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SUCCESSION OF ECTOMYCORRHIZAE AND THE NUTRIENT STATUS OF ICELANDIC FORESTS: AN APPROACH TO IMPROVE AFFORESTATION IN ICELAND

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ABSTRACT

Afforestation on Iceland has to face many problems due to the harsh climate and the difficult nutrient status of volcanic soils. Inoculation of tree seedlings with native mycorrhizae strains is therefore considered as a possibility to improve afforestation plans. A project was started last year to investigate soil nutrient status and ectomycorrhizal communities in native birch (*Betula pubescens*) and introduced Siberian larch (*Larix siberica*) forest habitats of different ages. The aim is to understand interactions between mycorrhizae and soil nutrients and their role in growth conditions of Icelandic forests. The first results of this still ongoing project indicate that the expected change in soil nutrients with stand age is only found under larch and only for C and soluble P in 0-10 cm soil depth. Soil N content did not change with stand age for either tree species, and neither did N content of the biomass (leaves/needles).

Keywords: Betula pubescens, Larix siberica, soil nutrients, ectomycorrhizae, afforestation

INTRODUCTION

Iceland's forest cover has been reduced to less than 1% since human settlement about 1125 years ago. This was followed by extensive soil erosion that has resulted in large barren areas and loss of soil organic matter (Arnalds and Kimble 2001; Oskarsson et al. 2004). To change this situation, afforestation in Iceland has been enhanced during the last decades (Arnalds 2004, 2005). However, the harsh climate and poor growth conditions on highly degraded soils render many problems. Organic C in degraded soil is reduced and atmospheric N input to soils is generally marginal and seldom exceeds 1 kg ha^{-1} yr^{-1}. Phosphorus is efficiently bound in volcanic soils and not directly available to plants. Hence, the nutrient status of soils is rather difficult for seedlings. The lack of soil biota supporting the availability and uptake of nutrients by trees acts as an additional barrier and makes successful afforestation a difficult task (Bowen 1984; Oddsdottir et al. 2002; Nielsen et al. 2003). Furthermore, frost heaving reduces the survival rate of seedlings. Since ectomycorrhizae have been shown to improve the establishment and growth of trees in poor soils (Enkhtuya et al. 2003), inoculation of trees with native mycorrhizal strains is expected to improve the success of afforestation in Iceland. However, knowledge in this field is inadequate, and this technique is not yet used by the Icelandic nurseries. The objectives of this study are to understand interactions between mycorrhizae and soil nutrients and their role in growth conditions of native and exotic tree species of Icelandic forests. We hypothesis that mycorrhizal communities and the soil nutrient status change with increasing age of forest habitats, and that the mycorrhizal diversity is lower in forests with exotic than indigenous tree species. Furthermore, we want to investigate if the presence or absence of certain mychorrizal strains can be related to the nutrient status of the soils and if it results in a better nutrition of the trees. To answer these questions, we examine species diversity

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of ectomycorrhizae and the nutrients status in soil and biomass in Icelandic forest habitats of different ages. Native birch (*Betula pubescens*) and the introduced Siberian larch (*Larix siberica*) were chosen as tree species. They are the most used tree species for afforestation in Iceland (Petursson 2002). Soil and biomass (leaves/needles) were analyzed for different nutrients. The presence of ectomycorrhizal fungi of birch in larch sites is tested by growing birch seedlings in soil from larch sites, and the presence of ectomycorrhizal fungi of larch in birch sites is tested by growing larch seedlings in soil from birch sites. Furthermore, birch and larch seedlings are grown in soil from heath land to investigate the presence of ectomycorrhizal fungi of birch and larch in non-forest sites (heath land). The study has been started in summer 2005 and will run until 2008. This paper will only represent preliminary results, as the study is still ongoing and data on mycorrhizal investigations as well as some soil data were not available at the time of submission. In the final data analysis we will examine the interaction between the soil and biomass data and the results of the mycorrhizal investigations. This paper should therefore only be considered as an extended abstract.

Methodology

Study site and sampling

The study was conducted in the forest area Hallormsstadur in East Iceland (14°44'W, 65°5'N), which is the largest forest areas in Iceland (Fig. 1). The average annual temperature of the region is 2.7 °C with a mean annual rainfall of 738 mm. The soil in that area is classified as Andosol. Investigations were carried out as a chronosequence study in four stands of Siberian larch (*Larix siberica*) (16, 22, 40, and 54-year-old) and two stands of native birch (*Betula pubescens*) (27 and 101-year-old). All larch trees were planted as part of an afforestation program, while birch regenerated naturally after the areas had been fenced to keep grazing sheep out. A treeless heath land was included in the study to represent the nutrient status and mycorrhizal community of the soils prior to afforestation (0 years). Sampling was carried out along five transects that had been located in each of the 7 study plots. In August 2005, mineral soil samples (0-10 cm and 10-20 cm depth) and biomass (leaves/needles) were collected in five randomly chosen positions along each transect. From the heath land, only soil was sampled. Soil sampling was carried out with a soil core sampler of 5 cm diameter after removal of the organic layer. This resulted in five soil samples per depth per transect. For sampling of biomass, 20 young but fully expanded leaves or the needles of 20 shoots were excised from five selected trees along each transect. Except for the five soil samples of one transect in each plot, all samples were mixed thoroughly by transect before analysis. Bulk density of each soil depth was determined on three undisturbed soil samples per plot.

Analysis of soil and biomass

Biomass and mineral soil samples were analysed for total carbon (C), nitrogen (N) and phosphorous (P). Soil samples were furthermore analysed for soluble phosphorous (soluble P) and major base cations (Na, K, Ca, Mg and Mn). The soil pH at the different plots had been determined in a previous study (Sigurdsson 2004). In the following, only results of C, N and P are represented. Total C and N content in soil and biomass was determined by dry combustion. Total P in soil was measured by nitric acid digestion, and soluble P by using oxalate acid extraction. Content of total P in plant tissues was determined by nitric acid digestion using concentrated HNO_3. Prior to analysis, all samples had been oven-dried at approximately 60 °C and ground finely.

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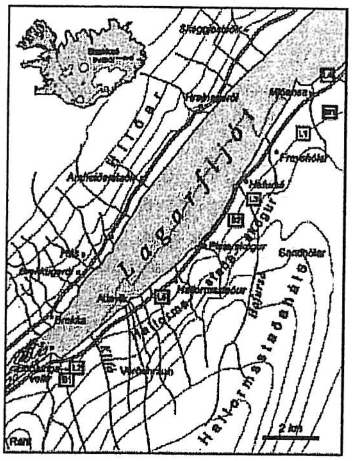

Fig. 1: Location of the study sites in the forest area Hallormsstadur in East Iceland.

MICROCOSMS

Ectomycorrhizal diversity was examined on soil samples (0-10 cm depth) incorporated into microcosms constructed from two 20 x 20 cm Perspex® plastic plates separated with a small plastic plugs. Between the plastic plates a 3-4 mm thin soil layer was sieved (4mm sieve). The soil was the mixed soil of the five samples of each transect of all study plots. Thus, there were 5 replicates of each study plot. One seedling of *Betula pubescens* or *Larix siberica* grown from surface sterilized seeds was introduced into each microcosm and each type of soil (birch, larch, and heath land soil, respectively). Microcosms were placed into growth chambers with 19 h light: 5 h dark photo-period and a 16:10°C day:night temperature and moistened at 2-3 day intervals with distilled water spray. Mycorrhizal colonization of larch and birch roots is monitored under a stereomicroscope every 14 days over 6-month period. The location (x-y coordinates) of individual ectomycorrhiza is recorded (Tammi et al. 2001) and ectomycorrhizae are classified morphologically, according to shape, colour, size and outer mantle characteristics. Individual ectomycorrhizae samples from different morphotypes are taken for rDNA identification analysis.

STATISTICS

All statistical analyses were conducted using SigmaStat statistical software (Systat Software, Inc., 2004). Soil data of each tree species were related to stand age by using simple linear regression. Data on total N and total C content in birch soil of 0-10 cm depth had to be 1/x transformed, and data on total N and total C content in larch soil of 10-20 cm depth had to be log10 transformed to achieve normal distribution.
Data on total N in birch soil of 10-20 cm depth were log10 transformed to achieve constant variances. Differences between tree species and between soil depths were tested by the *t*-test. The level of significance was $P < 0.05$. Standard error of the mean (SEM) of each plot is based on the results of the different transects in each plot.

RESULTS

SOIL

At 0-10 cm depth, average total C (% of dry weight) in soil of the heath land was 5.3 %. In 54-year old larch stands, total C content had reached an average of 8.3 %. This increase in C with stand age was significant ($P = 0.002$; $R^2 = 0.36$) (Fig. 2a). In birch stands, no significant change with stand age was detected. At an stand age of 101 years, the soil C content at 0-10 cm depth was 5.9 % and thus still similar to the heath land. Average total N (% of dry weight) in heath land was 0.3 % at 0-10 cm depth. Similar values were found at all six forest plots (range 0.2-0.3 %). There was clearly no significant change with stand age in either birch or larch. Soil C/N ratios were 22 and 23 in the two birch stands and ranged from 20-25 in the larch stands with the highest values in the oldest stands. Content of soluble and total P in heath land at 0-10 cm soil depth were 5.7 and 518.4 mg P kg^{-1} soil, respectively. In the oldest birch stand, 14.2 mg soluble P and 570 mg total P were determined per kg soil. There was no significant change with time for both fractions. In the oldest larch stand, 16.5 mg soluble P kg^{-1} soil were determined, which was a significant increase with stand age ($P < 0.001$; $R^2 = 0.64$) (Fig. 3a). In contrast, total P in the larch stands was not affected by stand age; soil in the 54-year old larch stand contained 528.7 mg total P kg^{-1} soil.

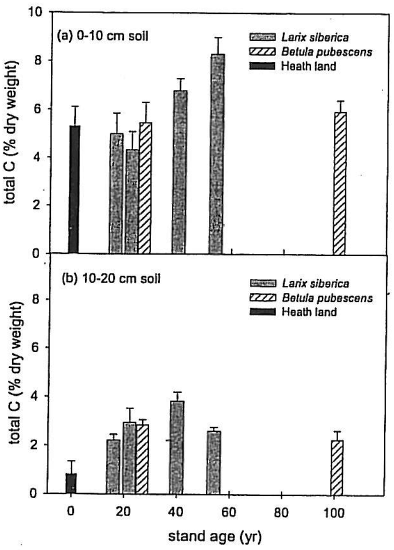

Fig. 2: Total C in (a) 0-10 cm and (b) 10-20 cm soil of the plots investigated. The increase in C content in 0-10 cm depth in the larch stands is significant (P = 0.002). Error bars are 1 SEM.

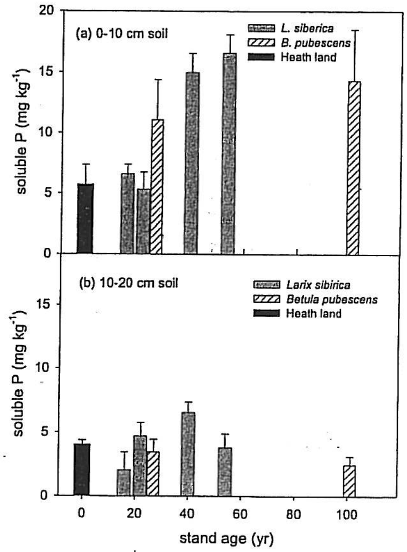

Fig. 3: Soluble P in (a) 0-10 cm and (b) 10-20 cm soil of the plots investigated. The increase in soluble P in 0-10 cm depth in the larch stands is significant (P < 0.001). Error bars are 1 SEM.

Except from total P content, all nutrients were significantly lower in the deeper soil layer than in 0-10 cm depth (*t* test: $P < 0.001$). At 10-20 cm depth, total C content in soil of the heath land was 3 %. Larch revealed an average of 2.6 % at an age of 54 years and birch an average of 2.3 % at an age of 101 years. There was no significant change over time for either tree species (Fig. 2b). Average N content was 0.2 % in heath land. In the 101-year old birch stand, average N content was 0.1 % . Also in the oldest larch stand, an average of 0.1 % N was determined in the soil. There was no clear effect of stand age. Soluble and total P in heath land were 4.0 and 486.6 mg P kg^{-1}soil, respectively. In the 101-year old birch plot, an average of 2.5 mg soluble P kg^{-1} soil was determined and an average of 480.7 mg total P kg $soil^{-1}$. There was no significant effect of stand age on either fraction. In the oldest larch stand, soluble and total P were determined to be 3.8 and 478.9 mg P kg^{-1} soil, respectively. Also here, no significant change with time had occurred (Fig. 3b).

BIOMASS

Total C content in leave tissue of birch was in average 46.8 % and 46.0 % in stands aged 27 years and 101 years, respectively. Larch needles had a similar average total C content, ranging from 44.5 % to 46.0 % . There was no significant effect of stand age. Total N in birch leaves was in average 1.6% in the 27-year old trees and 1.5 % in the 101-year old ones. For larch, N content ranged from 1.9% to 2.1%. No effect of stand age was found. However, the difference in N content between the two tree species was significant (t-test P = 0.001) (Fig. 4). The average C/N ratio of the biomass collected at the different plots was significantly higher for birch leaves (30

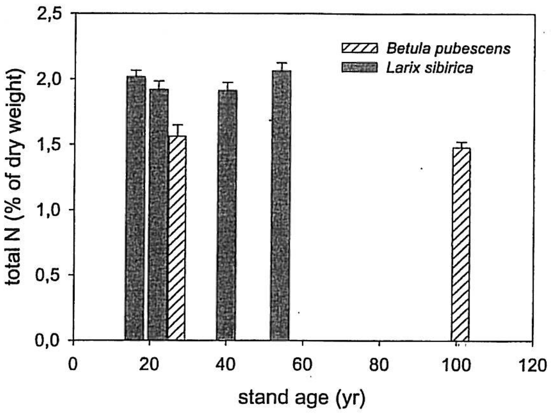

Figure 4: Total N content in leaves and needles of birch and larch trees, respectively.

DISCUSSION

A significant change with time in soil nutrient content was only found for C and soluble P in the larch stands in 0-10 cm in terms of an increase after about 40 years. In birch stands, no significant changes could be determined with time, although the oldest stand was more than 100 years old. However, only two different age classes of birch were included in the study, which restricts the interpretation of the trends. Nevertheless, the lack of change could be explained by the different history of the birch stands compared to the larch stands. While larch was planted, birch had regenerated naturally by keeping away grazing sheep. Thus, the soil may have been different from the beginning. Our assumption was that the treeless heath land represents the nutrient and mycorrhizal status of the soil prior to afforestation. However, in choronosequence studies like this, it must always be taken to consideration that inevitable differences in soil condition among the studied plots may affect results to some extent. Another study in Iceland has shown higher C sequestration rates under larch than under birch (Snorrasön et al. 2002). The study in included above and belowground (0-30 cm depth) C stocks. Results of the different compartments indicate that C content in soil under larch indeed increases faster than under birch, which is in consistence with the present study. The C content in the soils of the study were generally in the range of intact and fully vegetated Icelandic soils that had not been subject to degradation and loss of soil organic matter (Oskarsson et al. 2004). The higher C/N values in the older larch stands can therefore be attributed to the increase in C content, while N content did not change significantly with age. Volcanic soils like those found in Iceland have a strong tendency to fix P by Al- and Fe-humus complexes, allophane and imogölite. Therefore, most P in Icelandic soil is immobile and practically unavailable to the ecosystems (Dahlgren et al. 2004). Helgason (2002) has shown that a relatively high proportion of the soil P is bound in the organic matter that theoretically would mean that it could be transformed to the readily available pool. This may explain the observed increased in soluble P in the larch stands, while the total amount of P did not change. This increase might be due to the activity of ectomycorrhizal fungi. The result of the nutrient status of the biomass will be analysed more closely when the monitoring of the mycorrhizae in the microcosms is finished. At this point, however, results for N may indicate an improved nutrient supply as soil N content did not decrease and N content in the biomass did not change with time after afforestation, although it must be expected that the absolute N demand and uptake is higher in old forests than in young forests or the heath land. Nevertheless, at this stage of the project we can only state that the hypothesized increase in soil nutrients could only be confirmed for soluble P in the upper soil layer. In the next step of the project, the interaction between soil nutrients and mycorrhizal communities will be considered.

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