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The dynamics of water extractable organic matter (WEOM) in common arable topsoils: I. Quantity, quality and function over a three year period

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Abstract

Compared to total soil organic matter (SOM) the concentrations of water extractable organic matter (WEOM) are very small. Nevertheless, it is linked to many important soil functions. Numerous factors affect WEOM dynamics, most of them interacting in the same or in different directions. Therefore, there are still marked gaps in knowledge about WEOM. The majority of field studies have been done in forest ecosystems, and results on arable soils are scarce, contradictory and often do not fit to laboratory studies. Our purpose was to elucidate WEOM parameters in arable soils.

We followed the dynamics of WEOM in arable top soils located on three different research sites in Germany. We sampled nine soils differing in soil type, texture, and soil management. Samplings over three years were done in three depths (0–10, 10–20, 20–30 cm) three times a year (spring, summer, and fall). WEOM concentrations were quantified as WEOC after batch extraction. Quality was derived by optical methods (UV absorption, fluorescence spectroscopy). Additionally, WEON (water extractable organic nitrogen) and the biodegradable fraction (BWEOC) were quantified. Results are presented in three parts. For this first part we compared the differences in WEOM dynamics between three selected soils (Eutric Cambisol, Eutric Luvisol, and Haplic Chernozem) and the temporal variability of WEOM in each soil (seasonality).

Concentrations averaged over three years and for 0–30 cm showed no significant differences. WEOC and WEON ranged between 34–42 mg WEOC kg^{-1} d.m. and 1.9–2.9 mg WEON kg^{-1} d.m. The lack of significant differences was explained by the marked seasonality on all sites.

The Eutric Cambisol was characterized by a sharp decrease of WEOC/WEON concentrations with increasing depth (60.6 to 20.6 mg WEON kg^{-1} d.m. (dry mass), 1.7 to 0.48 mg WEON kg^{-1} d.m.) after more than 10 years under no-till management. SOM and total N also decreased from 12.9 g kg^{-1} C (0–10 cm) to 2.8 g kg^{-1} C (20–30 cm) and from 1.4 g kg^{-1} N to 0.43 g kg^{-1}. Highest SOM and total nitrogen contents of the Chernozem did not lead to highest WEOC and WEON concentrations. In contrast to quantity, the quality of WEOM differed temporally significantly between all soils, with the highest absorptivity in the Luvisol and highest humification in the Chernozem. Differences in BWEOC were small, ranging between 42 and 46%.

All soils were characterized by a marked seasonality. Variability of concentrations was more pronounced than that in quality. ANOVA gave indications that the quality was mainly influenced by the factor “site and/or soil” and the concentrations by the factor “seasonality”. WEOM dynamics did not show uniform patterns when the same field crop was planted on different sites.

A test for the suitability of spectral absorptivity measurements as predictor for biodegradability, as it is often mentioned in literature, gave weak results. While in the Cambisol ($r = -0.61$, $r^2 = 37\%$) and Chernozem ($r = -0.70$, $r^2 = 49\%$) negative correlations were found, no relation between BWEOC and absorptivity was detected in the Luvisol. Due to the marked dynamics of WEOM in arable soils general statements can hardly be concluded, even when results are based on iterated samplings.

Keywords: Water extractable organic carbon; Water extractable organic nitrogen; Arable soils; Absorptivity; Humification index; Bioavailability; Temporal variability

1. Introduction

A large number of important soil properties and functions are directly linked to the amount and quality of organic matter. Especially the dissolved and/or water extractable fraction in soil (DOM, WEOM) has a strong influence on many ecologically relevant processes. Besides its function as substrate for microorganisms (Zsolnay, 1996; Marschner and Kalbitz, 2003), it is well known that solubility and transport of organic contaminants as well as heavy metals through soils are linked to DOM/WEOM properties (Kalbitz and Wennrich, 1998; Raber

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et al., 1998; Marschner, 1999; Laor and Rebhun, 2002). Also, soil physical characteristics (e.g. soil structure, aggregation) depend on (dissolved) organic matter quality (Campbell et al., 2001; Jacinthe et al., 2001; Six et al., 2001; Rilling and Steinberg, 2002). This in turn may have an influence on sequestration of atmospheric CO_2 and release of trace gases (Piccolo et al., 1999; Six et al., 2000; Paustian et al., 2000, Ruser et al., 2001). With these complex functions the ecological significance of DOM/WEOM is not only restricted to the compartment “soil”. It is also environmentally relevant for groundwater quality, desertification and climatic change. Therefore, interest in DOM research drastically increased in the last two decades.

Recently, the most important factors controlling the dynamics of dissolved organic matter in soils were reviewed by Zsolnay (1996), Kalbitz et al. (2000), and Chantigny (2003). In summary, these factors can hierarchically be classified into an order of increasing influence: (i) environmental factors (e.g. climate, landscape, and hydrology), (ii) soil management (e.g. tillage, fertilization, liming, plant species, field crops), and (iii) land use (forest, grassland, arable). Nevertheless, DOM research is far from conceptual clarity in regards to most of the processes steering the dynamics of DOM. On the one hand, this is due to the lack of standard methods, and the results of the used methods are hardly comparable (Zsolnay, 1996). On the other hand, environmental and soil factors affecting spatial and temporal variability of DOM interact at the same time. Therefore, discrimination between cause and effect is often not possible, which is mainly true for field studies. This could be the main reason why most of the DOM research has been done in forest ecosystems, and results from laboratory studies concerning fate of DOM in soils are very often not confirmed by field studies (Kalbitz et al., 2000). Summarized, there is still a marked gap of knowledge about WEOM dynamics, in particular from field studies in arable soils (Chantigny, 2003; Kalbitz et al., 2003b).

To obtain deeper insights into the short- and mid-term dynamics of WEOM in arable soils, we followed the WEOM characteristics for three years on three research sites in Germany. In total, nine sampling locations differing in soil type, texture, soil organic matter, and/or soil management (i.e. fertilization, crops, and cultivation) were chosen. Main objectives of our research were

(i) to receive a not yet available data set about WEOM content, quality, and its function as substrate for mineralization in a broad range of typical German arable soils,
(ii) to quantify the temporal variability of these WEOM properties over three years (seasonality) and to compare this with the differences between sites
(iii) to quantify the influence of organic and inorganic fertilization on the WEOM fraction, and
(iv) to gather information about the WEOM heterogeneity within one field.

The presentation of the results was divided into three parts. In this first part we present data on the dynamics of WEOM in three different soil types (Eutric Cambisol, Eutric Luvisol, and Haplic Chernozem) at three research sites (Research Farm “Klostergut Scheyern”/GSF National Research Center for Environment and Health; Research area “Merzenhausen”/ Research Center Jülich; Research area “Bad Lauchstädt/UFZ Center for Environmental Research). Special emphasis was given to investigating the temporal changes of quantity, quantity, and biodegradability over three years. Influences by seasonality are mainly based on annual changes in (i) weather conditions (temperature, soil moisture), (ii) soil management and field crops, and (iii) phaenology (plant cover, and root exudates). Zsolnay (1996) and Campbell et al. (1999) reported that through crop rotation the C input varied from year to year. Therefore, there is likely an influence of the crops/cultivars on WEOC (Xu and Juma, 1993), but very few studies have compared this (Chantigny, 2003). Over the three year period some crops (winter wheat, potato) have been cultivated on more than one single site. As a result we could compare the seasonality of the same field crop on different sites.

Additionally to the above mentioned factors, divergent soil types, soil texture, and different regional climate cause differences in WEOM dynamics. These parameters were also considered when we compared the differences between the three sites with the seasonality on each site.

Two additional aspects were investigated. First, data on the influence of soil depth on WEOM dynamics are presented. The Research area “Scheyern” deviated in soil management from the other sites in that reduced tillage was carried on for more than 10 years. Even if there was no control plot on this site, we expected hints on how reduced tillage influenced the dynamics of the water soluble C fraction. Secondly, we tested if the reported usability of the rapid and simple optical measurement (namely the absorptivity) as a predictor for biodegradability is transferable to arable soils.

Furthermore the above mentioned research objectives (1) influence of mineral and organic fertilization on WEOM and (2) variability of WEOM within a field will be presented in two following publications.

2. Materials and methods

2.1. Site description

Three well documented study sites all under arable land use were chosen for our studies. These sites, located in the south, west and east of Germany, differed in regional climate, pedogenesis and soil characteristics. Soils chosen for this research differed distinctly in soil type, texture and/or organic carbon and nitrogen contents (Table 1).

On the first site “Klostergut Scheyern”, 40 km north of Munich in a Tertiary hilly landscape, we sampled a Eutric Cambisol. This soil developed from fluviatile deposits with loess as a subcomponent. The lowest organic carbon (8.1 g kg^{-1}) and total nitrogen (1.0 g kg^{-1}) contents were measured in this soil. Mean temperature in Scheyern is 8.7 °C with an annual average precipitation of 852 mm yr^{-1}. In 1990 farming practice changed from plough management to integrated farm