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Tree species and soil substrate effects on soil biota during early soil forming stages at afforested mine sites

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ABSTRACT

Development of soil microbial and soil fauna communities is a key factor in the soil forming process at reclaimed post-mine sites. The objective of this study was to determine the influence of reclaimed mine soil (RMS) properties (texture, pH, total organic carbon (TOC) and total nitrogen (TN)) and planted tree species on soil biological activity (dehydrogenase activity (DHA), microbial biomass carbon (MBC), enchytraeids (*Enchytraeidae*) and earthworm (*Lumbricidae*) communities). Research sites were located in southern Poland on an afforested sand mine pit (Szczakowa) and a sulphur mine spoil heap (Piaseczno). Study plots were arranged in pure tree stands of pine, larch, oak, birch and alder with 25- to 35-year-old trees growing on different RMS substrates: quaternary sands; quaternary loamy sands and loams; neogene clays; and mixed quaternary sands and neogene clay. Microbial biomass carbon depended mainly on the texture, TOC and TN content in the uppermost soil layer, whereas DHA was associated with the fine root annual increment. Earthworm biomass was significantly correlated with clay content, pH and TOC in the uppermost organic soil layers. Among planted tree species, black alder clearly altered soil microbial parameters, biomass and density of earthworms. The strongest effect on DHA was noted under birch trees. Among the studied tree species, deciduous trees (birch, alder and oak) had a greater impact on soil biological properties compared to coniferous trees (pine and larch).

1. Introduction

From an ecological standpoint, proper reclamation is the ecosystem restoration process that involves restoring as completely as possible a mined area back to the native biological system that was previously in place (Bradshaw, 1984; Bradshaw and Hüttl, 2001; Chambers et al., 1994; Pietrzykowski, 2014). Development of soil biota is one of the most important factors during the soil forming process and new ecosystem function (Chodak and Niklińska, 2010a,b; Chodak et al., 2009; Filcheva et al., 2000; Frouz et al., 2013). Soil organisms play a key role in the circulation of matter and flow of energy (Nielsen et al., 2011). Decomposition and transformation of organic matter in the soil are carried out by microorganisms, but these processes are more effective when *meso*- and macrofauna, such as enchytraeids and earthworms, break down plant residue, disperse it beneath the surface and distribute it among the soil profile (Curry, 2004). Soil fauna affect the most important soil forming processes (Aira et al., 2002; Curry, 2004; Frouz et al., 2013) and influence the air–water properties of soils by creating corridors, which favour aggregate soil structure (Brito-Vega et al., 2009; Lamandé et al., 2011). Earthworms are also involved in the formation of microstructures and humus layers at post-mining sites (Frouz et al., 2007), and earthworms can be good indicators of soil function and condition (Doube and Schmidt, 1997).

In a natural forest ecosystem, microbial activity and soil macrofauna biomass depend on the soil properties, mainly texture, pH, total organic carbon (TOC), total nitrogen (TN) and macronutrient content. Biological properties of natural forest soil also are influenced indirectly by tree species (Bauhus et al., 1998; Priha and Smolander, 1999; Priha et al., 2001). The influence of tree stands on soil biota has been noted during initial soil forming stages at

Abbreviations: RESP, basal respiration; C:N, total organic carbon:total nitrogen ratio; DHA, dehydrogenase activity; EB, earthworm biomass; ED, earthworm density; EnchD, enchytraeid density; FRB, fine root biomass; MBC, microbial biomass carbon; QsNC, mixed quaternary sands and neogene clay; NC, neogene clays; PCA, principal component analysis; RMS, reclaimed mine soil; RDA, redundancy analysis; Ql, quaternary loamy sands and loam; Qs, quaternary sands; TN, total nitrogen; TOC, total soil organic carbon.

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reclaimed mine sites (Chodak and Niklińska, 2010a, 2010b; Frouz et al., 2013; Šourková et al., 2005). Šourková et al. (2005) suggested a greater impact from planted tree species than reclaimed mine soil (RMS) properties and pointed to a higher microbial biomass under alder and oak compared to pine. In contrast, Chodak and Niklińska (2010a) indicated a greater impact from soil substrate texture compared to planted tree species on microbiological properties (including microbial biomass carbon (MBC), basal respiration (RESP) and enzyme activities). However, the study involved only two species: Scots pine and common birch. In a different study conducted on a sand mine cast, Chodak and Niklińska (2010b) indicated greater effects of deciduous species (birch and alder) on soil microbial activity compared to coniferous species (larch and pine); specifically, the highest MBC, RESP, MBC: TOC ratio, nitrogen mineralisation rate and dehydrogenase activity (DHA) were noted under birch stands.

The extent to which biological properties of RMS are affected by parent rock or planted tree species still remains unanswered. Transformation of the soil organic horizon by litterfall as well as differences in pH, chemical properties and nutrient concentrations in the uppermost soil layer are the major factors that determine effects of tree species on soil biological properties (Augusto et al., 2002; Filcheva et al., 2000; Hagen-Thorn et al., 2004; Reich et al., 2005; Shugalei, 2005). In addition to litterfall, roots are important in soil formation, especial fine roots (diameter < 2.0 mm) (Rosenvald et al., 2011). However, although fine roots represent only about 10% of a tree's underground biomass (Miller et al., 2006), they can deliver similar nutrient amounts into the soil as can litterfall under tree stand canopies (Burke and Raynal, 1994). Moreover, fine roots create a microhabitat around themselves (rhizosphere) by secreting their own substance, partly resulting from the decomposition of dead cells. In this zone, there are increased numbers and activity of microorganisms compared to the root-free portion of the soil (Parmelee et al., 1993; Phillips and Fahey, 2006).

The goals of this study were to (1) determine the effects of RMS properties (texture, pH, TOC and TN) and planted tree species on the soil biological parameters (DHA, MBC, enchytraeid density (EnchD) and the earthworm community (biomass, density and species diversity) and (2) to understand which of the two mentioned factors (soil substrate or tree species) influences soil biological parameters more.

2. Materials and methods

2.1. Study site

Study sites were selected at afforested post-mine sites that differed in soil substrate and in location in southern Poland: a spoil heap after a sulphur mine in Piaseczno and a sand mine cast in Szczakowa.

The Piaseczno mine is located near the Wisła River (N 50 33.622 E 21 34.185). In this region, the average annual air temperature is 7.0 °C, and precipitation is 650 mm year^{-1}. The site is conical in shape with an area of 120 ha and a height of up to 40 m. The spoil heap mainly consists of neogene Krakowiec formation clays, loose quaternary sands and quaternary loamy sands. During the first 2 years of initial reclamation carried out in 1970s, initial revegetation and soil stabilisation occurred on the spoil heap. Also during this time, legumes (mainly sweet clover (*Melilotus albus* L.)) and grasses (e.g., ryegrass (*Lolium* spp.)) were sown, and mineral fertilisation occurred twice with total doses of 80, 50 and 60 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K), respectively. In the most difficult areas, where vegetative death occurred, sweet clover and alfalfa (*Medicago sativa* L.) also were sown. Species mainly consisting of oak, pine, birch, larch and alder were planted on the flatter hilltops.

The Szczakowa sand mine cast is located in the Upper Silesia region of southern Poland (N 50 14.394 E 19 25.140). In this region, the mean annual air temperature is 8 °C, and the precipitation averages 700 mm year^{-1}. A disturbed area exists covering 3100 ha with an excavated depth of 5–25 m that resulted from open-strip mining. In the studied section of the mine cast, reclamation began in '70s. Reclamation treatments included re-grading the surface and adding organic amendments (approximately 300 m^3 ha^{-1}). The organic amendment was a mixture of the uppermost forest soil layer, selectively collected from the overlying forest soil prior to mining, with an average organic carbon content of 0.3–1.0%. Subsequent treatments included a 2-year cycle of fertilisation (with total amounts of 140, 130 and 150 kg ha^{-1} of N, P and K, respectively) and a 2-year cycle of lupine (*Lupinus luteus* L.) cultivation followed by incorporation of the biomass as green manure. The sites were then afforested using mainly Scots pine with a mixture of birch, larch, oak, black locust (*Robinia pseudoacacia* L.) and alder.

The research areas were determined using geographic information systems tools (ArcView 10, ESRI Poland). The Piaseczno sulphur mine spoil heap was covered by a regular 50 × 50-m grid of squares. Due to its large size (more than 3000 ha), the Szcakowa sand mine pit grid squares were arranged only on selected parts of the mine excavation within pine, birch, larch and alder stands, respectively. After the initial field recognition of soil substrates and tree species homogeneity, 12 points on the grid, representing tree × substrate combination variants, were selected.

Study plots were established within pure stands of 25- to 35-year-old Scots pine (*Pinus sylvestris* L.), European larch (*Larix decidua*), common birch (*Betula pendula*), European oak (*Quercus robur* L.) and black alder (*Alnus glutinosa*) trees growing on different RMS substrates: quaternary sands (Qs); quaternary loamy sands and loams (Ql); neogene clays (Nc); and mixed quaternary sands and neogene clay (QsNc) (Table 1).

2.2. Soil sampling

In each plot, soil samples were taken from the uppermost organic horizon (Oe) and two mineral layers (0–5 cm and 5–30 cm) twice per year (during 1-week sessions in May and September 2014). At each one are circular plots were sampled from five

Table 1
Combination of tested variants: tree species—reclaimed mine site substrate on studied post-mine sites in southern Poland. QsNc—mixed quaternary sands and neogene clays; Nc—neogene clays; Qs—quaternary sands; Ql—quaternary loamy sands and loams n.o.—did not occur on the given post-mine sites.

	Spoil heap of sulphur mine Piaseczno		Sand pit excavation Szczakowa	
Species/substrate	QsNc	Nc	Qs	Ql
Scots pine	Pine-QsNc	n.o.	Pine-Qs	Pine-Ql
European larch	Larch-QsNc	n.o.	n.o.	Larch-Ql
Silver birch	Birch-QsNc	n.o.	Birch-Qs	Birch-Ql
European oak	Oak-QsNc	Oak-Nc	n.o.	n.o.
Black alder	n.o.	Alder-Nc	n.o.	Alder-Ql