Natural and Man-Made Afforestation of Sandy-Textured Quarry Detritus of Open-Cast Oil-Shale Mining

LOIT REINTAM
Institute of Soil Science & Agrochemistry, Estonian Agricultural University,
Viljandi Road, Eerika, 51014 Tartu, Estonia
ELMAR KAAR
Forest Research Institute, Estonian Agricultural University,
Kreutzwaldi 5, 51014 Tartu, Estonia

Reintam, L., Kaar, E. 2002. Natural and Man-Made Afforestation of Sandy-Textured Quarry Detritus of Open-Cast Oil-Shale Mining. *Baltic Forestry*, 8 (1): 57–62.

Spontaneous natural development of a 60-year-old forest ecosystem on unlevelled quarry detritus was studied in comparison with the outcome of planned afforestation from the early 1960s on the levelled sandy detritus of oil-shale quarries at Viivikonna, North-East Estonia (27°45' E, 59°19' N). High productivity pine (*Pinus sylvestris*) stands have been formed not only during 60 years as a result of natural afforestation but also during 20–40 years as a result of forest rehabilitation. The annual rate of the growing stock was the highest (7.1–7.6 $\mathrm{m^3\ ha^{-1}}$) and average height (50–54 cm) and breast-height diameter increment (4–5 mm) were the largest in the planted forest. Both planted and sown man-made ecosystems on levelled detritus surpassed the mixed forest that developed naturally-spontaneously on unlevelled hilly detritus over a period of sixty years. A unitary layer of the forest floor and a well diagnosable O2–A–AC– BC profile of Calcaric Arenosol were formed already during 20–30 years after forest rehabilitation. Plant (forest) humus is prevalent in the development of intensive humus-accumulative processes. R_2O_3-humic-fulvic humus is rich in Ca-fulvates, owing to which pedogenetic weathering is still weak. The intensity of pedogenesis has been more considerable in levelled and rehabilited detritus, while increased content of organic carbon, base exchange capacity and nonsiliceous iron relationships were observed under the sown pine stand enriched naturally with silver birch (*Betula pendula*). Possible erosion of unlevelled hilly detritus could have decelerated spontaneous natural afforestation and inhibit soil formation processes.

Key words: Estonia, forest rehabilitation, spontaneous natural afforestation, primary pedogenesis, quarry detritus of open-cast mining.

Introduction

Open-cast oil-shale (kukersite) mining started in North-East Estonia already in the late 1930s–early 1940s. Until World War II rehabilitation was not practised and there began spontaneous afforestation of unlevelled hilly detritus which represents disintegrated rock debris turned out of the covering bedrock to the surface in the process of open-cast mining. Ordovician limestones form about 600–700 g $\mathrm{kg^{-1}}$ of detritus making it coarse and calcareous. Planned rehabilitation of calcareous detritus for forestry purposes has been carried out in the area of over 9000 ha since 1960. A survey of the silvicultural properties of quarry detritus as well as the first results of forest rehabilitation were published in the early 1970s (Vaus 1970; Kaar et al. 1971). Afforestation with 2–3-year-old seedlings proved to be highly effective (Kaar 1968, 1998). The soils formed on pure detritus during 20–40 years after forest rehabilitation were studied to ascertain the character and capacity of pedogenesis (Reintam & Kaar 1999; Reintam et al. 2000, 2001; Reintam 2001a, 2001b). Spontaneous afforestation and formation of forest–soil systems on unlevelled detritus have been discussed only in a brief conference presentation (Reintam & Kaar 2001).

This study focuses on the comparison of some results of the spontaneous and the planned afforestation of sandy-textured detritus at Viivikonna.

Material and methods

Three areas at Viivikonna (27°45' E, 59°19' N) were investigated: one was spontaneously afforested from 1940 on unlevelled hilly detritus, another was established by planting two-year-old seedlings of Scots pine (*Pinus sylvestris*) in 1963 and the third was established by sowing pine seeds in 1961. The average content of skeletal fractions was 635 g $\mathrm{kg^{-1}}$ in restored areas (Vaus 1970) and 210–500 g $\mathrm{kg^{-1}}$ in the spontaneously afforested area. Fine earth (< 2 mm) was quite similar in all areas, containing 638±12, 298±12 and 64±7 g $\mathrm{kg^{-1}}$ of sand, silt and clay, respectively. Specific surface area was 19±4 $\mathrm{m^2\ g^{-1}}$, base exchange capacity 8.4±2.1 cmol

kg^{-1} and the pH of water suspension 7.8±0.1. During the years that passed no human impact was exerted either on stocking density or on canopy structure. Stand inventory was carried out in circular plots of 0.05–0.1 ha in the restored areas in 1979, 1986 and 1998, and in the spontaneously afforested area in 1988 and 2000. Soil sampling by formed genetic horizons and their morphological description were carried out in 1988, 1996 and 2000 to a depth where signs of pedogenesis occurred. Well known methods of soil science were applied (Schoeneberger et al. 1998).

Milled dry litterfall (falling litter) and ground litter (forest floor), as well as fine earth with particle size less than 2 mm were analysed. Samples for the determination of particle size were treated with sodium pyrophosphate to break down aggregates. Sands were sieved and fractions finer than 0.05 mm were determined by pipette analysis (*Pipette Apparatus Table Model 7 Samples*). Base exchange capacity (BEC) and exchangeable bases were measured by the percolation of the samples with ammonium acetate at pH 7.0 and expressed in cmol kg^{-1}. Total amounts of organic carbon and nitrogen were measured by the Tyurin and Kjeldahl volumetric methods, respectively. The group and fractional composition of humus was determined by an alternate acid–alkaline treatment using the Tyurin–Ponomareva volumetric method (Ponomareva, 1957). The obtained results were expressed in percentages of organic carbon of plant origin (C_{plant}), which was obtained by the subtraction of residual kukersite ($C_{kukersite}$) from total (C_{total}) organic carbon. Tithionite-extractable (Fe_d) iron, oxalate-extractable amorphous iron, aluminium and silica were measured by Coffin and Tamm, respectively; iron activity was calculated after Schwertmann (van Ranst et al. 1999). The pH of water suspension was measured potentiometrically with a pH meter *Jenway 3071*. Specific surface area (SSA) was measured after Puri and Murari by means of water absorption from the steam-saturated atmosphere above 41% sulphuric acid (Kitse & Rooma 1984). The obtained results were expressed in $m^2\ g^{-1}$. All studied samples represented the average of different parts of the horizons. Accuracy requirements for laboratory techniques and measurements were satisfied as for any reference profile (Batjes & van Engelen 1997).

Results and discussion

As a result of scheduled plantation and sowing, high productivity stands were formed over 37 years (Table 1). The attained average height and breast-height diameter were close to the respective characteristics of the spontaneously developed natural stand when the latter was about a dozen years older. Concerning breast-height basal area and the growing stock, the planted pine stand appeared to be more productive than the sown stand, and both its total and annual productivity exceeded considerably those of the mixed forest, which had developed spontaneously over a period of sixty years (Fig. 1). In 1986–1998, the average annual increase in the growing stock of man-established pine stands, aged from 25 to 37 years, proved to be more than twofold larger compared with the respective parameters of the spontaneously formed mixed stand, aged 48 to 60 years, during a period of the same length (1988–2000). It means that surface levelling of detritus is of great importance both for formation of water relationships (Raid 1972) and for favourable initial progress of seedlings (Table 1).

The rate of annual increment in the growing stock appeared to be highest in the second and third decades of the development of the planted forest (Table 1). In

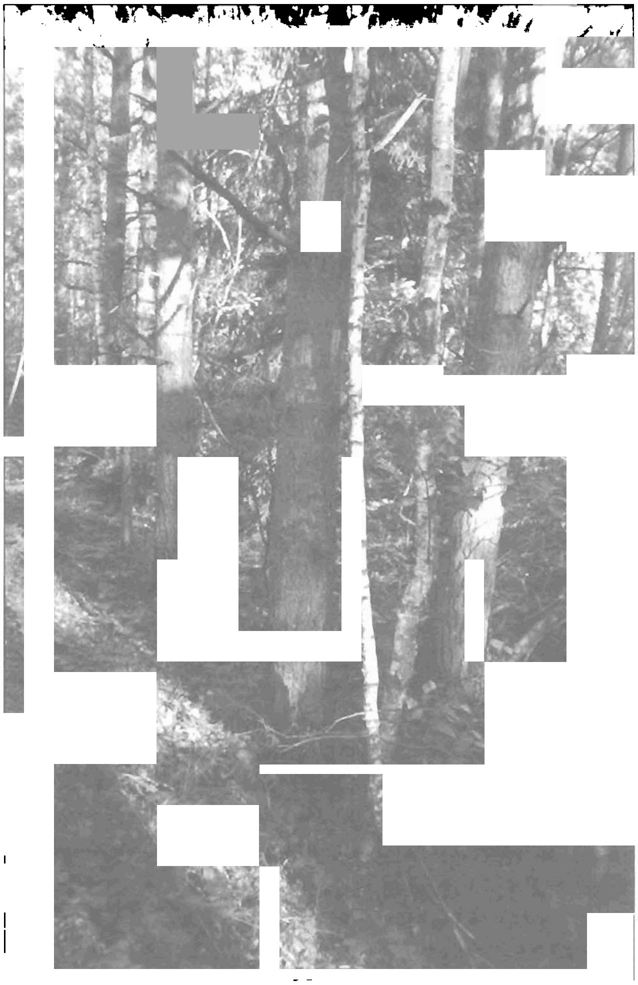

Figure 1. A 60-year-old stand (Scots pine mixed with silver birch and aspen) developing naturally-spontaneously since 1940

Table 1. Productivity characteristics of the stands

Mode of affor-estat-ion	Compo-sition of the first layer	Age	Stock-ing density	Average height		Breast-height diameter		Breast-height basal area, $m^2 ha^{-1}$	Growing stock	
				m	cm yr^{-1}	cm	mm yr^{-1}		$m^3 ha^{-1}$	$m^3 ha^{-1} yr^{-1}$
Spon-tane-ous	Pine (7)	48	0.57	17.1	35.6	19.2	4.0	18.2	149	3.1
	Birch (2)		0.26	18.1	37.7	14.8	3.1	6.2	57	1.2
	Aspen (1)		0.08	16.7	34.8	12.4	2.6	1.9	16	0.3
	Total		0.91	17.5	36.5	16.9	3.5	26.3	222	4.6
	Pine (7)	60	0.65	18.2	30.3	21.1	3.5	20.9	180	3.0
	Birch (2)		0.30	21.6	36.0	18.0	3.0	7.9	79	1.3
	Aspen (1)		0.09	17.9	29.8	13.7	2.3	1.8	9	0.2
	Total		1.04	19.2	32.0	19.3	3.2	30.6	268	4.5
Plant-ed	Pine (10)	18	1.30	8.8	54.1	8.3	4.6	25.2	127	7.1
		25	0.90	12.6	54.1	11.6	5.0	28.2	183	7.3
		37	0.90	17.7	50.0	15.1	4.0	33.3	280	7.6
Sown	Pine (10)	18	0.60	7.9	43.9	7.0	3.9	12.6	59	3.3
		25	0.50	10.0	40.0	8.4	3.4	14.7	80	3.2
	Pine (7)	37	0.50	15.8	42.7	15.4	4.2	16.0	123	3.3
	Birch (3)	35	0.30	18.2	52.0	19.0	5.4	7.9	69	1.9
	Total	37	0.80	16.4	45.6	16.3	4.4	23.9	192	5.2

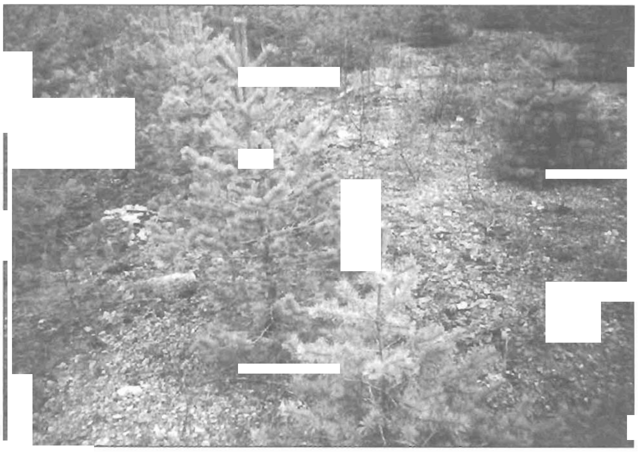

Figure 2. An uncoalesced pine stand younger than 10 years without ground litter, only some litterfall occurring under tree crowns

the case of the sown pine stand, whose development was completed in a natural way with spontaneously growing silver birch (*Betula pendula*), an increase in the annual increment occurred on transition from the third to the fourth decade. Similarly, it is possible to estimate the annual increments of the average height and breast-height diameter with respect to the temporal progress of stands. Although the spontaneously formed mixed stand is characterised by the reduced rate of productivity in the sixth decade, absolute increase in the height and thickness of pine and birch remained appreciable.

We had no data about the formation of forest ground litter on unlevelled detritus in the 1940s–1980s. The litterfall of the 60-year-old stand was poor in ash (63.3 g kg^{-1}) but rich in organic carbon and nitrogen (233 and 12.5 g kg^{-1}, respectively). Owing to the presence of silver birch and aspen (*Populus tremula*) in the tree layer as well as to the composition of ground vegetation (*Fragaria vesca, Pyrola rotundifolia, Convollaria majalis, Rubus saxatilis, Calamagrostis arundinacea, etc.*), exchangeable calcium (45 cmol kg^{-1}) formed more than 80% of base exchange capacity (55–56 cmol kg^{-1}) in the litterfall of the spontaneously developed stand. In spite of base saturation, the actual acidity of litterfall was slightly acid (pH of water suspension 5.8).

During the first decade following rehabilitation, young planted and sown stands had not yet coalesced (Fig. 2) and thin ground litter formed only in places under tree crowns. However, there had appeared a humus horizon in the form of transitional AC with thickness of 5–10 cm, and organic carbon of pedogenetic origin (15–20 g kg^{-1}), while the C : N ratio (31–87) was large. By the end of the second decade, falling and ground litter represented as everywhere a unitary layer with a depth of 2–3 cm and with a pool of 2.7–3.6 kg m^{-2}. These features appear to be common for any rehabilited stand in the region. An independent humus horizon (A) could already be distinguished from AC. After 37 years, a brownish black (10YR2/2) A-horizon also occurred in places here. Very dark greyish brown (10YR3/2) AC had deepened to a depth of 20–25 cm. Falling litter (litterfall) and *Moder*-type ground litter were already differentiated. In principle, in the conditions of spontaneous afforestation, soil formation must have been progressed in the same way, although the rate of processes was lower owing to probable erosion and the fragmentary formation of the forest floor due to unlevelled hilly topography (Fig. 3). Therefore its thickness was not more than 2–3 cm by the end of the sixth decade (Table 2) and the A-horizon was light (10YR4/2) in colour (Fig. 4). The main properties of the permanent forest floor appear to have been developed simultaneously with its formation and have been unchanged in time (Table 2). Its ash content is several times larger than that of litterfall. Without doubt, this phenomenon is related not only to natural transformation processes, but also to the activity of the soil fauna, especially earthworms. Earthworms are present almost everywhere in the thin topsoil under stands beginning from the age of 20–30 years. A slight increase in the C : N ratio in time tends to indicate a more intensive accumulation of carbon compared with the formation of nitogenous bridges in the polyphenolic rings of the humic-fulvic molecules of derived humus substances (Flaig 1971).

Table 2. Main properties of the forest floor

Forest	Age	Thickness, cm	Ash	Org. C	N	C/N	BEC, cmol kg^{-1}	pH
			g kg^{-1}					
Sponta-neous	48	1–3	274	195	12	16	55.2	6.4
	60	2–3	376	265	11	24	60.3	6.4
Planted	25	2–3	424	270	10	27	undet.	6.2
	37	2–3	344	300	11	27	56.9	5.8
Sown	37	2–3	217	304	10	30	65.9	6.0

Except in the subsoil under the spontaneously formed stand deeper than 35 cm, the fulvic composi-

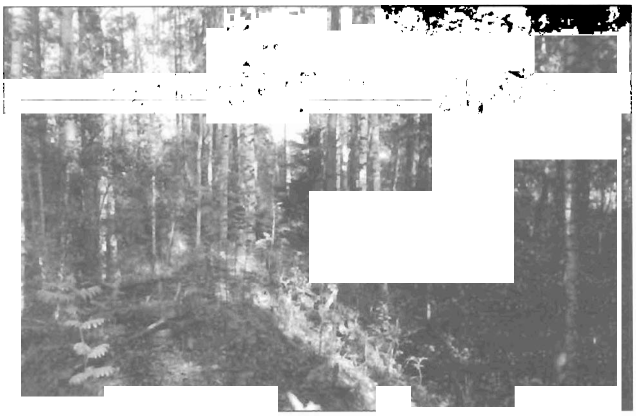

Figure 3. The poorly developed ground vegetation and forest floor on top of an unlevelled detritus hill under the spontaneously progressing birch–pine mixed stand

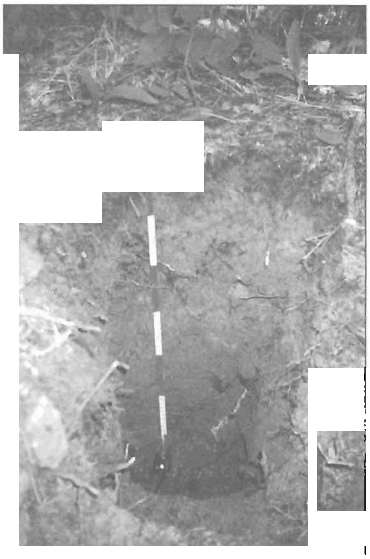

Figure 4. A 60-year-old profile of Calcaric Arenosol under naturally-spontaneously developed forest.

Table 3. Composition of plant-derived humus in percentages of organic carbon in 1998–2000

tion, total solubility and insoluble residue of plant-derived organic carbon ($C_{plant} = C_{total} - C_{kukersite}$) are similar in the forest floor (O2) and in mineral soil horizons (Table 3). Ca-fulvates (2nd fraction) have formed and fixed in the humus-accumulative soil section beneath the forest floor. At the same time, fulvic acids bound with mobile iron and aluminium (1st fraction) occur abundantly namely in the forest floor because of their scanty content in formed soil horizons (Reintam et al. 2001). Only a few free fulvic acids (1a fraction) are present. This situation explains the weak development of weathering (Reintam, 2001a; Table 4) against the background of the progress of humus-accumulative processes (Reintam 2001b; Reintam et al. 2001; Table 4). Fulvic acids bound with inactive sesquioxides and fine-dispersed mineral particles (3rd fraction), as well as substances fixed in the interlayeral structure of clay minerals (hydrolysate of 0.5 M sulphuric acid) are quite abundant. Such fixation of fulvic compounds seems to be characteristic of primary pedogenesis in any substrate (Reintam 1995).

The humic composition is different on different sites (Table 3). The total amount of humic acids as well as the amount of humic acids bound with alkaline earths (2nd fraction) are the largest under the planted stand where coalescence was attained earlier and the ground vegetation developed more rapidly than elsewhere. The proportion of humic acids bound with inactive sesquioxides and/or clay minerals is largest under the sown stand. This can be explained by the rapid progress of deep-rooted *Calamagrostis arundinacea* before the formation of the permanent forest floor there. The situation has resulted in the formation of humic humus (according to the H.a. : F.a. ratio) across the entire profile. In both other profiles, humus is fulvic-humic (ratio > 0.7) or humic-fulvic to fulvic (ratio < 0.7). A relatively slow formation of humic acids has taken place during the spontaneous progress of forest. As was already mentioned, the reason for this appears to be the probable erosion of long duration as well as the possible long-lasting absence of ground litter and ground vegetation on the top elements of topography (Fig. 3). Except for some rare horizons of soil under the spontaneously formed stand, humic-fulvic complexes bound with mobile sesquioxides (1st fraction) prevail everywhere, the respective ratio being highest for the forest floor.

The thin humus-accumulative section of formed Calcaric Arenosols is characterised by extremely weak differentiation, and increase in specific surface area, base exchange capacity and content of organic carbon in the epipedon (Table 4). R_2O_3-humic-fulvic humus is saturated with Ca-fulvates, owing to which pedogenetic argillisation is yet absent, and only a tendency for the layer-wise formation of nonsiliceous iron (Table 4), amorphous aluminium (0.6–1.0 g kg^{-1}) and silica (0.6–2.5 g kg^{-1}) can be observed. At the same time, it is still impossible to note any regularities in the weak layeral processes of pedogenetic silicate weathering. The high content of organic carbon in the uppermost 8–10 cm layer directly underneath the forest floor appears to be a result of both the chemical oxidation of residual kukersite pieces and pedogenetic processes. After subtraction of the residual carbon of kukersite (on average 23 g kg^{-1}) it is evident that pedogenetic processes and plant (forest) humus are prevalent. Ca^{2+} forms about 85–97% of base exchange capacity. Owing to the presence of the deep-rooted ground vegetation and spontaneous silver birch in the tree layer, the content of organic carbon of plant origin, base exchange capacity and the content of nonsiliceous iron are the highest in the soil under the sown forest.

Conclusions

High productivity forest ecosystems have formed as a result of the spontaneous natural and artificial afforestation of sandy quarry detritus. The plantation with 2-year-old seedlings developed more rapidly and was more vigorous. Spontaneous natural afforestation produced a mixed stand, the growth of which was several times lower. Although the *Moder*-type forest floor is characteristic of all sites, pedogenetic changes are less intensive here than in highly skeletal medium- and heavy-textured detritus. The development of cambic properties is still weak in formed Calcaric Arenosols.

Acknowledgements

This study was supported by the Estonian Science Foundation grant No 4090. We would like to thank Mrs. Raja Kährik for performing laboratory analyses and Mrs. Ester Jaigma for the linguistic revision of the English manuscript.

References

Batjes, N. H. & van Engelen, V. W.P. 1997. *Guidelines for the Compilation of a 1 : 2 500 000 SOTER Database (SOVEUR Project).* Report 97/06, International Soil Reference and Information Centre, Wageningen.

Flaig, W. 1971. Organic compounds in soil. *Soil Science*, **111**, 1. 19–33.

Kaar, E. 1968. Põlevkivikarjääride metsastamisest (Über die Aufforstung von Ölschiefertagebauen). *Metsanduslikud uurimused (Forest Research)*, **VI**, pp. 20–30. Valgus, Tallinn

Kaar, E. 1998.Recultivation in Estonia. *History of Forest Sciences. The History of Estonian Science*, **XII**, 175–193, Estonian Academy Publishers, Tallinn.

Kaar, E., Lainoja, L., Luik, H., Raid, L. & Vaus, M. 1971. *Põlevkivikarjääride rekultiveerimine.* Valgus, Tallinn.

Kitse, E. & Rooma, I. 1984. Mullateaduse laboratoorne praktikum. Eesti Põllumajanduse Akadeemia, Tartu.

Ponomareva, V.V. 1957. To the method for the study of soil humus after I.V. Tyurin's scheme. *Pochvovedenie (Soviet Soil Science)*, 8, 66–71.

Raid, L. 1972. Niiskustingimustest tasandatud põlevkivikarjääride pealmistes pinnasekihtides (Über den Wasserhaushalt der obrigen Bodenschichten der eingeebneten Kippen der Brennschiefertagebaue). In *Metsanduslikud uurimused (Foresty Research)*, **IX**, 159–171. Valgus, Tallinn (in Estonian with German and Russian summaries). Reintam, L. 1995. Temporal and spatial changes in organic agents in the progress of primary pedogenesis during thirty years. *Proc. Estonian Acad. Sci. Ecol.*, **5**, 3/4, 61–76.

Reintam, L. 1995. Temporal and spatial changes in organic agents in the progress of primary pedogenesis during thirty years. *Proc. Estonian Acad. Sci. Ecol.*, **5**, 3/4, 61–76.

Reintam, L. 2001a. Changes in the texture and exchange properties of skeletal quarry detritus under forest during thirty years. *Proc. Estonian Akad. Sci. Biol. Ecol.*, **50**, 31–39.

Reintam, L. Yu. 2001b. The humus state of initial soils under forest canopy on tailings of oil shale quarries. *Eurasian Soil Science*, **34**, 10, 1077–1085.

Reintam, L. & Kaar, E. 1999. Development of soils on calcareous quarry detritus of open-pit oil-shale mining during three decades. *Proc. Estonian Acad. Sci. Biol. Ecol.*, **48**, 251–266.

Reintam, L. & Kaar, E. 2001. Comparison of spontaneous and planned afforestation of sandy-textured quarry detritus of open-cast oil-shale mining. *Development of European Landscape. IALE European Conference Proceedings II. Publicationes Instituti Geographici Universitatis Tartuensis*, **92**, 480–485.

Reintam, L., Kaar, E. & Rooma, I. 2000. Formation and progress of soil organic matter under pine on quarry detritus of open-cast oil-shale mining. *Managing Forest Soils for Sustainable Productivity*, pp. 235–236. Soc. Portuguesa da Ciencia do Solo: Vila Real, Portugal.

Reintam, L., Kaar, E. & Rooma, I. 2001. Development of forest-soil systems on quarry detritus of open-cast oil-shale mining. *Ecosystems and Sustainable Development III. Advances in Ecological Sciences*, **10**, 645–656. WIT Press, Southampton, Boston.

Schoeneberger, P.J., Wysocki, D. A., Benham, E. C. & Broderson, W. D. (Revisers, Refiners, Compilers). 1998. *Field Book for Describing and Sampling Soils. Version 1.1.* National Survey Center, Natural Resources Conservation Service, U.S. Department of Agriculture, Lincoln, Nebraska.

Van Ranst, E., Verloo, M., Demeyer, A. & Pauwels, J. M. 1999. *Manual for the Soil Chemistry and Fertility Laboratory. Analytical Methods for Soils and Plants, Equipment and Management of Consumables.* University of Ghent: Gent, Belgium.

Vaus, M. 1970. *Eesti põlevkivikarjääride pinnaste metsakasvatuslikud omadused.* Valgus, Tallinn.

Received 26 February 2002

СПОНТАННО-ЕСТЕСТВЕННОЕ И РЕКУЛЬТИВАЦИОННОЕ ОБЛЕСЕНИЕ ПЕСЧАНЫХ ОТВАЛОВ СЛАНЦЕВЫХ КАРЬЕРОВ

Л. Рейнтам, Э. Каар

Резюме

Спонтанное развитие в течение 60 лет (с 1940 года) лесной экосистемы на сильнорасчлененных карьерных отвалах изучалось в Вийвиконна, Северо-Восточная Эстония (27° 45' в.д., 59° 19' с.ш.) в сравнении с посаженными (двухлетними саженцами) и посеянными лесами, представляющими собой продукт лесной рекультивации с начала 1960х годов. Во всех случаях сформировались высокопродуктивные сосняки. В состав древостоя сеянного сосняка естественно вошла берёза бородавчатая и осина. Наибольшие годовые приросты запаса (7,1-7,6 міга$^{-1}$), средней высоты (50 - 54см) и среднего диаметра (4 - 5мм) отмечались в посаженном с двулетними саженцами насаждении. По основным продукционным показателям посаженные и посевом созданные леса превосходят таковые естественных лесов на расчлененных отвалах. Сплошная лесная подстилка и хорошо диагностируемый 02-A-AC-BC профиль рендзины (калькарикового ареносоля) образовались уже в течение 20-30 лет после рекультивации. Полуторооксидно-гуматно-фульватный гумус содержит много кальциевых фульватов. Поглощенный комплекс также насыщен кальцием. Поэтому биологическое выветривание и образование глины развиты слабо. Интенсивность почвообразования более выражена в выравненных и рекультивированных отвалах, притом содержание органического углерода, ёмкость поглощения и показатели несиликатного железа являются наибольшими под сеянным лесом, с берёзой и возникшим напочвенным покровом. Возможная эрозия расчлененного холмистого отвала могла замедлить естественное облесение и тормозить почвообразование.

Ключевые слова: Эстония, лесная рекультивация, спонтанное естественное облесение, первичное почвообразование, карьерные отвалы.