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Storm flow flushing in a structured soil changes the composition of dissolved organic matter leached into the subsoil

Klaus Kaiser*, Georg Guggenberger

Institute of Soil Science and Soil Geography, University of Bayreuth, 95440 Bayreuth, Germany
Institute of Soil Science and Plant Nutrition, Soil Biology and Soil Ecology, Martin Luther University Halle-Wittenberg, Weidenplan 14, 06108 Halle, Germany

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Abstract

Dissolved organic matter increases typically in streams draining forested catchments during heavy rainstorms and snowmelt. Tracer methods and model calculations suggest that the storm flow flushing of dissolved organic matter is either due to lateral near-surface flow, i.e. within the organic forest floor, or preferential flow (funnelling) through the mineral soil. Both pathways should deliver forest floor-derived dissolved organic matter to streams that is hardly changed because of little to no interaction with mineral soil material and microorganisms. Here, we investigated the effect of rain storm induced vertical flushing through the mineral soil on the composition of dissolved organic matter in a structured Rendzic Leptosols under 90-year-old European beech (*Fagus sylvatica* L.). During two rainstorm periods in autumn 1998 with elevated transport of organic C, N, P and S from the forest floor into the subsoil, we sampled dissolved organic matter in forest floor leachates (sampled by zero-tension plate lysimeters), subsoil solutions (sampled by suction cups at 90 cm depth) and subsoil seepage (sampled by zero-tension plate lysimeters at 90 cm depth). The chemical composition of dissolved organic matter was characterised by fractionation with XAD-8 macroreticular resin, wet-chemical analyses of carbohydrates and lignin-derived phenols, and determination of the $\delta^{13}C$.

During both rainstorm periods, all tested chemical features of dissolved organic matter in forest floor leachate and subsoil seepage matched each other greatly. In contrast, dissolved organic matter in soil solution contained smaller portions of XAD-8-adsorbable organic C, less lignin-derived phenols, more carbohydrates and showed smaller $\delta^{13}C$ values than that in forest floor leachates and subsoil seepage. These results suggest a rather direct transfer of organic solutes from the forest floor into the subsoil and probably further to ground and surface waters during heavy rainstorms. Dissolved organic matter leaving the soil in heavy rainstorms by rapid water flow through macropores is likely less biodegradable, more UV-digestible and more reactive towards metals and organic pollutants than that released from soil at low rainfall intensity by matric flow.

Keywords: Dissolved organic carbon; Dissolved organic nitrogen; Dissolved organic phosphorus; Dissolved organic sulphur; Carbohydrates; Lignin-derived phenols; $\delta^{13}C$; XAD-8 fractionation

* Corresponding author. Present address: Institute of Soil Science and Plant Nutrition, Soil Biology and Soil Ecology, Martin Luther University Halle-Wittenberg, Weidenplan 14, 06108 Halle, Germany. Tel.: +49 345 55 22544; fax: +49 345 55 27116.

E-mail address: klaus.kaiser@landw.uni-halle.de (K. Kaiser).

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1. Introduction

Aquatic environments receive dissolved organic matter that originates from terrestrial forest ecosystems by different pathways. A smaller part derives directly from litter that is falling into surface waters (Meyer et al., 1998; Baldwin, 1999) but the major part is transported either vertically or laterally through the soil (Cronan and Aiken, 1985; McDowell and Likens, 1988; Dosskey and Bertsch, 1994). Under low-flow conditions, a general feature of the transport through soil is that dissolved organic matter released from the vegetation and the organic forest floor layer is largely retained within the mineral soil (McDowell and Likens, 1988; Guggenberger and Zech, 1993). Refractory, lignin-derived compounds are selectively removed from the soil solution while the more biodegradable, carbohydrate-rich microbial products remain preferentially dissolved (Kaiser et al., 2004). Therefore, at slow to moderate water movement (matric or base flow) through the soil, export of dissolved organic matter from forested catchments into ground and surface waters seems to be rather small (Easthouse et al., 1992; Hagedorn et al., 2000a).

Snowmelt and heavy rainstorms induce rapid water movement along macropores and certain flowpaths (funnelling; Young and Leeds-Harrison, 1990; Edwards et al., 1993; Hagedorn et al., 2000b). By this, the contact of organic and inorganic solutes with the soil matrix and thus sorptive retention is reduced (Luxmoore et al., 1990; Edwards et al., 1993; Riise, 1999). Consequently, concentrations of dissolved organic carbon and nitrogen in streams draining forested catchments rise significantly during snowmelt and heavy rainstorms suggesting flushing of dissolved organic matter from the forest floor (Jardine et al., 1990; Easthouse et al., 1992; Dosskey and Bertsch, 1994; Boyer et al., 1997; Hagedorn et al., 2000a; Buffam et al., 2001). Increased molar UV absorptivity and molecular weight, and greater abundances of aromatic compounds indicate that the stormflow-induced increase in dissolved organic matter goes along with a change in the composition of organic solutes (Boyer et al., 2000; Hagedorn et al., 2000a; Buffam et al., 2001; Maurice et al., 2002). Also the isotopic composition of dissolved organic carbon in streams and groundwaters varies with different hydrological conditions (Wassenaar et al., 1991; Hinton et al., 1998; Schiff et al., 1998). Therefore, it is reasonable to assume that during heavy rainstorms the composition of dissolved organic matter transported vertically into the subsoil will be different from that under matric flow conditions. This can change its biodegradability, its capability to interact with solids and solutes, and may be of relevance for the leaching of organically bound nutrients and pollutants from soil.

In strongly structured where seepage that percolates freely downward through the soil was collected by zero-tension plate lysimeters (Liator, 1988; Marques et al., 1996), we observed that the concentrations and fluxes of dissolved organic C, N, P and S in the seepage matched those with the forest floor leachates during two periods with intensive rainfall (Kaiser et al., 2000). In contrast, both concentrations and fluxes (as calculated using water fluxes that were estimated by hydrological models) with the soil solution that moves slowly following matric gradients or is held by capillary force and is sampled by suction cups were less than those with the forest floor leachates and subsoil seepage. The situation seemed ideal to test the assumption of changes in the composition of dissolved organic matter depending on changes in the flow regime of soil water. Consequently, we compared the composition of dissolved organic matter in soil solution and seepage with that of dissolved organic matter in forest floor leachates.

2. Materials and methods

2.1. Field experiments

The experiments were carried out in a 90-year-old European beech (*Fagus sylvatica* L.) stand near Betzenstein, Germany (49°44′N, 11°23′E, 520 m above sea level). Ground vegetation was little throughout the year and was dominated by *Anemone nemorosa* L. in early spring and later on by *Mercuralis perennis* L. The soils, derived from Upper Kimmeridgian dolomite, were strongly aggregated Rendzic Leptosols (FAO-Unesco, 1990) with loamy texture and large contents of organic C. Because of the strong aggregation, the large content of rock fragments (up to 85% in the subsoil) and preferential weathering along cracks in the bedrock connected