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Survival of black alder (*Alnus glutinosa* L.), silver birch (*Betula pendula* Roth.) and Scots pine (*Pinus sylvestris* L.) seedlings in a reclaimed oil shale mining area

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ABSTRACT

Early survival and growth of black alder, silver birch and Scots pine were investigated on reclaimed extremely stony and heterogeneous calcareous (pH 8) opencast oil shale mining areas (OOSMAs). Biomass allocation, production, leaf and root adaptations, and mineral nutrition in relation to tree species and soil heterogeneity were analysed. The adaptive strategies of tree species in first-year plantations on OOSMA were different. Scots pine allocated 1.5–2 times more biomass into leaves and fine roots than deciduous trees. The lower leaf/fine root biomass ratio was in proportion to the better survival (%) of seedlings, decreasing in the following order: black alder (93%) ≥ Scots pine (83%) > silver birch (64%). Deciduous trees improved mineral nutrition more by fine-root morphological adaptations than Scots pine; e.g. the mean specific root length (SRL, $m\,g^{-1}$) of short roots increased in the following order: Scots pine (62) < black alder (172) < silver birch (314). The effect of soil heterogeneity on growth and adaptations was minor. All studied species suffered from P and N, and deciduous species also from K deficiency. In the first year after planting, black alder was best adapted to the harsh conditions of the post-mining substrate. The approaches of this study can be used for other regions where wastelands require reclamation.

1. Introduction

Every year the opencast mining of oil shale in Northeast Estonia produces significant areas of degraded land, which needs restoration. Presently two underground mines and two opencast mines are in operation. As of 2006 the area damaged by oil shale opencast mining was 13,098 ha, of which 10,347 ha has been afforested (Kaar and Tomberg, 2006). The opencast oil shale mine sites are characterized by unfavourable conditions: heterogeneity, stoniness up to 100%, limited moisture, low nitrogen and organic content of mining spoil, and inhibited phosphorus uptake due to high pH (~8). These conditions make the selection of species for afforestation very complicated and cause survival problems of young plantations.

The goal of restoration is usually to develop a long-term sustainable ecosystem native to the area where mining occurred (Chambers et al., 1994). The restoration of post-industrial landscapes is often a challenge regarding multifunctional land use issues. Multifunctionality is important from the point of view of both natural capital and socio-economic values (Haines-Young et al., 2006). On the other hand, restoration provides several opportunities for the optimal use of landscape functions (de Groot, 2006). Afforestation is a potentially sustainable reclamation strategy for post-mining sites (Parrotta et al., 1997; Filcheva et al., 2000; Singh et al., 2002; Dutta and Agrawal, 2003; Pietrzykowski and Krzaklewski, 2007). Also, afforestation is an optimal tool for the reclamation of opencast mining areas in northeastern Estonia (Kaar, 2002). A total of 52 indigenous and introduced species have been planted; species of *Larix* have shown the best growth among coniferous trees, and the native deciduous species silver birch (*Betula pendula*) and black alder (*Alnus glutinosa*) have been the most successful deciduous trees (Lõhmus et al., 2007). New stands are of better quality than the overmoist stands that grew there before mining (Kaar, 2002). Presently conifer plantations make up over 90% of the afforested area, with Scots pine (*Pinus*

Abbreviations: OOSMA, opencast oil shale mining area; LOI (%), loss on ignition; *H* (cm), height of trees; *B* (g), biomass; RR (%), root ratio; FR/*R* (%), fine root ratio; *L*/FR, foliage/fine root ratio; SLA ($m^2\,kg^{-1}$), specific leaf area; LWA ($g\,m^{-2}$), leaf weight per area; FOE ($g\,g^{-1}\,yr^{-1}$), foliar assimilation efficiency; NUE ($g\,g^{-1}\,yr^{-1}$), N use efficiency; PUE ($g\,g^{-1}\,yr^{-1}$), P use efficiency; SRL ($m\,g^{-1}$), specific root length; SRA ($m^2\,kg^{-1}$), specific root area; RTD ($kg\,m^{-3}$), root tissue density; *D* (mm), diameter; *L* (mm), length; *V* (mm^3), volume of the root tip; RTFM (mg^{-1}), root tip frequency per dry mass; RTFL (cm^{-1}), root tip frequency per root length; EcM, ectomycorrhizal short roots.

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sylvestris) stands predominating (86%) (Lõhmus et al., 2006a). The quality of the substrate has declined and its stoniness has increased due to the thickening overburden in new mining areas. These harsh growing conditions might limit growth and survival of different tree species at different rates, and hence the reasonable choice of tree species for the reclamation of levelled opencast mines will be even more important in the future. For successful forestation and stability of plantations, the proportion of deciduous trees in the new stands should rise to 40–60%. Deciduous species have a number of advantages: the increased N and P availability in the soil, faster growth at young age and higher resistance to pests, diseases and fires in comparison with conifer monocultures (Kaar and Raid, 1996; Kaar, 2002; Vares et al., 2004; Lõhmus et al., 2006a). While most plant species appear to act as catalysts for ecosystem rehabilitation, broadleaf species seem to yield better results than conifers. Fast-growing black alder and silver birch are particularly suitable to establish; they grow well on degraded sites (Kaar and Raid, 1996; Kaar, 2002; Singh et al., 2002; Vares et al., 2004), and yield high quality timber. Hence they are preferred on mining spoil areas (Kaar, 2002). Black alder could be considered to be a “biological fertilizer” which improves soil nitrogen status, fixing N_2 in symbiosis with *Frankia* in its root nodules and increases phosphorus availability in soil by the activity of its roots and associated microbial communities (Giardina et al., 1995; Uri et al., 2002). Although Scots pine is a pioneer species, it is mostly a stress-tolerator (Grime, 1979).

Foliar and fine-root adaptations are among the key factors determining growth rate and species performance. However, the potential of different tree species for recultivation of exhausted opencast oil shale mines in relation to fine-root and leaf adaptations and to decreasing site quality in opencast oil shale mining areas are still poorly investigated. The higher growth rate of black alder corresponds to the higher activity of microbial communities in its rhizosphere, and the higher specific root area of short roots compared to conifers (Vares et al., 2004; Lõhmus et al., 2006b).

In this study, one-year-old black alder, birch and pine plantations established on calcareous spoil of opencast oil shale mines as perspective species for cultivation in alkaline wastelands were studied. The first years of stand growth are most critical for plant survival and development in the harsh conditions of an oil shale mining area (Lõhmus et al., 2006a,b).

The main aim of the present study was to analyse the early survival and adaptive strategy of black alder, silver birch and Scots pine seedlings in first-year plantations on oil shale mining spoil. In particular, we studied whole-tree biomass allocation and aboveground production, root and leaf adaptations, foliar assimilation and nutrient use efficiencies in relation to tree species and soil heterogeneity.

2. Materials and methods

2.1. Plantation

The study plantations were established on skeletal calcareous quarry detritus of an opencast oil shale mining area in Narva, Northeast Estonia (59°15′N, 27°42′E).

The area of the plantation was 0.7 ha. The mean soil parameters were the following: loss on ignition (LOI) 4.1%, pH_{KCl} 8.0, total nitrogen content 300 mg kg^{-1}, lactate soluble phosphorus 84.3 mg kg^{-1}. According to data of the Estonian Meteorological and Hydrological Institute, the growing season 2005 was rich in precipitation, which most probably favoured the survival of the seedlings. Three indigenous species – Scots pine (*P. sylvestris* L.), silver birch (*B. pendula* Roth.) and black alder (*A. glutinosa* (L.) Gaertn.) – were planted in 25 m × 25 m plots in three replications in the Latin square design in May 2005. One-year-old bare-rooted seedlings were used, and the planting arrangement 1.5 m × 1.5 m for Scots pine; 2.0 m × 2.0 m for black alder and for silver birch was employed. At the end of August 2005 survival (%), height H (cm) and height increment ΔH (cm) of trees in all replications were measured. In order to compare the growth potential of different tree species, the relative height increment $\Delta H/H$ (%) was calculated for the living trees.

2.2. Sampling and processing of model trees

2.2.1. Sampling

Trees in each replicate plot were categorized into three height classes: small, medium and high. When the leaf mass was close to maximum and no leaf fall occurred (early September 2005), one tree from each height class per plot was randomly selected and carefully excavated, for a total of 27 model trees.

2.2.2. Biomass, production and allocation

The aboveground part of model trees was divided into three compartments: leaves, shoots without leaves (trees had only current-year shoots) and stems. After drying at 70 °C until constant weight the dry mass of all fractions was determined. The compartments were weighed to 0.001 g. Annual aboveground production of a tree, ΔB_{tree} (g yr^{-1}), was calculated (1):

$$\Delta B_{tree} = B_{leaves} + B_{shoots} + 0.5 B_{stem}, \quad (1)$$

where B_{leaves}, biomass of leaves (g); B_{shoots}, biomass of shoots (g); and B_{stem}, biomass of stem (g).

As one-year-old seedlings were planted, the biomass and production of current-year shoots were equal. The production of the stem was calculated by dividing stem mass by the number of growing seasons. The relative annual production per tree $\Delta B/B$ was calculated as well.

Root ratio (RR, %; the proportion of the root system as part of total tree mass) and the ratio of fine roots (FR/R, %; the proportion of fine (<2 mm in diameter) roots in the root system) were calculated. The foliage/fine root (L/FR) ratio (Helmisaari et al., 2007) was calculated by dividing the biomass of leaves by the biomass of fine roots of a tree.

2.2.3. Leaf characteristics

From each model tree, all leaves or at least 25 leaves with petiole were taken and dried under pressure. Average single leaf area (including the petiole) was measured using the WINFOLIA programme and needle area using WINSEEDLE software. All measured single leaf blades with petiole and single pine needles were weighed to 0.0001 g. Specific leaf area SLA (m^2 kg^{-1}) and leaf weight per area LWA (g m^{-2}) were calculated. Foliar assimilation efficiency (FOE; g g^{-1} yr^{-1}) was calculated by dividing annual aboveground production by leaf mass. Foliar N and P use efficiency was calculated as aboveground production per foliar N or P accumulation (NUE, PUE g g^{-1} yr^{-1}).

2.2.4. Root characteristics

Root systems were washed with tap water free of soil after excavation (10–15 min washing time of a root system) and separated into living and dead roots. Before processing the root systems were stored in plastic bags in soil in a freezer at 5 °C not longer than three days after excavation. We tried to keep N and K leaching from roots low according to Clemensson-Lindell and Persson (1992). For alders, root nodules were separated (Lõhmus et al., 2006a). The proportion of dead roots was negligible, and hence dead roots were omitted from further analysis. To analyse belowground biomass allocation, root systems were divided into two diameter classes: