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Seedling biomass and element content of *Pinus sylvestris* and *Pinus nigra* grown in sandy substrates with lignite

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Abstract

Reclaimed mine soils in the Lusatian mining district (Eastern Germany) are often comprised of sandy materials containing high amounts of lignite. Lignite can absorb nutrients and water, but its high pyrite and Al content may restrict access of roots to these pools. We assessed the influence of lignite on growth, seedling shoot and root element content and root lengths of *Pinus sylvestris* L. and *Pinus nigra* Arn. in lignite-containing and lignite-free substrates. Rhizotrons were filled with mining substrate in which lignite was finely dispersed (L-substrate), a model substrate with alternating layers of quartz sand and lignite (SL-substrate), and a sandy substrate from a natural forest without lignite (S-substrate). After 11 months, shoot dry mass of *P. sylvestris* significantly decreased in the following order: S-substrate > SL-substrate > L-substrate, whereas root dry mass was similar in all substrates. *P. sylvestris* in S-substrate was characterized by high shoot and root contents of N and P, whereas plants grown on L-substrate had high shoot and root contents of Ca and a high root content of Al. In L-substrate, shoot dry mass of *P. nigra* was significantly greater than that of *P. sylvestris* and the Ca content in the roots of *P. nigra* was twice as high than in *P. sylvestris* roots ($P \leq 0.1$). The high Ca content in the roots may explain the better growth of *P. nigra* in these mining substrates which are often characterized by high Al content.

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Keywords: Black pine; Element content; Lignite; Mining substrate; Root length; Scots pine

1. Introduction

Forestry is the dominating land use after lignite mining in Lower Lusatia (Eastern Germany). Approximately 60% of the 45,000-ha re-cultivated mine spoils (Stähr, 2003) have been afforested, mainly with pine (*Pinus sylvestris* L. and *Pinus nigra* Arn.) (Preuβner, 1998). After mining, the soils are a mixture of sandy overburden material of different geological ages (Häge, 1996) and may contain up to 12.5% C (dry mass basis), the majority of which is in the form of lignite (Neumann, 1999). Although the substrate is nutrient-poor (Heinsdorf, 1994) and contains low amounts of plant-available water (Preuβner, 1998), pines grow well once they are established (Böcker et al., 1998; Katzur et al., 2000), indicating adequate water and nutrient supply. Lignite, which is present in the sandy matrix as finely dispersed dust and/or as lignite fragments up to 20 cm in diameter (Haubold-Rosar, 1998), may act as water and nutrient storage component in these soils (Baumann et al., 2005). However, root growth in the soils and access of roots to water and nutrients in the lignite may be limited by the high content of pyrite and Al (Schaaf, 2001; Schaaf et al.,

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1999) in the lignite. Pyrite and Al may limit nutrient uptake not only by reducing the pH (pyrite), which results in reduced availability of some nutrients, but also by competition with nutrients for uptake (Al). The reduction of the nutrient uptake consequently limits plant growth. In order to avoid low pH and/or high Al concentrations roots may not grow towards the lignite fragments.

Plant species show differential tolerance to drought, nutrient deficiency, or pH and Al levels. Thus, they may also differ in their reliance on the nutrient and water pools in the lignite and/or their capacity to access these pools. To test our hypothesis that lignite influences biomass production of pine in the first year of growth, we compared dry mass of shoots and roots, root lengths, and element content of *P. sylvestris* seedlings growing in lignite-containing and lignite-free substrates. We compared growth and nutrient uptake of *P. sylvestris* (Scots pine) and *P. nigra* (Black pine) on lignite-containing substrate to assess the behaviour of different plant species in the post-mining soils.

2. Materials and Methods

2.1. Experimental design

Rhizotrons [PVC boxes with a removable Plexiglas front, 33 cm (l)×20 cm (w)] with varying depth were used: the top 5 cm were 2.3 cm wide, whereas the remaining 28 cm were only 1 cm wide. This design was used to provide sufficient space for the shoots and uppermost roots and to ensure that most roots in the lower part would grow along the Plexiglas front. The rhizotrons were divided vertically in two chambers, each 10 cm wide. The rhizotrons were filled with three different substrates: (i) lignite dust-containing substrate (sieved to <2 mm in diameter (∅)) from mine overburden (0–60 cm depth) at Bärenbrück (Lower Lusatia, Germany) (hereafter L-substrate). This overburden is derived from lignitic material from the brown coal pit Jänschwalde (Lower Lusatia, Germany) and has properties representative of the Lusatian mining region [lignite-containing pyritic loamy sand, ameliorated with 190 t CaO ha^{-1} to a depth of 40 cm (Gast et al., 2001), pH (H_2O) 2.6–6.6 within the upper 60 cm, total N 0.1% N, (Wecker, 2003, personal communication) and 1.5–12.5% total C (Neumann, 1999)], (ii) alternating horizontal layers (4 cm thick) of quartz sand (∅ 0.1–0.4 mm) and lignite (∅<2 mm) from the brown coal pit at Jänschwalde starting with sand at the top (hereafter SL-substrate), and (iii) sandy soil (sieved to ∅<2 mm) from a naturally grown pine forest at Chorin (Brandenburg, Germany) which is lignite-free (hereafter S-substrate). Characteristics of the different substrates are listed in Table 1. The model substrate of alternating layers of sand and lignite (SL-substrate) was used to assess if the roots would potentially grow into lignite if it is in the pathway of roots growing vertically through the substrate. In substrates where lignite is distributed randomly, apparent ‘avoidance’ of lignite may simply be due to the fact that the roots did not encounter the lignite fragments during normal growth.

Each substrate was irrigated with its equilibrium soil solution. The equilibrium soil solution was prepared by mixing substrate/water at 1:3 (w/v). The mixture was left to stand for 24 h (stirred occasionally) after which the solutions were filtered (Filter 595, pore size <4 µm, Schleicher and Schuell, Germany). Irrigation was through porous ceramic cups (SMS 1–100, UMS, Munich, Germany) maintained by a hanging water column of − 30 cm. Two cups were placed horizontally in the substrates of each rhizotron, 2 cm from top and bottom of the rhizotrons, respectively. To obtain an equilibrium, the solution was percolated through the substrates in the rhizotrons for 5 weeks prior to planting. Element concentrations in the equilibrium soil solutions were analysed by inductively coupled plasma–atomic emission spectrometry ICP-AES (Ca, Mg, Na, Fe, Mn, Al), flame atom absorption spectrometry AAS (K) or ion chromatography (NO_3^-, SO_4^{2-}, Cl^-) (Table 2).

Seedlings of *P. sylvestris* were grown from seed in the three different substrates. Seedlings of *P. nigra* were grown from seed in L-substrate only. After 4 months, two seedlings were planted in each chamber of the rhizotrons (4 seedlings per rhizotron). *P. sylvestris* was grown on the 3 different substrates, whereas *P. nigra* was only grown on L-substrate. There were 4 replicate rhizotron

Table 1
Total element content of different substrates: lignitic mining overburden (L), quartz sand/lignite model substrate (SL), sandy soil from natural forest site (S)

Element	L-substrate	SL-substrate		S-substrate
		Quartz sand	Lignite	
C [mg g^{-1}]	58.0	0.2	577.3	22.4
N [mg g^{-1}]	1.2	n.d.	7.0	1.2
S [mg g^{-1}]	8.3	n.d.	15.2	0.8
P [mg g^{-1}]	0.13	n.d.	0.04	n.d.
Mg [mg g^{-1}]	1.05	n.d.	3.80	0.01
K [mg g^{-1}]	2.66	0.02	0.36	0.01
Ca [mg g^{-1}]	8.84	n.d.	16.52	0.03
Al [mg g^{-1}]	23.69	0.21	2.21	n.d.
Ca/Al	0.37	0.00	7.48	–
(Ca+Mg+K)/Al	0.53	0.10	9.36	–
pH (H_2O)	4.03	7.13	5.42	4.28
EC [µS cm^{-1}]	1920	101	362	101

n.d.=not detectable.

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