Oil Shale, 2004, Vol. 21, No. 3
pp. 183-193

ISSN 0208-189X

https://doi.org/10.3176/oil.2004.3.01

REHABILITED QUARRY DETRITUS AS PARENT MATERIAL FOR CURRENT PEDOGENESIS

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The studies were carried out in North-East Estonia (27°08′–27°47′ E, 59°19′–59°21′ N) where in the early 1960s forest rehabilitation of the levelled skeletal quarry detritus of open-cast oil-shale mining was initiated with two-year-old seedlings of Scots pine (Pinus sylvestris), silver birch (Betula pendula), hybrid alder (Alnus hybridum), etc. The formed genetic soil horizons (A–AC) were studied, described, and sampled to a depth of 20–25 cm where signs of pedogenesis were disappeared. Milled dry ground litter and fine earth with particle size less than 2 mm were analyzed. Methods well known in soil science were applied. The organic C and N of oil shale (kukersite), present in detritus, were subtracted from the obtained values when the organic matter of plant origin was calculated. Highly productive stands developed with an annual increment of 5.4 ± 0.6 m^3 ha^{-1} in the growing stock as well as with an average annual increase of 43.2 ± 2.6 cm in height, 4.1 ± 0.2 mm in breast-height diameter and 2.8 ± 0.3 dm^3 in the growing stock per tree. Calcaric Regosols and/or Rendzic Leptosols have formed on detritus. The depth of the A–AC sequence of the O2–A–AC–(B)C profiles is 21.6 ± 1.5 cm. An average of 1.36 ± 0.2 Mg ha^{-1} yr^{-1} of organic carbon and 49 ± 8 kg ha^{-1} yr^{-1} of nitrogen have accumulated in the humus section and in Moder-type ground litter. The level of organic carbon was the highest (1.57 ± 0.56 Mg ha^{-1} yr^{-1}) under deciduous stands, but also under pine with grasses. R_2O_3-humic-fulvic humus, rich in Ca-fulvates, is characteristic of both ground litter and of the epipedon which is close to mollic. The amount of ash elements in ground litter is 318 ± 46 kg ha^{-1} yr^{-1}; compared with initial detritus, the increase in base exchange capacity, clay content and specific surface area is accompanied with the progress of forest–soil system.

Introduction

Quarry detritus is a disintegrated pure rock debris occurring in areas of open-cast mining. As any other formation of the weathering crust, it represents specific parent material for the soil. After biological rehabilitation, it can

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develop into a soil as a result of contemporary pedogenetic processes that take place under direct human observation. The interactions between the mineral constituents of detritus and organic matter of plant origin are currently observable, which allows to ascertain and study changes in pure detritus as well as the trends and character of modern soil formation.

A great number of studies on the productivity and properties of mine soils have been carried out in different natural situations, but the concepts of the formation, functioning and development of plant–soil systems have not often been pointed out. Forest rehabilitation of the skeletal quarry spoil of open-cast oil-shale mining in the early 1960s opened up a possibility to use this rocky material for the special study of forest–soil system [1–3]. This paper is aimed particularly at the presentation of the outcome of primary pedogenesis on skeletal detritus as soil parent material in areas of oil-shale mining.

Material and Methods

Sites, Sampling, and Taxation

The studies were conducted in North-East Estonia (27°08′–27°47′ E, 59°19′–59°21′ N) altogether in fifteen reference areas where in 1961–1978 the afforestation of the skeletal calcareous quarry detritus (Fig. 1) of open-cast oil-shale mining was performed by using two-year-old seedlings of Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*), hybrid and black alder (*Alnus hybridum*, *A. glutinosa*), as well as by sowing seeds of Scots pine. Scots pine and silver birch were chosen as the main tree species as they predominate also in natural forest alvar site types in arid limestone and calcareous till landscapes.

Oil-shale is named ‘kukersite’ after the estate and the village of Kukruse in the vicinity of which burning and oil-containing shale was found.

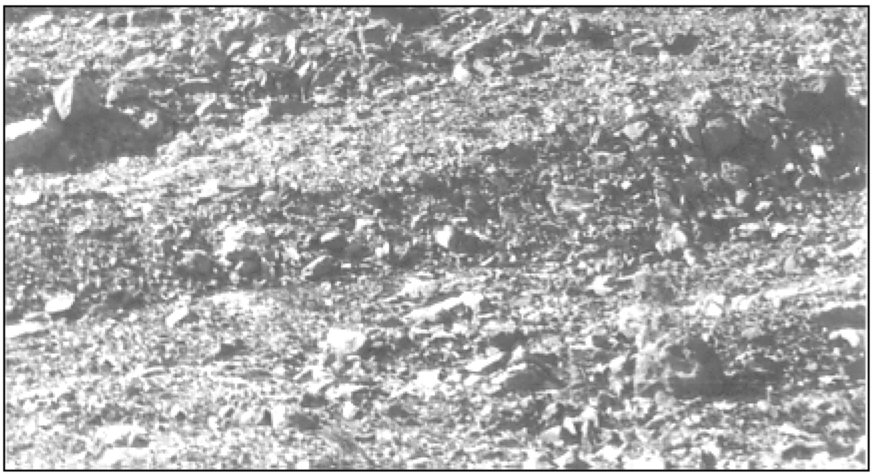

Fig. 1. Skeletal quarry detritus before afforestation

Kukersite has formed from the residues of green-blue algae in the Middle Ordovicium and it is covered with a complex of Ordovician ordinary and dolomitized limestones as well as Quaternary deposits. Mixed and restructured Ordovician-Quaternary material represents the skeletal detritus of open-cast mining there. The skeleton forms 400–750 g kg^{-1}, being almost entirely calcareous. Clay content varies in the range of 65–140 g kg^{-1} of fine earth which contains small fragments of residual kukersite yielding organic carbon in the amount of 14–20, rarely up to 40–50 g kg^{-1}. Mean annual temperature of +4.2 °C and precipitation of 584 mm are characteristic of the region. The sum of active temperatures (>10 °C) is 1,768, and the duration is 121 days. The annual amount of sunshine is 1,757 hours, and the duration of the permanent snow cover is 124 days.

The formed genetic soil horizons (A–AC) and initial detritus were studied, described and sampled in fifteen reference profiles to a depth of 20–35 cm where signs of evident soil formation were already disappeared and unchanged detritus was clearly distinguished. A well-known methodology of soil science, described in a great number of international and local manuals and handbooks, was applied. The soil horizons and detritus were sampled as an average from several particular points of the reference profiles. Bulk density was found in four replications using a steel cylinder of 50 cm^3. The stands were surveyed by Elmar Kaar in circular areas of 0.05 or 0.09 ha each. The number of trees, their height, breast-height diameter and age were measured, and basal area and the growing stock were calculated. These materials have been published in several joint papers cited above.

Analyses

Analyses were carried out by Raja Kährik in the laboratories of the Institute of Soil Science and Agrochemistry, Estonian Agricultural University. Milled dry forest floor (ground litter) and air-dry fine earth with a particle size less than 2 mm were used. 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 percolation of a sample with ammonium acetate at pH 7.0 and expressed in cmol kg^{-1}. The total amount of the organic carbon and nitrogen of soils and kukersite was measured by the Tyurin and Kjeldahl volumetric methods, respectively [4]. It is necessary to point out that the Anne method [5] is equivalent to the Tyurin method used. The organic carbon and nitrogen of oil shale (kukersite), present in detritus, were subtracted from the obtained total values when the organic matter of plant origin was calculated – knowing that organic carbon beneath young soil horizons was derived from the fragments of kukersite and assuming that such a kukersite-containing detritus was on the surface at the time when pedogenesis started. A similar problem has been also actual before [6].

Tithionite-extractable (total nonsiliceous) iron was measured by Coffin [5]. The group and fractional composition of humus was determined by an alternate acid–alkaline treatment using the Tyurin–Ponomareva volumetric method [4]. The obtained results were expressed in percentages of the organic carbon of plant (forest) origin.

Requirements for the accuracy of the laboratory techniques and measurements applied were satisfied. Statistically processed data include arithmetic mean (x), standard error of arithmetic mean (s_x) and coefficient of variation (V, %).

Results and Discussion

Progress of Vegetation and Productivity

During the first decade after forest rehabilitation, young stands did not yet coalesce and thin ground litter (forest floor) formed only under tree crowns. Limestone detritus cropped out everywhere between and beneath the young trees and/or among the spontaneous pioneer ground vegetation (*Tussilago farfara*, *Calamagrostis arundinacea*, *Chamanerion angustifolium*, *Ramischia secunda*, *etc*.).

Nevertheless, as a result of humification of the yet scattered plant residues and falling litter, a slight accumulation of organic carbon (15–20 g kg^{-1}), and the formation of the weakly perceivable AC-horizon in the top of the spoil was already evident [1]. As suggested by Fomina *et al*. [7], also the oxidation of the residual pieces of kukersite had begun and a slight darkening of the topsoil could be partially due to some humin-like substances that had formed there.

With the increase in stand coalescence, a steady forest floor with a depth of 2–3 cm and a mass of 2.7–3.6 kg m^{-2} formed under the stands in about 20–25 years. It means that the real rate of the formation of the forest floor

Table 1. **Primary Outcome of Pedogenesis on Quarry Detritus in a Forest Glade**

Properties	Horizon and depth, cm		
	OL 1.5	A 5	Detritus
Org. C, g kg^{-1}	243	19	Organic matter of plant origin is absent
N, g kg^{-1}	5.5	0.4	
C/N	44	48	
Humic acids, % of organic carbon	5.7	0	
Fulvic acids, % of organic carbon	7.8	5.4	
Total soluble, % of organic carbon	17.8	16.1	
pH	6.5	7.2	7.8
BEC, cmol kg^{-1}	72	20	14
Clay, g kg^{-1}	Absent	120	73
Skeleton, g kg^{-1}		410	650

was higher, with an increase of 1–3 mm yr^{-1} in thickness and 1.8–3.6 Mg ha^{-1} yr^{-1} in mass within the second and third decades. The top of the forest floor represented forest litter consisting of leaves, needles, moss and herb residues. The lower part represented the *Moder*-type forest floor. By this time, the whole surface was covered with the forest floor beneath which the A-horizon had formed even in the absence of the ground vegetation (Table 1).

Humus substances bound with mineral particles originated from ground litter which is an evident driving force for pedogenesis there. The plant humus of both ground litter and of the recently formed A-horizon are similar. The formation of a permanent forest floor within the second decade after afforestation appears to be the first sign of the developing a forest–soil system as well as the main prerequisite for further accumulation of moisture [8]. It served in turn as a prerequisite for the intensification of litter decomposition and for the development of interactions between organic agents and the mineral stratum of detritus already at that time and in the following years. Simultaneously with the formation and accumulation of the forest floor, an uptake of mineral nutrients by developing stands took place. This resulted in the average annual accumulation of ash elements in ground litter in the amount of 318 ± 46 kg ha^{-1}.

Table 2. **Annual Productivity of Stands**

Stand	Height, cm		Breast-height diameter, mm		Growing stock, m^3 ha^{-1}		Growing stock per tree, dm^3 ha^{-1}	
	$x \pm s_x$	V, %	$x \pm s_x$	V, %	$x \pm s_x$	V, %	$x \pm s_x$	V, %
All stands	43.2 ± 2.6	23	4.1 ± 0.2	19	5.4 ± 0.6	39	2.8 ± 0.3	40
Pine planted	44.7 ± 2.9	18	4.3 ± 0.3	18	6.1 ± 0.3	18	3.1 ± 0.4	37
Pine sown	31.6 ± 3.0	17	3.6 ± 0.6	32	2.3 ± 0.3	27	1.4 ± 0.6	37
Deciduous trees	51.3 ± 5.6	19	4.3 ± 0.2	10	6.4 ± 1.3	21	2.9 ± 0.3	20
80–90% of all cases	48.3 ± 2.2	13	4.4 ± 0.2	12	6.2 ± 0.4	23	2.8 ± 0.2	25

Fig. 2. A 36-year-old birch stand on quarry detritus

Fig. 3. A 30-year-old pine stand on quarry detritus

Although there have been found age differences in the productivity of stands [1], the intensive development of changes in detritus represents an outcome of a uniformly intensive production process (Table 2). Deciduous trees have surpassed coniferous trees (Figs 2 and 3), while the planting of the pine seedlings has been more successful than the sowing of seeds. Differences are more significant in the growing stock per tree and less significant in breast-height diameter.

Concerning the main productivity parameters (breast-height diameter, growing stock), planted pine, silver birch and hybrid alder are quite similar. The ground vegetation has developed best in the deciduous stands as well as during the first two decades in the pine stands grown by seeds. With the progress in the pine coalescence at the end of the second decade, the ground vegetation tends to disappear from the sown stands, and its importance decreases with pedogenetic activity. These phenomena render humus-accumulative process in soils more variable (Table 3).

Table 3. **Annual Increment in the Soil Organic Constituents of Plant Origin**

Stand	Organic carbon, Mg ha^{-1}		Nitrogen, kg ha^{-1}		Ash in forest litter, g kg^{-1}	
	$x \pm s_x$	V, %	$x \pm s_x$	V, %	$x \pm s_x$	V, %
All stands	1.36 ± 0.20	52	49 ± 8	56	318 ± 46	56
Pine planted	1.41 ± 0.27	52	49 ± 11	57	253 ± 33	40
Pine sown	1.04 ± 0.19	32	49 ± 21	76	350 ± 69	34
Deciduous trees	1.57 ± 0.56	62	50 ± 12	42	305 ± 72	41
80–90% of all cases	1.01 ± 0.08	26	39 ± 4	36	244 ± 32	45

Against the background of similar trends in forest productivity and annual increment in soil organic constituents, an opposite regularity appears to be characteristic of 80–90% of the formed forest–soil systems. The poor ground vegetation and the presence of residual kukersite in detritus result in the low accumulation of the organic carbon of plant origin in some high productivity stands.

Transformation of Detritus into Soil

In parallel with the completion of the perfect forest floor, a brownish black (10YR2/2) A-horizon with a thickness of 9.4 ± 1.5 cm had formed everywhere in about 25–30 years (Fig. 4).

Fig. 4. A 33-year-old profile (A–AC–BwC–C) of Calcaric Regosol on quarry detritus

A very dark greyish brown (10YR3/2) AC-horizon with a thickness of 12.2 ± 1.2 cm had deepened to a depth of 20–25 cm, in places even to a depth of 30–35 cm. Average annual thickness increment of the A–AC sequence is 5–11 mm, varying about twofold depending on the skeletonness of detritus and on the presence of the ground vegetation under the forest canopy. For example, the total pools of the organic carbon and nitrogen of plant origin in the parcel with grasses in the O–A–AC profile of only 30-year-old Calcaric Regosol were 7,391 and 238 g m^{-2}, respectively, while the respective figures for the parcel without grasses were 2,409 and 100 g m^{-2} [9]. The overwhelming majority of such differences were revealed for the A-horizon. Two- to threefold differences are characteristic also of the annual increments of nitrogen and organic carbon. An increase of 10 g kg^{-1} in the skeletonness of detritus tends to result in the 1% decrease in the pool of organic soil constituents. An average of 1.36 ± 0.2 Mg ha^{-1} yr^{-1} of organic carbon and an average of 49 kg ha^{-1} yr^{-1} of nitrogen of forest nature have accumulated annually in the humus profile and ground litter (Table 3). *Moder*-type ground litter and humus substances in the A–AC section represent the driving force for pedogenetic processes. Taking into account the average data of the content and composition of humus substances (Table 4), humification rate as the ratio of the all humic-fulvic complexes to total organic carbon, and the degree of humification as the ratio of the same complexes to all mobile fractions [10] are markedly high for such young formations, about 25–30 and 80–85% for the forest floor, and about 60–65 and 80–90% for the A–AC sequence, respectively.

Table 4. **Content and Composition[*] of Plant Humus**

Characteristics	Ground litter		A-horizon		AC-horizon	
	$x \pm s_x$	V, %	$x \pm s_x$	V, %	$x \pm s_x$	V, %
Organic C, g kg^{-1} of soil	322.0 ± 22.6	20	28.2 ± 6.0	47	12.8 ± 3.4	60
Nitrogen, g kg^{-1} of soil	9.0 ± 1.0	30	1.7 ± 0.3	18	1.2 ± 0.2	35
C : N	35.8 ± 3.6	28	16.6 ± 1.8	24	10.7 ± 1.4	28
Humic acids:						
1	6.3 ± 0.6	25	8.5 ± 1.0	25	11.4 ± 2.2	43
2	1.9 ± 1.2	174	5.7 ± 3.9	155	1.9 ± 1.7	200
3	2.2 ± 0.5	59	4.5 ± 2.0	100	2.1 ± 1.2	124
Σ	10.4 ± 2.0	54	18.7 ± 4.3	52	15.4 ± 3.5	50
Fulvic acids:						
1a	1.6 ± 0.2	37	6.5 ± 1.6	56	5.4 ± 2.5	105
1	10.3 ± 0.7	18	9.9 ± 3.0	68	12.1 ± 2.7	51
2	1.9 ± 0.9	137	13.1 ± 4.3	74	11.6 ± 5.8	112
3	1.6 ± 0.5	87	5.3 ± 2.0	82	9.0 ± 1.0	25
Σ	15.4 ± 1.4	26	34.8 ± 3.8	25	38.1 ± 8.2	48
Hydrolysate of 0.5 M H_2SO_4	5.5 ± 0.6	31	10.5 ± 1.6	34	20.1 ± 5.9	66
Total soluble	31.3 ± 2.6	24	64.0 ± 6.7	24	73.6 ± 12.2	37
Insoluble	68.7 ± 2.6	11	36.0 ± 6.7	42	26.4 ± 12.2	103
Humic : fulvic ratio	0.68 ± 0.18	37	0.53 ± 0.10	41	0.41 ± 0.10	55

* In percentages of organic C.

Pedogenetic changes in detritus are induced, always and everywhere, by the active R_2O_3-humic-fulvic humus (1st fractions) of litter origin (Table 4). Ca-humic-fulvic complexes (2nd fractions) are lacking in many cases, as a result of which the fractional composition of humus is characterized by great variability. The content of the fulvic acids bound with stable sesquioxides and mineral surfaces (3rd fraction) and of the substances present in the interlayeral structure of clay (hydrolysate) is relatively high already at the initial stages of pedogenesis.

The gradual upward transformation of these fractions as well as the increasing formation of mobile humic-fulvic complexes indicate some immobilization of soluble substances in parallel with the increase in the mollic properties of the humus horizon. Our earlier studies on primary pedogenesis revealed the same phenomena both in archaeological objects and in the till studied within a special experiment [11]. This allows to conclude that soil formation starts from the prevalent occurrence of fulvic substances, bound with the mineral stratum, which are further transformed into insoluble fractions. The humic-fulvic complexes bound with mobile sesquioxides appear to have become predominant not only after the weathering of detritus but also later during the formation of the permanent forest floor and the biogenic sesquioxides belonging to its composition. A large number of analyses showed that oxidized kukersite consists mainly (>99%) of insoluble fraction referred to as humin-like substances by Fomina *et al*. [7]. It means that kukersite does not yield soluble humus, and the latter in soil is completely of plant origin. Kukersite residues have an impact on the general status of humus, but they do not affect the organic-mineral interactions in forest–soil system.

The distribution of the calcareous skeleton within only some 20–25 cm indicates the physical breakdown of small stones under the impact of fulvic organic agents (Table 5).

Table 5. **Changes in the Properties of Quarry Detritus during 20–30 Years**

Properties	Initial detritus	A-horizon	AC-horizon
Depth, cm	Immeasurable	9.4 ± 1.5	12.2 ± 1.2
Skeleton (> 2 mm), g kg^{-1}	520 ± 36	350 ± 24	430 ± 52
Clay, g kg^{-1}	72 ± 3	84 ± 12	75 ± 6
Specific surface area, m^2 g^{-1}	26 ± 4	60 ± 11	38 ± 9
Bulk density, Mg m^{-3}	1.54 ± 0.07	1.01 ± 0.06	1.35 ± 0.01
Base exchange capacity, cmol kg^{-1}	15.8 ± 0.4	29.6 ± 1.1	19.3 ± 0.9
Total nonsiliceous Fe, g kg^{-1}	6.1 ± 0.9	6.6 ± 0.5	6.1 ± 0.5

This appears to be accompanied with the subsequent weathering of the gravel and sand fractions, and a slight but clear pedogenetic argillization characteristic of any calcareous parent material of soils. The decrease in the bulk density of detritus by about one third is induced by humus accumulation and the progress of the A-horizon, but is also due to the pedogenetic loosening of the top of initial detritus. The upward expansion of the solum, typical of accumulative pedogenesis [12, 13], appears to have occurred already within a few decades. Owing to both humus accumulation and slight pedogenetic argillization, an about twofold increase has taken place in specific surface area and base exchange capacity.

The decrease in skeletonness and bulk density, and the increase in specific surface area and base exchange capacity, slight in clay and nonsiliceous iron, within the formed A-horizon as well as in the transitional AC-horizon (Table 5), with the formation of which pedogenesis started on pure detritus, demonstrate a gradual development of the soil profile in depth and a subsequent development of the diagnostic horizons from the temporary transitional formations. The weathered cambic Bw-horizon, which is often the first outcome of primary pedogenesis on skeletal materials [14, 15], is not yet formed. The brownish hue in the top of unchanged detritus can indicate only the very first changes in the initial material, including the onset of the oxidation of residual kukersite [7].

Conclusions

The use of skeletal calcareous quarry detritus, rehabilited with Scots pine, silver birch, and several other tree species, and overgrown spontaneously with herbs and grasses, allows to obtain particular data about the synchronous current processes of forest production, changes in quarry detritus as the weathering crust, and soil formation. In spite of the high skeletonness of detritus, both the planting of two-year-old seedlings and the sowing of tree seeds are effective tools which guarantee the formation of high productivity stands already during twenty-thirty years. The intensity of initial pedogenesis increases after the formation of permanent ground litter (forest floor). This ensures the transformation of the initially transitional AC-horizon into the A-horizon beneath litter in the top of detritus, as well as the gradual progress of the A–AC sequence in depth. A considerable decrease in skeletonness and bulk density as well as an increase in specific surface area, base exchange capacity, and the content of clay and nonsiliceous substances have taken place in the A–AC sequence already during two-three decades simultaneously with its formation on pure quarry detritus. Initially formed Calcaric Regosols are close to Rendzic Leptosols and can develop into a Rendzic formations with further progress of the mollic properties in the epipedon.

Acknowledgements

This study was supported by the Estonian Science Foundation grants Nos. 2669 (1997–1999) and 4090 (2000–2002). I would like to thank Mrs. Raja Kährik for carrying out the laboratory analyses, Mrs. Ester Jaigma for the linguistic revision of the manuscript, and Mrs. Ilme Reintam for computer processing. Elmar Kaar, Igna Rooma and Ain Kull are appreciated for their collaboration and useful advice.

REFERENCES

1. *Reintam, L., Kaar, E., Rooma, I.* Development of forest–soil systems on quarry detritus of open-cast oil-shale mining // Ecosystems and Sustainable Development. 3. Advances in Ecological Sciences. 2001. Vol. 10. P. 645–656. WIT Press.
2. *Reintam, L., Kaar, E.* Development of soils on calcareous quarry detritus of open-pit oil-shale mining during three decades // Proc. Estonian Acad. Sci. Biol. Ecol. 1999. Vol. 48. P. 251–266.
3. *Reintam, L., Kaar, E.* Use of rehabilited quarry detritus for the study of forest–soil system development // Soil Science: Confronting New Realities in the 21st Century. Trans. World Congress of Soil Science. Bangkok, Thailand. 2002. CD ROM. Symp. Paper 174.
4. *Ponomareva, V.V.* To the method for the study of soil humus after I. V. Tyurin's scheme // Pochvovedenie (Soviet Soil Science). 1957. No. 8. P. 66–71.
5. *Van Ranst, E., Verloo, M., Demeyer, A., Pauwels, J.M.* Manual for the Soil Chemistry and Fertility Laboratory. Analytical Methods for Soils and Plants,

Equipment and Management of Consumables. – University of Ghent, Gent, Belgium, 1999.

6. *Rumpel, C., Knicker, H., Kögel-Knabner, I., Skjemstad, J.O., Hüttl, R.F.* Types of chemical composition of organic matter in reforested lignite-rich mine soils // Geoderma. 1998. Vol. 86. P. 123–142.
7. *Fomina, A.S., Pobul, L.J., Degtereva, Z.A.* Nature of the Baltic Shale-Kukersite Kerogen and Its Chemical Properties as Raw Material. – Tallinn, 1965 [in Russian].
8. *Raid, L.* Über den Wasserhaushalt der obrigen Bodenschichten der eingeebneten Kippen der Brennschiefertagebaue // Forestry Researches. 1972. Vol. 9. P. 159–171. Valgus, Tallinn.
9. *Reintam, L., Kaar, E., Rooma, I.* Development of soil organic matter under pine on quarry detritus of open-cast oil-shale mining // Forest Ecology and Management. 2002. Vol. 171. P. 191–198.
10. *Dell'Abate, M.T., Benedetti, A., Trinchera, A., Dazzi, C.* Humic substances along the profile of Typic Haplokerert // Geoderma. 2002. Vol. 107. P. 281–296.
11. *Reintam, L.* Temporal and spatial changes in organic agents in the progress of primary pedogenesis during thirty years // Proc. Estonian Acad. Sci. Ecol. 1995. Vol. 5, No. 3/4. P. 61–76.
12. *Targulian, V.O., Sokolova, T.A., Birina, A.G., Kulikov, A.V., Tselishcheva, L.K.* Arrangement, Composition and Genesis of Sod-Pale-Podzolic Soil Derived from Mantle Loams. Analytical Investigation. 10th Intern. Congress of Soil Science. Moscow, 1974.
13. *Reintam, L.* Pedogenetic changes in the quantity and distribution of textural and chemical soil constituents during thirty years // Proc. Estonian Acad. Sci. Biol. Ecol. 1997. Vol. 46. P. 174–190.
14. *Graham, R.C., Ervin, J.O., Wood, H.B.* Aggregate stability under oak and pine after four decades of soil development // Soil Sci. Soc. Am. J. 1995. Vol. 59, No. 6. P. 1740–1744.
15. *Beschow, H., Gransee, A., Merbach, W.* Soil development on loess substrate in central Germany – results of a long-term trial on soil formation // J. Plant Nutr. Soil Sci. 2000. Vol. 163. P. 359–366.

Received February 20, 2004