Available online at www.sciencedirect.com
ScienceDirect
Environmental Pollution 149 (2007) 173–181
ENVIRONMENTAL POLLUTION
www.elsevier.com/locate/envpol

Tree species effect on the redistribution of soil metals

Jan Mertens [a,*], Lotte Van Nevel [a], An De Schrijver [a], Frederic Piesschaert [b], Anne Oosterbaan [c], Filip M.G. Tack [d], Kris Verheyen [a]

[a] Laboratory of Forestry, Department of Forest and Water Management, Ghent University, Geraardsbergsesteenweg 267, B-9090 Melle, Belgium
[b] Institute of Nature Conservation, Kliniekstraat 25, B-1070 Brussels, Belgium
[c] Alterra, Wageningen University and Research Centre, Droevendaalsesteeg 3, 6708 PB Wageningen, The Netherlands
[d] Laboratory of Analytical Chemistry and Applied Ecochemistry, Department of Applied Analytical and Physical Chemistry, Ghent University, Coupure Links 265, B-900F0 Ghent, Belgium

Received 18 October 2006; received in revised form 4 January 2007; accepted 7 January 2007

Trees (33-year-old) growing on polluted dredged sediment have influenced the metal concentration in the upper soil layer and there was a significant tree species effect.

Abstract

Phytostabilization of metals using trees is often promoted although the influence of different tree species on the mobilization of metals is not yet clear. Soil and biomass were sampled 33 years after planting four tree species (*Quercus robur*, *Fraxinus excelsior*, *Acer pseudoplatanus*, *Populus* 'Robusta') in a plot experiment on dredged sediment. Poplar took up high amounts of Cd and Zn and this was associated with increased Cd and Zn concentrations in the upper soil layer. The other species contained normal concentrations of Cd, Cu, Cr, Pb and Zn in their tissues. Oak acidified the soil more than the other species and caused a decrease in the concentration of metals in the upper soil layer. The pH under poplar was lower than expected and associated with high carbon concentrations in the top soil. This might be assigned to retardation of the litter decomposition due to elevated Cd and Zn concentrations in the litter.

Keywords: Phytostabilization; Trees; Metals; Dredged sediment

1. Introduction

Metal polluted sites for dredged sediments are mostly set aside. These sites are often afforested or develop spontaneously into woodland. Growth of trees might induce several changes in the soil characteristics, and forests showed to play an important role in metal cycling and partitioning (Watmough et al., 2005; Andersen et al., 2004).

Trees are often postulated to be suited for phytostabilization, as they might stabilize metals in the soil. The vegetation cover and root growth will protect the soil surface from dispersal by wind and water erosion (Eviner and Chapin, 2003). Elevated evapotranspiration in forests reduces the flow of water through the soil and therefore might reduce the amount of metals that leach from the soil to the ground and surface waters (Pulford and Watson, 2003). Garten (1999) modeled the effect of a forest cover on the loss of ^{90}Sr by leaching from contaminated soil, mainly in shallow subsurface flow, and showed that such losses were reduced by approximately 16% under trees relative to grass. This was attributed to the greater rate of evapotranspiration by the trees. Plants can also enhance retention of elements by binding them with phenolics (Hattenschwiler and Vitousek, 2000), or root mucilage (Glinski and Lipiec, 1990).

On the other hand, tree growth might enhance metal mobility. Species that decrease pH increase metal solubility

* Corresponding author. Tel.: +32 9 264 90 37; fax: +32 9 264 90 92.
E-mail address: jan.mertens@ugent.be (J. Mertens).

0269-7491/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envpol.2007.01.002

(Finzi et al., 1998) and can enhance leaching of metals. Plant species influence metal availability by promoting low-molecular-weight organic acids through root exudation or litter decomposition. These acids act as ligands and, depending on the type exuded, have different effects on metal solubility and speciation (Jones and Darrah, 1994). Organic acids rich in humic acids form water-soluble complexes with metals, increasing solubility (Marschner, 1995). Preferential uptake of metals from the soil in the aboveground biomass actively mobilizes the metals and transports them to the crown canopy and the litter layer, two important parts of the food web.

Plant species differ in their effect on the biogeochemical cycles of metals through, e.g. organic acid input, cation uptake, and effects on soil pH and redox (Finzi et al., 1998; Eviner and Chapin, 2003). The aim of this study was to investigate if important differences between tree species could be found in metal compartmentalization on a disposal facility for dredged sediment after 33 years of tree growth. The metal concentrations in the different compartments are the net result of many biogeochemical interactions that took place over the preceding 33 years. The interest of this study is that different tree species can be compared on identical, new soil. At the time of planting, the site was very homogeneous and no soil profile had yet developed. This is in contrast to most polluted sites where a developed soil profile is gradually polluted from the surface soil down. Four broadleaved species had been planted: poplar (*Populus* 'Robusta'), oak (*Quercus robur*), ash (*Fraxinus excelsior*) and maple (*Acer pseudoplatanus*). Poplar is a species that takes up high amounts of Cd and Zn in its biomass (Vandecasteele et al., 2003; Mertens et al., 2004; Laureysens et al., 2004) and this can be compared to the other species showing normal concentrations (Mertens et al., 2004). Oak tends to acidify the soil more than for example ash and maple because of high lignin content and low amount of Ca in the litter (Augusto et al., 2002; Reich et al., 2005). Ash and maple have good litter quality and will promote fast decomposition, lower production of acids and formation of stable humus (Reich et al., 2005).

2. Materials and methods

2.1. Site description

This study area was a disposal site for hydraulically raised dredged harbor sediments near the harbor of Rotterdam (The Netherlands). It covers an area of 2.5 ha and was raised in the period 1960–1967. It was raised in four layers resulting in a package of 7 m thick dredged sediment. The last layer was raised in 1966–1967 and was 2 m thick. In 1970 the site was planted and, due to dewatering, the sediment layer depth had decreased to 5.3 m (Oosterbaan and van den Berg, 2002). In 1981, eight samples spread over the site were taken and analyzed for texture and metal concentration (Table 1; analysis methodology was not documented). The soil contained a rather high amount of clay (about 30%). The metal concentrations in the two sampling depths were not different.

Four blocks (20 m by 200 m) were planted in 1970–1972, each one with one of the following tree species: poplar (*P.* 'Robusta'), oak (*Q. robur*), ash (*F. excelsior*) or maple (*A. pseudoplatanus*). The trees were planted at distances of 1.8 m in the row and 2.75 m between the rows (densities of about 1970 trees ha^{-1}). In between shrubs and auxiliary trees were planted. In one half of each block main tree species and shrubs were thinned few times, the other half remained unthinned. In 2003, these shrubs and auxiliary trees had densities ranging from 480 to 1500 individuals per ha. The sampling places for the further investigation were selected so that no shrubs or auxiliary trees grew over it, aimed at observing primarily the effect of the main tree species.

Both the biomass and soil were sampled and analyzed in August 2003. At that time, the trees were in their 33rd growing season. Based on the results of this sampling, an extended soil sampling was done in July 2005.

2.2. Biomass

All biomass measurements were done in August 2003. Stem biomass was calculated by multiplying the stem volume and the wood densities for the given species (densities given by Rijsdijk and Laming, 1994). The stem volume was determined based on the measurements of the stem diameter at 1.3 m height (transect, $n \geq 36$ per species, August 2003) and the tree height measurements ($n = 12$ per species, equally distributed over the diameter classes) using the wood yield tables of Faber and Tiemens (1975) for poplar and Dagnelie et al. (1999) for the other tree species. The biomass of the branches was assumed to be one-third of the stem wood biomass (Oosterbaan and van den Berg, 2002).

From each tree species, four healthy trees with average diameter, equally spread over the length of the blocks were selected for sampling. Near every sample tree, autumn leaf litter fall was collected with circular traps of 0.24 m^2. The traps were emptied every month from September to November 2003 and weight was determined after drying at 70 °C in a forced air oven to constant weight. Monthly litter fall samples were pooled before analysis so that for every litter trap one sample was obtained. Wood was sampled by augering small cores with a Prezzler auger at 1.3 m height and total bark was removed with a fine knife in March 2004. Samples were dried at 70 °C in a forced air oven to constant weight. Subsequently the samples were milled and sieved before analysis. The metals were extracted by heating 0.5 g sample in 10 ml 65% HNO_3 p.a. and 2 ml 70% $HClO_4$ p.a. during 2 h of heating. Extracts were diluted and analyzed for Ca, Cd, Cr, Cu, Pb and Zn on ICP/OES (Perkin–Elmer OPTIMA 3300 DV). Samples were not rinsed before drying.

2.3. Soil

In 2003, soil samples were collected at the same places where biomass samples were taken. Thus four replicates in each block were taken. The litter layer (less than 1 cm thick) was removed. The upper horizon (H_1) was sampled; this horizon was about 5 cm thick and had a marked darker color than the soil underneath. The second horizon sampled (H_2) started directly under H_1 and was about 4–15 cm thick. This layer was well-structured and

Table 1
Results of soil sampling and analysis of 1981 ($n = 8$; Peeters, 1994)

Depth (cm)	<2 μm	2–63 μm	>63 μm
0–2	30.9 ± 1.5	37.5 ± 2.6	31.6 ± 2.4
25–30	31.4 ± 1.5	39.8 ± 1.3	28.9 ± 2.1

Depth (cm)	Cd	Cr	Cu	Pb	Zn	Ni	As
0–2	10.5 ± 0.8	202 ± 14	189 ± 10	303 ± 16	1196 ± 74	60.6 ± 3.2	64.6 ± 5.6
25–30	10.1 ± 0.6	204 ± 13	184 ± 10	290 ± 16	1166 ± 62	58.1 ± 2.6	65.5 ± 5.3