The Growth of Lodgepole Pine (*Pinus contorta* var. *latifolia* Engelm.) in a Reclaimed Oil Shale Mining Area, Abandoned Agricultural Land and Forestland

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Abstract

The main objective of the study was to analyse lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) growth in relation to soil nutrients in a reclaimed oil shale mining area (ROSMA), abandoned agricultural land (AAL) and forestland (FL). The growth–soil interactions and soil–needle chemical relationships were analysed and compared in lodgepole pine plantations at various sites. The impact of soil conditions on tree growth was significant; the height and diameter of trees were different between the studied sites. Despite the higher P and K concentrations in the soil in ROSMA, the concentrations of these elements in needles were lower compared to the AAL and FL. This may be caused by the high value of soil pH and K / Ca antagonism. Although the concentrations of the elements in the needles were lower in ROSMA, the needles were longer and heavier. This was possibly due to the higher N and P use efficiency in the lodgepole pine plantation in the ROSMA. The growth of lodgepole pine was better in more fertile environments, in our study the AAL or on the clay substrates of ROSMA compared to the FL.

Key words: lodgepole pine, growth, biomass, nutrient concentration, soil type

Introduction

Every year opencast oil shale mining in Estonia creates substantial areas of alkaline wasteland that require recultivation. As of 2006 exhausted oil shale mines covered 13,098 ha of land, of which 10,347 ha had been forested (Kaar and Tomberg 2006). In Eastern Europe, including Estonia, there is a clear tendency of increase in abandoned agricultural areas, brought about by drastic changes in the political and economic situation (Mander and Jongman 2000). During the last decade, more than 400,000 ha of agricultural land was abandoned in Estonia (Uri et al. 2007). Afforestation of these areas is a sustainable land use to reduce CO_2 emission and improve soil fertility. Sequestration of carbon in plant biomass and in soil is an important environmental effect of afforestation of disturbed and abandoned agricultural lands.

In the present study, we analyse the growth of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) in Estonian conditions. According to the Estonian Nature Conservation Act (2004), distributing exotic species in nature is not encouraged. However, lodgepole pine is a promising species for cultivation in park forests and green areas in Estonia. Also, lodgepole pine can be used as a suitable species besides native species for afforestation of reclaimed oil shale mining areas (ROSMA) and abandoned agricultural lands (AAL).

Lodgepole pine is a native North American tree species that occupies large territories there. Among the North American conifers it has the widest ecological range. Lodgepole pine has been found to grow well on nutritionally poor soils (Weetman et al. 1985), where it has advantages over other species (Despain 2001). Lodgepole pine is also adaptive to soil pH variability (Koch 1996). Commonly, the roots of this species are deeply distributed in sandy nutritionally poor soils (Laas 1987, Cohen et al. 1990). Young lodgepole pines grow fast and tolerate well severe climate conditions; therefore in northern Europe, it is cultivated for forestry purposes more widely than other non-indigenous pine species (Laas 2004).

Lodgepole pine has been used in forest plantations in different climate zones and on different types of soil. It has been reported that lodgepole pine has been planted on climatically harsh, exposed, nutrient-poor peat soils in Scotland (Lines 1996) and Ireland (Gallagher et al. 1987); on poor, dry, out-washed sand-fields in Denmark (Larsen 1980); and on subalpine or cold climate sites in New Zealand (Miller and Ecroyd 1987, Ledgard 1993, 2001). Lodgepole pine has also been used in plantations in Finland (Weissenberg 1972, Ruotsalainen and Velling 1993), Sweden (Rosvall et al. 1998, Knight et al. 2001) and Iceland (Sigurgeirsson 1988).

It is known that the exotic coniferous species have frequently higher productivity than *Pinus sylvestris* or native broad-leaved trees (Peterken 2001). *Pinus contorta* var. *latifolia* has been widely used in forest plantations in northern Sweden due to its high productivity (von Segebaden 1993). The clearest example of successful introductions of nonindigenous species is *Pinus contorta* var. *latifolia*, which is clearly superior to local *Pinus sylvestris* in productivity (Varmola et al. 2000). In Sweden, lodgepole pine is regarded as a more competitive species compared to Scots pine (Norgren 1996). Besides, from research conducted in Sweden it is known that lodgepole pine wood production is 36% higher compared to Scots pine (Elfving et al. 2001). In Lithuania, about 20 species of *Pinus* were introduced; however, only some of them in forests (Navasaitis 2004). *Pinus contorta* was found to be a promising species for Lithuania. This species may be planted there especially in areas unsuitable for farming, because it is resistant to *Heterobasidion annosum* (Žiogas 2006).

It has been suggested that in the reclamation of degraded landscapes, some fast-growing exotic species show better growth in the first years than native species (Parrotta 1999). The results from Lusatian lignite mining region in Germany indicate that black pine (*Pinus nigra*) grows better in the mining substrate than Scots pine (*P. sylvestris*), indicating that black pine may be a better choice for reforestation of post-mining landscapes than Scots pine (Baumann et al. 2006). Dutta and Agrawal (2003) concluded that exotic species may be recommended for preliminary rehabilitation of the coal mine spoil due to their fast growth and development.

Experimental cultures of lodgepole pine have been planted on different sites in Estonia. The total area of stands where lodgepole pine is dominant is 7 ha in Estonia (Laas 2004). The first experiments of the lodgepole pine cultivation were made at the present Järvselja Training and Experimental Forest District in 1908 (Kasesalu 2000). Kasesalu (2000) concluded that the growth of lodgepole pine and Scots pine is approximately the same in *Myrtillus* site type at Järvselja, and that lodgepole pine has better prospects mainly in park forests and green areas in Estonia.

In 1977, the Estonian Forest Institute had an opportunity to order seeds of various trees through the IUFRO seed bank catalogue. Lodgepole pine seedlings from seeds of different provenances of North America and from seeds collected in Estonia (Luunja, Kambja) were planted to Söe Arboretum and Narva ROSMA. Earlier observations indicated that the best growth is demonstrated by trees grown from local seeds (Luunja) in Söe Arboretum (Erik 1999) and the Narva ROSMA (Kuznetsova and Mandre 2005). These two areas were selected for this study.

The main objective of the study was to analyse lodgepole pine growth in relation to soil nutrients in the ROSMA, AAL and forestland (FL). To assess the growth of lodgepole pine and to find the suitable growth conditions for the studied species, the growth, biomass and nutrients were qualified considering that the trees obtaining higher growth and biomass would be more suitable for cultivation in these soil conditions. Analysis of the chemical composition of the soil and morphological and chemical characteristics of assimilative organs of trees serve as a foundation for understanding the status of trees and a forest site. Different authors have tried to evaluate the success of the restoration of the damaged areas with the help of growth and biomass production of various plants (Kumar et al. 1995, Singh and Singh 1999). The morphology of trees is used in monitoring to evaluate the state of trees in areas under human impact (Schubert 1985, Innes 1993, Озолинчюс 1996). Needle analysis has often been used as a diagnostic method of describing the nutritional status of trees (Brękke 1996) as well as their biomass increment and growth conditions (Niinemets et al. 2002). The thickness of shoots (Duryea 1984) and density of needles on the shoots have been used as an indicator of tree vitality (Pensa 2000). Optimal uptake and concentration of nutrients in tissues ensure balanced physiological processes and bioproduction (Aerts and Chapin 2000, Niinemets and Kull 2003, Niinemets and Lukjanova 2003).

The hypothesis of our study was that the AAL and ROSMA can offer better growth conditions for lodgepole pine compared to the FL. It was assumed that at a higher nutrient concentration in soil the growth of trees would be better.

The objectives of our study were: (i) to analyse the growth of trees in relation to soil nutrients in the ROSMA, AAL and FL, and (ii) to define the most suitable growth conditions for lodgepole pine from the studied areas.

Materials and methods

Study area

The study was carried out in three small experimental lodgepole pine plantations established in the Narva ROSMA, in Söe Arboretum (AAL) and at Luige

(*Calluna* forest site type) (FL) (Table 1, Figure 1). Considering that lodgepole pine is not a native species in Estonia and it was difficult to find similar stands to do replicates, this is a pilot study without replicates. The plantations at Narva and Söe were established in 1979 with 2-year-old seedlings. The planting arrangement was 3 × 3 m in Narva with 113 plants planted. In Söe the planting arrangement was 2 × 2 m and 64 plants were planted. The seeds of lodgepole pine originated from Luunja in these two plantations. The share of survived trees was 76.6% in Söe in 1997 (Erik 1999). Our monitoring of Narva plantation in 2001 showed that the share of survived trees there was 53%. The reason for trees dying on these sites could be heterogeneity of the substrate of the post-mining area and frost damage of trees in Söe. No information could be found about the origin of the seeds at Luige. The plantation at Luige was established in 1982. It is a plantation where lodgepole pines (50 trees) grow among Scots pines. The arrangement of trees is approximately 2 × 2 m.

Table 1. Plantations studied

Plantation	Location	Site	Soil type
Narva	59º16' N, 27º47' E	Reclaimed oil shale mining area (ROSMA)	*Spolic Anthrosol*
Söe	58º38' N, 26º21' E	Abandoned agricultural land (AAL)	*Gleyic Cambisol*
Luige	59º18' N; 24º43' E	Forestland (FL)	*Arenosol*

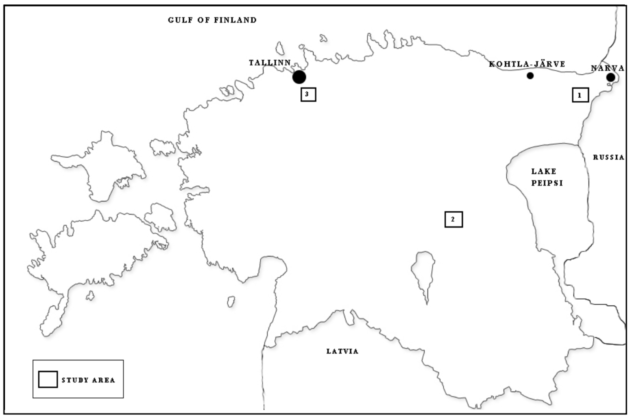

Figure 1. Location of study plantations in Estonia (1 – Narva, 2 – Söe, 3 – Luige)

Morphological measurements

Fieldwork was carried out in the studied plantations in September 2005. Considering that plantations are small (60 trees at Narva, 50 trees at Söe and Luige), no sample plots were established. The stem diameter at breast height (DBH) and the height (H) of all trees for each plantation were measured. The diameter of trees was measured to the nearest 0.1 cm with a caliper. The height of trees was measured to the nearest 0.1 m using a Suunto clinometer.

For the estimation of the state of trees in study areas, parameters of the morphometric evaluation system used in Central Europe (Manual for Integrated Monitoring 1993) were used. Considering that the assimilating mass and the photosynthetic productivity of conifers is allocated predominantly in the middle layers of the canopy (Mandre and Tullus 2002), for morphological measurements current-year needles and shoots were collected from the middle part of the tree crowns. Three model current-year shoots per tree were collected randomly from the crowns of 5 trees per each plantation. The collected needles and shoots were dried at 70ºC in a thermostat and weighed (g). From the collected samples, the length of needles (n = 150) and shoots (n = 15) was measured; the dry mass of 100 needles and shoots (n = 15) was weighed and the density of needles on shoots (needle number per unit shoot length) (n = 15) was calculated.

Laboratory analyses

Soil analysis

In all plantations, one soil pit was dug. The soil type was determined according to the FAO-UNESCO (1994) classification (Table 1). Three samples from the 0–20 cm soil layer were taken per plantation in September 2005. The soil samples were dried and sieved. The soil pH_{H2O} was measured with a pH meter (Mettler Toledo GmbH, InLab412 electrode, Germany). For the analysis of the soil total N the Kjeldahl method was used. Available phosphorus and potassium were determined by the flame photometric method. All soil samples were analysed in the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences.

Chemical analysis of needles

Three samples of current-year needles per plantation were collected for chemical analysis in September 2005. The collected needles were cleaned, dried and ground.

Determination of N in the needles was carried out according to the Kjeldahl method; P was determined in Kjeldahl Digest by FIAstar 5000, Stannous Chloride method, ISO/FDIS 15681; K was determined by the flame photometric method (Rùžička and Hansen 1981). The concentrations of nutrients (N, P, K) were determined in the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences.

Statistical analyses

Normality of variables was checked by the Kolmogorov–Smirnov, Lilliefors and Shapiro–Wilk's tests.

The dry mass of shoots was normalised by using a log-transformation. The data were analysed by one-way analysis of variance (ANOVA). The Tukey test was used for the multiple comparison of the mean. Correlations (r) between the growth parameters and nutrients were calculated. Throughout the study, the means are presented with the standard error of the mean (± SE). Statistical analyses were carried out with software STATISTICA 7.0 and the level of significance į = 0.05 was accepted in all cases.

Results

Soil characteristics

Significant differences were observed in the concentrations of macronutrients (NPK) and in the pH of the upper layer of Narva soil and soils of Söe and Luige (Table 2). The soil pH was statistically significantly the highest at Narva compared to the other soils. The analysis of soil nutrients showed that N concentrations in the Narva and Söe plantations were similar and more than three times higher compared to Luige. The available P and K concentrations were significantly higher in the Narva plantation compared to Söe and Luige plantations (Table 2).

Table 2. Soil characteristics in 0–20 cm soil layer: pH, and N, P and K concentrations

Plantation	pH	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
Narva	7.0±0.01^a	0.16±0.009^a	47.3±4.1^a	207.3±4.9^a
Söe	6.1±0.003^b	0.18±0.008^a	13.6±2.9^c	83.3±3.9^b
Luige	5.5±0.09^b	0.05±0.001^b	33.3±2.4^b	5.1±0.9^c

Values are given as the mean ± SE. ^{abc} letters indicate a statistically significant difference in the Tukey test at p = 0.05.

Tree measures: height and DBH in the plantations

Comparisons of the main growth characteristics between the studied stands are provided in Table 3. Comparative analysis showed a statistically significant difference in tree heights between stands. Although initial densities of Narva and Söe stands differed, the DBHs of lodgepole pine in these stands were similar. Despite the unfavourable soil conditions during the first years after the recultivation of oil shale mining spoil, the height and DBH of 25-year-old lodgepole pine in Narva was comparable to the results from Söe rather than to Luige.

Table 3. Comparison of tree height (H) and tree diameter at breast height (DBH) in the lodgepole pine plantations

Plantation	H (m)	DBH (cm)
Narva	9.1±0.4^b	14.5±0.7^a
Söe	11.5±0.6^a	15.1±0.9^a
Luige	5.9±0.1^c	8.7±0.3^b

Values are given as the mean ± SE. ^{abc} letters indicate a statistically significant difference in the Tukey test at p = 0.05.

Needles and shoots

The length of needles of lodgepole pine was significantly higher in the Narva plantation than in the other two sites (Figure 2). Lodgepole pine had a greater dry mass of 100 needles in the Narva site, but there was no significant difference in needle dry mass between the Narva and Söe sites. The length and dry mass of shoots were similar on the Narva and Söe sites, but they were significantly lower compared to the Luige site. The shorter shoots of lodgepole pine in the Narva and Söe sites had a higher needle density (Figure 2).

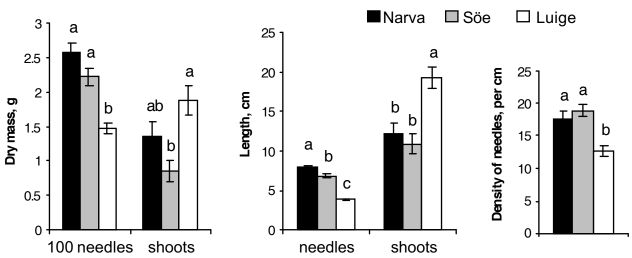

Figure 2. Morphological characteristics of lodgepole pine needles and shoots in a reclaimed oil shale mining area, abandoned agricultural land and forestland. Values are given as the mean ± SE. Different letters indicate a statistically significant difference (Tukey test, p = 0.05)

Nutrient concentration in needles

The concentrations of main mineral nutrients (NPK) in needles differed significantly between the Narva and the other two studied plantations (Söe, Luige) (Table 4). The lowest NPK concentrations in lodgepole pine needles were observed in the Narva plantation, although the concentrations of these elements in the Narva soil were higher compared to the other studied soils. The N / P ratio in needles was similar for the Söe and Luige plantations. For the Narva plantation, the N / P ratio was found to be higher. The N / K ratio was similar for all plantations.

Table 4. NPK concentrations and N / P, and N / K ratios in needles in the lodgepole pine plantations

Plantation	N	P	K	N / P	N / K
		%			
Narva	1.1±0.03^b	0.06±0.006^b	0.34±0.04^b	18.8^a	3.3
Söe	1.6±0.06^a	0.13±0.02^a	0.49±0.06^a	12.4^b	3.3
Luige	1.5±0.03^a	0.13±0.03^a	0.54±0.04^a	11.8^b	2.9

Values are given as the mean ± SE. ^{abc} letters indicate a statistically significant difference in the Tukey test at p = 0.05.

Relationships between growth parameters of trees and soil nutrient concentrations

The correlation between soil nutrients and growth parameters of trees was estimated including the data of all three plantations. The analysis showed that soil nutrients had a significant influence on many growth parameters of trees. The H and DBH of trees were positively correlated with the soil N concentration (r = 0.72, r = 0.89, $p < 0.05$, respectively). A strong positive correlation was found between the dry mass of needles and the soil N concentration (r = 0.83, $p <$ 0.05). The length of needles was positively correlated with soil N (r = 0.96, $p < 0.05$) and K concentrations (r = 0.73, $p < 0.05$). The dry mass and length of shoots were negatively correlated with the soil N concentration (r = –0.90, r = –0.92, $p < 0.05$, respectively).

Discussion and conclusions

Results of our study showed that the impact of soil nutrients on the growth of lodgepole pine was significant; the height and diameter of trees were different between the studied sites. The soils differed in nutrient concentrations as well as pH. The initial site conditions were most unfavourable in the Narva stand. As a result of mining, the relief is rugged, and the soil is heterogeneous and extremely stony. Oil shale mining spoil is very alkaline (pH_{KCl} = 8.0), the initial N and organic content are low (Kaar and Raid 1996, Lõhmus et al. 2006, 2007), and in young stands a significant proportion of the organic matter is formed from oil shale mining residues (Reintam et al. 2002). Comparing our data of soil analyses with earlier data about initial soil conditions (Kaar and Raid 1996, Lõhmus et al. 2006, 2007) we may conclude that the soil improvement during the first 25 years was remarkable. We can see that with the formation and development of soil the content of N increased and the soil pH decreased by 1 unit during the first 25 years. Our results are in accordance with the results reported by Lõhmus et al. (2007), who found that the soil pH decreased by 1 unit during the first 26 years in black alder and Scots pine plantations in a ROSMA. Despite the decrease of the soil pH in the Narva ROSMA, the soil pH is still slightly alkaline and significantly higher compared to the AAL and FL soils.

Plant nutrition depends on many factors: soil properties, climatic factors and physiological status of trees. The nutrients are dependent on one another and can interact with other elements. Also the pH value of soil affects the uptake of nutrients (Marschner 2002). It is known that alkalisation of soil inhibits the availability of several nutrients, causing serious deviations in the mineral composition of plants (Marschner 2002). Considering that in alkaline soils the mobility of P is limited (Marschner 2002), we can expect that for the lodgepole pine growth conditions on AAL and FL soils were quite favourable compared to the calcareous soil of the ROSMA. Apparently the alkaline soil at Narva opencast complicates the uptake of P and its deficiency can limit the growth of trees. Our results showed that the P concentration in soil was higher in the Narva ROSMA compared to the AAL and FL soils; however the P concentration in needles was smaller at Narva than on other studied soils. Several authors have also reported that N (Singh et al. 2002) and P (Fitter and Bradshaw 1974, Bloomfield et al. 1982) limit plant growth on abandoned coal mine soils. Niinemets and Kull (2003) suggested that plant productivity in calcareous wooded meadows is limited by both N and P. It is known that N and P depend more on the organic matter content of soil, while K is more related to the clay minerals (Piho 1967). This explains the higher concentration of K in the loamy soils of the Narva ROSMA. Although the available K concentration of soil was higher in the Narva ROSMA compared to the other sites, higher K concentrations in needles were observed in the AAL and FL soils with lower soil pH values. Its availability decreases in calcareous environments due to the Ca / K antagonism (Trémolières et al. 1998, Marschner 2002).

Many authors have emphasised that the interaction of different mineral elements in plant tissues and the balance of mineral elements are of great importance in tree growth and survival under stress conditions (Ingestad and Ågren 1988, Marschner 2002, Portsmuth et al. 2005). The scale of optimum nutrient concentrations and their ratios in the current-year needles have been found for lodgepole pine, growing in its natural area in North America (Brockley 2001). A comparison of the N / P and N / K ratios in the needles of lodgepole pine (Table 4) with the scale of ratios suggested by Brockley (2001) permitted us to conclude that there was a considerable deficiency of P (N / P > 13 – moderate to severe P deficiency) in the needles of lodgepole pine growing in the Narva ROSMA; but there was an optimum concentration of K in needles of all studied plantations (N / K > 4.5 – moderate to severe K deficiency).

Different adaptive strategies of lodgepole pine growth related to soil type have been reported earlier. Thus Pearson et al. (1984) and Landsberg (1986) found that the formation of the crown and biomass accumulation vary between different growth conditions. Our study revealed different relationships between soil nutrients and growth parameters of trees. The H and DBH of trees were increasing with increasing soil N concentration. The dry mass and length of needles were increasing with increasing soil N and K concentrations, although the dry mass and length of shoots were increasing with the decreasing of soil N concentration. Taking into account the results of the analysis described above, it can be concluded that the growth of trees was better in the ROSMA and AAL in the areas with a higher concentration of N in the soil. The growth of lodgepole pine in the FL was possibly limited by the low nutrient concentration in the soil. This could explain the lower forest productivity in this area.

We found that the dry mass and length of needles were superior in the Narva ROSMA and AAL compared to the FL. The density of needles on shoots differed significantly between sites: lodgepole pine produced shorter and lighter shoots with a greater needle number per unit shoot length in the Narva ROSMA and AAL compared to the FL. However, shoot length and needles number per unit shoot length did not correlate. Niinemets and Kull (1995) also did not find any correlation between shoot length and needle number per unit shoot length. However, Metslaid et al. (2005) found that the length of the shoot and the number of needles on the shoot, and also the length of the shoot and the needle mass of the shoot were the best correlated shoot variables in trees that had been growing in a variable understorey environment. Larger needles and greater density of needles on shoots found in the ROSMA and AAL, the areas with the highest concentration of N and K in the soil are among several factors influencing the crown architecture, which may contribute to the competitive success in trees. In the FL, the area with the smallest N concentration in the soil, we found longer and heavier shoots, which may also contribute to the resistance of the tree crowns to the winds, and other unfavourable factors. On the basis of the results of the study of morphological parameters it may be concluded that lodgepole pine uses different adaptive strategies of growth related to soil conditions.

Our results showed that the needles were significantly longer and heavier in the plantation in the Narva ROSMA compared to plantations on the AAL and FL soils, yet the concentrations of elements in needles were lower. This can be related to the higher nutrient use efficiency. It means that lodgepole pine growing in the ROSMA may need fewer nutrients for biomass production. Norgren (1996) reported that the higher N use efficiency of lodgepole pine compared to Scots pine is achieved through its low N investment per unit biomass. In the study realised in black alder Vares et al. (2004) found the highest N use efficiency in the ROSMA and the smallest one on AAL. Therefore we believe that having higher N use efficiency is an advantage for lodgepole pine growth on nitrogen-poor post-mining soil.

Generally, post-mining soils because of their unfavourable chemical and physical properties are a less desirable growth environment compared to native soils (Singh et al. 2006). Nevertheless, Reintam *et al*. (2002) argued that ROSMAs in Estonia have a high potential for forestry. Thus it was found that some exotic species, for example, larches (*Larix decidua*, *L. sibirica*) grow well in the ROSMA (Kaar 2002, Kuznetsova and Pärn 2004). Previous studies in ROSMA reported positive results of lodgepole pine cultivation in clayey areas (Kaar and Raid 1996) and similar growth of lodgepole pine and Scots pine in calcareous soils (Kuznetsova and Mandre 2006). An experiment in Finland confirmed that lodgepole pine has especially great advantages over Scots pine on strongly clayey soils (Tigerstedt 1986). This study showed that the growth of lodgepole pine in the Narva ROSMA was higher compared to the FL soil. Also, lodgepole pine growth in the Narva ROSMA showed more similarities with its growth on the AAL. This may indicate that lodgepole pine is not well adapted to the nutritionally poor sandy FL, and requires more favourable growth conditions similar to those in the AAL or in clay substrates of the ROSMA.

In conclusion, it may be said that lodgepole pine uses different growth adaptive strategies in relation to soil conditions. We cannot encourage the cultivation of lodgepole pine as a foreign species in forest, but on the basis of the results of the current study the use of this species for recultivation of the AAL and ROSMA may be recommended. Also the results of this study can be used as an example for other regions, where lodgepole pine is a common tree species and for areas subjected to restoration.

Acknowledgements

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References

Aerts, R. and Chapin III, F.S. 2000. The mineral nutrition of wild plants revisited: a re-evaluation of processes and patterns. *Advances in Ecological Research* 30: 1–67.

Baumann, K., Rumpelt, A., Schneider, B.U., Marschner, P. and Hüttl, R.F. 2006. Seedling biomass and element content of *Pinus sylvestris* and *Pinus nigra* grown in sandy substrates with lignite. *Geoderma* 136 (3–4): 573–578.

Bloomfield, H.E., Handley, J.F. and Bradshaw, A.D. 1982. Nutrient deficiencies and the aftercare of reclaimed derelict land. *Journal of Applied Ecology* 19 (1): 151–158.

Brække, F.H. 1996. Needle analyses and graphic vector analyses of Norway spruce and Scots pine stands. *Trees – Structure and Function* 11 (1): 23–33.

Brockley, R. 2001. Foliar sampling guidelines and nutrient interpretative criteria for lodgepole pine. Extension Note 52. British Columbia Ministry of Forests Research Program, Vernon, 8 p.

Cohen, W.B., Omi, P.N. and Kaufmann, M.R. 1990. Heating-related water transport to intact lodgepole pine branches. *Forest Science* 36 (2): 246–254.

Despain, D.G. 2001. Dispersal ecology of lodgepole pine (*Pinus contorta* Dougl.) in its native environment as related to Swedish forestry. *Forest Ecology and Management* 141 (1–2): 59–68.

Duryea, M.L. 1984. Nursery cultural practices: Impacts on seedling quality. In: Duryea, M.L. and Landis, T.D. (eds.), Forest Nursery Manual: Production of Bareroot Seedlings. Dr. W. Junk Publishers, Boston, Lancaster, p. 143–164.

Dutta, R.K. and Agrawal, M. 2003. Restoration of opencast coal mine spoil by planting exotic tree species: a case study in dry tropical region. *Ecological Engineering* 21 (2–3): 143–151.

Elfving, B., Ericsson, T. and Rosvall, O. 2001. The introduction of lodgepole pine for wood production in Sweden – a review. *Forest Ecology and Management* 141 (1–2), 15–29.

Erik, Ü. 1999. Keerdmänd (*Pinus contorta* Dougl. ex Loud.) Söe arboreetumis (Jõgevamaa) [Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in Söe Arboretum (Jõgeva County)]. *Dendroloogilised uurimused Eestis* [(*Dendrological Researches in Estonia*]) 1: 76–78 (in Estonian with English summary).

Estonian Nature Conservation Act. 2004. http://www.legaltext.ee/text/en/X90008.htm

FAO-UNESCO. 1994. Soil Map of the World. Revised Legend with Corrections. ISRIC, Wageningen.

Fitter, A.H. and Bradshaw, A.D. 1974. Responses of *Lolium perenne* and *Agrostis tenuis* to phosphate and nutritional factors in the reclamation of colliery shale. *Journal of Applied Ecology* 11: 592–608.

Gallagher, G.J., Lynch, T.J. and Fitzsimons, B. 1987. Lodgepole pine in the Republic of Ireland. II. Yield and management of coastal lodgepole pine. *Forest Ecology and Management* 22 (3–4): 185–203.

Ingestad, T. and Ågren, G.I. 1988. Nutrient uptake and allocation at steady-state nutrition. *Physiologia Plantarum* 72 (3): 450–459.

Innes, J.L. 1993. Forest Health: Its Assessment and Status. CAB International, Wallingford, 677 p.

Kaar, E. 2002. Põlevkivikarjääride rekultiveerimise tulemustest [Of some results of the reclamation of opencast oil shale mining pits]. *Akadeemilise Metsaseltsi toimetised* [*Proceedings of the Estonian Academic Forest Society*] 18: 123–131 (in Estonian with English summary).

Kaar, E. and Raid, L. 1996. Eesti põlevkivikarjääride metsanduslik rekultiveerimine, rekultiveeritud aladele rajatud puistute hooldamine ja majandamine [Afforestation of Estonian Oil Shale Opencast Sites and Management of Stands Planted on Recultivated Sites]. Final Report of Grant No. 366. MS at Estonian Naturalists' Society. Tartu (in Estonian).

Kaar, E. and Tomberg, E. 2006. Puistangute rekultiveerimisest [Recultivation of the quarry spoil]. In: Valgma, I. (ed.), Proceedings of the conference of Estonian miners 2006 by Estonian Mining Society: 90 years of oil shale mining in Estonia. Tallinn University of Technology, Tallinn, p. 78–83 (in Estonian).

Kasesalu, H. 2000. Keerdmänni (*Pinus contorta* Dougl. ex Loud.) kasvatamise tulemusi Järvseljal (Tartumaa) [Cultivation of the lodgepole pine (*Pinus contorta* Dougl. ex Loud.) at Järvselja (County Tartu)]. *Dendroloogilised uurimused Eestis [Dendrological Researches in Estonia]* 2: 113–123 (in Estonian with English summary).

Knight, D.H., Baker, W.L., Engelmark, O. and Nilsson, C. 2001. A landscape perspective on the establishment of exotic tree plantations: lodgepole pine (*Pinus contorta*) in Sweden. *Forest Ecology and Management* 1418 (1–2): 131–142.

Koch, P. 1996. Lodgepole Pine in North America. Vol. 3. IV. Processes. V. Products. Forest Products Society, Madison, Wisconsin.

Kumar, S., Bisht, N.S. and Rao, R.N. 1995. Afforestation of lateratic pans of Goa – a case study. *Indian Forester* 121 (3), 176–178.

Kuznetsova, T. and Mandre, M. 2005. Mineral composition of lodgepole pine on exhausted oil shale opencast mines. *Metsanduslikud Uurimused / Forestry Studies* 42: 106–115.

Kuznetsova, T. and Mandre, M. 2006. Chemical and morphological indication of the state of lodgepole pine and Scots pine in restored oil-shale opencast mining areas in Estonia. *Oil Shale* 23 (4): 366–384.

Kuznetsova, T. and Pärn, H. 2004. Some results of the afforestation of closed oil shale opencasts with exotic conifers. *Oil Shale* 21 (4): 321–331.

Laas, E. 1987. Dendroloogia [Dendrology]. Valgus, Tallinn, 824 p. (in Estonian).

Laas, E. 2004. Okaspuud [Conifers]. Atlex, Tartu, 359 p. (in Estonian).

Landsberg, J.J. 1986. Physiological Ecology of Forest Production. Academic Press, London, 198 p.

Larsen, J.B. 1980. Older provenance trials with *Pinus contorta* in Denmark. In: *Pinus contorta* as an Exotic Species. Proceedings of the IUFRO meeting 1980 on *Pinus contorta* provenances in Norway and Sweden. Research notes 30. Department of Forest Genetics, Swedish University of Agricultural Science, Garpenberg, p. 45–58.

Ledgard, N. 2001. The spread of lodgepole pine (*Pinus contorta*, Dougl.) in New Zealand. *Forest Ecology and Management* 141 (1–2): 43–57.

Ledgard, N.J. 1993. A review of research and management of natural regeneration of introduced lodgepole pine (*Pinus contorta* Dougl.) with particular emphasis on its unwanted spread in New Zealand. In: Lindgren, D. (ed.), *Pinus contorta* – From Untamed Forest to Domesticated Crop. Proceedings of IUFRO Workshop WP 2.02.06 and Frans Kempe Symposium. Swedish University of Agricultural Sciences, Uppsala, p. 388–406.

Lines, R. 1996. Experiments on Lodgepole Pine Seed Origins in Britain. Technical Paper 10. Forestry Commission, Edinburgh.

Lõhmus, K., Kull, A., Truu, J., Truu, M., Kaar, E., Ostonen, I., Meel, S., Kuznetsova, T., Rosenvald, K., Uri, V., Kurvits, V. and Mander, Ü. 2007. The reclamation of the North Estonian oil shale mining area. In: Mander, Ü., Wiggering, H. and Helming, K. (eds.), Multifunctional Land Use: Meeting Future Demands for Landscape Goods and Services. Springer, Berlin, Heidelberg, p. 387–401.

Lõhmus, K., Truu, J., Truu, M., Kaar, E., Ostonen, I., Alama, S., Kuznetsova, T., Rosenvald, K., Vares, A., Uri, V. and Mander, Ü. 2006. Black alder as a perspective deciduous species for reclaiming of oil shale mining areas. In: Brebba, C.A. and Mander, Ü. (eds.), Brownfields

III. Prevention, Assessment, Rehabilitation and Development of Brownfield Sites. Wessex Institute of Techonology Press, Southampton, Boston, p. 87–97.

Mander, Ü. and Jongman, R.H.G. 2000. Consequences of Land Use Changes. Advances in Ecological Sciences 5. Wessex Institute of Technology Press, Southampton, Boston, 328 p.

Mandre, M. and Tullus, H. 2002. Partitioning of nutrients and biomass in Scots pine canopy. Proceedings of the Estonian Academy of Sciences. Biology. Ecology 51 (3): 163–172.

Manual for Integrated Monitoring. 1993. Programme Phase 1993–1996. Environmental Report 5. Environment Data Centre, National Board of Waters and the Environment, Helsinki, 113 p.

Marschner, H. 2002. Mineral Nutrition of Higher Plants. Academic Press, London, San Diego, 889 p.

Metslaid, M., Ilisson, T., Vicente, M., Nikinmaa, E. and Jõgiste, K. 2005. Growth of advance regeneration of Norway spruce after clear-cutting. *Tree Physiology* 25 (7): 793–801.

Miller, J.T. and Ecroyd, C.E. 1987. Introduced Forest Trees in New Zealand: Recognition, Role and Seed Source. 2. *Pinus contorta* Loudon – Contorta Pine. *New Zealand Forest Research Institute Bulletin* 124 (2), 12 p.

Navasaitis, M. 2004. Dendrologija [Dendrology]. Margi Raštai, Vilnius, 855 p. (in Lithuanian).

Niinemets, Ü. and Kull, K. 2003. Leaf structure vs. nutrient relationships vary with soil conditions in temperate shrubs and trees. *Acta Oecologica* 24 (4): 209–219.

Niinemets, Ü. and Kull, O. 1995. Effects of light availability and tree size on the architecture of assimilative surface in the canopy of *Picea abies*: variation in shoot structure. *Tree Physiology* 15 (12): 791–798.

Niinemets, Ü. and Lukjanova, A. 2003. Total foliar area and average leaf age may by more strongly associated with branching frequency than with leaf longevity in temperate conifers. *New Phytologist* 158 (1): 75–89.

Niinemets, Ü., Ellsworth, D.S., Lukjanova, A. and Tobias, M. 2002. Dependence of needle architecture and chemical composition on canopy light availability in three North American *Pinus* species with contrasting needle length. *Tree Physiology* 22 (11): 747–761.

Norgren, O. 1996. Growth analysis of Scots pine and lodgepole pine seedlings. *Forest Ecology and Management* 86 (1–3): 15–26.

Parrotta, J.A. 1999. Productivity, nutrient cycling, and succession in single- and mixed-species plantations of *Casuarina equisetifolia*, *Eucalyptus robusta*, and *Leucaena leucocephala* in Puerto Rico. *Forest Ecology and Management* 124 (1): 45–77.

Pearson, J.A., Fahey, T.J. and Knight, D.H. 1984. Biomass and leaf area in contrasting lodgepole pine forests. *Canadian Journal of Forest Research* 14 (2): 259–264.

Pensa, M. 2000. Hariliku männi okaste püsivuse kronoloogia Ahtme EJ mõjupiirkonnas asuvas puistus [Chronology of needle retention in Scots pine trees growing near the Ahtme Power Plant]. *Metsanduslikud Uurimused / Forestry Studies* 33: 177–185 (in Estonian with English summary).

Peterken, G.F. 2001. Ecological effects of introduced tree species in Britain. *Forest Ecology and Management*, 141(1–2): 31–42.

Piho, A. 1967. Kaaliumi sisaldus ja vormid ENSV muldades [Potassium content and forms in soils of ESSR]. *EMMTUI teaduslike tööde kogumik* [*Transactions of EMMTUI*] 10: 110–122 (in Estonian).

Portsmuth, A., Niinemets, Ü., Truus, L. and Pensa, M. 2005. Biomass allocation and growth rates in *Pinus sylvestris* are interactively modified by nitrogen and phosphorus availabilities and by tree size and age. *Canadian Journal of Forest Research* 35 (10): 2346–2359.

Reintam, L., Kaar, E. and Rooma, I. 2002. Development of soil organic matter under pine on quarry detritus of open-cast oil-shale mining. *Forest Ecology and Management* 171 (1–2): 191–198.

Rosvall, O., Andersson, B. and Ericsson, T. 1998. Beslutsunderlag för val av skogsodlingsmaterial i norra Sverige med trädslagsvisa guider (Species-Specific Guidelines for Choosing Forest Regeneration Material for Northern Sweden). Redogörelse 1, SkogForsk. Forestry Research Institute of Sweden, Uppsala, 66 p. (in Swedish with English summary).

Ruotsalainen, S. and Velling, P. 1993. *Pinus contorta* provenances in northern Finland – first 20 years. In: Lindgren, D. (ed.), *Pinus contorta* – From Untamed Forest to Domesticated Crop. Proceedings of IUFRO Workshop WP 2.02.06 and Frans Kempe Symposium. Swedish University of Agricultural Sciences, Uppsala, p. 122–136.

Ružička, J. and Hansen, E.H. 1981. Flow Injection Analysis. John Wiley and Sons, New York, 468 p.

Schubert, R. 1985. Bioindikation in terrestrischen Ökosystemen. Gustav Fischer Verlag, Jena, 327 p.

Sigurgeirsson, A. 1988. Stafafura á Íslandi. Vöxtur, ástand og möguleikar (*Pinus contorta* Dougl. in Iceland: growth, condition and potential). In: Ársriti Skógræktarfélags Íslands, p. 3–36 (in Icelandic with English summary).

Singh, A.N. and Singh, J.S. 1999. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. *Forest Ecology and Management*, 119 (1–3): 195–207.

Singh, A.N., Raghubanshi, A.S. and Singh, J.S. 2002. Plantations as a tool for mine spoil restoration. *Current Science* 82(12): 1436–1441.

Singh, A.N., Zeng, D.H. and Chen, F.S. 2006. Effect of young woody plantations on carbon and nutrient accretion rates in a redeveloping soil on coalmine spoil in a dry tropical environment, India. *Land Degradation & Development* 17 (1): 13–21.

Tigerstedt, P.M.A. 1986. Arboretum Mustila 1922. Finnish Dendrological Society, Helsinki, 230 p.

Trémolières, M., Sánchez-Pérez, J.M., Schnitzler, A. and Schmitt, D. 1998. Impact of river management history on the community structure, species composition and nutrient status in the Rhine alluvial hardwood forest. *Plant Ecology* 135 (1): 59–78.

Uri, V., Lõhmus, K., Ostonen, I., Tullus, H., Lastik, R. and Vildo, M. 2007. Biomass production, foliar and root characteristics and nutrient accumulation in young silver birch (*Betula pendula* Roth.) stand growing on abandoned agricultural land. *European Journal of Forest Research* 126 (4): 495–506.

Vares, A., Lõhmus, K., Truu, M., Truu, J., Tullus, H. and Kanal, A. 2004. Productivity of black alder (*Alnus glutinosa* (L.) Gaertn.) plantations on reclaimed oil-shale mining detritus and mineral soils in relation to rhizosphere conditions. *Oil Shale* 21 (1): 43–58.

Varmola, M., Salminen, H., Rikala, R. and Kerkelä, M. 2000. Survival and early development of lodgepole pine. *Scandinavian Journal of Forest Research* 15 (4): 410–423.

von Segebaden, G. 1993. Lodgepole pine in Sweden – a situation report. In: Lindgren, D. (ed.), *Pinus contorta* – From Untamed Forest to Domesticated Crop. Proceed-

ings of IUFRO Workshop WP 2.02.06 and Frans Kempe Symposium. Swedish University of Agricultural Sciences, Uppsala, p. 8–23.
Weetman, G.F., Yang, R.C. and Bella, I.E. 1985. Nutrition and fertilization of lodgepole pine. In: Baumgartner, D.M., Krebill, R.G., Arnott, J.T. and Weetman, G.F. (eds.), Lodgepole Pine. The Species and Its Management. Symp. Proc. Coop. Exten. Serv., Washington, p. 225–232.
Weissenberg, K.V. 1972. Experiences of Lodgepole Pine in Finland. Paper presented at the meeting of the Nordic working group on provenance research and seed procurement. Varparanta, 5–19 August 1972, Suonenjoki, 73 p.
Žiogas, A. 2006. Pathological condition of introduced pines in forests of Lithuania. IUFRO Working Party 7.03.10, Proceedings of the Workshop 2006. Gmunden, Austria, p. 341–345.
Озолинчюс, Р. 1996. Хвойные: морфогенез и мониторинг [Conifers: Morphogenesis and Monitoring]. Aesti, Каунас, 340 с. (in Russian).

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РОСТ СОСНЫ СКРУЧЕННОЙ (*PINUS CONTORTA* VAR. *LATIFOLIA* ENGELM.) НА РЕКУЛЬТИВИРОВАННЫХ ОТВАЛАХ СЛАНЦЕВЫХ КАРЬЕРОВ, ЗАБРОШЕННЫХ СЕЛЬСКОХОЗЯЙСТВЕННЫХ УГОДЬЯХ И В ЛЕСОПОСАДКАХ

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Резюме

Основная цель работы заключалась в анализе роста сосны скрученной, произростающей на разных типах почвы, и выявлении наиболее подходящего места произростания для данного вида сосны.

Взаимодействие между ростом деревьев и почвы, а также химическая взаимосвязь между почвой и хвоей были проанализированы в насаждениях сосны скрученной в разных условиях произрастания.

Было установлено существенное влияние почвы на рост сосны. Деревья из разных насаждений отличались по высоте и диаметру. Несмотря на то, что концентрации P и K в почве рекультивированных отвалов сланцевых карьеров (РОСК) были выше, содержание этих элементов в хвое были ниже, чем в хвое в заброшенных сельскохозяйственных угодьях (ЗСУ) и лесопосадках (Л). Это может зависеть от высокой щелочности почвы и K/Ca антагонизма. Хотя содержание элементов в хвое было ниже на РОСК, хвоя здесь были длиннее и тяжелее, что может быть связано с более высокой эфективностью использования N и P сосной скрученной на РОСК.

Полученные результаты показали, что сосна скрученная растет лучше на ЗСУ и глиняных субстратах РОСК; худший рост наблюдался на бедной питательными веществами лесной песчаной почве.

Ключевые слова: скрученная сосна, рост, биомасса, питательные вещества, тип почвы