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Quantity and quality of dissolved organic carbon released from coarse woody debris of different tree species in the early phase of decomposition

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ABSTRACT

The release of dissolved organic carbon (DOC) from decomposing coarse woody debris (CWD) may result in large DOC inputs to the forest soil. Here we investigated the influence of tree species on the amounts and quality of DOC from CWD in the early phase of decomposition.

Logs from 13 tree species were exposed in winter 2008/2009 on the soil in a temperate *Fagus sylvatica* L. forest in Germany. Runoff solutions were periodically collected for 17 months from June 2011–November 2012 underneath logs and the net release of DOC was calculated for each log on an annual scale. The quality of DOC was assessed by its contents of soluble phenols, hydrolysable carbohydrates and by spectroscopic properties. Prior to field exposure of CWD, bark and sapwood were analyzed for their initial element content and water extractable DOC.

Concentrations of DOC in log runoff were much (3–10 times) higher than in throughfall for all tree species. Average concentrations in runoff were largest under *Quercus* and *Prunus* and lowest under *Tilia* and *Fraxinus*. Accordingly, the net release of DOC from the logs was largest under *Quercus* and *Prunus* amounting to 60 and 56 g C m^{-2} projected log area yr^{-1}, respectively. The DOC net release for the tree species was positively related to the initial phenol content of sapwood, but not to *C/N* ratios in bark and sapwood. On a monthly to annual scale, the amount of precipitation had only a small influence on the net release of DOC, but the DOC net release was larger in the growing than in the dormant season. The concentrations of hydrolysable carbohydrates in log runoff were largest for *Prunus* and *Quercus* and lowest for *Fraxinus* and *Tilia*. Average concentrations of total phenols in runoff ranged from about 2 to 7 mg L^{-1} with *Quercus*, *Fraxinus*, *Betula*, *Picea* and *Larix* representing the upper range. Spectroscopic properties indicate that the DOC leached from logs is microbially modified and oxidized in comparison to DOC in initial bark and wood extracts.

Our results suggest that the DOC release from CWD is tree species specific in terms of quantity and quality and causes huge DOC fluxes to the soil underneath CWD.

1. Introduction

The mass loss through decomposition of coarse woody debris (CWD) is driven by respiration, fragmentation and leaching of substances (Harmon et al., 1986). In forest floor leachates underneath *Pseudotsuga* logs, concentrations of dissolved organic carbon (DOC) up to 250 mg L^{-1} were found (Spears and Lajtha, 2004) and up to 300 mg L^{-1} in log runoff (Hafner et al., 2005), exceeding the DOC concentrations in the throughfall by far. Kuehne et al. (2008) found DOC concentrations in runoff from *Fagus* logs increasing with decomposition stage from 28 to 118 mg L^{-1}. DOC concentrations in forest floor leachates also doubled after addition of shredded wood to the soil surface (Lajtha et al., 2005). Large DOC inputs into the soil underneath CWD might cause accumulation of soil organic matter (Kalbitz and Kaiser, 2008; Kahl et al., 2012; Goldin and Hutchinson, 2013) as well as changes in soil microbial communities (Brant et al., 2006; Yurkov et al., 2012).

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While drivers of CWD decomposition have been intensively studied (Harmon et al., 1986, 2000; Weedon et al., 2009; Herrmann and Bauhus, 2013), those for DOC release from CWD have not been investigated in detail. The release of DOC from CWD under field conditions seems to increase with decomposition stage of CWD (Hafner et al., 2005; Kuehne et al., 2008) which is different to the DOC release from leaf and needle litter being much larger from fresh than from decomposed litter (Don and Kalbitz, 2005). In the case of forest floor percolates under different tree species, DOC release from the forest floor increased with *C/N* (Michel and Matzner, 2002; Kindler et al., 2011; Borken et al., 2011). Based on the large amount of aromatic moieties in DOC, the decomposition of lignin is seen as a major source for DOC from leaf and needle litter (Kalbitz et al., 2006). Hence, the wide *C/N* ratio and the high lignin content of CWD suggest large rates of DOC release during CWD decomposition.

The amount and composition of DOC from CWD may differ with tree species since the lignin of coniferous wood is primarily formed by guaiacyl-units combined with low amounts of p-hydroxyphenyl-units, whereas deciduous wood is formed by syringyl and guaiacyl units in a 1:1 ratio with traces of p-hydroxyphenyl-units (Wong, 2009). Moreover, coniferous wood generally decomposes slower than deciduous and wood of narrow *C/N* decomposes faster than wood of wide *C/N* (Weedon et al., 2009). Tree species specific decomposition rates likely also influence the DOC release.

Besides decomposition stage and wood properties, the environmental conditions should also be important for the DOC release from CWD. DOC fluxes in forest floors were generally shown to increase with precipitation at the monthly to annual scale (Park and Matzner, 2003; Schmidt et al., 2011; Gielen et al., 2011; Borken et al., 2011). The respiration of CO_2 from CWD and hence the decomposition rate was correlated to temperature (Herrmann and Bauhus, 2013) suggesting also a larger DOC release in the growing season than in the dormant season. However, relations of DOC release from CWD to precipitation and seasonality have not been reported so far.

Here, we investigated the release of DOC from CWD of 13 temperate forest tree species in the early stage of decomposition. We hypothesized that (i) the amount and composition of DOC released from CWD is tree species specific and affected by the initial chemical properties of bark and sapwood, (ii) the net release of DOC increases with precipitation and (iii) the net release of DOC is larger in the growing than in the dormant season.

2. Materials and methods

2.1. Study site and sampling

Freshly cut logs of 30–40 cm diameter and 4 m length from 13 tree species of the temperate forest zone (*Acer sp., Betula sp., Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Larix decidua, Picea abies, Pinus sylvestris, Populus nigra, Prunus avium, Pseudotsuga menziesii, Quercus sp., Tilia sp.*) were obtained from the forest authority of the Federal State of Thuringia, Germany.

Logs were exposed to the forest soil in late 2008 until beginning of 2009 in the *Hainich* forest area (Central Germany, 51°38′N, 10°78′E), in the frame of the so-called *Biodiversity Exploratories*, a priority program of the Deutsche Forschungsgemeinschaft (DFG) (Fischer et al., 2010). A set of 13 logs (1 per species) was exposed each in 3 spatially separated beech (*Fagus sylv.* L.) forest sites of a "selection forest" management type with wide age distribution of beech trees. In total we collected runoff from 39 logs. The experimental plots are located between 420 and 520 m a.s.l. and the average annual temperature is 6.5–8.0 °C.

The soil has developed from loess deposits over calcareous bedrock and is classified as Luvisol (WRB, 2006). The forest floor is mull type with an Oi layer and a shallow (<1 cm) Oe layer. The averaged cumulative throughfall during the 17 months observation period was 536 mm.

2.2. Initial bark and wood properties

A disc of 5 cm was cut from each log before exposure to the soil. After drying, sapwood chips were obtained by drilling across several year rings starting from the youngest year ring towards the center. Subsamples of bark and the sapwood chips were milled by ball mill (MM2, Retsch GmbH, Haan, D). The C and N content was analyzed using a CN analyzer (Vario MAX, Elementar, Hanau, D). To investigate the water soluble fractions, subsamples of bark and sapwood were chopped by a cutting mill (SM200, Retsch GmbH, Haan, D) to small pieces of <3 mm in diameter. Those were extracted with water (ratio of wood chips to water: 1:15) at 20 °C for 24 h under continuous overhead shaking and concentrations of hydrolysable carbohydrates, water soluble phenols and spectroscopic properties of DOC (Fourier-transform infrared spectra, FTIR) were determined in the extracts.

2.3. Runoff from logs and throughfall

Runoff from logs was collected about 2 years after the exposure of the logs and lasted from July 2011 through November 2012. Small gutters (10 × 30 cm) were installed beneath the logs. Solutions were sampled in 2.0 L bottles which were located in buckets in the mineral soil next to the logs, avoiding exposition to high temperatures and light. All runoff and throughfall samples were stored in the laboratory at 2 °C and filtered using Millipore water prewashed cellulose acetate filters (0.45 μm, Whatman OE 67, GE Health Care Europe, Freiburg, D). The filtrates were kept frozen until DOC concentrations were analyzed by elemental analysis (N/C 2100 Analyzer, Analytik Jena, D). Furthermore, the pH and conductivity of the solutions were determined.

At each plot, throughfall amount (sampler type: RS200, UMS, Munich, Germany) and concentrations of DOC in throughfall were determined at the same intervals as for the runoff. Depending on the amount of throughfall, runoff samples were taken periodically within 1–2 weeks after major precipitation events. The sampling period was composed of 13 sampling dates.

2.4. Flux calculations and net release

Fluxes of DOC with runoff from each log were calculated by multiplying the DOC concentration in runoff at a single sampling date with the respective throughfall amount and referred to m^{-2} projected log area. Evaporation from logs under the forest canopy is considered negligible at the annual scale. Net release of DOC from logs results from the difference of DOC flux in runoff minus DOC flux in throughfall.

2.5. Hydrolysable carbohydrates

Carbohydrates in log runoff and in the initial wood extracts were analyzed following the procedure of Johnson and Sieburth (1977) and Johnson et al. (1981). In short, freeze dried DOC samples were hydrolyzed with 12 M H_2SO_4. The resulting carbohydrate monomers were reduced to sugar alcohols (alditols) using potassium borohydride (10%). After complexation by 3-methylbenzthiazolinon-2-hydrazon (MBTH reagent), the carbohydrate content was detected spectrophotometrically at 635 nm (UV 1800, Shimadzu).