Geoderma 288 (2017) 204–212

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Phenolic matter from deadwood can impact forest soil properties

Kenton P. Stutz[a,*], Daniel Dann[a], Janna Wambsganss[a], Michael Scherer-Lorenzen[b], Friederike Lang[a]

[a]Chair of Soil Ecology, Institute of Forest Sciences, University of Freiburg, Freiburg D-79085, Germany
[b]Geobotany, Faculty of Biology, University of Freiburg, Freiburg D-79085, Germany

ARTICLE INFO

Article history:
Received 6 August 2016
Received in revised form 5 November 2016
Accepted 9 November 2016
Available online 18 November 2016

Keywords:
Coarse woody debris
Soil chemistry
Lignin
Brown-rot fungi
White-rot fungi

ABSTRACT

Deadwood is a key factor in forest ecosystems, yet how it influences forest soil properties is uncertain. We hypothesized that changes in soil properties induced by deadwood mainly depend on the amount of released phenolic matter. Consequently we expected softwood- and hardwood-related deadwood effects on soil to be explained by unequal enrichment of phenolic substances. We measured differences in the quantity and composition of soil organic matter (SOM), pH, nutrient concentrations, and enzymatic activity between paired control and treatment points influenced by deadwood of silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.), and checked for correlations with total C and phenolic matter; the latter was quantified as aromaticity of water-extractable organic C through specific UV absorbance at 280 nm. Near fir deadwood, aromaticity and effective cation exchange capacity (CEC) increased while pH decreased. In comparison, concentrations of water-extractable organic C, effective CEC, exchangeable Ca^{2+} and Mg^{2+}, base saturation, and available molybdenum-reactive P increased near beech deadwood while exchangeable Al^{3+} decreased. For fir deadwood, soil properties strongly correlated almost exclusively with total C. For beech deadwood, numerous strong correlations with aromaticity indicated that extractable phenolics influenced soil properties. These differences in correlations imply that deadwood affects soil through the composition of added phenolic matter, which would stem from differing decay processes and organisms. Decayed, particulate lignin from brown-rot in fir deadwood as opposed to oxidized, dissolved lignin from white-rot in beech deadwood would account for our observations.

1. Introduction

Deadwood, primarily coarse woody debris (>10 cm; CWD), is a key factor in forest ecosystems (Harmon et al., 1986; Lachat et al., 2014). Specifically deadwood can influence soil organic matter (SOM) composition, exchangeable cations, nutrient concentrations, and pH (Bade et al., 2015; Goldin and Hutchinson, 2013; Kappes et al., 2007; Kayahara et al., 1996; Krzyszowska-Waitkus et al., 2006; Spears and Lajtha, 2004; Zalamea et al., 2007). Effects on soil associated with deadwood are unsurprising given the widely recognized role of SOM in soil chemical, biological, and physical properties.

However, deadwood strongly differs compositionally from bulk SOM, and how deadwood generally influences soil properties is unclear due to contradicting observations between softwood and hardwood species (woody gymnosperms and angiosperms, respectively). The two taxa release different quantities of and compounds within dissolved organic matter (Bantle et al., 2014). As such, several studies found that coniferous deadwood acidified soil (Krzyszowska-Waitkus et al., 2006; Spears and Lajtha, 2004). In comparison, soil samples near European beech (*Fagus sylvatica* L.) and oak (*Quercus* spp.) deadwood had higher pH values compared to nearby reference samples (Kappes et al., 2007). Similarly the effects of deadwood on enzymatic activity are inconclusive (Gonzalez-Polo et al., 2013; Spears et al., 2003).

A possible mechanistic explanation for changes induced by deadwood is the enrichment of phenolic compounds from deadwood in soils. Forest soils have more phenols (in absolute terms) than soils of other land uses (Buondonno et al., 2014). More specifically within forests, soil phenolic matter can spatially relate to single trees via leaf and root detritus (Spielvogel et al., 2016). They can also alter soil chemistry to such an extent that unique forest ecosystems such as Northern California's coastal pygmy forests are perpetually sustained (Northup et al., 1998).

Crucially, deadwood is a large source of phenolic compounds, and thus traits related to the phenolic composition of wood may explain how deadwood affects soils. Softwoods and hardwoods have unequal

Abbreviations: WEOC, water-extractable organic carbon; POC, Particulate organic carbon; $SUVA_{280}$, Specific ultraviolet absorbance at 280 nm; MRP, Molybdenum-reactive phosphorus.

* Corresponding author.
E-mail address: kenton.stutz@bodenkunde.uni-freiburg.de (K. Stutz).

http://dx.doi.org/10.1016/j.geoderma.2016.11.014
0016-7061/

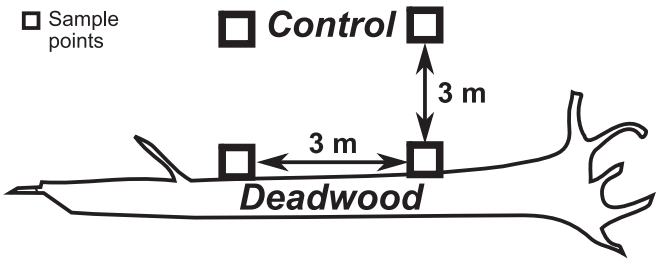

Fig. 1. Schematic of paired *deadwood* and *control* sampling points spatially related to downed, decomposing CWD.

phenolic concentrations and compositions—primarily in terms of guaiacyl- and syringyl-type lignin. As lignin with higher percentages of guaiacyl units decay more slowly than lignin with less guaiacyl units (Talbot et al., 2012; softwood and hardwood lignin, respectively), softwoods typically decompose—and thus influence soil—more slowly than hardwoods (Strukelji et al., 2013; Weedon et al., 2009).

The central question of our study is whether deadwood influences soil properties through the input of phenolic substances from deadwood. We hypothesize that changes in soil properties depend on the quantity of phenolic matter released from deadwood. Consequently we predict softwood/hardwood deadwood effects on soil to be explained by differences in the enrichment of phenolic substances. We tested our hypothesis by quantifying differences in the amount and quality—*i.e.*, composition and extractability—of SOM, pH, nutrients, and enzymatic activity between samples influenced by CWD of silver fir (*Abies alba* Mill., softwood) and European beech (hardwood), and samples from paired control points without current influence of CWD. We compared results by species and checked whether properties correlated with total C or phenolic content.

2. Materials and methods

Samples for this study came from the Conventwald, a strictly protected (since 1970) 15.4 ha, mature silver fir and European beech stand in the central Black Forest, Germany (7° 57′ 50″ E, 48° 1′ 20″ N; WGS84). Mean annual temperature is 6.6 ° C and annual precipitation is 1500–1750 mm. The soil is a Hyperdystric Skeletic Folic Cambisol (Hyperhumic, Loamic) (WRB, 2014) derived from paragneiss with a moder forest floor type.

Samples from the Oa and top 10 cm of the Ah horizons were taken from paired treatment and control points 3 m apart (*deadwood* and *control* points, respectively; Fig. 1). In total, eight pairs for each species were sampled from four beech and four fir downed CWD. Sampled CWD were a minimum of 100 m apart and were therefore assumed to be independent from each other. They also lay parallel to the slope to limit confounding microclimate and topographic effects. Sampled fir and beech CWD did not differ in diameter ($p > 0.05$) and degree of decomposition (five decay classes from Lachat et al., 2014; $p > 0.05$), yet fir CWD had more remaining volume than beech CWD (visually estimated from diameter at sampling points; $p < 0.05$). The exact age of selected CWD was unknown, but sampled fir CWD was most likely older than beech CWD as an inventory at the same site in 1995 found 85% of CWD was fir when only 43.5% of standing volume was fir (Hohlfeld, 1995; Weber, 2004).

The quantity and quality—size, composition, extent of decay, and degree of accessibility—of SOM were measured through total

Table 1
Method, citation, and procedural conditions for each investigated property. Both Oa and Ah samples were analyzed unless noted otherwise. Equipment for each analysis is listed in Appendix A.

Property	Method	Citation	Conditions
Total C & N	Dry combustion	Nelson and Sommers (1996)	Milled to ≈ 10 µm, dried at 105 °C; Sn-foil capsules, thermalized at 1150 °C, reduced at 850 °C
Aromaticity	UV absorbance at 280 nm	Weishaar et al., (2003) ;	1:50 Oa, 1:25 Ah; ultra-pure water, mixed, stood ≥16 h; filtered[A] <0.45 µm; pH not buffered
Water-extractable OC	Thermal oxidation	Forstliche Analytik (2014, A3.2.2.1)	1:5 Oa, 1:2.5 Ah; ultra-pure water, mixed, stood ≥16 h; filtered[A] <0.45 µm
Particulate OC & mineral C (Ah)	Density fractionation & ultrasonic disaggregation	Golchin et al. (1994), Graf-Rosenfellner et al. (2016)	SPT[B] (ρ = 1.6 g cm^{-3}); centrifuged at 3500 rpm, 26 min; filtered[C] >1.5 µm; 400 J ml^{-1}, amplitude 60%
pH	Water & pH meter	Forstliche Analytik (2014, A3.1.1.1)	1:5 Oa, 1:2.5 Ah; ultra-pure water, shaken, stood ≥8 h
Effective CEC	NH_4Cl & ICP-OES	Forstliche Analytik (2014, A3.2.1.1), Trüby and Aldinger (1989)	1:40 Oa & Ah; 0.5 M NH_4Cl solution (Merck, CAS-Nr. 12125-02-9), shaken well, stood ≥12 h; filtered[D] ([pre-saturated with 0.5 M NH_4Cl)
Available molybdenum-reactive P (Ah)	Citric acid & CFA	Forstliche Analytik (2014, A3.2.3.4), Murphy and Riley (1962)	1:10 Ah; 1% citric acid monohydrate solution by mass (Merck, CAS-Nr. 5949-29-1), 2 h agitated, stood ≥12 h, 30 min again agitated; filtered[E]
Functional activity & diversity (Oa)	Community-level physiological profiling	Garland and Mills (1991), Zak et al. (1994)	1:1000 Oa, 100 µL; 31 substrates in triplicate[F], 144 h, 28 °C dark incubation; absorbance at 590 nm, turbidity not corrected for

[A] Cellulosenitrate filter (Sartorius Stedim Biotech).
[B] Sodium polytungstate (TC-tungsten compounds, CAS-Nr. 12333-13-0).
[C] Glass microfibers filter (VWR International bvba, 696).
[D] Paper filter (Sartorius Stedim Biotech, Grade 391 Blue).
[E] Folded paper filter (Munktell Grade 131, P-free)
[F] EcoPlate™ (BIOLOG).