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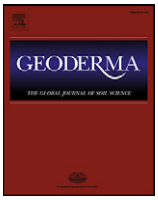

Effects of temperature and associated organic carbon on the fractionation of water-dispersible colloids from three silt loam topsoils under different land use

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ABSTRACT

The release and stability of soil water-dispersible colloids (WDC) in the soil structure are critical for colloid-facilitated soil organic carbon sequestration and contaminants transport. In this study, the potential effects of temperature and associated organic carbon (OC) on the release of WDCs in three silt loam topsoils with the same clay content (~20%) under different land uses were investigated. A soil fractionation method was used for simulating the release of colloids from the soil under environmental conditions where mobilization and sedimentation processes occur sequentially. The surface loading of OC has been characterized by the analysis of organic carbon content of WDC with the measurements of the specific surface area (SSA). The effects of fractionation temperature on colloidal properties (e.g., particle size and zeta potential) were systematically investigated and the aggregation kinetics of WDC in salt electrolyte influenced by temperature was assessed by dynamic light scattering (DLS).
Experimental results demonstrated that the amount of extracted WDC from three soils decreased when the fractionation temperature increased. A more rapid sedimentation of WDC at higher temperatures outweighed the effect of temperature on WDC mobilization from bulk soil in the shaking step. The sedimentation of WDC at various temperatures indicated that the temperature dependence of the water viscosity (η) was a dominate parameter and caused lower efficiency of WDC mass gained at higher temperature according to the Stoke's law. After introducing the factor of $\eta_{7\,^{\circ}\mathrm{C}}/\eta_{\mathrm{T}}$, the temperature effect only on WDC mobilization during shaking step could be described and the whole fractionation process could be successfully timely determined along the two shaking and sedimentation steps. Activation energies (E_a) of about 10 kJ mol^{-1} could be now calculated for the WDC mobilization processes from the three topsoils.
The associated organic carbon contents of WDC (WDC(OC)) and the mineral surface of WDC blocked by organic carbon ($SSA_{OC\text{-}block}$) after various shaking temperatures and shaking time were further determined in order to examine the WDC(OC) effect on the release of WDC from soil matrix. The results demonstrated that the escape of the mobile clay fraction (F) from soil at short shaking times is favored by the presence of effective surface loading by an OC layer ($SSA_{OC\text{-}block}$), which is known to stabilize its colloidal state through electrosteric effects. The WDC(OC) surface concentration has been also used to estimate the clay-associated OC distribution in the three topsoils.
In Ca^{2+} solution, an increase of temperature favors the colloidal stability of WDC as measured from the shift of critical coagulation concentration (CCC) to higher concentrations of Ca^{2+}. In total, the results from this study revealed that temperature and WDC(OC) distribution are critical parameters when considering soil WDC release and stability in natural bulk soils.

1. Introduction

Soil water-dispersible colloids (WDC) are particles < 2 μm of clay fraction which are released from larger soil aggregates into soil water. They may be made of individual or associated soil particles in small aggregates mainly composed of aluminosilicates and oxides. The dispersion and the mobilization of WDC from soil solid matrix in soil water (Mccarthy and Degueldre, 1993) are thus depending on the stability of soil aggregates (Seta and Karathanasis, 1996). WDC are recorded to be responsible for the preferential transfer of nutrients and contaminants absorbed on them in soil structure (DeNovio et al., 2004; Czigány et al., 2005; Henderson et al., 2012; Li et al., 2013; Jiang et al., 2015; Missong et al., 2016) and are extensively studied in recent years. Soil organic matter (SOM) associated with WDC can be sequestered and transported into deeper soil layers or surrounding water

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matrices (Pokrovsky et al., 2016) which is considered to be an effective mechanism for protecting SOM from microbial degradation and loss to the atmosphere thus affecting the global carbon cycle (Kaiser and Guggenberger, 2003; Tisdall and Oades, 1982). Colloid-facilitated transport of heavy metals and organic contaminants were also considered to be one important mechanism affecting the mobility and redistributions of contaminants in soil (Li et al., 2013; Van Den Bogaert et al., 2015; Yin et al., 2010). The release of WDC from soil matrix, their chemical characteristics, colloidal stability and important roles for adsorption or/and desorption of contaminants and nutrients were systematically investigated (Mohanty et al., 2015; Séquaris et al., 2013; Abgottspon et al., 2015; Li et al., 2013; Jiang et al., 2015). Under certain physical chemical conditions, WDC may be released from soil solid matrix and enter the surrounding environment (Brubaker et al., 1992). The release of WDC from soil structure is related to soil erosion and is influenced by interaction mechanisms between chemical, geological, hydraulic and biological factors (Brubaker et al., 1992; Mohanty et al., 2015; Mohanty et al., 2016; Shainberg et al., 1992). In particularly, the stability of released mobile soil colloids in the soil structure is closely associated with the conditions of solution chemistry, such as natural organic matter, pH, ionic species, electrolyte concentration and sodium adsorption ratio (Jarvis et al., 1999; Jiang et al., 2012; Kjaergaard et al., 2004a; Séquaris et al., 2013; Tian et al., 2013). Particle aggregation can occur and produce large aggregates, through which the fine particles may result in rapid deposition (Nicholas and Walling, 1996; Areepitak and Ren, 2011). However, there is still large unknown regarding the soil water temperature and organic matter effects on the mobility and characteristics of WDC released from soil matrix.

In 2015, the average global surface temperature was 0.87 °C higher than in 1951–1980 and it was the warmest year during 1880–2015 (NASA, 2015). Global climate change may influence soil erosion through changing rainfall (rainfall amount, intensity, and spatiotemporal distributions) and soil temperature (Nearing et al., 2004). Increased impact from rainfall may induce the production of WDC by the soil erosion (Seta and Karathanasis, 1996; Zhuang et al., 2007). Several studies have addressed the issue that variations in temperature may complexly influence the stability of soil aggregates. In a two years field study, under typical Mediterranean climatic conditions, the stabilities of soil aggregates decreased in winter and increased in summer when the increasing temperature may promote soil aggregation through soil drying and warming (Dimoyiannis, 2009). On the other hand, higher temperatures may result in higher evaporation rates and thus elevate the soil moisture with increasing rainfall events, which would potentially increase soil erosion (Nearing et al., 2005). Using a 180-day incubation experiment with a mollisol soil, Wang et al. found that, the increase in temperature (10, 30 and 50 °C) may result in decrease of 2–0.25 mm macro-aggregates content and induce the disruption of macro-aggregates into micro-aggregates and silt-clay size fraction (Wang et al., 2016). Temperatures may also influence the colloidal stabilities of WDC. At different electrolyte concentrations, flocculation and deposition processes of WDC only occur when the repulsive force among particles (electrostatic double-layer interaction energy) is reduced (Hiemenz and Rajagopalan, 1997). García-García et al. found that increasing temperature reduced the sedimentation of bentonite colloids in water (García-García et al., 2009). It is reported that for alumina particles, an increase in temperature reduced the surface charge density and thus reduced their colloidal stability due to the decrease of the inter-particle pair potential (Tarì et al., 2000). Until now, only few studies have investigated the effects of temperature variations, induced by climate change, on the release and characteristics of WDC from soil matrix (Kalinin et al., 2003). The effect of temperature on colloid stability has been modeled by proposed quantitative models which need to be verified with soil samples (Jarvis et al., 1999; Laegdsmand et al., 2007). So et al. found, using the end-over-end shacking technique, that the release of soil clay from total soil was largely depended on shaking time, suspension concentration, container size and air-gap between the suspension and the increase of the dispersion temperature (from 20 to 24 °C) had rather minor effect (So et al., 1997). However, in our previous study, the shaking temperature (7, 23, 35 °C) was found to affect the diffusion of WDC from bulk soil (Jiang et al., 2013).

Soil organic matter (SOM) is a binding agent or a core in the formation of aggregates which may increase the soil aggregate stability (Six et al., 2000; Tisdall and Oades, 1982). Due to the close associations between OM and mineral surfaces, an inverse correlation relationship was found between grain size and SOM content (Oades, 1988). The protection of SOM by clay minerals can largely change the SOM turnover processes in soil (Parfitt et al., 1997; Tipping and Jardine, 2012). Specifically, the contribution of fine mineral particles on preservation of SOC has been previously reported (Burke et al., 1989; Mayer and Xing, 2001). Christensen pointed out in his research that distribution of SOM within clay-size organo-mineral particles was around 50%–75% of total SOM (Christensen, 2001). However, a highest OC surface loading (OC content to specific surface area (SSA) ratio) can be observed in coarse particles, which is due to an overestimation of the direct OC adsorption at the mineral surface. Indeed, a significant proportion of SOM is not associated as organo-mineral complexes and is thus independent on the available mineral surface area of soil particle (Christensen, 1996; Kaiser and Guggenberger, 2003; Séquaris et al., 2010). Until now, the information regarding the relationships between SOM and surface area of various particle sizes affected by different land use types and the effect of the mineral associated SOM on the release of WDC were still limited.

In the present study, we attempted to quantify the influence of fractionation temperature and associated organic matter on the physical-chemical properties of WDC released from silt loam topsoils. A WDC fractionation method including shaking and sedimentation processes was selected to assess the potential effects of temperature (7, 15, 23, 35 °C) on the release of WDC from three German silt loam topsoils. The methodology, based on batch experiments, allows quantitative and accurate measurements of soil aggregate stability under controlled experimental conditions (temperature, time, shaking rate and sedimentation vessel volume). Compared with the single shaking process, this approach can better simulate the WDC release process by a two-step mechanism in which the dispersion of WDC from soil aggregates was followed by the sedimentation of dispersed WDC as in the case of deposition in soil pore structure (Ryan and Elimelech, 1996). The potential effect of the temperature on the sedimentation process alone for WDC dispersion was verified by the Stoke's law and enabled us to validate directly the relative mobilization extent of WDC from soil samples during the shaking time with different temperatures. The temperature dependence of the mobilization rates of WDC from soils and the related activation energies E_a using empirical Arrhenius equation were characterized for the first time in the three soils. The colloidal properties of WDC including hydrodynamic diameter (d_z), zeta potential, surface area of released WDC affected by fractionation temperatures were determined. The aggregation kinetics of WDC at various temperatures was investigated by dynamic light scattering in Ca^{2+} solution. Furthermore, the OC distribution and OC blocked mineral surface properties in WDC after fractionation at the different temperatures were systematically characterized and were compared with other soil fractions. The effect of WDC associated OC (OC surface loading) on the release of WDC along the increasing shaking time was also investigated. The results of this work will be helpful for better understanding the environmental behaviors of natural soil WDC.

2. Materials and methods

2.1. Soil description

Three typical topsoil (0 cm to 10 cm) samples under various types of land use were collected in Germany. They were Selhausen (50°52′08″N; 6°26′59″E; arable luvisol, average annual temperature and mean annual precipitation are 9.8 °C and 690 mm, respectively which has been under intensively conventional agriculture for at least 100 years (Bornemann