



Soil biota in post-mining sites along a climatic gradient in the USA: Simple communities in shortgrass prairie recover faster than complex communities in tallgrass prairie and forest



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ABSTRACT

Soil biota were studied at four post-mining areas along a climatic gradient in the USA. The natural climax vegetation was hardwood forest (TN, IN), tallgrass prairie (IL), or shortgrass prairie (WY). Two chronosequences were used in each state, each contained young (2–5 y) and old (15–20 y) post-mining and a site with the area's climax vegetation. All sites were sampled in spring 2008 and 2011. Microbial biomass, microbial respiration, ergosterol, composition of microbial community (using phospholipid fatty acids), community composition of soil nematodes and macrofauna, soil chemistry, and soil microstructure (using thin soil sections) were studied. Total carbon and nitrogen content increased with successional age, while total phosphorus was often greater in young post-mining sites than in climax sites. Microbial biomass in forest chronosequences increased with age, actinobacteria were associated with prairie sites, and fungi were associated with forest sites. Root-feeding nematodes and macroflora were dominant in the shortgrass prairie sites. Earthworms were absent in such shortgrass sites but were present in the wetter, eastern sites. In forest chronosequences, other saprophages, litter transformers, and microphagous groups were also abundant. Absence of saprophagous groups, and especially earthworms, resulted in the absence of bioturbation in shortgrass prairie sites while worm casts and other biogenic structures formed an important part of the soil profile in other chronosequences. Both young and old restoration sites were much closer to the climax condition in shortgrass prairie than in the other sites. The shortgrass prairie soil community contained abundant root-feeding organisms, which may establish quicker than the more saprophagous soil biota that were abundant at the other sites. In chronosequences other than the one in shortgrass prairie, bioturbation played an important role in topsoil formation, which result to complex soil profile development compare to shortgrass prairie which may contribute to faster recovery communities in shortgrass prairie in comparison with tallgrass prairie and forest.

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1. Introduction

Studies of succession often focus on the aboveground rather than the belowground parts of ecosystems (Glenn-Lewin et al.,

1992; Prach and Rehoukova, 2006). Soil development largely determines plant community characteristics as well as other key ecosystem properties, during succession (Frouz et al., 2001, 2008). Soil and soil biota, however, play a crucial role in ecosystem succession by affecting the establishment of plants species and competition among plants (Brown and Gange, 1989; Thompson et al., 1993; Topp et al., 2001; De Deyn et al., 2003; Prach and Rehoukova, 2006; Frouz et al., 2008), and the soil biota affects soil formation by influencing the distribution of organic matter, aggregate formation, etc. (Six et al., 1998, 2004; Frouz et al., 2007,

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2009). The succession of soil biota also affects the successional changes in other soil processes such as decomposition and nutrient cycling (Frouz and Novakova, 2005; Frouz et al., 2008).

There are two major forms of interaction between plant-soil development and soil biota (plant-soil feedback) during succession, which are root- and litter-related. Root-related interactions are associated with living tissues of primary producers, namely roots and root-derived organic matter (Bonkowski et al., 2000; Mahaming et al., 2009; Putten Van der et al., 2009; Kardol and Wardle, 2010). Plants invest large amounts of assimilates into mycorrhizal fungi that are beneficial to the plant in many soil-based interactions (Smith and Read, 2008). Root exudates also support a high density of bacteria in the rhizosphere which, combined with protozoan grazing, release additional nutrients to plants (Bonkowski et al., 2000). Plant pathogens, herbivores and plant parasites may also accumulate in the rhizosphere causing (negative) plant-soil feedback (Kardol et al., 2006). Root-associated organisms substantially affect plant growth and consequently plant community composition during succession as shown by many examples with mycorrhizae (Nara, 2006; Püschel et al., 2007), herbivores (Gibson and Brown, 1991; Fagan and Bishop, 2000; Rasmann et al., 2011; Roubícková et al., 2012), and other soil biota (De Deyn et al., 2003).

In litter-related interactions, plant litter effects the formation and physical structure of the topsoil layer (Ponge, 2003; Putten Van der et al., 2009). Besides the roots, plant litter represents a major source of C input into soil and forms the base of the soil food web. The organic matter entering the soil affects the soil biota that feeds directly or indirectly on litter (Ponge, 2003). The soil biota modifies the rate of organic matter decomposition and nutrient release as well as the distribution of organic matter and the formation of aggregates. The latter two have direct impacts on soil sorption and water holding capacity (Six et al., 2004). In turn, these modifications of the soil environment influence the composition of soil biota and soil processes and contribute to soil formation and modification (Sheu and Parkinson, 1994).

Changes of many ecosystem properties, including soil properties, along climatic gradients have recently received considerable attention (Austin and Sala, 2002; Fierer et al., 2009). Although many studies have compared various parameters in steady state conditions along climatic gradients, the changes in successional processes and successional dynamics along these gradients have seldom been explored (Prach and Rehoukova, 2006; Alberti et al., 2011; Fridley and Wright, 2012). This is particularly true for the soil portion of the ecosystem, such that we have very limited knowledge about how the pathway and rate of succession differs among climatic zones.

Mining, and surface mining in particular, causes severe disturbance of ecosystems (Bradshaw, 1983, 2000; Hüttel and Weber, 2001). Soil in mined sites is replaced by overburden, which differs substantially from developed soils (Bradshaw, 1983, 2000; Huggett, 1998; Sourkova et al., 2005a, 2005b). Original soil may be salvaged from disturbed areas or covered by overburden. In many reclamation technologies, overburden is covered by salvaged topsoil or topsoil. If there is lack of topsoil some reclamation technologies use suitable overburden materials as topsoil substitute before reclamation. This approach has been common for coal mining reclamation in the USA since the Surface Mining Control and Reclamation Act of 1977 (SMCRA) became law. These capping materials are more similar to recent soils than the overburden in physical properties, but because of the disturbance caused by soil salvage and stockpiling and by the spreading of the organic matter, the microbial activity in these soils is usually depleted (Ingram et al., 2005; Anderson et al., 2008; Ganjgunte et al., 2009). Soil recovery in post-mining sites is essential for the reconstruction of

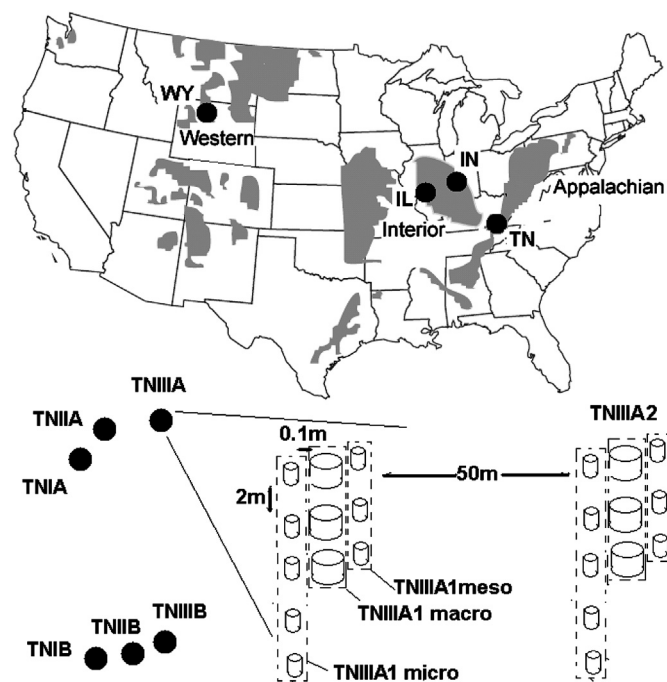


Fig. 1. Map of USA with location of sampling areas: Tennessee (TN), Indiana (IN), Illinois (IL), and Wyoming (WY), coal producing areas of USA are marked gray (based on Annual Coal Report 2008 of Energy information administration), TN site is used as an example to demonstrate sampling design applied on all the sites in one sampling year (the same design was repeated in second sampling year). Samples for macrofauna are labeled macro, samples for mesofauna and chemistry meso, and samples for nematodes and microflora micro.

functional ecosystems, and the study of post-mining soil development thus has large potential for practical application (Bradshaw, 1983, 2000). Moreover, post-mining soils represent unique models for the study of succession because mining creates similar sites over time, which facilitate a chronosequence approach (Frouz et al., 2001, 2008). Because legal regulations have required a certain standard of post-mining soil reclamation, chronosequences of post-mining soil established in similar ways can be found across large geographic areas. The USA is among the largest coal producers worldwide (Höök and Aleklett, 2009), and coal mining is located in three major regions of the country (Appalachia, the Interior, and the West) (Fig. 1), which cover different climatic zones (Höök and Aleklett, 2009). In the current study, we explored how the direction and rate of soil biota succession vary along a continental climatic gradient across the USA. We used a set of chronosequences of post-mining soils distributed along a 2500-km climatic gradient from Tennessee to Wyoming in the USA. The study sites encompassed major vegetation biomes, namely temperate deciduous forest in Appalachia and in the Interior, tallgrass prairie in the Interior, and shortgrass prairie in the West (Fig. 1).

Classical succession studies dealing with aboveground part of ecosystem conclude that communities become more simple and succession less apparent with decreasing precipitation (McMahon, 1980). In our study we aimed to test if soil communities also become more simple and succession less apparent with decreasing precipitation. Because root:shoot ratios in forest ecosystems are generally much lower than in grassland (Mokanay et al., 2006), we hypothesized that soil communities in a forest ecosystem would be more dependent on litter input, while a communities in grassland ecosystem would depend more on the roots, as a consequence fungal pathways of the food web would be more pronounced in a forest and bacterial pathways would be more pronounced in grassland.

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