Special Section: Dissolved Organic Matter in Soil

The guest editors introduce the contributions to the special section, Dissolved Organic Matter in Soil, with a focus on the three main directions in this complex and growing research effort.

Dissolved Organic Matter: Linking Soils and Aquatic Systems

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Dissolved organic matter (DOM) plays a crucial role in many important processes that take place in terrestrial and aquatic systems. These include carbon and nutrient cycling, pedogenesis, and microbial metabolism. Here we highlight the results of studies that demonstrate the role of DOM in linking terrestrial and aquatic systems. We emphasize three fundamental aspects of the research, which together show the importance of DOM in linking terrestrial and aquatic systems: First, tracing DOM properties during its transport through terrestrial and aquatic systems is a powerful tool for improving our conceptual understanding of the mechanistic drivers of DOM dynamics. Second, linking DOM dynamics to important physical processes such as hydrology provides important insights into the nature of terrestrial–aquatic links. Third, interrelations between DOM dynamics and human impacts on ecosystems highlight how the role of DOM in coupled terrestrial–aquatic systems may change in the future. New measurement and modeling approaches have enabled a more thorough assessment of all three aspects of DOM dynamics. They show that both natural and anthropogenic drivers not only greatly influence DOM dynamics in soils, but owing to the mobility of DOM, also have substantial influence on aquatic systems. This physical connection of soils and surface waters demonstrates the importance of understanding fundamental processes such as nutrient cycling, pedogenesis, and microbial metabolism at a whole-landscape scale.

Abbreviations: DOM, dissolved organic matter.

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Dissolved organic matter is the most mobile form of organic matter in soils (Kalbitz et al., 2000). Therefore, it contributes substantially to the cycling and distribution of carbon and nutrients within and between ecosystems (e.g., Bolan et al., 2011; Chantigny, 2003; Cleveland et al., 2004; McDowell et al., 2004). Dissolved organic matter is also an important component of the global C cycle; it is a potential source of both CO_2 and the stabilized carbon present in subsoils (e.g., Kalbitz and Kaiser, 2008; Van Hees et al., 2005). Furthermore, DOM contributes to soil forming processes and feeds microbial metabolism in lakes, rivers, and the ocean (e.g., Jansen et al., 2003; Ogawa and Tanoue, 2003). The potential to use DOM as an indicator of environmental change was discovered in aquatic and marine sciences long ago (e.g., Thomas, 1997). An analogous use in soil science today is desirable. However, a comprehensive understanding of DOM dynamics in terrestrial ecosystems in relation to aquatic ecosystems remains challenging due to complex interactions of biogeochemical and hydrological processes at different scales. In an effort to bring together scientists working on different aspects of this important topic, a dedicated session was organized at the General Assembly of the European Geosciences Union (EGU) in Vienna in 2013. This special issue highlights important work presented in this session, as well as research developed as a result of the ensuing scientific discussion. The contributions revolve around three central topics related to the dynamics of DOM in terrestrial and related aquatic ecosystems.

Improving our Conceptual Understanding of DOM Dynamics in Terrestrial and Aquatic System by Tracing Changes in DOM Properties

To understand the dynamics of DOM during its transport through ecosystems a prerequisite is the need to trace DOM origin as well as its transformations during transport. Roth et al. (2014) applied electrospray ionization Fourier transform ion cyclotron resonance mass spectrometry to identify ecosystem-specific molecular characteristics of DOM from various rivers, bogs, and soils. They successfully identified unique molecular formulas for each ecosystem, and they identified a possible influence of pH on all samples as well as a possible influence of vegetation on soil-derived samples of dissolved organic matter. Gottselig et al. (2014) investigated colloidal fractions containing P, Al, Fe, and C in stream water of a forested catchment through Asymmetric Flow Field Flow Fractionation (AF4). This approach for the first time enabled the tracing and conceptual definition of inputs and source regions of fine colloidal and nanoparticulate fractions. Their results suggest an important role for Fe and Al associated with DOM as carriers of P.

Focusing on transformations of DOM during transport through the critical zone, Vazquez-Ortega et al. (2014) studied the influence of Al- and Fe(oxy)hydroxide surfaces on the fractionation of DOM. In a series of column experiments, they studied DOM solutions derived from organic horizons in a grassland and mixed conifer forest in the Jemez River Basin Critical Zone Observatory in New Mexico, USA. They found evidence for kinetic DOM exchange reactions, supporting the recently proposed conceptual view of DOM leaching through the soil profile (Kaiser and Kalbitz, 2012). Their results are consistent with the zonal model of organic matter adsorption at mineral surfaces (Kleber et al., 2007). Jeanneau et al. (2014) also studied changes in composition of DOM during transport. In a wetland found in an agricultural catchment they examined spatiotemporal changes in DOM composition by thermally assisted hydrolysis and methylation coupled to gas chromatography mass spectrometry. On the basis of their experiments, they established a link between the depth distribution of plant-derived DOM and water table fluctuations.

Interactions of DOM with Hydrology

Hydrologic regimes often govern the transport of DOM through soils to aquatic systems. In turn, interactions of DOM with solid soil phases during transport can affect hydrology. Van Gaelen et al. (2014) used variations in dissolved organic carbon (DOC) concentrations and DOM composition to identify pathways for transport of DOM to surface waters in an end-member mixing model. Via their approach, they differentiated pathways in forested catchments from those in grassland catchments and quantified the changing contributions of each catchment to stream DOC concentrations during rain events. They identified seeps as an important pathway of DOC delivery to streams in grassland catchments with shallow water tables. They also found increased riparian zone transport pathways and throughfall to be an important factor in rising stream DOC concentrations in forested catchments with deep water tables. Focusing on throughfall, Klotzbücher et al. (2014) examined the effects on DOM concentration and composition when throughfall amounts in a spruce forest were artificially doubled during a 6-yr experiment. They found that neither DOM concentrations nor composition were altered as a result of the increased throughfall, indicating a direct control of precipitation on DOM amounts exported from the forest floor to the soil.

Within the soil matrix, Lamparter et al. (2014) investigated the effects of DOM on soil hydraulic properties in the form of the wettability of quartz sand particles. Their results indicate a strong alteration of the original wetting properties as a result of adsorption of DOM and microbial activity. In another approach to linking aquatic to terrestrial systems, Rieckh et al. (2014) focused on the effects of alterations in pedology and soil structure induced by soil erosion on fluxes of dissolved organic and inorganic carbon. For their study, they used a 3-yr biweekly time series of dissolved carbon flux measurements in four soils with different erosion regimes. Their results indicate that soil erosion influences dissolved carbon fluxes through modified hydraulic and transport properties, as well as terrain-dependent boundary conditions.

Interrelations between DOM Dynamics and Human Impact on Ecosystems

Human impacts potentially have a large influence on the ecosystem dynamics of DOM, both directly (e.g., through the input of manure) and indirectly (e.g., by altering pathways of DOM genesis and transport). Conversely, DOM has the potential to alter and possibly attenuate the effects of human disturbance of ecosystems, such as in polluted soils. Kiikkilä et al. (2014) studied the influence of forest management in the form of stem-only and whole-tree harvested sites on the molecular properties of DOM that could be potentially leached from a boreal peatland. Among other findings, they observed that peat DOM was more N-rich under both harvesting regimes as compared to nonharvested sites. Furthermore, they observed that changes in water tables associated with forestry operations affect DOM properties in peat by changing the availability of oxygen. De Troyer et al. (2014) performed a survey of soil solution DOC concentrations in the topsoil of 87 agricultural soils with contrasting properties. They compared directly measured DOC concentrations with those obtained after drying and rewetting, and those stored moist and cold for 1.5 yr. They concluded that DOC concentrations are strongly affected by drying and rewetting processes, whereas DOC concentrations in freshly sampled soils are predominantly determined by biological processes.

The influence of DOM on other anthropogenic processes was assessed in two other studies. Thangarajan et al. (2014) studied the influence of DOM from various anthropogenic sources, such as piggery and dairy effluent, on priming effects of soil carbon in several anthropogenically influenced soils, including landfill and metal contaminated soils. An important result of their study was that C-rich wastewater can cause increased CO_2 evolution due to a strongly increased priming effect of soil carbon. Refaey et al. (2014) investigated the effects of the addition of DOM on Cu, Zn, and Ni adsorption by several Egyptian clay-rich soils. In particular they studied the effects of the timing of DOM additions to the soil material, that is, before or concurrently with addition of heavy metals. They found that the timing of DOM addition had a significant effect on the affinity of Cu for the solid phase, enhancing adsorption when DOM was added first. In contrast, the timing of DOM addition had no effect on the adsorption of Zn and Ni. This underlines the importance of considering the sequence of events in environmental studies involving DOM and heavy metals.

Future Outlook

The new and exciting scientific developments described in this issue underline the pivotal role of DOM as a link between terrestrial and aquatic systems. They also show that significant advancements have been made in the understanding of that role. New approaches with respect to molecular characterization and modeling enable a more detailed tracing of the origin of DOM and its transformations along its journey from the soil to surface waters. An intricate interplay between differences in the molecular composition of DOM and in hydrological pathways results in marked variability in the behavior of DOM from different origins. This means that human impacts such as changes in land use or land management will not only influence the specific area where the changes take place, but through the influence on DOM dynamics, land use changes will affect a much larger area that includes the linked aquatic systems. However, the ecosystem dynamics of DOM remain exceptionally complicated, and fully quantifying the link it provides between the terrestrial and aquatic systems remains a challenging task indeed. Further research dedicated to this issue is needed, in particular with respect to linking processes operating at the molecular scale to those operating at the catchment scale. The work presented in this special section provides important directions and starting points for such future endeavors. A further unravelling of the dynamics of DOM along its journey through the soil using the novel methodology presented herein appears to be an exciting next step to test and further develop the proposed models for the interaction of DOM and hydrology. This in turn will be of crucial value to further understanding of the coupling between human action and DOM dynamics across the boundary of soil and water systems and across different scales. Understanding the coupled dynamics of land and water at multiple scales is of particular importance in the context of global carbon cycling (e.g., Raymond et al., 2013; Regnier et al., 2013).

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