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Correspondence of measured soil carbon fractions and RothC pools for equilibrium and non-equilibrium states

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ABSTRACT

The link between carbon turnover model pools and measurable carbon fractions is of key interest for initial parameterisation and subsequent validation of dynamic soil carbon models. In this study we performed the established particle-size fractionation of soils from 54 intensively monitored sites in Germany and from archived samples from 5 other long-term experiments in Germany and the United Kingdom. The Rothamsted carbon (RothC) model was then used to compare the measured soil C fractionation from the 54 intensively monitored sites against modelled pools using spin-up equilibrium runs whilst dynamic (non-equilibrium) model runs were performed when comparing data from the long-term experiments. We detected good agreement between measured soil C fractions and modelled pools, indicated by correlation coefficients of 0.73 and 0.81 for the resistant plant material pool (RPM) and 0.91 and 0.94 for the humus pool (HUM) for the intensively monitored and the long-term sites, respectively. Slightly larger errors were detected for the intensively monitored sites together with a bias in the relationship between the RPM pool and particulate organic matter fraction. This bias detected for the intensively monitored sites indicated that the equilibrium assumption for arable agricultural sites, even though under crop cover for at least 50 years, might not be entirely valid. From the relative mean absolute error of 11% for the HUM pool and 26% for the RPM pool of the combined data set we conform that the measured fractions can be used to estimate the RothC model pools in arable soils. Given the magnitude of these errors, however, we rather suggest to apply the fractionation approach instead of using an equilibrium assumption for the RothC initialisation of arable sites.

1. Introduction

Against the background of global climate change and for the preservation of soil productivity the quantification of changes in soil carbon is highly relevant. Dynamic models of soil carbon turnover are valuable tools to improve our understanding and to provide reliable predictions of soil organic carbon response to changes in climate or management (Smith et al., 2002; Schmidt et al., 2011). Basically, such models of soil carbon turnover can be divided into two categories: they either consider soil organic matter as a continuum of compounds of different degradability (e.g. Bruun et al., 2010) or they conceptualize it into discrete pools that release carbon at different rates with different turnover time, e.g. in the Rothamsted carbon model RothC (Coleman and Jenkinson, 2005). RothC defines one inert organic matter pool (IOM) and four active compartments: decomposable plant material (DPM), resistant plant material (RPM), humus (HUM) and carbon stored in the microbial biomass (BIO). No matter how the soil carbon quality is characterized, it remains a challenge to link measured fractions with soil C pools which are indirectly derived from the evolution of carbon stocks and carbon fluxes using simulation models (Smith et al., 2002; Olk and Gregorich, 2006).

Apart from fractionation-based estimation of initial pool sizes, the assumption of TOC equilibrium is by far the common model approach (Foereid et al., 2012). Here, a spin-up run is performed to derive initial

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pools for which the available climatic input data is looped until the simulated TOC content is stable for a given amount of carbon inputs. This amount of carbon inputs could be adjusted, or inversely estimated, in such a way that the simulated TOC stocks match the measurement.

The establishment of a link between measurements and simulation of soil carbon pools is required for the initial parameterisation and validation of carbon turnover models. Due to the sensitivity of the model simulations to the initial parameters used (Wutzler and Reichstein, 2007; Ludwig et al., 2010; Scharnagl et al., 2010; Hashimoto et al., 2011; Foereid et al., 2012; Weihermüller et al., 2013; Nemo et al., 2016), an initial parameterisation method based on independent measurements is highly desirable (Skjemstad et al., 2004). However, models with a discrete pool structure are inherently conceptual with turnover rates assigned to each pool whilst experimental procedures designed to split the soil total organic carbon (TOC) into separate fractions are operationally defined (Olk and Gregorich, 2006). Consequently, an understanding of the relationship between physically defined soil C pools and the conceptual pools in soil C models is important to ensure they accurately represent the key processes controlling soil C dynamics. Several attempts have been made to define fractionation procedures, which correspond to the conceptual model pools of RothC. Balesdent (1996), for instance, applied a suite of chemical and physical fractionation procedures and identified a good correspondence between the organic matter in the particle-size fraction > 50 μm and the RPM pool of RothC. The author further detected correspondence between the organic carbon in the particle-size fraction < 50 μm and sum of the HUM, BIO and IOM pools. Skjemstad et al. (2004) related the particulate organic matter (POM) fraction > 53 μm to the RPM pool, the fraction < 53 μm to the HUM pool and the inert pool IOM was related to charcoal carbon isolated by photo-oxidation. Based on data from two long-term field experiments they found good agreement between fractions and pools after calibrating the RPM turnover rate. Zimmermann et al. (2007) separated a fraction > 63 μm, which was further separated into two classes of light and heavy density, dissolved organic carbon and resistant carbon by NaOCl oxidation. They found good correlation between the model pools, which were derived assuming dynamic equilibrium, and experimentally determined fractions for a comprehensive data set of arable, grassland and alpine sites in Switzerland. Based on the same fractionation approach Leifeld et al. (2009) reported that both, spin-up equilibrium or measured fractions initialisation, allowed to simulate satisfactorily the TOC dynamic of a 27-year field experiment in Switzerland. Dondini et al. (2009) also essentially followed the approach suggested by Zimmermann et al. (2007) and found that the RothC pools matched the measured fractions within one standard error for a long-term conversion trial in Ireland. Xu et al. (2011) also applied the approach of Zimmermann et al. (2007) to eight Irish grassland sites and detected good correlation between the HUM pool and the measured fractions, however the correlation between RPM and the respective fraction was poor. They further recommended that the fractionation result should differ by < 10% from the RPM pool for accurate model initialisation. Weihermüller et al. (2013) essentially followed the fractionation approach suggested by Skjemstad et al. (2004) and determined a correlation coefficient of 0.84 between the RPM pool and the fractionation result for a data set comprising 39 sites located in lower Saxony, Germany. Finally, Nemo et al. (2016) investigated the effects of three initialization procedures on the model performance and concluded that the fractionation-based model initialisation of the RPM pool was more efficient than the equilibrium-based initialisation approaches. Notably, almost all of the above-mentioned studies relate fractions to pools originating from model runs based on an equilibrium spin-up approach. Only the study of Skjemstad et al. (2004), covering a relatively short span of 18 years, related fractions to pools estimated by dynamic (non-equilibrium) model runs, which may be more appropriate than equilibrium models for arable sites.

On the other hand, repeated inventories suggest that in recent decades losses of carbon have occurred from arable soils, e.g. Bellamy et al. (2005). Several studies reported that arable soils are not necessarily in TOC steady state equilibrium. E.g. Steinmann et al. (2016a) report temporal trends in the arable topsoil TOC concentrations of North Rhine-Westphalia, Germany, between 1979 and 2015 that were related to changes in land use and management practice. In a more detailed study, Steinmann et al. (2016b) detected positive changes in the humus management for the south-western part of North Rhine-Westphalia as a consequence of the implementation of environmental minimum standards within the framework of the European agricultural reform (Cross Compliance) in 2006. Nemo et al. (2016) also conclude that a TOC steady state assumption may not be valid for arable soils.

Thus, our objectives were to elucidate: (i) whether and to what degree the relations between fractions and RothC model pools reported in literature are valid for dynamic (non-equilibrium) situations, as well as (ii) to quantify how the relation between fractions and model pools differs between equilibrium situations and dynamic long-term experiments.

2. Material and methods

In order to answer the questions outlined above, RothC was applied to 54 intensively monitored sites under long-term arable cropping, for which we assume equilibrium state. Further, RothC was applied to 5 long-term experiments with repeated sampling, resulting in 35 data pairs of fractions and pools. To ensure consistency, a single fractionation procedure was applied to the samples of the intensive monitoring sites and the archived sample material of the long-term experiments.

2.1. Experimental sites

The 54 intensive monitoring (IM) sites are all located in the federal state of North Rhine-Westphalia, Germany, which covers an area of about 34,000 km^2. All sites are privately owned and have been used as arable land under conventional agricultural practice for at least the last 50 years. The total soil organic carbon (TOC) stocks in the plough layer varied between 32 and 127 t ha^{-1}. Also the textural properties cover a broad spectrum of silty-loamy to sandy soils, only three sites have clay contents higher than 25% (Fig. 1).

Four out of the five long-term experiments (LE) are also located in North Rhine-Westphalia, Germany. The Hoosfield experiment was established in 1852 at Rothamsted (Harpenden, UK) to examine the effects of different mineral fertilisers and organic manures on the yield of

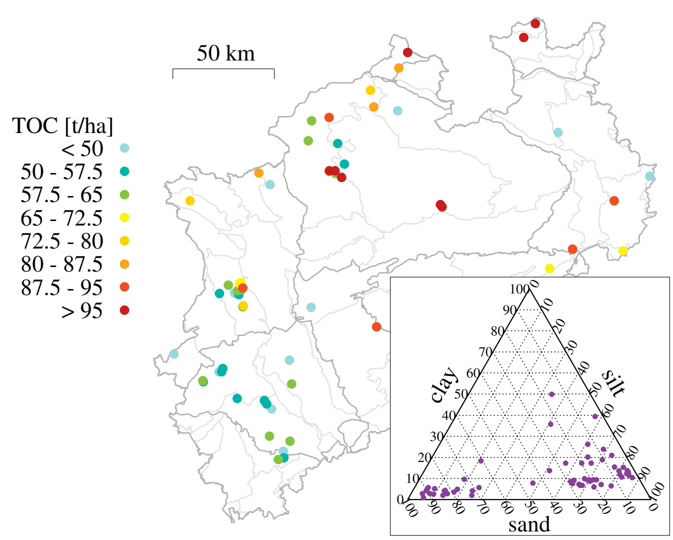

Fig. 1. Location and total organic carbon (TOC) stocks of the intensive monitoring sites. Ternary plot shows textural composition.