Oil Shale, 2006, Vol. 23, No. 4
pp. 366–384
ISSN 0208-189X

CHEMICAL AND MORPHOLOGICAL INDICATION OF THE STATE OF LODGEPOLE PINE AND SCOTS PINE IN RESTORED OIL SHALE OPENCAST MINING AREAS IN ESTONIA

T. KUZNETSOVA*, M. MANDRE

Department of Ecophysiology
Institute of Forestry and Rural Engineering
Estonian University of Life Sciences
18b Viljandi mnt., 11216 Tallinn, Estonia

Experimental comparative investigations of lodgepole pine (Pinus contorta) and Scots pine (Pinus sylvestris) plantations were carried out on exhausted oil shale opencast sites in Estonia, with the aim to assess the perspectives to avoid monocultures and to broaden the species list in the recultivation of areas destroyed by mining. The levelled detritus of the Narva opencast (59º15' N, 27º48' E) is characterized by rather extreme growth conditions for conifers: very alkaline (pH > 8.0) and stony substrate, lack of N in soil, destroyed water regime etc. The concentrations of nutrients vary in the growth substrate between plots and under different species. The needles of Scots pine contain more P, K, Ca than the needles of lodgepole pine. Comparison of the nutrient composition of two conifer species in 21–23-year-old plantations showed the deficiency of N, P and K and optimal concentrations of Ca an Mg in needles. Research indicated that lodgepole pine and Scots pine differ in their needle and shoot biomass as lodgepole pine formed longer and heavier needles and shorter and thicker shoots than Scots pine. Regardless of unfavourable soil conditions a good growth of stands have developed on levelled opencasts. From a practical point of view and taking into account the aim of the present study, besides the native Scots pine lodgepole pine from the list of introduced tree species for recultivation of oil shale opencast mining areas may be promising.

Introduction

Vast areas of land all over the world have been rendered unproductive by human activities [1]. Ecosystem destruction by mining for coal, quarrying for minerals, and other processes to meet demands of industries, is an inevit-

* Corresponding author: e-mail *tatjana.kuznetsova@rmk.ee*

able part of civilization [2]. The increasing human need for these resources will certainly accelerate further degradation of natural habitats, as most of the mining areas are on the land that was previously occupied by forests or agriculture. The mineral extraction process drastically alters the physical and biological nature of a mined area. Strip-mining, commonly practiced to recover coal reserves leads to acceleration of erosion of biological diversity and creation of several other environmental problems [3], destroys vegetation [4], causes extensive soil damage and destruction [5] and alters microbial communities [6].

The goal of restoration is usually to develop a long-term sustainable ecosystem native to the area where mining had occurred [7]. Restoration aims to return the degraded system to some form of cover that is protective, productive, aesthetically pleasing [8] and to establish stable nutrient cycles of plant growth and microbial processes [9]. Plantation is the oldest technology for restoration of lands damaged by human activity [10]. Forest plantations can play a key role in harmonizing long-term rehabilitation of the forest ecosystem [11], in restoring productivity and biological diversity to degraded areas [12]. However, some researchers state that naturally developed vegetation shows as good growth as the vegetation of cultivated areas [4]. Moreover, investigations conducted in recent years have suggested that monocultures may in long-term perspective give negative results in the restoration of vegetation [13].

The choice of plantation species is likely to greatly influence both the rate and the trajectory of rehabilitation processes [14]. The presence of different tree species in a productive system can result in a better structure and increased nutrient availability of soil [15].

The role of exotic or native species in rehabilitation needs careful consideration, because we may have to use species combinations (native, exotic or combination thereof) that are capable of surviving in new conditions [16, 17]. For artificial introduction, use of species that are well adapted to the local environment should be emphasized [18, 19]. Indigenous species are preferable to exotics because they are most likely to fit in with a fully functional ecosystem and to be climatically adapted [20].

A desired species for planting on mine spoils should possess the ability to grow on poor and dry soils, to develop the vegetation cover in a short time and to accumulate biomass rapidly, to bind soil for arresting soil erosion and checking nutrient loss, and to improve the status of soil organic matter and soil microbial biomass, thereby enhancing the supply of nutrients available to plants [21]. In addition, if possible, the species should be also of economic importance.

In Northeast Estonia, until 2005, the area damaged by opencast mining was 12 900 ha, and forest rehabilitation of the skeletal calcareous detritus of oil-shale opencast mining has been carried out in an area of 10 188 ha since 1960.

Technogenically spoiled areas need restoration, but it is important to select tree species suitable for the afforestation of these areas. In the first stage of forest rehabilitation the levelled and skeletal calcareous detritus was initiated with sets of Scots pine [5]. Kaar [22] recommends that in the interests of biodiversity attention should be paid also to other tree species besides Scots pine, which so far prevails among trees planted (86%). A possible species for introduction for afforesting spoil areas is lodgepole pine, which is known as rather tolerant to pH and nutrient deficit in soil [23].

The aims of the present study are (i) to carry out the comparison of two pine species, Scots pine and lodgepole pine growing in plantations established on calcareous spoils of oil shale opencasts, (ii) to estimate the suitability of lodgepole pine for recultivation. The main attention was paid to estimation of the growth and biomass of needles and shoots and content of nutrients. For the interpretation of the status of trees it is necessary to clarify nutrition conditions of the growth substrate on the detritus of the Narva opencast.

Material and methods

Study area

The research was conducted in Narva (59º15' N, 27º48' E) opencast in Northeast Estonia. Two lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) (LP) and two Scots pine (*Pinus sylvestris* L.) (SP) stands planted on the levelled detritus of the Narva opencast were monitored and compared in 2004:

LPI – a LP site planted in 1983,
LPII – a LP site planted in 1982,
SPI – a SP site planted in 1982,
SPII – a SP site planted in 1981.

One sample plot (0.1 ha) was established in each plantation. Overbark diameter at breast height and the height of trees were measured on sample plots.

Main characteristics of the studied pine plantations are presented in Table 1.

Table 1. **Main characteristics of the studied pine plantations on Narva oil shale opencast**

Sample plot	Age, yr.	Number of trees per ha	Mean diameter at breast height $D_{1,3}$, cm	Mean height H, m	Basal area, $m^2\ ha^{-1}$	Growing stock, $m^3\ ha^{-1}$
LPI	21	2300	10.9	9.1	21.4	113
LPII	22	2450	9.0	8.8	15.4	81
SPI	22	2040	8.5	7.9	11.7	55
SPII	23	1220	11.5	10.4	12.7	75

Climatically the studied area belongs to the Atlantic-continental region, where the influence of the Baltic Sea is strongly felt. According to the Estonian Meteorological and Hydrological Institute, the annual amount of precipitation in this area for the last ten years was 753 mm, the wettest months of the year in 2004 were June, July and September. The amount of precipitation in 2004, when our studies were carried out, was 820 mm (Jõhvi weather station).

Morphological analysis

For the estimation of the state of the trees morphometric parameters (dry mass of needles and shoots and length of needles and shoots) suggested in relevant handbooks were used [24].

The current-year main shoots and needles of trees were collected in autumn 2004 after the growth had stopped. As trees vary, five shoots were collected from the crowns of 10 trees of each sampling site to get an average sample. From the collected samples dry mass (DM) of 100 needles and dry mass of shoots (g) at constant temperature (70 ºC) in a thermostat ($n = 50$), length of needles (cm) ($n = 500$) and length of shoots (cm) ($n = 50$) were determined.

Analysis of soil and plant material

To characterize the growth substrate, in 2004 soil samples were collected from a layer of 30 cm depth taking into consideration that in the case of coniferous trees on average 80% of the roots assimilating nutrients are located in the upper 10–30 cm layer of soil [25, 26]. Five samples were taken from all sites and one average sample for the site was formed for analysis. The samples were dried and sieved (sieve No. 2).

The concentrations of mineral elements available to plants (N, P, K, Ca, Mg) in the soil and in the current-year needles were determined in the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences.

Soil pH_{H_2O} was determined in the laboratory of the Department of Eco-physiology of the Forestry and Rural Engineering Institute of the Estonian University of Life Sciences with a pH meter (Mettler Toledo GmbH, InLab412 electrode, Germany). For the analysis of N in soil the Kjeldahl method was used, for available P, Ca and Mg in soil a Flow Injection Analyser (FiaStar 5000) and for K a Flame Photometer were used.

Determination of N in the needles was carried out according to the Kjeldahl method; determination of P was carried out in Kjeldahl Digest by Fiaster 5000, stannous chloride method, ISO/FDIS15681; determination of Ca in Kjeldahl Digest by Fiaster 5000, *o*-cresolphtalein complexone method ISO3696; Mg was determined by Fiastar 5000, titan yellow method, ADSTN90/92; K was determined by the flame photometric method [27].

Statistical analysis

Average characteristics of the studied pine plantations were calculated in FoxPro.

Means of the samples, standard deviation, and correlations between the parameters (r) were calculated using MS Excel 9.0. Normality of variables was checked; the length and dry mass of shoots were normalized by log-transformation. The data were analysed by analysis of variance (ANOVA) in Systat (SPSS, Chicago, USA). The Bonferroni test was used for the multiple comparison of means.

Results and discussion

Characterization of the growth conditions of trees

Establishment of vegetation on abandoned mined lands is hindered by physical factors such as low availability of soil moisture, stony substrate of an uncertain structure, disturbed conditions of air and nutrition. The upper layers of spoils lack connection with groundwater and their moisture regime depends on meteorological conditions (precipitation, air temperature). It was shown also by Williams et al. [28] that especially in arid areas limited rainfall during the growing season and high surface temperatures often limit plant establishment and growth.

Analysis of the upper soil layers (30 cm) showed that the reaction of the soil samples from all study sites of the Narva opencast was alkaline. In two lodgepole pine sites (LPI, LPII) pH was on average 8.1; in the sites of Scots pine soil pH was 8.0 (SPI) and 8.2 (SPII). Lodgepole pine succeeds in nutrient-poor soils also according to literature data [23] and it is not very demanding about soil pH, although its growth becomes inhibited when soil $pH > 8$ [29]. Scots pine is likewise relatively tolerant of disbalanced nutrients and relatively high soil pH [30]. Although the soil reaction does not directly limit plant growth, the availability of several nutrients to plants depends on it. It is known that in an alkaline soil the mobility of several nutrient elements necessary for plants decreases and the mineral nutrition of plants becomes complicated [31–33]. It is known that when pH rises over 7, the mineralization processes of N will intensify, and its assimilation by plants will fall [34–36]. Considering the relatively slow decomposition of the litter of conifers [37, 38], it may be an additional reason of the disturbed N cycling and N deficency in the growth substrate in our study sites. Marschner [26, 33] has accented that soil alkalinity decreases availability of N and P to plants.

The soil analysis confirmed heterogeneity of the substrate in the Narva opencast mining area. Concentrations of major elements in soil were very variable between different species and between sites (Fig. 1). For example, as compared to the lodgepole pine site LPII, the substrate of LPI has almost 22% less N available to plants, 57% less K and 30% less Ca, but the concentrations of P and Mg were by 8.6% and 14.5% higher, respectively (Fig. 1). Likewise, in site SPI of Scots pine the concentrations of N, K and Ca were higher while site SPII showed higher concentrations of P and Mg. Analogous results about the variable concentration of elements in opencast spoils have been reported by in earlier studies [39–42]. Also Reintam and Kaar [5] found that pedogenesis of opencast detritus differs in intensity and chemically by regions, depending significantly on tree species and density of vegetation. The level of organic carbon was the highest under deciduous stands, but also under pine with grasses. The poor ground vegetation and the presence of residual kukersite in detritus result in a low accumulation of the organic carbon of plant origin in some high productivity stands. Sparse vegetation growth on abandoned mine soils also results from low content of organic matter, low levels of plant nutrients, particularly P [43], N [44] and K concentrations [45].

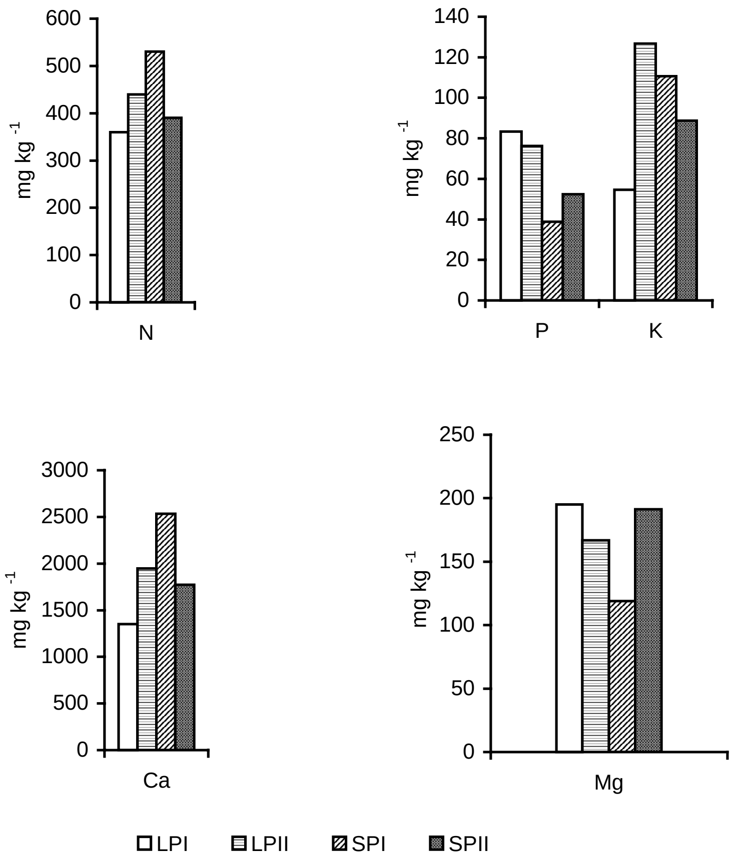

Fig. 1. Chemical composition of growth substrate in the Narva opencast area

From the aspect of mineral nutrition of plants the balance of the concentration of nutrients in soil is considered to be an important factor. Our research results showed that the ratios of the main nutrients differed in the growth substrates of four sites on oil shale opencast spoils. The ratio of N : P : K in the detritus of lodgepole pine was 1 : 0.23 : 0.15 (LPI) and 1 : 0.17 : 0.29 (LPII). The ratio of N : P : K in the detritus of Scots pine was 1 : 0.07 : 0.21 (SPI) and 1 : 0.13 : 0.23 (SPII). The differences in the ratios of nutrients in the substrate should be reflected in the growth and development of trees.

Mineral composition of needles

The needle diagnostic method is one of the possibilities of assessing the status of trees [24] in both in industrial areas and in natural forest ecosystems [25, 32, 41, 46–48].

Considering rather large differences in the concentrations of nutrients available to plants in the detritus of the study sites, rather large variation in the needle analysis could also be expected. Analysis of needle samples collected from different sites indicates not only differences between the two species in the concentrations of nutrients (Fig. 2), but also differences in the chemical composition of the needles of the same species from different sites. It was found that the content of P, K and Ca in Scots pine needles was higher than in the needles of lodgepole pine. No significant differences were observed between nitrogen concentrations in lodgepole pine needles from different sites. However, chemical analysis of Scots pine needles revealed an 11% difference between the two sites with the higher concentration in the site SPI.

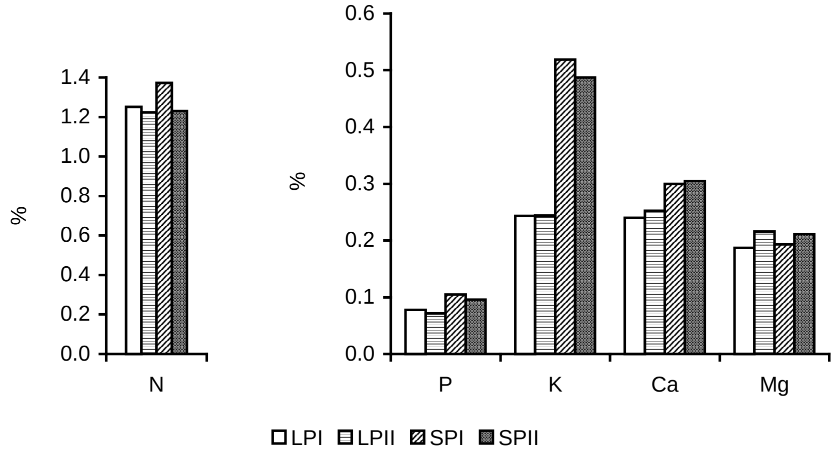

Fig. 2. Concentration of mineral elements in current-year needles of lodgepole pine and Scots pine

For most coniferous trees growth-limiting element is nitrogen [32, 49]. In this study we compared the obtained results with the optimum N concentrations in needles suggested by several authors [50–52] (Table 2) and with figures indicating N deficiency in pine needles [41, 53, 54]. Tests conducted by Raid [54] showed that an especially strong N deficiency (concentration in needles 0.92–1.15%) develops in pine seedlings in *Cladina* and *Calluna* site types. According to Porgasaar [53] the nutrition of Scots pine can be regarded as good if the N concentration in needles at the end of the growing season is 2.0–2.5%, while N shortage is great if its concentration in needles is 1%. Ingestad [50] states that for optimum growth of pine the N concentration in needles has to be 2.4–3.0%. According to Wehrmann [51] 1.8–3.2% is needed. Brække and Salih's [52] data show in current-year needles of Scots pine deficiency when the N concentration is 1.2–1.5%. Considering all these figures we can say that the needle samples collected from trees on opencast spoils in autumn 2004 indicate a severe N deficit. Our data on the deficit of N in the needles of Scots pine confirm the results of Kaar and Raid [41], who found only 0.7–1.03% N in the needles of Scots pine growing on Narva opencast. However, some authors state that Scots pine tolerates N deficiency relatively well, using optimally the nitrogen assimilated from the soil [25]. Most probably Scots pine mobilizes N from old tissues to form new needles if the conditions for N uptake are hard.

Table 2. **Concentration of elements in current-year needles of Scots pine in Narva opencast and comparisson with optimum scales elaborated by Ingestad [50], Wehrmann [51] and Brække, Salih [52]**

Element, %	Ingestad [50]	Wehrmann [51]	Brække, Salih [52]	Narva opencast	
				SPI	SPII
N	2.4–3.0	1.8–3.2	>1,8	1.37	1.23
P	0.15–0.4	0.2–0.3	>0,18	0.11	0.096
K	0.9–1.6	0.55–0.9	>0,6	0.52	0.49
Ca	0.04–0.3	0.05–0.24	>0,07	0.3	0.3
Mg	0.12–0.18	0.06–0.13	>0,08	0.19	0.21

As lodgepole pine is an exotic species in Estonia, we use for the comparison and assessment of its nutrition on opencast detritus the scale of the concentrations of nutrients in the current-year needles presented by Ballard and Carter [55] and Brockley [56], which can help to draw conclusions about the supply of nutrient elements also in the trees growing on opencast detritus. The scale was developed for the lodgepole pine growing in its natural area in North America, and thus the comparison made is conditional. Comparison of our data with the scale of Ballard and Carter [55] (Fig. 3) improved by Brockley [56] (where <1.00% – N severely deficient; 1.00–1.15% – moderately to severely deficient; 1.15–1.35% – slightly to moderately deficient; >1.35% – N adequate) allows us to say that lodgepole pines growing on opencast detritus show slight to moderate N deficiency. However, if compared to van den Driessche's [57] results on the lodgepole pine foliar N concentration of 1.63–1.73% dry wt., we can be convinced of the deficit of N on the Narva opencast. Earlier investigations [58] of mineral nutrition of conifers growing on oil shale mine sites have shown that needles of *Pseudotsuga menziesii*, *Pinus contorta* and *Picea pungens* had N and P deficit.

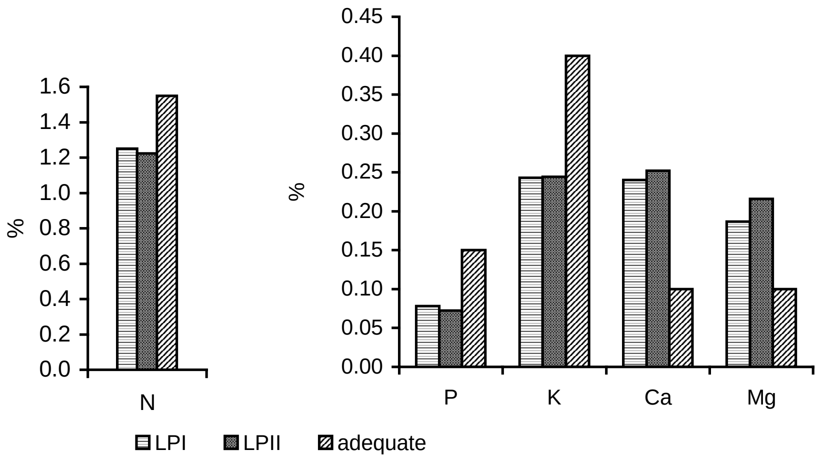

Fig. 3. Adequate macronutrient concentration in lodgepole pine needles in Narva in comparison with the scale elaborated by Ballard and Carter [53]

In the samples collected in 2004 the concentration of phosphorus in the needles of Scots pine in the two sites was 0.11% and 0.096%. Considering the scales of needle P concentrations by Ingestad [50], Wehrmann [51] and Brække, Salih [52] (Table 2), we can say that current-year needles of Scots pine suffer a severe P deficiency. A study by Kaar and Raid [41] also showed that the concentration of P in the needles of Scots pine on the detritus of Narva opencast is not over 0.16%.

The concentration of P in the needles of lodgepole pine growing in the Narva opencast mine was only 0.072% and 0.078% of dry wt. (Fig. 3), which should indicate P deficit in the tissues (<0.08% P) [56].

Comparison of the two pine species suggests P deficency in the needles in both of them. The concentrations of P in spoil detritus were not reflected in the P concentrations of needles. Consequently, in alkaline substrate P compounds that are difficult to assimilate by plants are formed. Assimilation of phosphate ions from soil is the most successful when the pH is 6.5–7.5 [59]. As pH of spoil detritus in the study sites is higher (8.0–8.2), the alkalinity of the substrate should be considered the reason for P deficit.

An earlier study by Kaar and Raid [41] showed that the pine plantations were mostly sufficiently supplied with potassium, and the supply of calcium and magnesium was high in all opencasts. The results of our study indicated a deficiency of K in pines. Compared with the scales of Ingestad [50], Wehrmann [51] and Brække, Salih [52] (Table 2) needles of Scots pine showed K deficiency. According to Brockley [56] the nutrition of lodgepole pine can be regarded as optimum when the K concentration is over 0.40%, while a severe deficiency occurs in case the K concentration in needles is below 0.30%. According to Ballard and Carter [55] the optimum K concentration in needles is 0.40%. Hence, also lodgepole pine plantations suffer rather severe K deficiency on levelled opencast mines (Fig. 3). Data by Kärblane [59] and Marschner [33] show that the supply of plants with K is disturbed at pH 7.5–8.5. Potassium is hard to obtain in arid soil [60]. As K is involved in starch formation, translocation of sugars, development of chlorophyll, protein synthesis, cell division, and growth [61], thus K deficiency may result in many changes in physiology and metabolic processes of trees.

The plantations of Scots pine and lodgepole pine had a sufficient supply of calcium and magnesium. Comparison of our data with the scales of optimum concentrations of elements published by Ingestad [50], Wehrmann [51] and Brække, Salih [52] (Table 2) shows that the current-year needles of Scots pine on the sample plots contained optimum amounts of Ca and Mg. As to lodgepole pine, the concentration of Ca and Mg in the current-year needles was even higher than optimum (Fig.3) at comparison with the scales by Ballard and Carter [55] and Brockley [56] (optimum Ca concentration in needles > 0.10%, Mg > 0.08%). It is known that intensive K accumulation may be accompanied by inhibited accumulation of Ca and its low concentrations in tissues and vice versa [26]. So, at intensive accumulation of Ca into Scots pine needle tissues falling K concentration was observed.

Ratios of different nutrients in tissues promise to be better indicators of plant nutrient status than absolute concentrations [62]. Optimum growth of trees occurs under balanced nutrition conditions [63–65]. It is known that trees can assimilate nutrients in relatively optimum ratios also from rather disbalanced and nutrient-poor soils [26]. The ratios of the nutrients (N : P : K) in the needles of pines in plantations on opencast detritus did not vary significantly between the different sampling plots of lodgepole pine (LPI and LPII) and Scots pine (SPI and SPII). The ratio of N : P : K in the needles of lodgepole pine was 1 : 0.06 : 0.16 (LPI) and 1 : 0.06 : 0.20 (LPII), this ratio in the needles of Scots pine was 1 : 0.09 : 0.38 (SPI) and 1 : 0.08 : 0.39 (SPII).

Comparison of the absolute values of the ratios of nutrients in the needles of lodgepole pine with the scale of ratios suggested by Brockley [56] as important indicators of the status of trees allows us to confirm severe deficiency of P and K and optimum concentration of Mg in the needles of lodgepole pine growing on opencast detritus. According to Brockley [56]:

*N : P > 13 – moderate to severe P deficiency (our analysis: LPI – 16.0, LPII – 17.0);

*N : K > 4.5 – moderate to severe K deficiency (LPI – 5.2, LPII – 5.0);

*N : Mg < 15 – no Mg deficiency (LPI – 5.2, LPII – 4.9).

The nutrient concentrations seemed to be low if compared with defined standards for optimum concentrations based on laboratory experiments with Scots pine seedlings [50, 51] and on Scots pine forest stands in Finland, Sweden and Norway [52]. From the other hand, the indicated concentrations of N and K in the needles of Scots pine growing on opencasts did not differ from these values obtained in *Vaccinium* and *Oxalis-Myrtillus* forest types [32, 66, 67]. Following from that we can suppose that content of elements in the needles of our study area is sufficient for good growth of trees.

Morphological analysis

The morphology of trees is considered in monitoring systems that evaluate the state of trees in areas under human impact [24, 68]. One of the most important tests of tree quality is estimation of the biomass and growth parameters of assimilating organs – leaves or needles.

From the standpoint of tree productivity an important indicator is needle mass, which is affected from photosynthesis, metabolism and growth processes. The better the growth conditions, the heavier are the needles and the more vigorous is tree growth. Various investigations of fertilizer consumption reveal that also the length of needles and the dry mass of 100 needle pairs reflect rather well the soil conditions of forest site types [41]. Results of earlier studies of forest plantations on oil shale opencast sites correspond, as to the needle length and dry mass, mostly to plantations in *Cladina* site type and partly to *Vaccinium vitis-idaea* site types [41].

It is known that besides the quality of the substrate also climatic as well as biotic factors are of importance [69]. According to the literature, in precipitation-rich years pine needles are characterized by elevated length and mass values as well as nitrogen and phosphorus concentrations in needles [59]. In dry years, on the contrary, needles are shorter and lighter, their N and P concentrations are lower, but they are rich in K. The year 2004 was rich in precipitation (yearly precipitation amount 820 mm according to data of the Estonian Meteorological and Hydrological Institute), and it is possible that this favoured the formation of needle mass. Therefore, studies should be continued to clarify problems that cropped up.

Our investigations on Narva opencast showed that the average length of the needles on the main shoots of Scots pine from two sample plots formed in 2004 was 4.3 and 4.7 cm. From investigations in the same climatic conditions in Lahemaa National Park it is known that the average length of the needles on the main shoots was 4.5–5.5 cm in 1991–1994 [70, 71]. Results obtained by us did not differ significantly from the average length of Scots pine needles in Estonia [72] and other measurements in the same climatic zone [70, 71]. However, the dry mass of the needles in two stands on the oil shale opencast was notably smaller (DM of 100 needles was 1.23 and 1.26 g) (Fig. 4) than that of the trees measured in Lahemaa National Park in 1990–

1992 [70]. Still, as compared with the results obtained in a strongly alkalized area (pH of soil 8.1) near Kunda cement plant (DM of 100 needles on the main shoots was 0.91 g) [70], the dry mass of needles of pines growing on the sites of oil shale opencast is on average 34% higher.

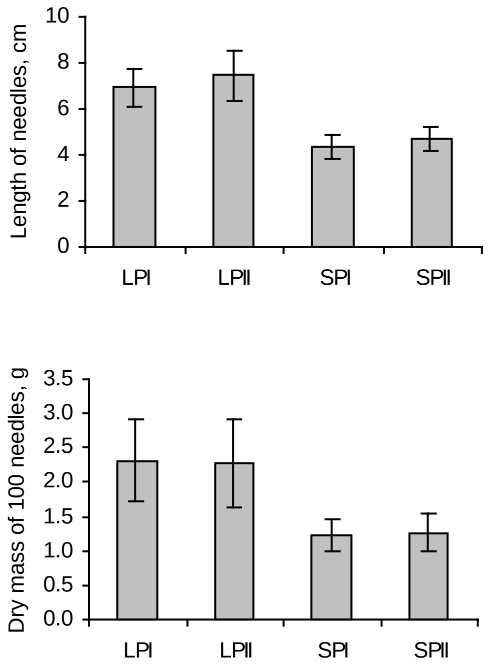

Fig. 4. Length of needles and dry mass of 100 needles (mean±SD) of lodgepole pine and Scots pine in the Narva opencast mine area

Our investigation showed the needles of lodgepole pine to be 1.7 times as long and 1.9 times as heavy as the needles of Scots pine. This can be explained by the difference in the genotype. Kishchenko [73] argues that the annual increment of needles depends on the internal reserves of the organism and intensity of growth rather than on the length of the growing period.

By use the multiple comparison of means the statistically significant differences were found between two sample plots for the length of the needles of lodgepole pine ($p < 0.05$), but not between two sample plots of Scots pine ($p > 0.05$). However, there was a significant difference between two species of pines ($p < 0.05$) in the length of needles (Fig. 4). Dry mass of 100 needles analysis showed that the dry masses of needles of a certain species (both lodgepole pine and Scots pine) in two plots were similar ($p > 0.05$), but dry masses of 100 needles differed significantly between species ($p < 0.05$) (Fig. 4). Correlation analysis revealed a strong relationship between the length and dry mass of the needles of both lodgepole pine and Scots pine (LPI r = 0.66, LPII r = 0.86, SPI r = 0.73, SPII r = 0.81, $p < 0.001$).

We cannot make any particular conclusions from results of ANOVA as we do not know if variability of the mass and length of shoots depends on the sampling point or on tree species. The variability of shoot parameters between sample plots within species was significant. Comparing the mean shoot length of two species we can confirm that the shoots of Scots pine showed a more intensive length increment than lodgepole pine shoots ($p < 0.05$) (Fig. 5). The dry mass of the shoots of the two pine species did not differ significantly ($p > 0.05$), but was somewhat higher in the case of lodgepole pine (Fig. 5).

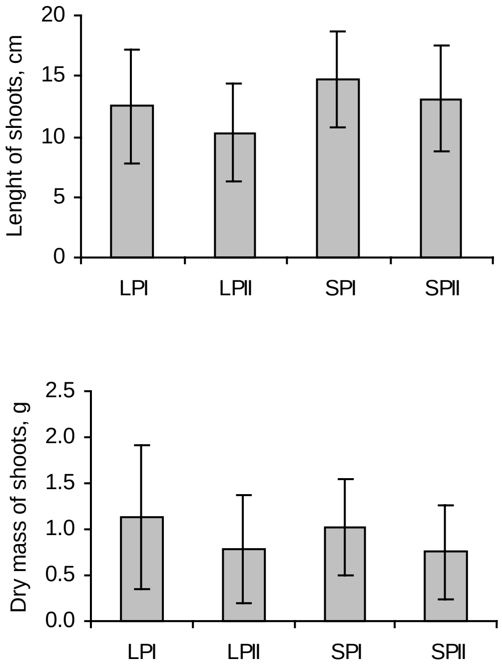

Fig. 5. Length of shoots and dry mass of shoots (mean±SD) of lodgepole pine and Scots pine in the Narva opencast mine area

Our investigations showed that lodgepole pine and Scots pine differ in their needle and shoot biomass as lodgepole pine formed longer and heavier needles and shorter and thicker shoots than Scots pine. Possible reasons for the superior growth rate of lodgepole pine compared to Scots pine were investigated in Sweden. Norgren [74] showed that lodgepole pine seedlings had greater mass than those of Scots pine of the same age. The growth analysis showed that the faster relative growth rate in lodgepole pine seedlings was linked with a higher leaf area and nitrogen use efficiency. From research in Sweden it is known that lodgepole pine is estimated to produce 36% more wood than Scots pine and it survives better in the young stages, but is less stable against wind and snow load after being planted [75]. This higher stemwood production can be achieved through a faster rate of total biomass production or by allocating a larger proportion of the biomass produced to stem growth [74]. Comparison of the mean annual increment of height and diameter of lodgepole pine and Scots pine showed no differences between the studied species ($p>0.05$).

Conclusions

The levelled and skeletal calcareous detritus of oil shale opencast sites is characterized by unsuitably high pH ≥ 8 and disbalanced nutrition substrate for the growth of trees. Extreme growth conditions affect the physiological state of trees, especially mineral nutrition processes. Because of the alkaline pH of the growth substrate elevated amounts of Ca and Mg and deficit of N, P and K developed in the tissues of needles. Differences were revealed between the two species investigated, which were due to differences in the metabolism and demand of nutrients. Scots pine accumulates larger amounts of P, K and Ca than lodgepole pine. The relatively stable ratio of N : P : K in the needles of pines on different sample plots indicated their ability to obtain mineral nutrients from soil in balanced ratios.

Lodgepole pine had greater needle mass and length, shorter and thicker shoots than Scots pine. According to the mean annual increment of height and diameter lodgepole pine and Scots pine did not differ essentially.

In spite of unfavourable soil conditions (stony substrate, too high pH for successful assimilation of phosphorus, low N reserved, disturbed water regime), stands on abandoned levelled opencast mines show good growth. In general we may say that although the reaction of detritus in opencast sites is not suitable for optimum growth of several tree species, Scots pine and lodgepole pine can grow there. From a practical point of view and considering the necessity to avoid Scots pine monocultures in recultivation processes, lodgepole pine may be suitable to grow in post-mining landscapes.

In recent years, interest in rehabilitating the land disturbed by mining activity has grown from the point of species selection. Rehabilitation of degraded landscapes needs research for identification of stress-tolerant plant species having a positive influence on soil fertility and for maximizing ecosystem productivity under a wide range of degraded site conditions. The current research needs to be continued and more investigation is needed for final conclusions.

Acknowledgements

This study was financially supported by the Estonian Ministry of Education and Research (project No. 0432153s02). The authors would like to thank Prof. Andres Kiviste and Dr. Jaan Klõsheiko for their help in data processing.

REFERENCES

1. *Choi, Y. D., Wali, M. K.* The role of *Panicum virgatum* (switch grass) in the revegetation of iron-mine tailings in northern New York // Restor. Ecol. 1995. Vol. 3, No. 2. P. 123–132.
2. *Bradshaw, A. D.* The reconstruction of ecosystems // J. Appl. Ecol. 1983. Vol. 20, No. 1. P. 1–17.
3. *Singh, A. N., Raghubanshi, A. S., Singh, J. S.* Plantations as a tool for mine spoil restoration // Current Science. 2002. Vol. 82, No. 6. P. 1436–1441.
4. *Karu, H., Luud, A., Pensa, M., Rull, E., Vaht, R.* Development of vegetation on reclaimed oil shale opencast mines // Environment and Oil Shale Mining in North-East Estonia. Publ. Inst. Ecol., 9. / Liblik, V., Punning, J.-M. (eds.). Tallinn, 2005. P. 121–135 [in Estonian with English summary].
5. *Reintam, L., Kaar, E.* Use of rehabilited quarry detritus for the study of forest – soil system development // 17th World Congress of Soil Sciences. Paper 174. Bangkok, Thailand, 2002. P. 1–10.
6. *Corbett, E. A., Anderson, R. C., Rodgers, C. S.* Prairie revegetation of a strip mine in Illinois: fifteen years after establishment // Restor. Ecol. 1996. Vol. 4, No. 4. P. 346–354.
7. *Chambers, J. C., Brown, R. W., Williams, B. D.* An evaluation of reclamation success on Idaho's phosphate mines // Restor. Ecol. 1994. Vol. 2, No. 1. P. 4–16.
8. *Hobbs, R. J., Norton, D. A.* Towards a conceptual framework for restoration ecology // Restor. Ecol. 1996. Vol. 4, No. 2. P. 93–110.
9. *Sopper, W. E.* Reclamation of mine land using municipal sludge // Advances in Soil Science. Vol. 17. New York: Springer-Verlag, 1992. P. 351–431.
10. *Filcheva, E., Noustorova, M., Gentcheva-Kostadinova, S., Haigh, M. J.* Organic accumulation and microbial action in surface coal-mine spoils, Pernic, Bulgaria // Ecol. Eng. 2000. Vol. 15, No. 1–2. P. 1–15.
11. *Parotta, J. A., Turnbull, J. W., Jones, N.* Catalyzing native forest regeneration on degraded tropical lands // For. Ecol. Manage. 1997. Vol. 99, No. 1–2, P. 1–7.
12. *Schaller, N.* The concept of agricultural sustainability // Agric. Ecosyst. Environ. 1993. Vol. 46, No. 1–4, P. 89–97.
13. *Holl, K. D.* Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA // J. Appl. Ecol. 2002. Vol. 39, No. 6. P. 960–970.
14. *Parotta, J. A.* The role of plantation forests in rehabilitating degraded tropical ecosystems // Agric. Ecosyst. Environ. 1992. Vol. 41, No. 2. P. 115–133.

15. *Montagnini, F., Sancho, F.* Impacts of native trees on tropical soils: a study in the Atlantic lowlands of Costa Rica // Ambio. 1990. Vol. 19, No. 8. P. 386–390.
16. *Lugo, A. E.* Tree plantation for rehabilitating damaged lands in the tropics // Environmental Rehabilitation. Vol. 2. Ecosystem Analysis and Synthesis / M. K. Wali (ed.). The Hague, The Netherlands: SPB Academic Publishing, 1992. P. 247–255.
17. *Moravcik, P.* Development of new forest stands after a large scale forest decline in the Krušné hory Mountains // Ecol. Eng. 1994. Vol. 3, No. 1. P. 57–69.
18. *Jordan, W. R., Peters, R. L., Allen, E. B.* Ecological restoration as a strategi for conserving biological diversity // Environ. Manage. 1988. Vol. 12, No. 1. P. 55–72.
19. *Dobson, A. P., Bradshaw, A. D., Baker, A. J. M.* Hopes for the future: restoration ecology and conservation biology // Science. 1997. Vol. 277, No. 5325. P. 515– 522.
20. *Piha, M. I., Vallack, H. W, Reeler, B. M., Michael, N.* A low-input approach to vegetation establishment on mine and coal ash wastes in semiarid regions. 1. Tin mine tailings in Zimbabwe // J. Appl. Ecol. 1995. Vol. 32, No. 2. P. 372–381.
21. *Singh, A. N., Singh, J. S.* Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region // For. Ecol. Manage. 1999. Vol. 119, No. 1–3. P. 195–207.
22. *Kaar, E.* Coniferous trees on exhausted oil shale opencast mines // Responses of Conifers to Stress Factors. Metsanduslikud uurimused (Forestry Studies), 36 / M. Mandre (ed.). Tallinn, 2002. P. 120–125.
23. *Weetman, G. F., Yang, R. C., Bella, I. E.* Nutrition and fertilization of lodgepole pine // Lodgepole Pine. The Species and Its Management. Symp. Proc. / D. M. Baumgartner, R. G. Krebill, J. T. Arnott, G. F. Weetman (comps., eds.). Pullman: Washington St. Univ. Coop. Exten. Serv., 1985. P. 225–232.
24. Manual for Integrated Monitoring. Programme Phase 1993–1996. Environmental Report 5. 1993. – Helsinki : Environment Data Centre, National Board of Waters and the Environment.
25. *Orlov, A. J., Koshel'nikov, S. P.* 1971. Soil Ecology of Scots Pine. – Moscow : Nauka [in Russian].
26. *Marschner, H.* Mineral Nutrition of Higher Plants. – London, Orlando, San Diego: Academic Press, 1986.
27. *Ruzicka, J., Hansen, E. H.* Flow Injection Analysis. – New York: John Wiley and Sons, 1981.
28. *Williams, B. D., Brown, R. W., Sidle, R. C., Mueggler, W. F.* Greenhouse evaluation of reclamation treatments for perlite-pumice mine spoils. 1990. Res. Pap. INT-426. USDA, Forest Service, Intermountain Research Station.
29. *Koch, P.* Lodgepole Pine in North America. Vol. 3. IV. Processes. V. Products. – Madison, Wisconsin, For. Prod. Soc., 1996.
30. *Mandre, M., Ots, K.* The height growth of trees // Dust Pollution and Forest Ecosystems. A Study of Conifers in an Alkalized Environment. Publ. Inst. Ecol., 3. / M. Mandre (ed.). Tallinn, 1995. P. 117–118.
31. *Keren, R., Gast, R. G., Bar-Josef, B.* pH dependent boron adsorption by Na-montmorillonite // Soil Sci. Soc. Am. J. 1981.Vol. 45, No. 1. P. 45–48.

32. *Mandre, M.* Changes in the nutrient composition of trees // Dust Pollution and Forest Ecosystems. A Study of Conifers in an Alkalized Environment. M. Mandre (ed.). Publ. Inst. Ecol., 3. Tallinn, 1995. P. 44–65.
33. *Marschner, H.* Mineral Nutrition of Higher Plants. – London, San Diego: Academic Press, 2002.
34. *Eriksson, H.* Effects of Tree Species and Nutrient Application on Distribution and Budgets of Base Cations in Swedish Forest Ecosystems. PhD Thesis. Silvestria, 2. Swedish University of Agricultural Sciences, 1996.
35. *Arvidsson, H.* Wood Ash Application in Spruce Stands. Effects on Ground Vegetation, Tree Nutrient Status and Soil Chemistry. PhD Thesis. Silvestria, 221. Swedish University of Agricultural Sciences, 2001.
36. *Bäckman, J. S. K., Klemedtsson, Å. K.* Increased nitrification in acid coniferous forest soil due to high nitrogen deposition and liming // Scand. J. For. Res. 2003. Vol. 18, No. 6. P. 514–524.
37. *Hendrickson, O. Q., Burgess, D.* Nitrogen-fixing plants in a cut-over lodgepole pine stand of southern British Columbia // Can. J. For. Res. 1989. Vol. 19, No. 7. P. 936–939.
38. *Prescott, C. E., Corbin, J. P., Parkinson, D.* Availability of nitrogen and phosphorus in the forest floors of Rocky Mountain coniferous forests. – Can. J. For. Res. 1992. Vol. 22, No. 4. P. 593–600.
39. *Vaus, M.* Silvicultural properties of the detritus of oil shale opencast mines in Estonia. Tallinn: Valgus, 1970 [in Estonian].
40. *Raid, L., Vaus, M.* Soils of the graded overburden dumps // Reclamation of the Oil Shale Mines / E. Kaar, L. Lainoja, H. Luik, L. Raid, M. Vaus. Tallinn: Valgus, 1971. P. 56–70 [in Estonian].
41. *Kaar, E., Raid, L.* Afforestation of Estonian oil shale opencast sites and management of stands planted on recultivated sites // Final report of Grant No. 366. – Tartu: MS at Estonian Naturalists' Society. 1996. P. 1–68 [in Estonian].
42. *Reintam, L.* Changes in the texture and exchange properties of skeletal quarry detritus under forest during thirty years // Proc. Estonian Acad. Sci. Biol. Ecol. 2001. Vol. 50, No. 1. P. 5–13.
43. *Fitter, A. H., Bradshaw, A. D.* Responses of Lolium perenne and Agrostis tenuis to phosphate and other natritional factors in the reclamation of colliery shale // J. Appl. Ecol. 1974. Vol. 11, No. 4. P. 592–608.
44. *Williams, P. J.* Investigations into the nitrogen cycle in colliery spoil // The Ecology of Resource Degradation and Renewal / M. J. Chadwick, G. T. Goodman (eds.). Oxford: Blackwell Scientific Publications, 1975. P. 259–274.
45. *Chadwick, M. J.* Methods of assessment of acid colliery spoils as a medium for plant growth // Ecology and Reclamation of Devastated Land / R. J. Hutnik, G. Davis (eds.). London: Gordon and Breach, 1973. P. 81–91.
46. *Riispere, A.* Mineral nutrition of Scots pine (*Pinus sylvestris* L.) on alvar soils. III. Estimation of the supply of pine with nutrients by comparative analysis of needles // Proc. Estonian Acad. Sci. Biol. 1969. Vol. 18, No. 3. P. 205–232 [in Russian].
47. *Landis, T. D.* Mineral nutrition as an index of seedling quality // Evaluating Seedling Quality: Principles, Procedures, and Predictive Abilities of Major

Tests / M. L. Duryea (ed.). Corvallis: Forest Research Laboratory, Oregon State University, 1985. P. 29–48.

48. *Mandre, M.* Conditions for mineral nutrition and content of nutrients in Scots pine (*Pinus sylvestris*) on dunes in Southwest Estonia // Metsanduslikud uurimused (Forestry Studies), 39. Tallinn, 2003. P. 32–42.
49. *Ingestad, T., Lund, A. B.* Theory and techniques for steady state mineral nutrition and growth of plants // Scand. J. For. Res. 1986. Vol. 1, No. 5. P. 439–453.
50. *Ingestad, T.* Macroelement nutrition in pine, spruce and birch seedlings in nutrient solutions // Medd. Statens Skogsforskningsinst. 1962. Vol. 51, No. 7. P. 1–150.
51. *Wehrmann, J.* Möglichkeiten und Grenzen der Blattanalyse in der Forstwirtschaft // Landwirtsch. Forsch. 1963. Vol. 16, No. 2. P. 12–23.
52. *Brække, F. H., Salih, N.* Reliability of foliar analysis of Norway spruce stands in a Nordic gradient // Silva Fenn. 2002. Vol. 36, No. 2. P. 489–504.
53. *Porgasaar, V.* Mineral nutrition of Scots pine and its diagnostics (Cand. Sci. Thesis). Tartu, 1973 [in Estonian].
54. *Raid, L.* Relationships between the growth of Scots pine seedlings and chemical composition of needles // Forestry Studies, 17. Tallinn, 1982. P. 80–93 [in Estonian with Russian and German summary].
55. *Ballard, T. M., Carter, R. E.* Evaluating Forest Stand Nutrient Status. Land Management Report No. 20. 1985. Victoria : British Columbia Ministry of Forests. P. 1–60.
56. *Brockley, R.* Foliar Sampling Guidelines and Nutrient Interpretative Criteria for Lodgepole Pine. British Columbia Ministry of Forests Research Program. 2001. Extension Note No. 52. Vernon. P. 1–8.
57. *van den Driessche, R.* Relationship between spacing and nitrogen fertilization of seedlings in the nursery, seedling mineral nutrition, and outplanting performance // Can. J. For. Res. 1984. Vol. 14, No. 3. P. 431–436.
58. *Mandre, M., Kuznetsova, T.* Conditions for mineral nutrition of conifers on reclaimed oil shale mine sites // Forestry Studies, 41. Tallinn, 2004. P. 17–26.
59. *Kärblane, H.* (comp.). A Manual of Plant Nutrition and Fertilization. – Tallinn: Ministry of Agriculture, 1996 [in Estonian].
60. *Kozlowski, T. T., Kramer, P. J., Pallardy, S. G.* The Physiological Ecology of Woody Plants. – San Diego, New York: Academic Press, 1991.
61. *Smith, W. K., Hinckley, T. M.* (eds.). Ecophysiology of Coniferous Forests. – San Diego: Academic Press, 1995.
62. *Perry, D. A.* Forest Ecosystems. – Baltimore, London: Oregon State University, 1994.
63. *Ingestad, T.* Mineral nutrient requirements of *Pinus sylvestris* and *Picea abies* seedlings // Physiol. Plant. 1979. Vol. 45, No. 4. P. 373–380.
64. *Linder, S.* Foliar analysis for detecting and correcting nutrient imbalances in Norway spruce // Ecol. Bull. Vol. 44. Copenhagen: Munksgaard, 1995. P. 178–190.
65. *Sigurdsson, B. D.* Environmental Control of Carbon Uptake and Growth in a *Populus trichocarpa* Plantation in Iceland. Doctoral Thesis. 2001. Uppsala.

66. *Pensa, M., Sellin, A.* Needle longevity of Scots pine in relation to foliar nitrogen content, specific leaf area, and shoot growth in different forest types // Can. J. For. Res. 2002. Vol. 32, No. 7. P. 1225–1231.
67. *Ots, K.* The content of chemical elements in the needles of Scots pine in the area influenced by the Kunda Cement Plant // Forestry Studies, 35. Tartu, 2001. P. 27–37 [in Estonian].
68. *Schubert, R.* (ed.). Bioindikation in terrestrischen Ökosystemen. – Jena: Gustav Fischer Verlag, 1985.
69. *Terasmaa, T.* Changes in the health of middle-aged degrading Scots pine stand of *Vaccinium vitis-idaea* site tipe as a result of fertilization // Forestry Studies, 27. Tartu, 1996. P. 112–124 [in Estonian with English summary].
70. *Mandre, M., Rauk, J., Ots, K.* Needle and shoot growth // Dust Pollution and Forest Ecosystems. A Study of Conifers in an Alkalized Environment. Publ. Inst. Ecol., 3. / Mandre, M. (ed.). Tallinn, 1995. P. 103–111.
71. *Ots, K.* Impact of Air Pollution on the Growth of Conifers in the Industrial Region of Northeast Estonia. Doctoral Thesis. Estonian Agricultural University. Tartu, 2002.
72. *Laas, E.* Dendrology. Tallinn: Valgus, 1987 [in Estonian].
73. *Kishchenko, I. T.* Effect of climatic factors of the growth of representatives of the genus *Pinus* (Pinaceae) under conditions of introduction // Russian Journal of Ecology. 2004. Vol. 35, No. 4. P. 249–254.
74. *Norgren, O.* Growth analysis of Scots pine and lodgepole pine seedlings // For. Ecol. Manage. 1996. Vol. 86, No. 1–3. P. 15–26.
75. *Elfving, B., Ericsson, T., Rosvall, O.* The introduction of lodgepole pine for wood production in Sweden – a review // For. Ecol. Manage. 2001. Vol. 141, No. 1-2. P. 15–29.

Presented by J. Kann
Received December 8, 2005