Proc. Estonian Acad. Sci. Ecol., 1995, 5, 3/4, 77—84
https://doi.org/10.3176/ecol.1995.3/4.02

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

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Presented by L. Reintam

Received 16 March 1995, accepted 15 April 1995

Abstract. First years after the treatment (in 1987) of forest soil with mineral fertilizers and powdered oil-shale ash in a heavily damaged 50-year-old Scots pine ecosystem showed a comparatively small effect ($B<0.95$) of liming on the stand characters. However, in comparison with the effect of only NPK fertilization on the volume growth and the health state of trees, liming (NPK+oil-shale ash) tended to increase the positive influence of fertilizers. Under the influence of oil-shale ash the mortality of the trees was lower, the density of the stand rose more, and the mean radial increment of trees was by 26% greater than after the NPK treatment without a lime agent.

Key words: Scots pine, liming, oil-shale ash, growth, forest condition.

INTRODUCTION

A great number of investigations into the growth of different plant species in polluted areas and on highly acid forest soils show that soil chemistry can essentially affect the growth of trees as well as ground vegetation. According to an ecosystematic hypothesis put forward by Ulrich (1981, 1982) acidification processes (natural acidification plus that caused by acid deposition from the atmosphere) in soils cause the decoupling of the biomass production/decomposition cycle and lead to mobilization of soil-bound metal ions, primarily aluminium, manganese, and iron. Toxic effects of these ions, particularly the toxicity of Al in forest soils coupled with the deficiency of Ca, cause the reduction of the total mass of fine roots, then the disruption of the water status in trees, disturbances in the plant uptake of base cations, nutrient elements N and P, the infection of roots and shoots by pathogens and, finally, the death of affected trees. The data about the relation between the survival rate and root growth for conifers indicate that, for instance, the Norway spruce have 50% survival at 55% root growth reduction under acidification. However, already a 30—35% root growth reduction may lead to a 100% mortality in the long-term perspective (Sverdrup & Warfvinge, 1993).

In addition to direct toxicity, Al essentially interferes with the uptake of Ca by fine roots when the soluble ions are in equimolar concentrations. In the growth process Ca is incorporated at a constant rate in the production of sapwood from cambial derivatives. The demand for Ca per unit area of cambium is essentially constant. Suppressed cambial growth reduces the functioning of sapwood as it is continuously transformed into the heartwood core (Shortle & Smith, 1988). Typically both healthy and declining trees have the same number of sapwood rings, but in healthy trees the rings are wider.

Some laboratory studies on the dependence of spruce injuries on the Al concentration and the existence of Ca in the soil suggest that the Ca/Al ratio plays an essential role in the decline of forests. Rost-Siebert (1983) mentioned that a reduction in plant growth occurred at Ca/Al ratios below 2.0. Yet Ogner & Teigen (1981) in their experiments with potted spruce seedlings did not find any effect of Al on the growth of various spruce clones at a soil pH of 3.2 and Ca/Al ratio of 0.1 of the soil solution. The growth of eucalyptus was even found to be stimulated under the influence of aluminium (Mulette, 1975).

The growth characters of many tree species have quite frequently been found to be badly influenced as soluble Al rises in the soil or the Ca/Al ratio decreases in the root zone of trees (Göransson & Eldhuset, 1987; Arovaara & Ilvesniemi, 1990; DeWald et al., 1990; Ilvesniemi, 1992; Sverdrup & Warfvinge, 1993). Nevertheless, the importance of Al toxicity for plant injuries does not seem to be very clear. It is evident that big differences in experimental results still exist.

Foresters and researchers in Finland have noteworthy experience in long-term and large-scale experimenting with the influence of liming on soil characters and on the growth of conifer species. The use of lime material in pine and spruce forests did not yield positive results for the stand's volume growth in a great number of the cases of the first post-treatment. The negative effect of liming was often found to be alleviated by applying nitrogen fertilizers (Derome et al., 1986). Considering the experience of Finnish colleagues we did not use the lime material (oil-shale ash) without fertilizers in our experiment.

Liming has been a common measure to regulate the soil pH of non-calcareous agricultural soils all over the world. In Estonia powdered oil-shale ash as a cheap and available lime material has been widely used on agricultural land, but not on forest soils. No results of oil-shale ash liming of mineral forest soils are known to us as yet. Thus, the results of this experiment may be the first attempt to describe the effects of oil-shale ash on the growth of a forest stand. This is a continuation of presenting the results of a liming experiment in Pikasilla Forest District, Estonia, in a heavily degraded middle-aged pine stand. The liming effects of oil-shale ash on the forest soil characters of the stand were described in a previous paper (Terasmaa & Sepp, 1994).

MATERIAL AND METHODS

In 1987 the sampling plots (area of each 0.1 ha), not treated (unfertilized plots) and fertilized only with mineral fertilizers ($N_{150}P_{100}K_{100}$) or with mineral fertilizers (in the same dosages) plus powdered oil-shale ash (10 000 kg · ha^{-1}, that is about 7500 kg $CaCO_3$), were set up in a 50-year-old pine stand of *Vaccinium* site type. The stand was growing on poor sandy podzol (the layer of sand $>$2.0 m), where the A-horizon was practically lacking. The main characteristics of the site type are as follows:

— high soil acidity: the pH(H_2O) values of the humus layer and of the upper part of the mineral soil layers were 3.4—4.2;
— low Ca content in the root zone of trees in the soil: 0.25 meq · 100 g^{-1};
— high content of the extractable Al in the humus layer (up to 58.2 mg · 100 g^{-1}) and in the upper mineral layers (9.9—12.3 mg · 100 g^{-1}). It is essential to note that on this site type the main mass of the fine roots of pine trees is under the humus layer.

In 1987 the stand was characterized by a high mortality of trees. During the last decades the weakened and dead trees had already been felled out for several times. Therefore the average density of the stand had decreased to 53% of the fully stocked stand. The density of the stand was not uniform. On different sample plots the density varied from 45 to 56%. In some spots of the stand totally unstocked gaps were found.

After setting up the sample plots, all the dead trees were again felled on all the plots. Afterwards the number and the volume of dead trees (died after 1987) were determined in 1989, 1991, and 1993.

The volume of living trees in the sample plots was calculated in 1987 and 1991. For the volume calculations the breast height diameter ($D_{1.3}$) of all trees was measured with a caliper and registered by 1.0 cm diameter classes. For at least 1/3 of the total number of trees on the sample plots, the height was measured to an accuracy of 0.1 m. For the determination of the radial increment of trees samples were taken with an increment borer five years after the soil treatment with NPK and oil-shale ash.

The growth trends of the stand in different sample plots were determined using the calculated data.

RESULTS AND DISCUSSION

The long-term experience in the fertilization of Estonian forests has shown that a positive effect of mineral fertilizers on the tree growth becomes quickly apparent. In pine stands of quality classes II—III of *Vaccinium* site type, the positive effect of mineral fertilizers had usually lasted for five to eight years and in middle-aged forests the volume of the stand had increased 10.8 to 26.4 $m^3 \cdot ha^{-1}$ (Seemen & Tälli, 1992). As was shown in an earlier paper (Terasmaa & Sepp, 1994) the liming effect of oil-shale ash on the forest soil appeared quickly after the liming. So, we hoped to see the effect of liming also in the growth of trees and the condition of the stand. Changes in the main characteristics of the stand from 1987 to 1991 are presented in Table 1. Quite a high mortality of trees was characteristic of the stand during the first years after the establishment of the experimental area. The number of dead trees was particularly big on unfertilized sample plots with 360 dead trees per ha in 1993. It was an abnormally high rate of dieback in comparison with the data of two yield tables (that have been used in Estonia) for 50—60-year-old pine forests of site quality class II:

Author and reference of yield table	Number of dead trees (age 50—56 years)
Tjurin (Krigul, 1969)	192
Mikhnevich (Захаров et al., 1962)	216

During the whole monitoring period (1987—93) the mortality of trees on the control (unfertilized) plots was by 67—88% higher than the data in the yield tables referred. Evidently the number of dead trees was too big for a middle-aged pine stand of low density. During the same period

Table 1

Changes in characteristics of a pine stand after fertilization and liming

Characteristics of living trees	Unfertilized			NPK			NPK+ash		
	1987	1991	Difference	1987	1991	Difference	1987	1991	Difference
Diameter, cm	14.3±0.2	16.4±0.3	2.1	14.1±0.2	16.6±0.2	2.5	13.8±0.3	16.0±0.3	2.2
Height, m	15.8±0.2	17.9±0.2	2.1	15.4±0.2	17.7±0.3	2.3	15.0±0.3	17.7±0.2	2.7
Basal area, $m^2 \cdot ha^{-1}$	15.9	14.5	−1.4	14.8	14.4	−0.4	17.1	18.5	1.4
Volume, $m^3 \cdot ha^{-1}$	121.5	122.4	0.9	110.2	120.7	10.5	124.9	154	29.1
Number of trees, ha^{-1}	987	683	−304	947	663	−284	1150	920	−230
Density	0.51	0.45	−0.06	0.48	0.45	−0.03	0.56	0.57	0.01

the condition of the stand on fertilized (NPK) and limed (NPK+oil-shale ash) sample plots showed a tendency to improve. The number of dead trees on NPK or NPK+ash plots was respectively 297 and 290 trees per ha.

The tendency towards an improvement of the forest condition after the NPK or NPK+oil-shale ash treatment became even more evident when the total set of dead trees was analysed by different diameter classes (Fig. 1) or the difference in their mortality was shown as the percentage of dead trees among the total number of trees (living+dead) on the sample plots (Fig. 2). After NPK+ash treatment most of the dead trees were classified as dominated or suppressed trees. The posttreatment situation on the control plots and those fertilized only with NPK was not similar to this one. On these plots there had also been dominants or codominants among the dead trees, whose diameter and height markedly exceeded the mean parameters of the stand.

The following circumstances prove that after the beginning of the experiment the volume of living trees had grown mostly due to the effect of oil-shale ash (Table 1):

— smaller absolute and relative number of dead trees;

— somewhat smaller mean stem diameter of dead trees. The differences were not significant ($B<0.95$), but in 1993, for example, the diameters of the dead trees on NPK+ash, NPK, and untreated sample plots were 10.3 ± 0.1, 11.1 ± 0.2, and 11.0 ± 0.2 cm, respectively.

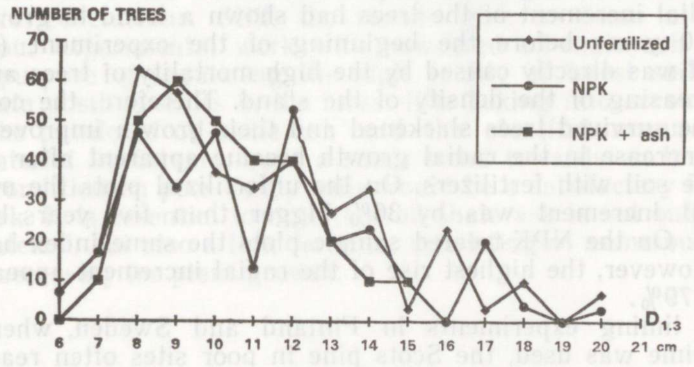

Fig. 1. Number of dead trees in different diameter classes (1987—93).

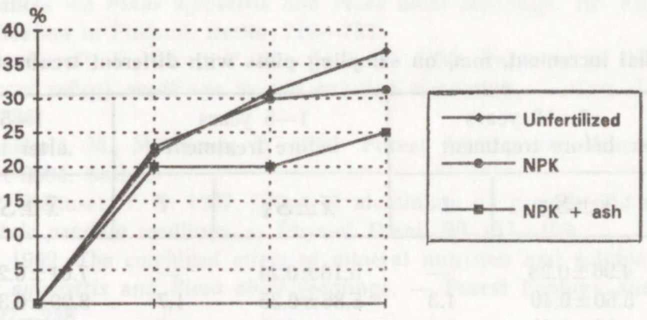

Fig. 2. Percentage of dead trees on different sample plots.

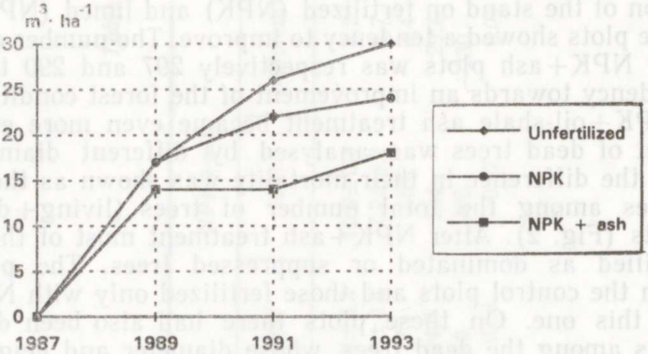

Fig. 3. Volume of dead trees on different sample plots.

From 1987 to 1993 the loss of high-quality stemwood through the death of trees was by 40% smaller after liming than on unfertilized plots and by 25% smaller than on NPK-treated plots (Fig. 3).

It is also essential that on untreated sample plots the density of the stand fell from 0.51 to 0.45 due to the highest dieback of trees. The same trend of change was observed on the sample plots fertilized with NPK. It was only on the oil-shale ash treated plots that the density of the stand did not decrease during the first years after the treatment.

The radial increment of the trees had shown a trend to grow already at least 10 years before the beginning of the experiment (Table 2). Probably it was directly caused by the high mortality of trees and a continual decreasing of the density of the stand. Therefore, the competition between the survived trees slackened and their growth improved. A considerable increase in the radial growth became apparent after the treatment of the soil with fertilizers. On the unfertilized plots the mean five-year radial increment was by 36% bigger than five years before the experiment. On the NPK-treated sample plots the same index had grown by 53%. However, the highest rise of the radial increment appeared after liming — 79%.

In the liming experiments in Finland and Sweden, where mostly dolomitic lime was used, the Scots pine in poor sites often reacted with a slight growth decrease (Derome et al., 1986; Popovič et al., 1988). In these experiments the lime substance seemed to affect the tree growth

Table 2

Radial increment, mm, on sampling plots with different treatment

Version	6—10 years before treatment		1—5 years before treatment		1—5 years after treatment	
	$\bar{x} \pm S_{\bar{x}}$	t	$\bar{x} \pm S_{\bar{x}}$	t	$\bar{x} \pm S_{\bar{x}}$	t
Unfertilized	4.96±0.28	—	5.16±0.24	—	7.01±0.21	—
NPK	5.60±0.40	1.3	5.86±0.35	1.7	8.99±0.33*	5.0
NPK+ash	4.57±0.31	0.9	4.87±0.29	0.7	8.71±0.29*	4.9

* significant at the 0.1% level.

negatively directly after the treatment and a small growth decrease was usually comparatively long-lasting, up to 10—20 years. According to the Finnish results, liming alone reduced the volume growth of different pine stands by an average of about 3% (0.15 $m^3 \cdot ha^{-1} \cdot a^{-1}$) throughout 18 years (Derome et al., 1986). The results were different when the lime material was used together with a nitrogen fertilizer. Particularly in middle-aged or mature pine stands (age >50 years) on dry and poor sites the interaction between lime and nitrogen was evident and the volume growth of pine stands after CaN treatment exceeded the volume growth both on untreated stands and on those treated only with Ca or N.

In Finland and Sweden the negative effect of liming without fertilizers was stronger in spruce forests than in pine stands. And after complex treatment in spruce stands the effect of the interaction between Ca and N was usually not so marked as in pine stands.

In nitrogen-deficient stands the losses in growth after liming are probably the result of a lower availability of nitrogen for the trees. Lime stimulates the soil microbial activity but also the processes of the incorporation of N into the soil organic matter. An impaired root and mycorrhiza function may also occur. The negative short-term effects may change into positive effects in a long perspective. The improved soil chemistry leads to a better humus status, to an improved root functioning and a better availability of mineral nutrients for the trees (Persson, 1988; Popovič et al., 1988).

On the whole, the effect of oil-shale ash liming on the growth and health condition of the pine stand was not high. However, the first results of its experimental use on mineral forest soil cannot serve as the basis for essential conclusions. Still, the results give us some assurance to continue our experimental work with powdered oil-shale ash in forests with the purpose of regulating the high acidity of forest soils in some sites to gain positive shifts in the forest life. Taking into account the low price of the powdered oil-shale ash and the plentiful resources of this liming material in Estonia, even a small trend towards an improvement of forest condition on poor sandy soils would be a satisfactory final result of the work. It is essential to note that oil-shale ash is not only a simple liming material, but also a lime fertilizer consisting of numerous chemical elements necessary for plant growth.

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