Proc. Estonian Acad. Sci. Ecol., 1994, 4, 3, 101–108
https://doi.org/10.3176/ecol.1994.3.01

LIMING WITH POWDERED OIL-SHALE ASH IN A HEAVILY DAMAGED FOREST ECOSYSTEM. I. THE EFFECT ON FOREST SOIL IN A PINE STAND

Tõnu TERASMAA and Ragnar SEPP

Estonian Research Institute of Forestry and Nature Conservation, Rôômu Rd. 2, EE-2400, Tartu, Estonia

Presented by J. Martin

Received January 7, 1994; accepted June 1, 1994

Abstract. A fertilization and liming experiment with mineral fertilizers and powdered oil-shale ash was carried out in a heavily damaged 50-year-old Scots pine ecosystem in South Estonia. Root rot and scleroderris canker were frequently found in the stand. The site is characterized by low pH values of the soil (typical podzol, derived from fine sand). The treatment of the soil surface with powdered oil-shale ash (10 000 kg·ha^{-1}) proved to be highly effective in reducing the acidity of forest soil and thus in improving environmental conditions for forest growth. During the 5.5-year experiment the pH of the limed soil rose significantly in comparison with the unlimed soil. At the same time other characteristics of soil acidity (hydrolytic acidity $H_{8.2}$, exchangeable acidity $H_{5.6}$) and the content of exchangeable aluminium decreased essentially.

Key words: forest soil, acidification, acidity, aluminium content, liming, oil-shale ash.

INTRODUCTION

Scientific and technological progress, which determines the character of our every-day civilization, exerts an ever growing impact on the ecological state of our planet. Nowadays it is well known that atmospheric pollution with different kinds of industrial wastes can seriously affect the natural environment far from the industrial centres. In very many places of the world forests are one of the most damaged natural associations. Forest tree species, especially coniferous ones, demonstrate considerable sensitivity to such atmospheric pollutants as SO_2, peroxide-acetylate nitrates, and ozone.

In Estonia, where electric power is produced mainly in big oil-shale-fired power plants, huge quantities of SO_2 are flying into the atmosphere through the chimneys of the plants. In some areas in the northeastern part of Estonia sulphur depositions over 50 kg·ha^{-1}·yr^{-1} in terms of pure sulphur have been observed (Frey et al., 1988). However, it is characteristic of Estonia that simultaneously with comparatively high SO_2 pollution the proton load has been quite low because of big amounts of alkalic ash emitted together with SO_2 into the atmosphere through the chimneys of the thermal power plants. Therefore, acid rains are not frequent in Estonia. Acid precipitation here is caused mainly by SO_2 released in the central part of Europe. In Estonia acid rains are most frequently registered in the southern area of the country. At times rains with pH values below 5.1 (even 4.0 and lower) have been registered there. This is also the region where quite severely damaged pine forests of *Cladonia* and *Vaccinium* site types can be found. As a rule, these forests grow on acid sandy soils poor in nutrients and bases.

In 1987, when we started to investigate the problem of massive dieback of the trees in some of the pine stands in the southern part of Estonia, we proceeded from the hypothesis that one of the causes of the degradation of pines in poor site conditions might be related to the acid precipitation in that region and thus to the raising acidification of forest soils. This hypothesis is widely known and it was successfully applied by Ulrich already in the early 1980s (Ulrich, 1981; 1982; 1983).

The aim of the present study was to investigate the possibility of using oil-shale ash as a liming agent in a forest ecosystem for protecting forest soils from acidification and, together with some mineral fertilizers, for improving the health of injured pine stands. In Estonia the most easily available liming agent is powdered oil-shale ash, which has been widely used as a lime fertilizer for agricultural crops but so far has not been tested for liming forests on mineral soils.

MATERIAL AND METHODS

In 1987 a permanent sample area with 0.1 ha sample plots was set up in the Pikasilla Forest District in Estonia. To improve the health of trees in a heavily damaged Scots pine (*Pinus sylvestris* L.) stand experiments with mineral fertilizers (N150P100K100) and powdered oil-shale ash (10 000 $kg \cdot ha^{-1}$, i.e. about 7500 kg $CaCO_3$) were planned. The test area is located about 15 km south from Lake Võrtsjärv. In 1987 the state of health of the trees in a 50-year-old Scots pine stand was quite poor. Root rot (*Heterobasidion annosum* (Fr.) Bref.) and scleroderris canker (*Gremmeniella abietina* (Lagerb.) Morelet) were widely spread in the forest. Massive dieback of trees had caused an essential decrease of the density of the stand. Because of understocking the mean density was only 53% of the fully stocked stand. It was typical of the stand that not only the suppressed trees but also the codominant and dominant ones were dying out. The main stand characteristics of the experimental stand were as follows:

forest structure – 10P
mean diameter – 14 cm
mean height – 15.6 m
site quality class – II
age – 50 years
soil type – podzol on sand without an A-horizon

Sample plots (0.1 ha, fertilized and unfertilized) of the fertilization experiment were set up in three repetitions. In one of the experimental variants mineral fertilizers were applied jointly with powdered oil-shale ash, which was manually spread on the surface of the soil.

Dust-like oil-shale ash is a volatile byproduct of the combustion of finely ground oil-shale. The main mass (45%) of volatile ashes is caught by cyclones.

This fraction is characterized by a high degree of fineness (Ø < 0.03 mm). As observed by Withers (1993), the particle size is one of the physical factors that can have a particularly substantial effect on lime reactivity in a short term. This fraction was also used in the present experiment. The powdered ash of this fraction has a great neutralizing effect and it contains a considerable amount of nutrient elements. The neutralizing effect is up to 81% calculated on the basis of $CaCO_3$. Calcium, sulphur, magnesium, and potassium in powdered oil-shale ash are easily soluble and available for plants. About 30–50% of the total content of calcium (CaO 45.4%) is soluble in water. The solubility of sulphur (total content of SO_3 is 4.6%) is approximately the same. Potassium (K_2O 6%) and magnesium were less soluble in water. The amount of soluble trace elements in powdered oil-shale ash is also noteworthy.

The soil of the sample plots was determined as a fine-grained sandy podzol, where the mineral soil layer was covered by a 5–6 cm layer of unincorporated mor-type forest humus. According to the rate of the decomposition of organic matter it falls into two equal 2.5–3.0 cm layers of F and H. The following successive horizons are the eluvial E(A2) horizon (2–4 cm) and B1, B2, and BC horizons overlying the C horizon at 120 cm depth.

After liming in 1987, soil samples were periodically (once or twice per year) taken from the overlying soil horizons of treated and untreated with oil-shale ash sample plots from 7–9 different spots at a depth of 15–20 cm. The soil samples were analysed chemically in the Laboratory of Chemistry of the Estonian Research Institute of Forestry and Nature Conservation. All pH changes were measured in the field moisture conditions of soil samples. Hydrolytic acidity ($H_{8.2}$) was determined from the 1M Na-acetate extraction (pH 8.2–8.3). Exchangeable acidity ($H_{5.6}$) and mobile Al^{3+} content were determined from the 1M KCl extraction (pH 5.5–6.0).

In August and September 1987 samples of precipitation were also collected some kilometres away from the sample plots under investigation, but in open land. The aim was to get some data on the rainwater pollution level in this region. For that plastic collectors and funnels were used. The rainwater samples were collected immediately after prolonged rains and were stored in cold and dark until the determination of ion contents in them.

RESULTS AND DISCUSSION

As a starting point for the present experiment we studied the main characteristics of the soil in detail (Table 1). The data presented in Table 1 are the mean characteristics of soil samples collected from different spots of the sample area. Quite high pH values of the upper horizons of the soil can harmfully influence the development of the root system of the trees in the stand. Consequently, even the smallest shift in the soil towards increasing acidity may deteriorate the growth conditions of the stand. Preliminary studies of the pH and ion contents of the rainwater of the area of the present forest massif did not show any essential risk of soil acidification due to strongly acid precipitation. The analyses of the rainwater samples of the August and September of 1987 (all together 19 observations) showed that pH of the rainwater was predominantly normal (pH 5.1–6.1). The whole range of pH varied from 4.5 to 6.5. The ion concentrations of three anions (SO_4^{2-}, NO_3^-, Cl^-) of the rainwater were also low ($<2.5\ mg \cdot l^{-1}$) or normal ($2.6–5.0\ mg \cdot l^{-1}$) in most of the observations. Only one of the rainwater samples showed a high SO_4^{2-} content: $13.8\ mg \cdot l^{-1}$. Today we have for comparison the data of Frey and Palo (1993) on the precipitation chemistry from May to October 1990 of the same permanent sample area at Pikasilla. The authors claim that the mean pH of rainwater there was normal and precipitation did not cause direct acidification in the stand.

Table 1

Main characteristics of soil

Horizons	pH		Acidity, meq·100 g^{-1}		Al^{3+}, mg·100 g^{-1}	Available in Ca lactate solution, mg·100 g^{-1}	
	H_2O	KCl	$H_{8.2}$	$H_{5.6}$		P_2O_5	K_2O
F	4.2	3.6	59.9	5.03	46.8	94.5	226.0
H	4.1	3.5	68.4	2.66	58.2	50.0	59.5
E	3.4	3.2	6.3	0.09	9.9	4.2	7.1
B1	4.1	4.0	8.5	0.06	12.3	9.5	4.8
B2	4.5	4.5	2.2	0.03	1.6	5.9	3.6
B3	4.8	4.7	1.4	0.04	2.0	11.8	3.6
B4	5.5	4.6	1.4	0.03	1.5	9.5	4.8
BC	5.7	4.9	0.7	0.03	0.3	10.8	4.8
C	5.6	4.5	0.6	0.02	0.5	9.5	2.4

The liming experiment showed that powdered oil-shale ash could be highly effective in fighting the acidity of sandy soils in a forest ecosystem.

During a 5.5-year-long experiment the natural variations in the pH in the control plots were not significant. Vertical variations in pHH_2O and pHKCl in the control plots ranged from 3.7 to 4.2 and from 2.9 to 3.6, respectively (Fig. 1). The changes that took place in the forest soil after liming (Fig. 1 and Table 2) are much more essential. It is noteworthy that there was a moderately to strong relationship between pHH_2O and pHKCl in the moss layer of the soil surface, in the humus layer, and in the upper mineral soil horizons in the control plots: R^2 was 0.22 and 0.74 in the moss layer and in the H layer, respectively. Quite a significant linear correlation was found between pHH_2O and pHKCl in the soil samples of the limed plots: five years after liming R^2 varied from 0.69 up to 0.96.

By the second year after liming pHH_2O had increased by 3.0 units in the moss layer and by 3.3 pH units in the F layer. There was no essential change of acidity in the mineral soil horizons by that time. But pH had increased by 2.5–3.0 units in the humus layer and in the E horizon by the fifth year after liming. By that time the liming effect was also recorded in the B1 horizon: pH had rose by 1.1 units. Herewith it is essential to note the exponential, not arithmetic, nature of pH values. Expressed as the concentration of hydrogen ions, the oil-shale ash showed its really high efficiency in neutralizing soil acidity. For example, during the 5.5-year observation period the soil reaction had changed over 2000 times in the humus layer while the E horizon was over 6000 times less acid. Though the solubility of the powdered oil-shale ash is not so high and its neutralizing effect not so rapid as for chalk-lime (Marschner et al., 1992), its efficiency in forest soils is evident. Moreover, the oil-shale ash supply in Estonia is great and its $CaCO_3$ equivalence is higher than, for example, for wood ash, which is recommended as a liming agent for agricultural and forest soils in the USA (Ohno, 1992).

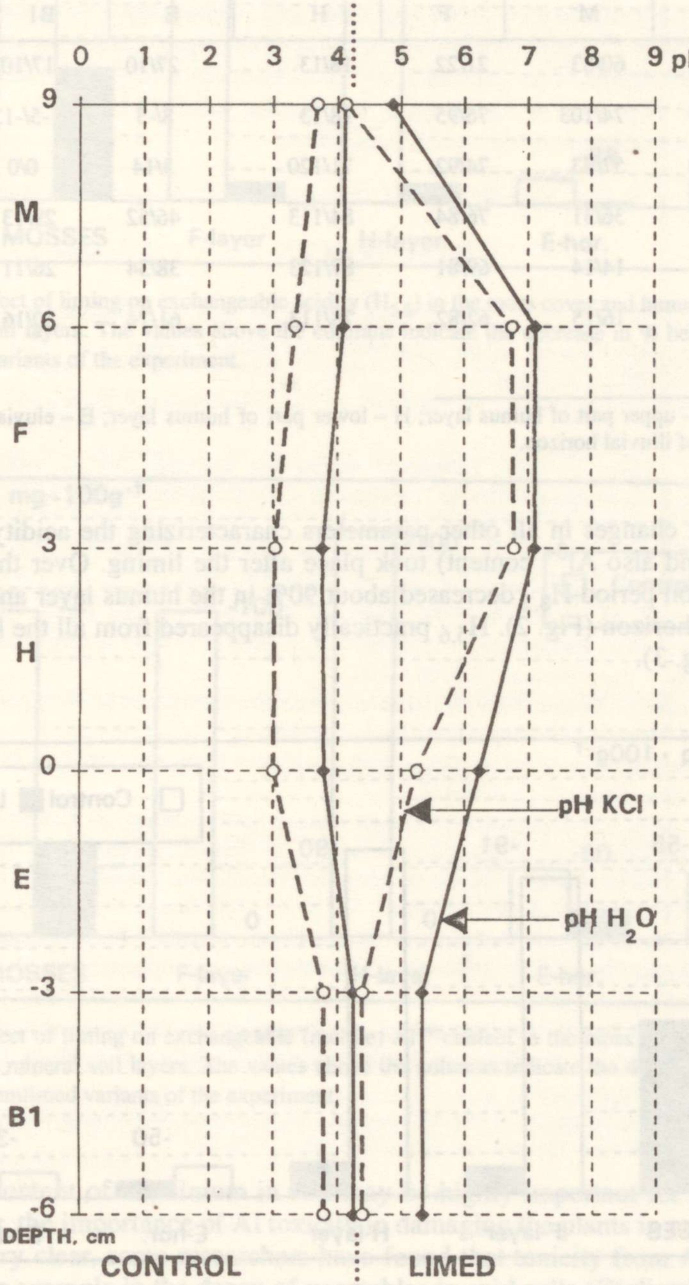

Fig. 1. The pHH_2O and pHKCl profiles of the control and limed plots 5.5 years after the oil-shale-ash treatment.

Table 2

Changes of pH H_2O/pH KCl in different soil horizons expressed as the change ratio in % between the limed and the control plots

Time	Horizons				
	M	F	H	E	B1
05.88	60/83	21/22	18/13	27/10	17/10
09.89	74/103	76/95	18/13	8/-3	-5/-13
05.90	57/83	74/92	71/120	3/14	0/0
05.91	36/31	76/84	84/113	46/52	29/13
09.91	14/14	69/81	87/123	38/34	26/11
10.92	16/15	62/82	78/113	61/74	30/16

M — mosses; F – upper part of humus layer; H – lower part of humus layer; E – eluvial horizon; B1 – upper part of illuvial horizon.

Significant changes in all other parameters characterizing the acidity of soil ($H_{8.2}$, $H_{5.6}$, and also Al^{3+} content) took place after the liming. Over the whole experimentation period $H_{8.2}$ decreased about 90% in the humus layer and nearly 50% in the E horizon (Fig. 2). $H_{5.6}$ practically disappeared from all the horizons of the soil (Fig. 3).

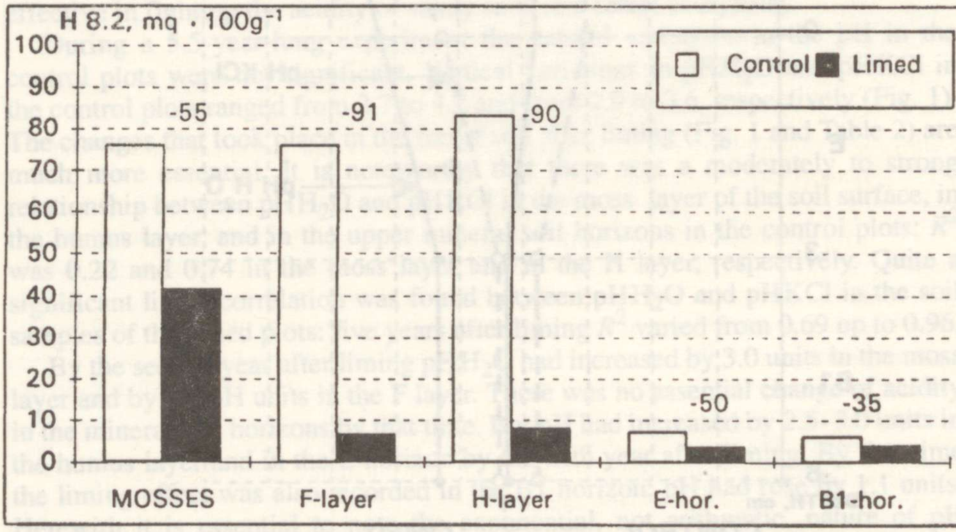

Fig. 2. Effect of liming on hydrolytic acidity ($H_{8.2}$) in the moss cover and humus and uppermost mineral soil layers. The values above the columns indicate the decrease in % between limed and unlimed variants of the experiment.

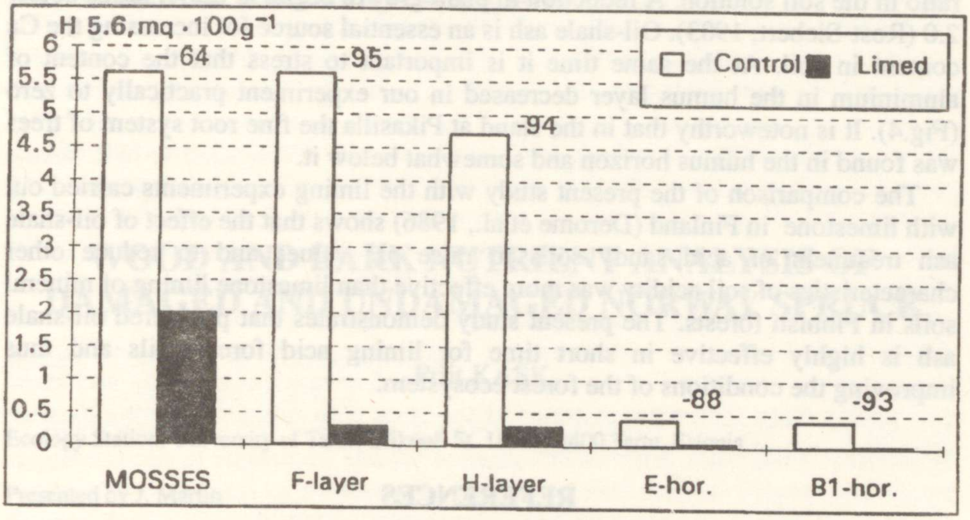

Fig. 3. Effect of liming on exchangeable acidity ($H_{5.6}$) in the moss cover and humus and uppermost mineral soil layers. The values above the columns indicate the decrease in % between limed and unlimed variants of the experiment.

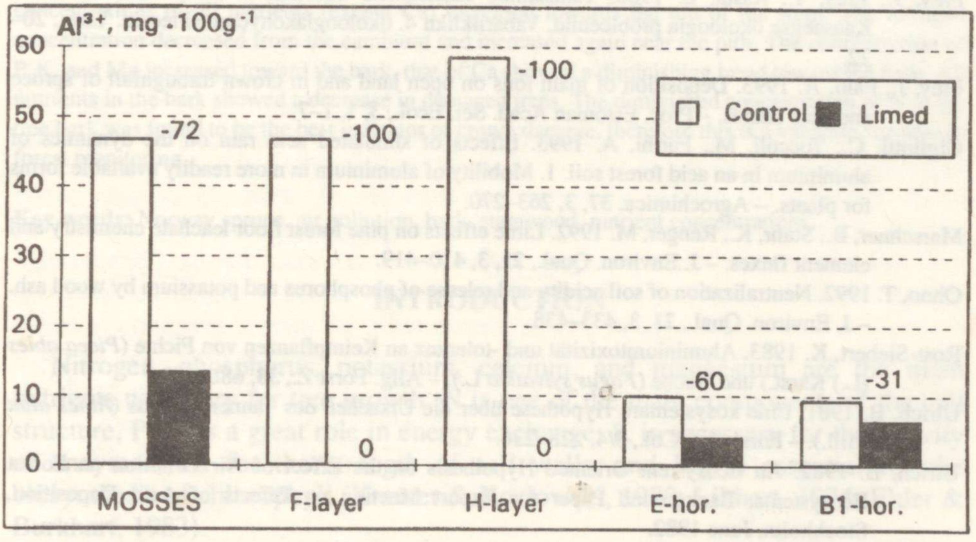

Fig. 4. Effect of liming on exchangeable (mobile) Al^{3+} content in the moss cover and humus and uppermost mineral soil layers. The values above the columns indicate the decrease in % between limed and unlimed variants of the experiment.

The content of aluminium in soil may be highly important for plant growth. However, the importance of Al toxicity in damaging the plants in natural systems is not very clear, some researchers have found that toxicity from Al is the main factor for example in the decay of vegetables in acid soils (Gigliotti et al., 1993). Bauch & Schröder (1982) found higher levels of Al in epidermal tissues of the roots of damaged fir compared to healthy trees. It has been also found that root damages were not directly related to Al concentration, but depended on the Ca/Al ratio in the soil solution. A reduction in plant growth began at Ca/Al ratios below 2.0 (Rost-Siebert, 1983). Oil-shale ash is an essential source for increasing the Ca content in soil. At the same time it is important to stress that the content of aluminium in the humus layer decreased in our experiment practically to zero (Fig.4). It is noteworthy that in the stand at Pikasilla the fine root system of trees was found in the humus horizon and somewhat below it.

The comparison of the present study with the liming experiments carried out with limestone in Finland (Derome et al., 1986) shows that the effect of oil-shale ash treatment of acid sandy soils to raise pH values and to reduce other characteristics of soil acidity was more effective than limestone liming of mineral soils in Finnish forests. The present study demonstrates that powdered oil-shale ash is highly effective in short time for liming acid forest soils and thus improving the conditions of the forest ecosystem.

REFERENCES

Bauch, J., Schröder, W. 1982. Zellulärer Nachweis einiger Elemente in den Feinwurzeln gesunder und erkrankter Tannen (*Abies alba* Mill.) und Fichten (*Picea abies* (L.) Karst.). – Forstwiss. Cbl., 5, 285–294.

Derome, J., Kukkola, M., Mälkonen, E. 1986. Forest Liming on Mineral Soils. Results of Finnish Experiments. Solna.

Frey, J., Frey, T., Rästa, E. 1988. Tähtsamate saasteainete koormus 1987. a. sademetes. In: Kaasaegse ökoloogia probleemid. Vabariikliku 4. ökoloogiakonverentsi teesid. Tartu, 20–22.

Frey, J., Palo, A. 1993. Deposition of main ions on open land and in crown throughfall of spruce and pine stands. – Proc. Estonian Acad. Sci. Ecol., **3**, 1, 1–7.

Gigliotti, C., Toccoli, M., Farini, A. 1993. Effects of simulated acid rain on the dynamics of aluminium in an acid forest soil. 1. Mobility of aluminium in more readily available forms for plants. – Agrochimica, **37**, 3, 263–270.

Marschner, B., Stahr, K., Renger, M. 1992. Lime effects on pine forest floor leachate chemistry and element fluxes. – J. Environ. Qual., **21**, 3, 410–419.

Ohno, T. 1992. Neutralization of soil acidity and release of phosphorus and potassium by wood ash. – J. Environ. Qual., **21**, 3, 433–438.

Rost-Siebert, K. 1983. Aluminiumtoxizität und -toleranz an Keimpflanzen von Fichte (*Picea abies* (L.) Karst.) und Buche (*Fagus sylvatica* L.). – Allg. Forst Z., **38**, 686–689.

Ulrich, B. 1981. Eine kosystemare Hypothese über die Ursachen des Tannensterbens (*Abies alba* Mill.). – Forstwiss. Cbl., 3/4, 228–236.

Ulrich, B. 1982. An Ecosystem Oriented Hypothesis on the Effect of Air Pollution on Forest Ecosystems. Background Paper for Expert Meeting on Effects of Acid Deposition, Stockholm, June 1982.

Ulrich, B. 1983. A concept for forest ecosystem stability and of acid deposition as a driving force for destabilization. In: Effects of Accumulation of Air Pollutants in Forest Ecosystems. Dordrecht, Reidel, 1–32.

Withers, P. 1993. The influence of particle size on the agronomic effectiveness of agricultural liming materials. – Outlook on Agriculture, **22**, 3, 175–181.