Science of the Total Environment 447 (2013) 99–107

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

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

Forest floor leachate fluxes under six different tree species on a metal contaminated site

Lotte Van Nevel [a,*], Jan Mertens [b], An De Schrijver [a], Lander Baeten [a], Stefaan De Neve [c], Filip M.G. Tack [d], Erik Meers [d], Kris Verheyen [a]

[a] Forest & Nature Lab, Department of Forest and Water Management, Ghent University, Geraardsbergsesteenweg 267, B-9090 Melle, Belgium
[b] Faculty of Applied Bioscience Engineering, University College Ghent, Ghent University Association, Schoonmeersstraat 52, B-9000 Ghent, Belgium
[c] Department of Soil Management and Soil Care, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
[d] Laboratory for Analytical Chemistry and Applied Ecochemistry, Department of Applied Analytical and Physical Chemistry, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

HIGHLIGHTS

► We examined tree species effects on leachate fluxes of Cd, Zn, DOC, H^+ and cations.
► Cd fluxes in aspen leachate were slightly higher compared to the other tree species.
► Differences in metal leachate fluxes were much smaller than metal fluxes in leaf litterfall.
► We found significant differences in DOC, H^+ and cation leachate fluxes between species.
► Differences in DOC, H^+ and cation leachate fluxes might influence metal mobilization.

ARTICLE INFO

Article history:
Received 22 June 2012
Received in revised form 20 December 2012
Accepted 21 December 2012
Available online 1 February 2013

Keywords:
Forest floor leachate
Tree species
Trace metals
DOC
Base cations
Phytostabilization

ABSTRACT

Trees play an important role in the biogeochemical cycling of metals, although the influence of different tree species on the mobilization of metals is not yet clear. This study examined effects of six tree species on fluxes of Cd, Zn, DOC, H^+ and base cations in forest floor leachates on a metal polluted site in Belgium. Forest floor leachates were sampled with zero-tension lysimeters in a 12-year-old post-agricultural forest on a sandy soil. The tree species included were silver birch (*Betula pendula*), oak (*Quercus robur* and *Q. petraea*), black locust (*Robinia pseudoacacia*), aspen (*Populus tremula*), Scots pine (*Pinus sylvestris*) and Douglas fir (*Pseudotsuga menziesii*). We show that total Cd fluxes in forest floor leachate under aspen were slightly higher than those in the other species' leachates, yet the relative differences between the species were considerably smaller when looking at dissolved Cd fluxes. The latter was probably caused by extremely low H^+ amounts leaching from aspen's forest floor. No tree species effect was found for Zn leachate fluxes. We expected higher metal leachate fluxes under aspen as its leaf litter was significantly contaminated with Cd and Zn. We propose that the low amounts of Cd and Zn leaching under aspen's forest floor were possibly caused by high activity of soil biota, for example burrowing earthworms. Furthermore, our results reveal that Scots pine and oak were characterized by high H^+ and DOC fluxes as well as low base cation fluxes in their forest floor leachates, implying that those species might enhance metal mobilization in the soil profile and thus bear a potential risk for belowground metal dispersion.

1. Introduction

Metal polluted soils are often afforested in order to prevent dispersion of the metals in the environment, a technique called phytostabilization (e.g. Dickinson, 2000; Mertens et al., 2007; Pulford and Watson, 2003). Trees can potentially be very well suited for phytostabilization purposes due to their extensive root systems and high transpiration capacity (Pulford and Watson, 2003). On the other hand, tree growth might enhance metal leaching to groundwater because of soil acidification and production of dissolved organic matter (Mayer, 1998). Tree species can exert a significant influence on soil acidity and dissolved organic carbon (DOC) leaching, which has been found to be significantly related to litter quality (De Schrijver et al., 2012; Hobbie et al., 2007; Reich et al., 2005). Tree species with litter rich in calcium (Ca) were associated with lower soil acidity, increased earthworm abundance and diversity, as well as higher forest floor turnover rates (De Schrijver et al., 2012; Hobbie et al., 2006; Jacob et al., 2009; Reich et al., 2005). In contrast, species producing litter with low contents of base cations and high concentrations of organic acids have been shown to decompose slowly and enhance soil acidification and DOC leaching (Finzi et al., 1998; Hagen-Thorn et al., 2004; Konova, 1966).

Tree species producing contrasting leaf litter in terms of chemical composition and degradability thus have a different influence on the

* Corresponding author. Tel.: +32 9 264 90 38; fax: +32 9 264 90 92.
E-mail address: Lotte.VanNevel@UGent.be (L. Van Nevel).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2012.12.074

composition and reactivity of the forest floor leachate and the soil solution (Strobel et al., 2001). Forest floor leachate composition is highly relevant, in particular the fluxes of DOC and protons (H^+) as these are expected to increase metal leaching. Numerous studies have shown that the forest floor is the major source of DOC in forest ecosystems (Cronan and Aiken, 1985; Currie et al., 1996; Michalzik and Matzner, 1999; Michalzik et al., 2001; Qualls et al., 1991; Vandenbruwane, 2008). DOC is one of the most actively cycling soil organic carbon (C) pools and its significance in forest ecosystems has been highlighted because of its ecological function in transport and cycling of nutrients and metals in soils (Kalbitz et al., 2000; Michalzik and Matzner, 1999; Qualls and Haines, 1991; Qualls et al., 1991; Tipping and Hurley, 1992). Tree species producing forest floor leachate with high DOC concentrations are stimulating base cation (Finzi et al., 1998) and metal leaching (Strobel et al., 2001). Leaching of base cations causes soil acidification (Finzi et al., 1998; Marschner, 1995) while metal leaching to groundwater poses serious risks for ecosystems and human health (WHO, 2000).

In the Campine region in northern Belgium, zinc (Zn) and lead (Pb) were refined from the end of the 19th century until the 1970s, resulting in an extended area of about 700 km^2 diffusely polluted by cadmium (Cd) and Zn in particular (Ceenaeme et al., 2004). The dominant sandy texture of the soils in the region intensifies the risk for metal leaching and dispersion. Sandy soils are characterized by a low cation exchange capacity (CEC), low acid neutralizing capacity and low metal sorption (Andersen et al., 2002). In a previous field study in the Campine region, we revealed a significant tree species effect on Cd and Zn redistribution in the soil profile, only ten years after afforestation of a metal polluted site (Van Nevel et al., 2011). Whereas the previous study focused on tree species effects on metal (re)distribution patterns, the present field study aims at unraveling one of the processes behind those patterns, namely forest floor leachate chemistry. This paper is therefore a follow-up of our previous paper (Van Nevel et al., 2011).

The potential feedback mechanisms between metal accumulation in trees, leaf litter quality, the composition of the forest floor leachate and the soil solution thus all affect metal mobility. Therefore, metal mobility is likely to be strongly species dependent and strategies for phytostabilization of metals need to carefully consider the importance of tree species selection. Here we aim to unravel the tree species effects on fluxes of Cd, Zn, DOC, H^+ and base cations in forest floor leachate, with respect to metal mobilization. For estimating the risk of metal leaching to deeper soil layers, the DOC, H^+, base cation and metal fluxes in the forest floor leachates are of particular interest. Nevertheless, to our knowledge, no field studies incorporating fluxes and interrelationships of DOC, base cations and metals in forest floor leachates exist. Furthermore, we found no field studies comparing metal leaching from the forest floor under different tree species.

We hypothesize that (i) tree species with low litter quality (in terms of base cations and C/N ratio) produce high DOC and H^+ and low base cation fluxes, being favorable for metal mobilization in the soil and thus eventually causing risk for metal leaching and (ii) tree species with high metal concentrations in their leaf litter give rise to higher metal fluxes in their forest floor leachates, also causing risk for belowground metal dispersion.

2. Materials and methods

2.1. Site description

The study site was the forest 'Waaltjesbos' (51°13′23″ N, 5°15′01″ E) in Lommel (north-east Belgium), which covers an area of 203 ha. The site was planted in 1996–1998 with different tree species in homogeneous blocks, and established as a public forest. Before that, the site had been under agricultural use, at least for several decades. The soil is a well-drained nutrient poor sandy soil (Podzol; IUSS WRB classification). The site is situated in between two zinc smelters; one of them was closed in 1974, while the other is still operational. Full descriptions of the site are given in Van Nevel et al. (2011).

The study site has been exposed to aerial metal deposition during several decades, resulting in soil pollution of mainly Cd and Zn and to a lesser degree of Pb, copper (Cu), arsenic (As) and mercury (Hg). The historical soil pollution in the region is diffuse, with Cd concentrations in the upper 30 cm of the soil in Waaltjesbos up to 5.0 mg kg^{-1} (average 1.93 mg kg^{-1}), exceeding the soil sanitation threshold of 1.59 mg kg^{-1} (Van Nevel et al., 2011). As a characterization of the study site, soil characteristics pH-KCl, OC content, together with total and extractable soil Cd and Zn concentrations in the topsoil (0–5 cm) and at 10–20 cm depth are given in Table 1 (see Van Nevel et al., 2011).

2.2. Experimental set-up and sampling

Six tree species were selected that are suited for sandy soils in the study region and with potential to be used in future afforestations: oak (*Quercus robur* and *Q. petraea*), silver birch (*Betula pendula*), black locust (*Robinia pseudoacacia*), aspen (*Populus tremula*), Scots pine (*Pinus sylvestris*) and Douglas fir (*Pseudotsuga menziesii*). Those species have divergent leaf litter quality and show different metal concentrations in their leaf litter. Hence, forest floor leachates under these trees are expected to reflect the biogeochemical interactions that took place over the preceding years.

Forest floor leachate was collected using zero-tension lysimeters, constructed from 30 cm long PVC guttering (324 cm^2) covered with wire netting (1.5 mm mesh size). Each lysimeter was connected with flexible PVC tubing to a 2-l polyethylene (PE) bottle installed beneath the lysimeter. The bottles were placed below ground level to avoid the growth of algae and to keep the samples cool. As no ectorganic horizon (Of + Oh) was discernible yet under this young forest (Jabiol et al., 1995), the lysimeters were installed directly

Table 1
Soil characteristics pH-KCl (–), OC content (g kg^{-1}), total and extractable soil Cd and Zn concentrations (mg kg^{-1}) at 0–5 cm and 10–20 cm depth (average ± st.dev); values followed with the same letter did not differ, first capital letters denote species effects and should be read vertically ($p<0.05$), second small letters denote differences between soil layers and should be read horizontally ($p<0.05$); see Van Nevel et al. (2011) for statistical analysis.

	pH-KCl		OC	
	0–5 cm	10–20 cm	0–5 cm	10–20 cm
Silver birch	4.5 ± 0.3$^{A\ a}$	4.3 ± 0.2$^{A\ a}$	19 ± 5$^{A\ a}$	14 ± 6$^{A\ a}$
Oak	4.4 ± 0.2$^{A\ a}$	4.5 ± 0.3$^{AB\ a}$	17 ± 1$^{AB\ a}$	18 ± 5$^{A\ a}$
Black locust	4.4 ± 0.3$^{A\ a}$	4.5 ± 0.3$^{AB\ a}$	32 ± 9$^{BC\ a}$	15 ± 8$^{A\ a}$
Aspen	5.4 ± 0.6$^{B\ b}$	4.7 ± 0.3$^{B\ a}$	29 ± 6$^{C\ b}$	18 ± 9$^{A\ a}$
Scots pine	4.5 ± 0.3$^{A\ a}$	4.7 ± 0.3$^{B\ a}$	20 ± 7$^{AB\ a}$	16 ± 7$^{A\ a}$
Douglas fir	4.4 ± 0.4$^{AB\ a}$	4.7 ± 0.1$^{B\ a}$	17 ± 4$^{AB\ a}$	19 ± 7$^{A\ a}$
	Cd		Zn	
	0–5 cm	10–20 cm	0–5 cm	10–20 cm
Silver birch	1.42 ± 0.86$^{AB\ a}$	1.50 ± 0.72$^{A\ a}$	87 ± 52$^{AB\ a}$	73 ± 44$^{A\ a}$
Oak	1.45 ± 0.42$^{A\ a}$	1.96 ± 0.92$^{A\ a}$	86 ± 29$^{A\ a}$	109 ± 68$^{A\ a}$
Black locust	1.70 ± 0.70$^{AB\ a}$	2.15 ± 1.12$^{A\ a}$	123 ± 62$^{AB\ a}$	135 ± 70$^{A\ a}$
Aspen	3.55 ± 1.44$^{C\ b}$	2.20 ± 1.30$^{A\ a}$	267 ± 91$^{C\ b}$	120 ± 72$^{A\ a}$
Scots pine	2.34 ± 0.67$^{BC\ a}$	1.88 ± 0.59$^{A\ a}$	142 ± 38$^{BC\ a}$	118 ± 23$^{A\ a}$
Douglas fir	1.55 ± 0.29$^{AB\ a}$	1.88 ± 0.72$^{A\ a}$	117 ± 69$^{AB\ a}$	93 ± 34$^{A\ a}$
	Cd ($CaCl_2$)		Zn ($CaCl_2$)	
	0–5 cm	10–20 cm	0–5 cm	10–20 cm
Silver birch	0.56 ± 0.21$^{A\ a}$	0.68 ± 0.31$^{A\ a}$	32 ± 11$^{A\ a}$	28 ± 14$^{A\ a}$
Oak	0.67 ± 0.22$^{A\ a}$	0.81 ± 0.24$^{A\ a}$	38 ± 11$^{A\ a}$	41 ± 19$^{A\ a}$
Black locust	0.58 ± 0.18$^{A\ a}$	0.64 ± 0.40$^{A\ a}$	30 ± 9$^{A\ a}$	34 ± 20$^{A\ a}$
Aspen	0.45 ± 0.15$^{A\ a}$	0.52 ± 0.21$^{A\ a}$	33 ± 17$^{A\ a}$	26 ± 13$^{A\ a}$
Scots pine	0.87 ± 0.50$^{A\ a}$	0.72 ± 0.38$^{A\ a}$	43 ± 19$^{A\ a}$	43 ± 34$^{A\ a}$
Douglas fir	0.64 ± 0.15$^{A\ a}$	0.57 ± 0.14$^{A\ a}$	36 ± 15$^{A\ a}$	26 ± 5$^{A\ a}$