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Tree species effects on litter decomposition in pure stands on afforested post-mining sites

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ABSTRACT

Tree litter decomposition on disturbed post-mining sites has been mainly studied within successional gradients, whereas almost no results were shown from afforested spoil heaps. Litterfall and its decomposition rate are considered the most important ecological processes for soil restoration during stand development on such initial forest habitats. These processes allow development of a functional ecosystem and productive forest stands. Moreover, the pedogenesis process on such "soilless"' habitats can be significantly improved and accelerated by tree species selection during afforestation.

The main aim of the study was to determine litter decomposition rates of nine tree species used for afforestation of a lignite mine spoil heap. We assumed that leaf litter decomposition rates would differ among tree species studied and that the site conditions would significantly influence this process.

Our study was conducted on the spoil heap of the lignite open cast mine in Bełchatów, central Poland. We studied leaf litter decomposition of *Alnus glutinosa*, *Betula pendula*, *Pinus sylvestris*, *Quercus robur*, *Q. rubra* and *Robinia pseudoacacia* in pure stands of these species (home stands), and litter decomposition of *Acer pseudoplatanus*, *A. glutinosa*, *Fagus sylvatica*, *Prunus serotina*, *Q. rubra*, and *R. pseudoacacia* in Scots pine stands. We used the litterbag method. The experiments lasted for three years and the samples were collected every three months.

Leaf litter decomposition calculated for home stands after three years of decomposition was 94.4% of the initial leaf mass for *A. glutinosa*, 70.9% for *R. pseudoacacia*, 70.1% for *P. sylvestris*, 68.3% for *B. pendula*, 66.9% for *Q. rubra* and 61.5% for *Q. robur*. In Scots pine stands, after three years of the experiment, 92.3% of the initial leaf mass decomposed for *P. serotina*, 85.7% for *A. glutinosa*, 83.5% for *A. pseudoplatanus*, 65.2% for *R. pseudoacacia*, 50.9% for *Q. rubra* and 40.1% for *F. sylvatica*. *A. glutinosa*, *R. pseudoacacia* and *Q. rubra* leaves decomposed significantly faster in home stands than in Scots pine stands. Site aspect significantly influenced litter decomposition of the species studied, with higher rates mostly on the western slope.

Our study revealed that the decision on tree species used for afforestation might shorten the period needed for soil restoration and achievement of sustainability of novel ecosystems. Proper selection of main and admixture tree species for afforestation of the post-mining sites might reduce the renewal period of the soilless and newly created habitats, which may provide noticeable ecological and economical effects during stand management.

1. Introduction

Studies on biomass decomposition are one of the most dynamically developing branches of forest ecology in recent years (e.g. Austin et al., 2014; Berg, 2014; Frouz et al., 2015; Jurkšienė et al., 2017). Its importance at the global scale is multiplied by climate change because the process of decomposition plays significant roles in the cycling of elements in ecosystems, having huge influence on carbon fluxes (e.g. Dilly and Munch, 1996; Makkonen et al., 2012). Climate, litter chemistry and soil characteristics with high importance for activity of microorganisms are the main factors affecting decomposition (Berg and Staaf, 1980; Aerts, 1997; Davey et al., 2007; Jurkšienė et al., 2017). At the global scale, climate is the most important, affecting also litter chemistry and microbial community changes (Aerts, 1997). However, at local scales the importance of climate unsurprisingly fades, giving way to litter chemistry and soil characteristics, the relative importance of which vary among different studies (e.g. Davey et al., 2007; Ayres et al., 2009; Prescott, 2010; Urbanová et al., 2014). The body of studies on decomposition allows creation of general theories and conclusions. One of the most examined principles is the home-field advantage theory

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(HFA), where many authors stated that decomposition of particular litter is faster beneath the parent canopy (e.g. Ayres et al., 2009; Austin et al., 2014). However, detailed studies should be performed to understand given circumstances, for instance how admixtures of species affect accelerating decay rates of more recalcitrant coniferous litter (Polyakova and Billor, 2007; Prescott, 2010).

At local scales the process of decomposition is very important as its rate affects the functionality of ecosystems, among which novel ecosystems, or somehow disturbed areas and their biological characteristics are uncertain (Hobbs et al., 2006). Plenty of papers focusing on that topic have compared the decomposition rates of a particular group of species from particular climatic zones or various habitats. However, there are few studies addressing this problem on post-industrial sites (e.g. Frouz, 2008; Esperschütz et al., 2013, Urbanová et al., 2014), where the process of decomposition itself often determines the development and sustainability of novel ecosystems. This in turn is inherently uncertain, as disturbed post-mining soil substrates differ considerably from naturally developed soils by having lower soil organic matter content, microbiological activity, porosity, permeability and water-holding capacity, higher bulk density and often high toxicity (Indorante et al., 1981; Helingerová et al., 2010; Shrestha and Lal, 2011; Jagodziński et al., 2014). Studies conducted on post-industrial sites (e.g. Frouz, 2008; Esperschütz et al., 2013; Urbanová et al., 2014) focused mainly on successional traits and assessed the effects of natural processes of ecosystem development. Thus, large-scale experiments are needed to assess the effects of planned management activities during the course of reclamation; such studies were undertaken in India (e.g. Dutta and Agrawal, 2001) and USA (e.g. Lawrey, 1977). The main conclusion from these studies is that early-successional species should be preferred in post-mining land reclamation, as they, in contrast to late-successional, slow-growing species, are characterized by high rates of litterfall and relatively fast litter decomposition. Although this research contributed valuable recommendations for further reclamation activities, there is still a need to broaden detailed studies.

Despite the rather spotty occurrence of post-industrial terrains, in sum they constitute a considerable area. For example, in Poland the hypothetical afforestation of all degraded lands might increase forest area by about 64,000 ha (Horodecki et al., 2015), legitimizing a large interest in them. Afforestation of post-mining areas, if possible, provides for the long-term process of pedogenesis. In the harsh conditions of post-mining lands, the initiation of soil formation processes plays a key role in their restoration (Dutta and Agrawal, 2001; Jagodziński and Kałucka, 2010; Esperschütz et al., 2013; Kałucka and Jagodziński, 2016). The proper tree species selection and the mode of admixture can significantly accelerate restoration due to the amount of litter production and its rate of decay. Knowledge about the rate of decomposition of particular plant material in specific habitat conditions allows forest managers to properly modify the species composition for successful land reclamation, affecting both biological and economical aims.

The aim of this study was to determine the rate of leaf litter decomposition of main, as well as of admixture tree species, used in afforestation for post-mining site reclamation. We tested the influence of litter type (determined by litter of particular tree species), stand variants (home stands *vs*. Scots pine stands) and site exposure (western slope *vs*. plateau of the lignite mine spoil heap) on decomposition rates. We determined litter decomposition of nine tree species in various stand and habitat conditions. We hypothesized that (H1) particular leaf litter decomposition rates would differ significantly among the nine species studied (in home stands and Scots pine stands growing on a lignite mine spoil heap, separately). Moreover, we assumed that according to the home-field advantage theory, the rate of leaf-litter decomposition of particular tree species would be faster within the home than the Scots pine stands (H2). However, the alternative hypothesis states that this theory would fail in the harsh conditions of post-industrial sites with only initial phases of pedogenesis. Additionally, we tested whether the decay rate was lower on the plateau of the spoil heap than on the western slope, where insolation and soil temperature should be higher (H3).

2. Material and methods

2.1. Study site

The study was conducted on the external spoil heap of the "Bełchatów" lignite mine (Mount Kamieńsk; Central Poland; 51.1247°N, 19.2540°E). The average annual air temperature for a 20-year-long period (1996–2015) was 8.65 °C, whereas the average annual precipitation was 665 mm (Institute of Meteorology and Water Management rapport, 2016) for the nearest meteorological station (51.4319°N, 19.2353°E, 179 m a.s.l.). The growing season lasts 210–220 days (Zielony and Kliczkowska, 2012).

Mount Kamieńsk was created during the years 1977–1993 from very diversified raw rocks (mostly quaternary and in the lower strata, tertiary) originated from open pit overburden (Goździk et al., 2010; Pietrzykowski, 2010). Phytotoxic tertiary deposits were usually located inside the heap beyond the range of plant roots (Goździk et al., 2010). However, there are some places with tertiary substrates lying in the outer layers, where high acidity was neutralized with lake chalk from the open pit or alkaline ash from a nearby power plant. Before establishment of tree stands, the plateau of the heap was sown with mixed grass species and legumes and also mineral fertilizers were applied (N and K – 60 kg ha^{-1}, P – 70 kg ha^{-1}) to enhance the soil substrate (Pietrzykowski and Daniels, 2014). Forest reclamation was conducted according to the biodynamic method (Wójcik and Krzaklewski, 2010), i.e. the ground was planted with target tree species with a significant share of additive ones. Almost the whole area of the spoil heap is covered by forest. At the beginning of 2016, 54% of forest area was covered by stands 26–30 years old, and the oldest trees were 31 years old (https://www.bdl.lasy.gov.pl/portal/mapy). The highest occurrences in overall forest area were *Betula pendula* (27%) and *Pinus sylvestris* (25%). *Robinia pseudoacacia* and *Alnus glutinosa* stands constituted 13% and 11% of forest area, respectively. *Quercus robur* and *Q. petraea* stands covered 5.6% of the total afforested area of the spoil heap. Remaining tree species studied as admixtures covered altogether less than 2% of total forest area (1.1% for *Quercus rubra*, 0.6% for *Acer pseudoplatanus*, 0.1% for *Fagus sylvatica*). *Prunus serotina* was listed in the forest management plan as an understory species in 27 of 55 forest compartments on the spoil heap.

2.2. Experiment details

For this study, in 2011 we established 24 sample plots on the lignite mine spoil heap with stands of the following tree species: *Alnus glutinosa* (4 stands), *Betula pendula* (4), *Pinus sylvestris* (10), *Robinia pseudoacacia* (2), *Quercus robur* (3) and *Q. rubra* (1; Table 1). Although *Q. rubra* often appears on the spoil heap as an admixture, we found a few pure stands and decided to set up an experimental plot in one of them having sufficient area. For each stand, we measured all diameters at breast height and height for at least 25% of trees, and determined tree age based on ring number at the base of at least eight model trees harvested in each stand. Based on this data we calculated basal area and stocking density for each stand. The soil surface layers were analysed based on soil pit excavation (1.5 m deep) in the center of each study site – in this study soil granulometry, organic layer thickness and pH (measured in 1:5 soil suspension in H_2O) were used for site descriptions (Table 1). We also measured organic layer soil temperature (around 3 cm beneath mineral soil surface) at one hour intervals using HOBO data-loggers (HOBO U22-001 Water Temperature Pro v2 and/or HOBO U23-001 Pro v2 Temperature/Relative Humidity) for each plot (for this study we showed data only for stands used to determine slope aspect effect on litter decomposition rates; Table 2).

We established two sets of experiments. In 24 stands of 6 tree