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Original article

The effect of earthworms and other saprophagous macrofauna on soil microstructure in reclaimed and un-reclaimed post-mining sites in Central Europe

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Abstract

Soil macrofauna density and the distribution of macrofauna faeces and other structures in topsoil were studied in two chronosequences of post-mining sites, the first overgrown by spontaneously developed vegetation and the second reclaimed by planting alder. Each chronosequence consisted of three plots of the respective age of 15, 23 and 40 years since heaping. Density of all macrofauna groups, and earthworms in particular, was higher in reclaimed than in un-reclaimed sites. Soil microstructure formation was closely related to soil fauna density and activity. Faster earthworm colonization resulted in more rapid accumulation of earthworm coprolites in topsoil and consequent formation of humus layer in reclaimed than in un-reclaimed sites. Low density of earthworms in intermediate succession stages of un-reclaimed sites resulted in low soil mixing and in accumulation of litter fragments and macrofauna faecal pellets in soil surface, where they formed a massive fermentation layer. The study showed that besides plant establishment, successful colonization of post-mining sites by soil fauna seems to be critical for soil development as the substantial part of newly formed soils consisted of soil macrofauna faeces.
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Keywords: Earthworms; Soil macrofauna; Soil microstructure; Soil development; Reclamation; Post-mining sites

1. Introduction

In the Czech Republic, large areas of colliery, i.e. produced by coal mining, spoil heaps are formed by materials excavated from up to 200 m depth during opencast mining. Soil development on the heaps is crucial for the reconstruction of functional ecosystems.

The soil formation relates closely to vegetation development and soil organisms activity [2,4,14,16]. Traditionally, more attention is paid to the effects of plants, though the role of soil biota in the formation of upper organic soil horizons is also important [4,9,11,13]. There are several studies available on soil biota in European post-mining areas [3,6,10,17], most of them dealing with the succession of soil organism communities, but research aimed on the functional relationships between soil biota and soil formation is rare [5,6,14].

In this study, we focused on the comparison of soil macrofauna density with the occurrence of soil morphological structures produced by soil fauna and on the evaluation of the role of these structures in upper soil horizons formation.

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2. Material and methods

The study was carried out on colliery spoil heaps located in the North Bohemian coal mining district near the town of Sokolov, Czech Republic. The heaps were formed by tertiary clay material of pH about 8 [6]. Spoil material contains about 4% of fossil carbon; C content of topsoil may reach 10% in 40-year-old sites [15]. Heap vegetation was formed by mosaic of reclaimed and un-reclaimed sites of various ages. Two neighbouring chronosequences, each consisting of three plots of the respective age of 15, 23 and 40 years since heaping (referred as initial middle and late succession), were chosen for the study. Initial and intermediate sites were located in the central part of one large heap about 1.5 km distant from surrounding semi-natural landscape; the oldest sites of both chronosequences were located closer to surrounding landscape (0.5 km), about 5 km from the younger sites. The plots of the first chronosequence were overgrown by spontaneously developed vegetation; those of the second were afforested with alder trees. At un-reclaimed sites, the upper part of heap consisted from a mosaic of 1-m high elevations and depressions as formed by heaping machinery. Herbaceous vegetation, especially *Tussilago farafara* and *Calamagrostis epigeios*, dominated in the initial stage. The middle stage of succession was covered by *Salix caprea* shrubs, while tree cover dominated by *Populus tremuloides* and *Betula* spp. developed at the oldest plot. The reclaimed sites were levelled and afforested with the mixture of *Alnus glutinosa* and *Alnus incana* about 5 years after heaping. Grasses, mostly weed *Calamagrostis epigeios*, were abundant in the youngest plot. In older plantations, the tree canopy closed which resulted in the decrease of herb cover. No additional seed or soil was spread on the top of reclaimed heaps, so organic horizons developed in situ in both chronosequences under study.

Soil macrofauna were sampled two times a year (May and September/October) in 1997–1998 and in 2000–2001 at reclaimed and un-reclaimed plots, respectively. On each sampling occasion, three soil samples (625 cm^2 in area, depth of 10 cm) were taken at each reclaimed plot; separate sets of samples were taken from depressions and elevations at un-reclaimed plots (tree samples per site and microhabitat). Soil animals were extracted using modified Kempson apparatus [10].

One undisturbed soil sample (5 × 5 cm, 10 cm in depth) was taken from each sampling location to study soil microstructure [8]. The samples were dried out and embedded in epoxy resin. After hardening, vertically oriented thin soil sections were prepared according to Rusek [13]. Slides were observed under various magnifications using normal and polarized light. To quantify the distribution of dominant structures in soil profile, a stereological approach was used [1]. Each slide was divided into strips each representing 1 cm depth from top of the litter up to 1–2 cm below the bottom of the humus layer. For each 1 cm strip 1000 randomly selected optical fields were observed under 240× magnification using a Leica (Germany) stereomicroscope. The intercept of individual structures was recorded with the cross projected in the centre of optical the field. The proportion of intercepts targeting individual structures was assumed to be proportional to the area of these structures on the slide with respect to volume of this structure, in particular the soil layer. The following structures were distinguished for quantification: mineral spoil, pores, leaf litter, other litter (mostly woody fragments), roots, and faecal pellets of arthropod litter feeders and earthworm coprolites (Fig. 1). Densities of individual groups of soil macrofauna in reclaimed and un-reclaimed sites were compared by *t*-test. χ^2 test was used for testing if the frequency of intercepts for individual soil particle types distributed uniformly between various sites. In all cases particle distribution in the top 5 cm was used for the χ^2 test.

3. Results

The density of all groups of soil macrofauna studied was higher in reclaimed than in spontaneous sites. The difference was most pronounced in earthworms, significant for all three age classes (Fig. 2). Species composition of earthworm community differed. Epigeic species (*Dendrobaena octaedra* and *Lumbricus rubellus*) dominated both chronosequences; however, in reclaimed sites also endogeic earthworms were present [7].

Thin soil section analysis revealed mostly grass litter in initial stages of reclaimed sites. No macroscopically visible organic matter was observed in initial stages of un-reclaimed sites. In these sites apparent differences in porosity were found between depression and elevation. In elevation, the clay displayed a lamellar structure, whereas the structure was more compact in elevation which resulted in significantly higher occurrence of pore space in elevation (χ^2 test, $P < 0.001$). In initial stages, earthworm coprolites were abundant in reclaimed sites but almost absent in un-reclaimed sites (χ^2 test, $P < 0.001$, Fig. 3). In intermediate succession stages of reclaimed sites, most of the leaf litter was transformed into faecal pellets of millipedes and diptera larvae, which formed the majority of the fermentation layer, which is of the moder type. Organic matter in

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