization processes (Sollins et al., 1996). These gaps in knowledge lead to uncertainty when simulation models of carbon turnover are applied to the soil system (e.g. Powlson et al., 1996). The goal of the priority program SPP1090, "Soils as Sinks and Source for CO_2" by the Deutsche Forschungsgemeinschaft established in 2000, is to improve the scientific understanding of mechanisms involved in soil organic matter stabilisation. This will be used to improve tools for predictions about the impact of environmental change and land management on SOM dynamics and a quantitative understanding of SOM regulation. In existing concepts of SOM stabilisation, especially in experimental work, there is no differentiation between mineralisation of plant litter and stabilisation processes within the soil itself. Such a differentiation seems of importance for the understanding of turnover processes in soil.

The interaction between OM and polyvalent cations is one of several possibilities of SOM stabilisation (Baldock and Skjemstad, 2000; Gillet and Ponge, 2002; Gregorich et al., 2003; Gleixner et al., 2002; Wattel-Koekkoek et al., 2003). Soil particle size or aggregation for example are further important factors. Because of such interactions, mineral bound SOM may be protected against microbial attack and should therefore be more stable than the water soluble fractions. From a chemical point of view, SOM can be divided into components varying in their solubility, which is strongly dependent on the interaction of the SOM with polyvalent cations and mineral surfaces (e.g. Sposito, 1989; Stevenson, 1994). Pyrophosphate anions are able to remove cations from SOM by building metal–pyrophosphate complexes, resulting in solubilization of OM fractions, which can be extracted (Bascomb, 1968; Greenwood and Earnshaw, 1984).

Land use and management as well as climate and soil texture influence not only SOM content but its composition as well (West and Post, 2002). The term composition will be used here to describe nature and content of functional groups (e.g. carboxylic, phenolic) within the organic material. Sorption characteristics of SOM such as the cation exchange capacity (CEC) are strongly affected by SOM functional groups (Almendros, 1995; Gressel et al., 1995). A variety of infrared bands (Table 1) are characteristic

Table 1
Peak assignments of absorption bands in FTIR spectra indicating functional groups

Wave number	Vibration	Remarks
2920 cm^{-1} 2860 cm^{-1}	Asymmetric and symmetric C–H stretching vibrations of CH_3 and CH_2 groups	The C–H bands are usually superimposed as a shoulder of the broad O–H band located at 3600–3000 cm^{-1}, which is not discussed here, as the intensity of the O–H band is influenced by water content.
1698–1740 cm^{-1}	C=O stretching vibrations of, e.g., COOH, CONH, COOR groups	Occur in carboxylic acids, cyclic and acyclic aldehydes and ketones (Van der Marel and Beutelspacher, 1976). Günzler and Böck (1990) stated that in this region other functional groups rarely show intense absorption bands.
1600–1640 cm^{-1}	C=O stretching vibrations of COO^- anion	From carboxylic acid anions (Celi et al., 1997). 1600–1613 cm^{-1} are also assigned to stretching vibrations of aromatic C=C double bonds conjugated with C=O or COO^- bonds or both, i.e. of unsaturated ketones, carboxylic acids or amides (MacCarthy and Rice, 1985; Günzler and Böck, 1990).
1081 cm^{-1}	C–O stretching vibrations of C–O–C groups	e.g. in cellulose, among other compounds.