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EARLY GROWTH AND FLORISTIC DIVERSITY OF HYBRID ASPEN (*POPULUS X WETTSTEINII* HÄMET-AHTI) PLANTATIONS ON A RECLAIMED OPENCAST OIL SHALE QUARRY IN NORTH-EAST ESTONIA

A. TULLUS[(a)*], T. SOO[(a)], H. TULLUS[(a)], A. VARES[(a)]
A. KANAL[(b)], E. ROOSALUSTE[(c)]

[(a)] Department of Silviculture, Institute of Forestry and Rural Engineering
Estonian University of Life Sciences
5 Kreutzwaldi St., 51014 Tartu, Estonia

[(b)] Chair of Physical Geography and Landscape Ecology, Institute of Geography
University of Tartu
46 Vanemuise St., 51014 Tartu, Estonia

[(c)] Chair of Plant Ecology, Institute of Botany and Ecology
University of Tartu,
40 Lai St., 51005 Tartu, Estonia

*The early growth of the trees, foliar and soil properties, and floristic diversity were studied in 5-year-old hybrid aspen plantations in four sites: A1-levelled oil shale quarry spoil (*Calcaric Regosol*), A2-levelled quarry spoil covered with the mixture of removed former* Calcaric Cambisol *horizons, B1-former arable land on* Calcaric Cambisol, Chromic Cambisol *and* Rendzic Leptosol, *B2-former arable land on* Mollic Planosol*. In the quarry area trees had grown significantly faster in site A2. Overall fastest growth was observed on former arable land (B2). Significantly higher pH and lower values of P in the substrate and of foliar N and P were estimated in A1. TWINSPAN classification and DCA ordination showed substantial differences in vegetation composition between the sites. Vegetation of the quarry site A2 resembled more to B1 and B2 than to A1.*

Introduction

Land disturbed or destroyed by mining and similar activities is an inevitable part of civilization [1]. Estonian oil shale opencasts quarries are usually reclaimed as forest lands, a few areas also as agricultural lands. Altogether

* Corresponding author: e-mail *arvo.tullus@emu.ee*

10 347 ha of the reclaimed areas had been afforested by 2006 [2]. Approximately 86% of the reclaimed areas have been afforested with Scots pine (*Pinus sylvestris* L.) [3]. In addition some other local tree species such as silver birch (*Betula pendula* Roth.) and black alder (*Alnus glutinosa* (L.) Gaertn.) and a number of exotic species (mainly *Picea*, *Pinus*, *Larix*, also *Populus* spp) have been used. The wide use of Scots pine for afforestation of abandoned oil shale opencast sites is due to its successful establishment and adaptation under harsh conditions [3]. On the other hand, it can be argued that large monocultural pine stands present a high fire hazard and they are threatened by pests [3]. Wider use of silver birch and black alder, due to its fast growth and meliorative properties, is recommended for such areas [3–7].

A suitable species for afforestation of quarry spoils should be able to grow on poor and dry soil, establish vegetation cover as quickly as possible, prevent erosion or nutrient leaching and improve the soil organic matter status and microbial biomass. Notwithstanding, some tree species might also differ in their influence on soil biological activities, such as the presence of mychorrhizae or the composition of microbial communities, which in turn may affect soil chemistry [8]. For example the specific root area and length has been found to be significantly higher under alder than under pine trees [9].

Hybrid aspen (*Populus x wettsteinii* Hämet-Ahti) is an artificial cross between European aspen (*P. tremula* L.) and North-American trembling aspen (*P. tremuloides* Michx.). It has been most widely studied and cultivated in Sweden and Finland, both on agricultural and forest land, and has shown higher biomass productivity compared to its parent species in boreal conditions [10, 11]. The results from Lusatian lignite mining region in Germany have indicated that the cultivation of fast-growing poplars, their hybrids (including hybrid aspen) and willows in short-rotation plantations is an adequate tool for establishing sustainable land use systems in the post-mining landscapes [12]. Hybrid poplars have been found to have good potential for reforestation of reclaimed surface-mined lands also in the Appalachian coal producing region in the USA [13].

Considering possible environmental impacts of monospecific plantations with exotic tree species, cultivation of hybrid aspen is not recommended on traditional forest lands in Estonia [14]. At the same time it can be seen as an alternative deciduous tree for afforestation of abandoned agricultural land. Opencast mining is carried out in large areas and the environmental impact of reforesting ecologically degraded landscapes with exotic tree species on the adjacent natural ecosystems is considered to be smaller.

Since 1999 hybrid aspen has been cultivated on former arable land in Estonia. The early growth of hybrid aspen on abandoned agricultural land in Estonia has been highly variable. Trees have grown faster on automorphic and semi-hydromorphic soils; hydromorphic clay soils have been less favourable [15]. In 2000 two experimental plantations with hybrid aspen were established in Aidu oil shale opencast. In the current paper we evaluate the early growth results from these plantations and compare them to the plantations growing on former arable land.

To achieve a successful restoration of exhausted mining areas, the soil has to be remediated and the vegetation re-established [16]. With the formation of permanent plant cover, skeletal quarry detritus, which is a disintegrated rock debris in areas of opencast oil shale mining, can develop into the soil of a productive forest ecosystem [5, 17–20]. Vegetation restoration on levelled quarry spoil is a successional process, depending on different factors. The substrate of exhausted oil shale opencasts is very unfavourable for reoccupation by plants, especially due to its uttermost dryness and the extreme temperatures of its surface [21]. Easily acquirable water for plants is basically absent in the top layers of quarry spoil, or appears in small quantities only in spring and autumn [22]. In primary successions, community development accompanies the development of the habitat. The establishment of different species can be determined by chance, the state of the habitat, and interactions between new species and those already present [23].

From a successional point of view, the current study focuses on four sites that are basically at the same stage on a time scale (5-year-old forest plantations) but in substantially different ecological conditions. Development of vegetation in levelled quarry spoil follows primary succession. In another site, quarry spoil has been covered with previously removed soil offering more favourable conditions for vegetation development. The vegetation analysis of plantations on former arable land in two sites as an example of secondary succession was included for comparative purposes. The differences between the sites in terms of species composition, species richness, diversity and life-history characteristics were investigated.

The principal aim of the study was to analyse ecologic relations that determine the growth speed of hybrid aspens and formation of plant cover in reclaimed quarry sites and on similar former arable soils. The nutrition conditions of the trees, fertility and productive capacity of the studied sites are characterized according to interactions between chemical soil properties, foliar and growth properties of the trees and floristic diversity of the field layer.

The objectives of this study were: (i) to describe the early growth of hybrid aspen in two sites on reclaimed oil shale opencast and compare it with the results from automorphic arable soils in two sites: in the same region with the quarry area and in South-Estonia; (ii) to study relations between tree growth, foliar and soil properties and define the most limiting growth factors for hybrid aspen in reclaimed quarry areas; (iii) to describe and compare the floristic diversity and vegetation structure in plantations established on reclaimed quarry and on abandoned agricultural land.

Materials and methods

Study area

The study focuses on two hybrid aspen plantations established for the reclamation of Aidu oil shale opencast in spring 2000 (Table 1). Micropropagated plants belonging to clones C05-99-8 until C05-99-34 were used. The first plantation had been established directly on levelled quarry spoil. The spoil is a heterogeneous mixture of Ordovician limestone and Quaternary sediments and contains over 75% of rubble and limestone blocks. The other plantation lies on part of the opencast that had been reclaimed as agricultural land. Before mining the topsoil from 12 different soil types suitable for reclamation [24] was removed and put into storage piles. In this paper, the term "topsoil" is considered synonymous with zone of organic-C accumulation and illuvation in the natural soil. After levelling of the exhausted quarry spoil it was covered by previously removed soil with the approximate depth of 40–60 cm [4]. Four experimental plots were created randomly within the first plantation and three within the second plantation (Table 1). The hybrid aspen plantations from Aidu opencast were compared to plantations established on abandoned agricultural land, where a network of 51 permanent experimental plots has been created in Estonia [15]. For comparison, three plots in the same region with the quarry sites and four plots from plantations on South-Estonian *Planosols*, where hybrid aspen has shown good growth potential [15], were selected (Table 1). All the soil types included in group B1 (Table 1) existed in

Table 1. **Characteristics of the study area. Site codes: A1– levelled quarry spoil, A2 – levelled quarry spoil covered with the former soil, B1 – former arable land on *Calcaric Cambisol*, *Chromic Cambisol* and *Rendzic Leptosol* in North-Estonia, B2 – former arable land on South-Estonian *Planosols*. Analysed properties: T – tree growth, S – soil, L – tree leaves, P – vascular plant cover**

Plantation	Site code	Plot	Location	Soil type according to WRB [26]	Analysed properties
Aidu 1	A1	1	59º19'N, 27º03'E	*Calcaric Regosol*	T, S, L, P
Aidu 1	A1	2	59º19'N, 27º03'E	*Calcaric Regosol*	T, S, L, P
Aidu 1	A1	3	59º19'N, 27º03'E	*Calcaric Regosol*	T, S, L, P
Aidu 1	A1	4	59º19'N, 27º03'E	*Calcaric Regosol*	T, S, L, P
Aidu 2	A2	1	59º20'N, 27º04'E	*Calcaric Cambisol* mixt.[a]	T, S, L, P
Aidu 2	A2	2	59º20'N, 27º04'E	*Calcaric Cambisol* mixt.[a]	T, S, L, P
Aidu 2	A2	3	59º20'N, 27º04'E	*Calcaric Cambisol* mixt.[a]	T, S, L, P
Sõeru	B1	1	58º53'N, 24º42'E	*Chromic Cambisol*	T, S, P
Sõeru	B1	2	58º53'N, 24º42'E	*Rendzic Leptosol*	T, S, P
Mikkeri	B1	3	59º30'N, 26º35'E	*Calcaric Cambisol*	T, S, P
Sikka	B2	1	58º14'N, 27º19'E	*Mollic Planosol*	T, S, L, P
Sikka	B2	2	58º14'N, 27º19'E	*Mollic Planosol*	T, S, L, P
Laaska	B2	3	58º20'N, 26º33'E	*Mollic Planosol*	T, S, L, P
Laaska	B2	4	58º20'N, 26º33'E	*Mollic Planosol*	T, S, L, P

[a] Mixture of removed former *Calcaric Cambisol* horizons

the quarry area before mining [24]. We limited our selection in all sites, so that available moisture content in 75 cm soil depth would remain <150 mm as calculated by Kitse and Leis [25].

In the following text the studied sites are referred to as codes (A1, A2, B1, B2) which are explained in Table 1.

Dendrometric characteristics

Total tree height at the end of the fifth growing season and height increment of the fifth year were measured for all the trees within the studied experimental plots. All the studied plantations are quite sparsely spaced and tree canopies have not closed yet. Therefore it was decided to rely only on the height growth of the trees for evaluating their growth speed and production potential and not to include biomass calculations per unit area in the current study.

Soil properties

From plots within site A1, which lies on levelled quarry spoil with available moisture being as low as 9 mm per 100 mm soil depth [27], the fine earth fraction between rock debris was taken for analysis. In the case of A2 samples from the top of mixed layer of former *Calcaric Cambisol* were analysed. The total nitrogen was determined by the Kjeldahl procedure. To analyse available phosphorus and potassium, Mehlich 3 extracant was used. The pH in 1M KCl suspensions was measured in the ratio 10 g : 25 ml. The soil samples were analysed in the Laboratory of Agrochemistry of Agricultural Research Centre in Saku.

Leaf properties

Ten model trees, based on the distribution of diameter at breast height (DBH), were selected from sites A1, A2 and B2 from each plot, altogether 110 trees. 15 leaves were collected from each model tree from the middle part of the canopy. After drying at +70 °C the leaves were weighed, single leaf blade area was measured with WINFOLIA ver. 5.0a (Regent Instruments Inc.) software and leaf weight per area (LWA, $g\ m^{-2}$) was derived. Foliar concentrations of NPK of all model trees were determined.

Floristic data

A transect of four 2×2 m experimental plots was created within each experimental area in order to analyse the vascular plant cover of the studied hybrid aspen plantations. Altogether 28 plots were established in plantations of Aidu opencast and 28 plots on former arable land. On every plot a species list of vascular plant and moss species was compiled following the guidebooks [28, 29]. The total percentage cover and percentage cover of individual species were recorded. Vascular plant species were grouped into life form and seed dispersal mode categories according to Lindacher [30] and into life-span categories following Krall *et al*. [31]. When one species was listed as belonging to more than one category, all of these categories were taken into account.

Data analysis

Statistical analyses of the growth traits, and foliar and soil properties were carried out with Statistica 7 [32]. One-way ANOVA was used to test the significance of differences between site means of growth traits, and foliar and soil properties. Tukey HSD multiple comparison test was applied to determine significant differences between group means after one-way ANOVA. Distance weighted least squares fitting procedure was used for smoothing the distribution curves of tree height (stiffness 0.25). Level of significance $\alpha = 0.05$ was applied in all cases.

Statistical analysis of plant cover was carried out with PCORD-4 [33] and Statistica 7. Species richness (S), evenness (E) and Simpson's diversity index (D) were calculated for all plots and compared between the sites with one-way ANOVA. Floristic data was classified with TWINSPAN clustering method [34] using the default options and 5 pseudospecies cut levels; the maximum level of divisions was 6. Detrended Correspondence Analysis (DCA, [35]) was applied with default options in order to analyse the positioning of species and plots from four different sites along the ordination axes. Logarithmic transformation of the data was applied prior to TWINSPAN and DCA.

Results and discussion

Dendrometric characteristics

Trees had grown significantly faster during the first five years in the former quarry site where levelled spoil had been covered with removed soil (A2) compared to the plantation that had been established directly on levelled quarry spoil (A1). The height of the trees varied from 0.2 to 3.6 m in A1 and from 0.8 to 4.0 m in A2. The height increment of the fifth year varied from 0.1 to 0.7 m in A1 and from 0.2 to 0.9 m in A2. The comparison of main dendrometric characteristics between studied sites in the Aidu opencast and on former arable land is given in Table 2.

A few experimental plantations with poplars and their hybrids have been established on levelled oil shale opencasts in Estonia in the 1960ies [6, 36]. The early growth results have been considered quite promising although the aim has been to use poplars as pioneer species and to replace them in the course of time with more perspective species, e.g. silver birch and *Larix* spp [37]. But in terms of the whole rotation period, the use of poplars has not justified itself due to considerable damage by tree trunk rot [6]. In two

Table 2. **Comparison of tree height (H) and height increment of the fifth year (Z) in hybrid aspen plantations in studied sites ± 1 standard error**

Site	Plots	Trees	H (m)	Z (m)
A1	4	161	1.1 ± 0.05 c[a]	0.3 ± 0.01 c
A2	3	54	2.0 ± 0.08 b	0.4 ± 0.02 b
B1	3	302	2.0 ± 0.05 b	0.5 ± 0.02 b
B2	4	334	3.4 ± 0.04 a	0.9 ± 0.01 a

[a] Letters within each column denote significant differences between means determined by Tukey HSD test (p <0.05) after one-way ANOVA.

experimental poplar plantations established on levelled oil shale opencasts in 1962 and 1964 the mean height at age 5 was estimated 2.1 and 3.2 m; the mean height increment was 0.3 and 0.8 m respectively [7, 36]. According to unpublished data provided by Elmar Kaar the following traits have been recorded for a poplar stand in mining area at age 25: height: 21.7 m, DBH: 26.5 cm, growing stock: 281 m^3 ha^{-1}**.** We can see that height and height increment of 5-year-old poplar stands and the hybrid aspen in quarry site A2 (Table 2) are roughly comparable. At the same time the poplar stands had been established directly on quarry spoil.

The distribution of hybrid aspens by height is shown in Fig. 1. We can observe clear difference between sites A1, A2 and B2. The distribution curves of tree height in sites A2 and B1 are more overlapping although trees higher than 4 m were missing in the quarry site. There was also no statistically significant difference in mean values of H and Z between sites A2 and B1 (Table 2). Thus the growth rate of hybrid aspens in quarry site covered with previously removed soil has been comparable with the results from former arable land on similar soil in the same region.

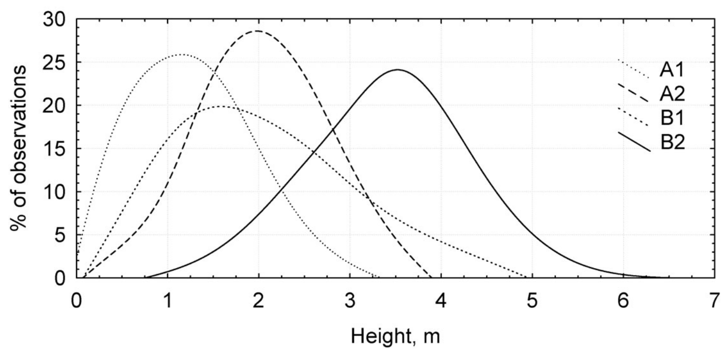

Fig. 1. Distribution of the trees by height in studied sites.

Soil properties

Significant differences were observed in concentrations of macronutrients (NPK) and in pH of the upper part of the quarry soils and humus horizons of former arable soils (Fig. 2).

Quarry spoil, as fresh calcareous parent material for soil development, had the highest pH value, in the other soils pH decreased according to soil development and decreasing of parent material calcareousness from North- to South-Estonia. The early growth of hybrid aspen has been found to be in negative correlation with pH of the arable soils in Estonia [15]. Generally the biogenic elements, such as N and P, are more depending on organic matter content of soil than geogenic K which is more related to clay minerals [38]. The highest total nitrogen content was discovered in quarry area which was covered with former soil (Fig. 2). The lowest phosphorus content was found in fresh spoil. The other soils were characterized by good phosphorous supply. Hybrid aspen growth on bare quarry spoil was obviously limited by N and P deficiencies. There were no differences in potassium content between soils; the availability level could be considered as an average. As generally known, available nutrients for root uptake during growing season depend on both nutrient pools and soil moisture. We should consider that element concentrations are expressed as content per unit weight of fine earth, not storage per unit area or volume, which reduces the potential of bare spoil to supply nutrients even more.

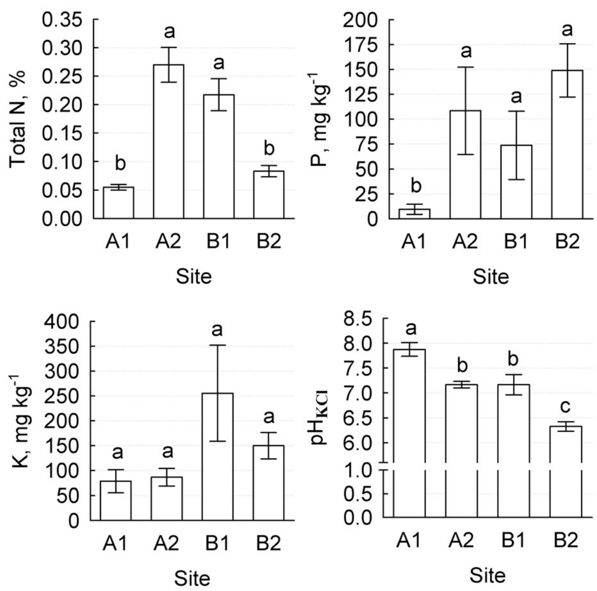

Fig. 2. Comparison of the concentrations of total N, extractable P and K and pH of the substrate between studied sites. Whiskers denote ± 1 standard error, letters denote significant differences between means determined by Tukey's test ($p < 0.05$) after one-way ANOVA.

The formation of organo-mineral soil layers is of prime importance for the reestablishment of the ecosystem. By restoring the topsoil we increase soil water holding capacity and increase biological potential. Topsoil that is replaced on levelled spoil does not have the same integrity of structure, porous continuity trough profile as is seen in naturally developed soils. However, the initial average height growth of trees is similar between sites A2 and B1 (Table 1), moreover, the tree height variability is even lower on restored soil (Fig. 1). Thus reshaping the soil banks to a gently undulating topography, changing subsoil properties and replacing topsoil creates quite homogenous initial growth environment for aspen plantation. Fear that the storage of topsoil in deep piles for years reduces the functional capacity of soil microorganisms is not so serious. The nitrogen potential of the removed soil has been preserved well in soil depots, as the vitality of *Azotobacteria* has survived well and the content of ammonium nitrogen inside soil depot has even increased [39]. This could explain the significantly higher concentration of N in site A2 (Fig. 2).

Leaf properties

The foliar concentrations of main mineral nutrients (NPK) and the sizes of leaves differed significantly between model trees taken from hybrid aspen plantations of Aidu opencast and abandoned agricultural land (Fig. 3, Table 3).

Plant nutrition in different sites depends of several factors, e.g. from physiological status of trees, from chemical soil properties and from climatic factor. Therefore it is also complicated to draw firm conclusions. Generally, sufficient nutrient supply may increase and shortage may reduce foliar nutrient concentration. At the same time nutrients are not independent from each other and can interact with other elements. The lowest nitrogen content of aspen leaves growing on site A1 (Fig. 3) reflects well the poor nitrogen and water supply from the quarry spoil (Fig. 2). As we do not know present Ca data of soil, we can be indirectly guided by pH values (Fig. 2). While

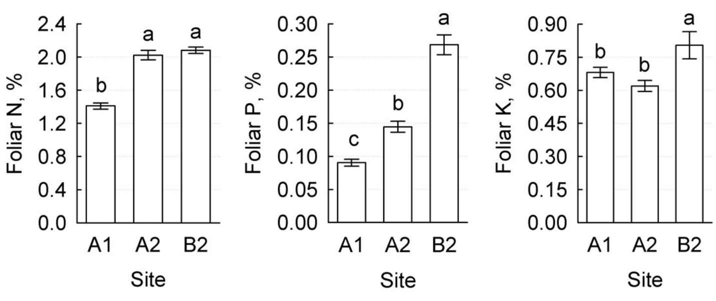

Fig. 3. Comparison of the foliar concentrations of NPK of hybrid aspens between studied sites. Whiskers denote ± 1 standard error; letters denote significant differences between means determined by Tukey's test ($p < 0.05$) after one-way ANOVA.

Table 3. **Comparison of foliar characteristics in plantations of Aidu mine and abandoned agricultural land (B2) ± 1 standard error**

Site	Plots	Model trees	Single leaf:		
			weight, g	blade area, cm^2	LWA[b], g/m^2
A1	4	40	0.15 ± 0.006 b[a]	14.7 ± 0.58 b	101.1 ± 0.91 a
A2	3	30	0.17 ± 0.004 b	17.2 ± 0.43 b	97.1 ± 1.34 b
B2	4	40	0.23 ± 0.012 a	22.5 ± 1.09 a	102.0 ± 0.94 a

[a] Letters within each column denote significant differences between means determined by Tukey's test (p <0.05) after one-way ANOVA.
[b] LWA – leaf weight per area.

phosphorus uptake is more dependent on root development and $CaCO_3$ content, we can see that these conditions are most favourable for aspen in arable soils and worst in calcareous spoil. *Populus* species are colonized by both arbuscular and ectomycorrhizal fungi [40, 41]. Both types of mycorrhizal fungi can facilitate uptake of nutrients required for young tree growth, but in some periods they can act as inhibitors, as they form a sink that competes for carbon. It should be noted that capability for mycorrhiza development by mycobionts is probably worse in bare spoil without humus horizon. The potassium content in leaves is more evenly distributed than phosphorus. Although available potassium content of studied soils is even (Fig. 2), the highest K content was estimated for B2 (*Mollic Planosols*) with lower pH value (Fig. 2). As known, potassium moves into roots better in moist soils, and potassium availability is relatively weak in calcareous environment because of Ca/K antagonism [42].

The leaves were significantly bigger in plantations on former arable soils compared to the plantation with reestablished soil in Aidu opencast (Table 3), although the concentration of N was two times lower in former arable site B2 and concentrations of P and K were comparable in all soils (Fig. 2). It has been long recognized that plants growing under soil moisture or nutrient shortage have smaller leaves and lower growth rates than plants growing under more favorable conditions. The lower LWA in site A2 indicates differences in water supply, soil reaction or microclimate between sites. The bigger leaves on abandoned fields are as ashy as those growing on spoil. The size of the leaves has been regulated by abiotic conditions, as of water and perhaps nitrogen supply as well, while the light conditions are presumably comparable in the studied sites.

Usually the spoils or minesoils are chemically or physically less desirable growth environment than the native soils [43, 44]. North-Estonian abandoned oil shale opencast areas have high forestry potential [19]. Reeder and Berg [45] indicated that net N mineralisation and nitrification are generally smaller in geologic materials than in soils, and that a smaller portion of the total N in geogenic materials is potentially mineralizable. Nitrogen deficiency can be overcome in the short term by the application of industrial or organic fertilizers, and in the long term by the introduction of nitrogen-fixing plant species [23]. Since the spoil is calcareous, nitrate is preferable to ammonia in order to avoid NH_3 volatilization. The studies of Scots pine needles in Estonian oil shale opencast areas [46, 47] have shown the deficiency of N, P and K, optimal concentration of Mg and optimal or overabundant concentration of Ca in needles.

Fertilizing with N or NP or NPK has had a positive effect on the growth of Scots pine on such lands [46]. Our study showed significant deficiency of N in the substrate (Fig. 2) and N and P in the leaves (Fig. 3) of hybrid aspens growing on quarry spoil compared to trees growing on quarry spoil covered with soil and on former arable land.

Floristic diversity

Altogether 113 vascular plant and 19 moss species were described on 56 plots within 14 experimental areas in the hybrid aspen plantations of Aidu opencast and on former agricultural land. Out of the 113 vascular plant species, 6 species (*Achillea millefolium* L., *Artemisia vulgaris* L., *Deschampsia cespitosa* (L.) P. Beauv., *Sonchus arvensis* L., *Taraxacum officinale* Weber ex Wigg. s.l., *Tussilago farfara* L.) were found in all four sites (A1, A2, B1 and B2). They are all widespread perennials in Estonia [28, 31]. None of the moss species was common to all sites. *Ceratodon purpureus* (Hedw.) Brid. was the most common moss species in site A1. The same species has been described as the first bryophyte to colonise levelled oil shale mining landscapes in Estonia [21].

The total percentage cover of the field layer was > 60% in all sites with continuous A-horizon but over two times lower on quarry spoil in site A1 (Table 4). Species richness was significantly higher in B2. The highest values for species evenness (E) and Simpson's diversity index (D) were recorded on quarry spoil. In such ecologically extreme conditions individual species have not yet succeeded to dominate over others.

The studies have shown that natural forestation of abandoned oil shale opencasts usually produces a mixed stand with lower productivity compared to artificial afforestation [30]. At the same time the analysis of vegetation restora-

Table 4. **Comparison of the average total percentage cover of the field layer, species richness (S), evenness (E) and Simpson's diversity index (D) between studied sites, ±1 standard error**

Site	% cover	S	E	D
A1	27 ± 6.0 c[a]	12.5 ± 0.77 b	0.89 ± 0.019 a	0.86 ± 0.011 a
A2	82 ± 1.0 a	15.3 ± 0.92 b	0.77 ± 0.016 b	0.81 ± 0.017 ab
B1	60 ± 3.2 b	14.6 ± 1.28 b	0.69 ± 0.026 b	0.74 ± 0.032 b
B2	75 ± 1.8 ab	20.5 ± 1.08 a	0.71 ± 0.025 b	0.78 ± 0.029 ab

[a] Letters within each column denote significant differences between means determined by Tukey HSD test (p <0.05) after one-way ANOVA.

tion on oil shale opencasts in Estonia has indicated that spontaneous succession on calcareous and stony spoils may have several advantages in terms of increased plant diversity [48]. The study of long-term vegetation recovery on reclaimed coal surface mines in the eastern USA [49] indicated that the vegetation composition in the reclaimed sites is following a successional trajectory towards the surrounding forests and some reclamation efforts (e.g. retention of nearby seed sources) should be considered in order to accelerate the process. The plantations that we focused on in the current study are situated quite near to the edge of the opencast and are surrounded by exhausted areas that have been reclaimed as agricultural and forest lands during the past 40 years. Therefore the availability of nearby seed sources was good.

Despite the environmental differences between the sites, the division of vascular plant species by life form followed rather similar patterns (Table 5). In our study, development of vegetation cover represented primary succession in site A1 and that on former arable land (B1, B2) represented secondary succession. The study of changes in species traits during succession in the Czech Republic has also indicated that trends of life-history characteristics of constituent species did not differ significantly between primary and secondary series after the first 10 years of succession [50]. All sites were dominated by hemicryptophytes (Table 5). A similar trend has been observed by Wiegleb and Felinks [51], who studied the chronosequence of early primary succession in post-mining landscapes of eastern

Table 5. **Division of vascular plant species into life form, dispersal mode and life-span categories in studied sites**

Life form:	1[a]	2	3	4	5	6	H	L
A1 (%)	8	5	14	49	14	10	–	–
A2 (%)	–	–	9	67	17	–	–	7
B1 (%)	3	–	9	52	13	13	2	8
B2 (%)	4	1	8	58	11	12	–	6
Dispersal mode:	I[b]	II	III	IV	V			
A1 (%)	14	48	2	29	7			
A2 (%)	17	33	6	32	12			
B1 (%)	16	36	4	35	9			
B2 (%)	18	33	6	33	10			
Life-span:	A[c]	B	P	T	S			
A1 (%)	12	15	52	15	6			
A2 (%)	8	8	84	–	–			
B1 (%)	17	15	62	6	–			
B2 (%)	16	8	69	6	1			

[a] Life form categories: 1 – phanerophytes; 2 – nanophanerophytes; 3 – chamaephytes; 4 – hemicryptophytes; 5 – geophytes; 6 – therophytes; H – half parasites; L – lianas

[b] Dispersal mode categories: I – autochorous; II – anemochorous; III – hydrochorous; IV – zoochorous; V - anthropochorous

[c] Life-span categories: A – annuals; B – biennials; P – perennials; T – trees; S – shrubs

Germany and found that hemicryptophytes dominated on all study sites, even in pioneer stands. The comparison of vascular plant species from the four sites with respect to seed dispersal mode and life-span revealed also similarities. As a difference, higher proportion of woody plants in A1 could be pointed out. Seeds of woody plants from A1 are mainly wind-dispersed that facilitates their arrival. Their germination on uncolonized spoil is easier as the competition with tall herbaceous plants is missing.

According to classification (TWINSPAN) and ordination (DCA) the vegetation composition of 5-year-old hybrid aspen plantation in the quarry site with reestablished soil was more similar to the plantations on former arable soils than to the plantation on quarry spoil (Fig. 4).

Consequently covering of the quarry spoil with a previously removed soil had promoted vegetation restoration. We must consider that, besides providing a more fertile growth environment, the reestablished soil could contain seed bank from the pre-mining period. At the same time soil removal, loading and transport into storage, and its use for recovering the area after mining is used mainly when the aim is to reclaim the area as arable land and this is a very expensive process when compared with reforestation of bare quarry spoil [52].

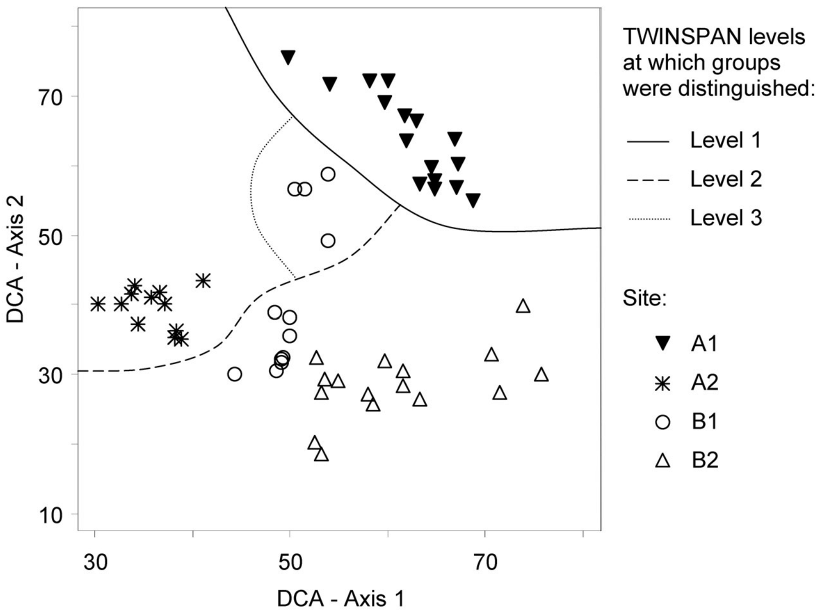

Fig. 4. Biplot of DCA Axis 1 (Eigenvalue = 0.42) and Axis 2 (Eigenvalue = 0.42) scores for 56 plots at four sites, with TWINSPAN classification groupings.

Conclusions

The early growth speed of hybrid aspens in the extreme substrate conditions of the levelled quarry spoil is significantly slower compared to the results from the quarry area covered with the former soil and from former arable soils. The growth rate of hybrid aspens in quarry site covered with previously removed soil has been comparable with the results from former arable land in the same region but it is significantly slower compared to the results from South-Estonian *Planosols* where hybrid aspen has shown promising growth potential on former arable land.

Significant deficiency of P in the substrate and N and P in tree leaves was observed in plantations established on bare quarry spoil, resulting in below optimal growth speed of hybrid aspens. It could be overcome by fertilization during the early growth stage.

Covering the spoil with former soil after mining can be seen as a promoting but expensive tool for ecological restoration of exhausted oil shale opencasts. It accelerates the development of the ground vegetation and creates a more fertile environment for forest plantations. During the five year time span the vegetation of the site with reestablished soil resembled that of former agricultural land.

Despite the relatively slow growth speed of hybrid aspen during the first five years after planting in the reclaimed quarry areas, the monitoring should proceed through the whole rotation period. The study of the suitability of using deciduous trees for reclamation of quarry areas should continue in Estonia in order to reduce the environmental risks caused by the large share of monocultural Scots pine plantations in the mining region.

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REFERENCES

1. *Bradshaw, A. D.* The reconstruction of ecosystems. Presidential address to the British Ecological Society, December 1982 // J. Applied Ecol. 1983. Vol. 20, No. 1. P. 1–17.
2. *Kaar, E., Tomberg, E.* Recultivation of the quarry spoil // 90 years of oil shale mining in Estonia. Proceedings of the Conference of Estonian Miners 2006 by

Estonian Mining Society / I. Valgma (ed.). Department of Mining, Tallinn University of Technology, 2006. P. 78–83 [in Estonian].
3. *Kaar, E.* Coniferous trees on exhausted oil shale opencast mines // Forestry Studies. 2002. Vol. 36. P. 120–125.
4. *Kaar, E.* Recultivation in Estonia // History of Forestry. Series Pages of the History of Science of Estonia XII (Collected papers) / T. Meikar (ed.). Tallinn: Estonian Academy Publishers, 1998. P. 175–193 [in Estonian with English and German summaries].
5. *Vares, A., Lõhmus, K., Truu, M., Truu, J., Tullus, H., Kanal, A.* 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. 2004. Vol. 21, No. 1. P. 43–58.
6. *Kaar, E., Raid, L.* Einige Ergebnisse der Rekultivierung eingeebneter Schiefertagebauen // Forestry Studies. 1992. Vol. 25. P. 109–117 [in Estonian with German and Russian summaries].
7. *Kaar, E.* Of some results of the reclamation of opencast oil shale mining pits. Forest Research: Past and Present // Proceedings of the Estonian Academic Forest Society. Vol. 18 / T. Meikar, Ü. Tamm (eds.). Tartu: Forest Research Institute of EAU, 2002. P. 123–131 [in Estonian].
8. *Spears, J. D. H., Lajtha, K., Caldwell, B. A., Pennington, S. B., Vanderbilt, K.* Species effects of *Ceanothus velutinus* versus *Pseudotsuga menziesii*, Douglas-fir, on soil phosphorus and nitrogen properties in the Oregon cascades // For. Ecol. Manage. 2001. Vol. 149, No. 1. P. 205–216.
9. *Ostonen, I., Lõhmus, K., Alama, S., Truu, J., Kaar, E., Vares, A., Uri, V., Kurvits, V.* Morphological adaptions of fine roots in scots pine *(Pinus sylvestris* L.), silver birch (*Betula Pendula* Roth) and black alder (*Alnus glutinosa* (L.) Gaertn) stands in recultivated areas of oil shale mining and semicoke hills // Oil Shale. 2006. Vol. 23, No. 2. P. 187–202.
10. *Yu, Q., Tigerstedt, P. M. A., Haapanen, M.* Growth and phenology of hybrid aspen clones (*Populus tremula* L. × *Populus tremuloides* Michx.) // Silva Fennica. 2001. Vol. 35, No. 1. P. 15–25.
11. *Rytter, L., Stener L.-G.* Productivity and thinning effects in hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) stands in southern Sweden // Forestry. 2005. Vol. 78, No. 3. P. 285–295.
12. *Bungart, R., Hüttl, R. F.* Production of biomass for energy in post-mining landscapes and nutrient dynamics // Biomass and Bioenergy. 2001. Vol. 20, No. 3. P. 181–187.
13. *Casselman, C. N., Fox, T. R., Burger, J. A., Jones, A. T., Galbraith, J. M.* Effects of silvicultural treatments on survival and growth of trees planted on reclaimed mine lands in the Appalachians // For. Ecol. Manage. 2006. Vol. 223, No. 1–3. P. 403–414.
14. *Tullus, H.* Guidelines for fast-growing forest plantations as an alternative land use. 2005. http://www.agri.ee/public/juurkataloog/MAAELU/lisa_001.pdf (5.02.2008) [in Estonian].
15. *Tullus, A., Tullus, H., Vares, A., Kanal, A.* Early growth of hybrid aspen (*Populus × wettsteinii* Hämet-Ahti) plantations on former agricultural lands in Estonia // For. Ecol. Manage. 2007. Vol. 245, No. 1–3. P. 118–129.
16. *Bradshaw, A. D.* Restoration of mined lands – using natural processes // Ecol. Engineering. 1997. Vol. 8, No. 4. P. 255–269.

17. *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.
18. *Reintam, L.* Rehabilited quarry detritus as parent material for current pedogenesis // Oil Shale. 2004. Vol. 21, No. 3. P. 183–193.
19. *Reintam, L., Kaar, E., Rooma, I.* Development of soil organic matter under pine on quarry detritus of open-cast oil-shale mining // For. Ecol. Manage. 2002. Vol. 171, No. 1–2. P. 191–198.
20. *Reintam, L., Kaar, E.* Natural and man-made afforestation of sandy-textured quarry detritus of open-cast oil-shale mining // Baltic Forestry. 2002. Vol. 8, No. 1. P. 57–62.
21. *Laasimer, L.* Occupation of levelled oil-shale pits by plants // Forestry Studies. 1973. Vol. 10. P. 168–185 [in Estonian with English summary].
22. *Raid, L.* Über den Wasserhaushalt der obrigen Bodenschichten der eingeebneten Kippen der Brennschiefertagebaue // Forestry Studies. 1972. Vol. 9. P. 159–171 [in Estonian with German and Russian summaries].
23. *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.
24. *Leedu, E., Murdam, L.* The recultivation of Estonian open-cast oil-shale pits into fields and the microbiological state of stripped topsoil during its storage // J. Agric. Sci. 1996. Vol. 7, No. 4. P. 342–356.
25. *Kitse, E., Leis, R.* The range of available moisture, humus supply and yield potential of the Estonian arable soils // Transactions of Estonian Agricultural University. 1996. Vol. 187. P. 65–76.
26. WRB. World reference base for soil resources 2006. World soil resources report 103. Rome: Food and Agriculture Organization of the United Nations. 2006. 145 p.
27. *Rooma, I., Kitse, E., Leedu. E.* Technogenic field soils in Kohtla-Järve district. Application aspects of geography in agriculture. Tallinn-Saku: EMMTUI, ETA, GI, EGS. 1982. P. 18–25 [in Estonian].
28. *Kukk, T., Kull, T.* Atlas of the Estonian flora. – Tartu: Institute of Agricultural and Environmental Sciences of the Estonian University of Life Sciences, 2005. 528 p.
29. *Ingerpuu, N., Vellak, K.* Estonian bryoflora. – Tartu: EPMÜ ZBI, Eesti Loodusfoto, 1998.
30. *Lindacher, R.* PHANART. Datenbank der Gefässpflanzen Mitteleuropas. Erklärung der Kennzahlen, Aufbau und Inhalt. – Zürich: Geobotanisches. Inst. ETH, Stiftung Rübel 125, 1995. 436 S.
31. *Krall, H., Kukk, T., Kull, T., Kuusk, V., Leht, M., Oja, T., Reier, Ü., Sepp, S., Zingel, H., Tuulik, T.* Guidebook of Estonian Vascular Plants / M. Leht (ed.). – Tartu: 1999 [in Estonian].
32. StatSoft, Inc. STATISTICA (data analysis software system), version 7. 2004 [www.statsoft.com].
33. *McCune, B., Mefford, M. J.* Multivariate Analysis of Ecological Data. Version 4.0 - MjM Software, Gleneden Beach, Oregon, USA, 1999.
34. *Hill, M. O.* TWINSPAN – a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. - Cornell University, Ithaca, New York, 1979.

35. *Hill, M. O.* DECORANA – a FORTRAN program for detrended correspondence analysis and reciprocal averaging. – Cornell University, Ithaca, New York, 1979.
36. *Kaar, E.* Über die Aufforstung von Ölschiefertagebauen // Forestry Studies. 1968. Vol. 6. P. 20–30 [in Estonian with German and Russian summaries].
37. *Kaar, E., Lainoja, L., Luik, H., Raid, L., Vaus, M.* Restoration of oil shale open-cast mines. Ministry of Forestry and Nature Conservation of ESSR. 1971. 116 p. [in Estonian].
38. *Piho. A.* Potassium content and forms in soils of ESSR // Soil Science and Agrochemistry. Transactions of EMMTUI. 1967. Vol. 10. P. 110–122 [in Estonian].
39. *Leedu, E., Murdam, L.* The microbiological state of deposited calcareous humus soil foundation of open-cast oil-shale pits connected with soil nitrogen // Transactions of Estonian Agricultural University. 1996. Vol. 187. P. 77–86 [in Estonian with English summary].
40. *Harley, J. L., Harley, E. L.* A check-list of mycorrhiza in the British flora // New Phytol. 1987. Vol. 105 (Suppl). P. 1–102.
41. *Lodge, D. J., Wentworth, T. R.* Negative associations among VA-mycorrhizal fungi and some ectomycorrhizal fungi inhabiting the same root system // Oikos. 1990. Vol. 57, No. 3. P. 347–56.
42. *Trémolières, M., Sánchez-Pérez, J. M., Schnitzler, A., Schmitt, D.* Impact of river management history on the community structure, species composition and nutrient status in the Rhine alluvial hardwood forest // Plant Ecology. 1998. Vol. 135, No. 1. P. 59–78.
43. *Singh, A. N., Zeng, D. H., Chen, F. S.* Effect of young woody plantations on carbon amd nutrient accretion rates in a redeveloping soil on coalmine spoil in a dry tropical environment, India // Land Degradation & Development. 2006. Vol. 17, No. 1. P. 13–21.
44. *Day, A. D., Tucker, T. C., Thames, J. L.* Response of plant species to coal-mine soil materials // Environmental Geochemistry and Health. 1983. Vol. 5, No. 1. P. 10–14.
45. *Reeder, J. D., Berg, W. A.* Nitrogen mineralization and nitrification in a Cretaceous shale and coal mine spoils // Soil Sci. Soc. Am. J. 1977. Vol. 41, No. 5. P. 922–926.
46. *Kaar, E.* Beitrag zur Düngung der Waldkulturen auf den eingeebneten Kippen der Brennschiefertagebaue // Forestry Studies. 1972. Vol. 9. P. 146–158 [in Estonian with German and Russian summaries].
47. *Kuznetsova, T., Mandre, M.* Chemical and morphological indication of the state of lodgepole pine and Scots pine in restored oil shale opencast mining areas in Estonia // Oil Shale. 2006. Vol. 23, No. 4. P. 366–384.
48. *Pensa, M., Sellin, A., Luud, A., Valgma, I.* An analysis of vegetation restoration on opencast oil shale mines in Estonia // Restoration Ecol. 2004. Vol. 12, No. 2. P. 200–206.
49. *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.
50. *Prach, K., Pysek, P., Smilauer, P.* Changes in species traits during succession: a search for pattern // Oikos. 1997. Vol. 79, No. 1. P. 201–205.
51. *Wiegleb, G., Felinks, B.* Predictability of early stages of primary succession in post-mining landscapes of Lower Lusatia, Germany // Applied Veget. Sci. 2001. Vol. 4. P. 5–18.

52. *Toomik, A., Liblik, V.* Oil shale mining and processing impact on landscapes in north-east Estonia // Landscape and Urban Planning. 1998. Vol. 41, No. 3–4. P. 285–292.

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