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Long-term impact of lime on the humus form in a beech stand on sandy till

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Abstract

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The study aims at describing long-term changes taking place in the humus form after liming. 4000 kg Ca per ha was applied to a stand of Fagus silvatica on sandy till in south Sweden in 1955. The humus form and the soil profile were studied 30 years later as regards macro- and micromorphological properties, CEC, base saturation, pH, organic carbon, nitrogen, phosphorus and potassium. Stand revision was carried out. The results show that the humus form had changed from mull-like moder to mull. This had been followed by a redistribution of nutrients, with decreased concentrations of nitrogen, phosphorus and potassium in the top soil. pH and base saturation had increased. Despite the change of humus form, the stand growth was not affected by liming.

Key words: Mull, mull-like moder, lime, soil micromorphology, soil biology.

ODC 114.356; 114.465; 114.164; 114.6.

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Introduction

During recent years increasing attention has been paid to the liming of forest soils as a means of counteracting soil acidification. Lime is generally considered to increase pH and improve soil structure and biological activity.

A great number of investigations show the beneficial impact of lime on structure in clayey soils (Perman & Manell, 1937; Wiklander, 1963; Ledin, 1981). Altemüller (1972) described the microscopic effects of calcium hydroxide on three different soils; sandy, silty and clayey, respectively. He found that it was not possible to observe any change in the arrangement of grains or aggregates of the treated soils. Chauvel et al. (1981), using a micromorphological technique, reported a better preserved soil fabric after compaction of soil to which lime had been added than when no lime had been added. After the addition of lime the material was much more resistant to water action and its bearing capacity increased. However, it is believed that these results are less relevant as regards coarse textured forest soils with a very low clay content. In the latter case other processes such as increased biological activity seem more important.

The knowledge of the impact of lime on soil biology is mainly based on relatively short-term experiments. For instance, several incubation experiments showed that soil respiration increased after liming (Popović, 1983). This increase did not result in any net mineralization of nitrogen due to nitrogen being immobilized in the microflora. Similarly, Lundmark & Nömmik (1984) showed that incubation of soil from a clear-felled area, at a site characterized by mor and Orthic Podzol, resulted in less mineralized nitrogen in soil from a limed plot than in soil from an unlimed control plot. In accordance with the immobilization of nitrogen, most liming experiments have not resulted in any increase in forest production (Popović & Andersson, 1984).

However, it is proposed that the long-term impact of lime on soil leads to drastic changes in the type of litter turnover and to a change in the humus form towards calcareous mull. Van Breemen & Brinkman (1976) claim that the humification process is favoured by reltively high activities of divalent metal cations. Such conditions are found in Mollisols and Vertisols. The change towards mull is generally considered to increase the site's productivity. In conclusion, liming might have a restrictive influence on production in the short run whereas the long-term impact is regarded to be the reverse. This illustrates the background of the present project on long-term impact of lime on the humus form. The study is part of the project "Long-term Effects of Methods in Forestry on Soil Processes" (Olsson, 1983*a*) and is financed by funds from the Swedish Council for Forestry and Agricultural Research.

Materials and methods

The studies were carried out in a stand of Fagus silvatica L. at Frodeparken in the province of Halland in south Sweden (56°52'N, 12°60'E, 150 m a.s.l.), where lime was applied in 1955 in a large series of fertilization experiments (Popović, 1967). Lime was applied as 10 000 kg limestone, i.e. 4 000 kg calcium, per ha on one plot, 40×40 m^2, whereas another was not treated and left as a control. At the time of the present study, 1982, the stand was 65 years old.

The site is characterized by sandy till (Fig. 1) on archaean bedrock, base mineral index 6.5 (Tamm, 1934) and mesic moisture condition with lateral surface/subsurface water flow during longer periods (Hägglund & Lundmark, 1977). Major climatic conditions are a mean annual temperature of +6.5°C and an annual precipitation of 1 046 mm, resulting in a high humidity of 400 mm (Tamm, 1959). The original soil profile before liming was a Dystric Cambisol (FAO-Unesco, 1974) with the A horizon about 12 cm thick, the Bw horizon about 45 cm and the BC about 20 cm thick. The humus form was a mull-like moder.

Stand revision was carried out by the Department of Forest Yield Research, Swedish University of Agricultural Sciences. At soil sampling for chemical analyses of the limed and unlimed soil, 9 and 10 horizons respectively were distinguished. The sampling was performed with a

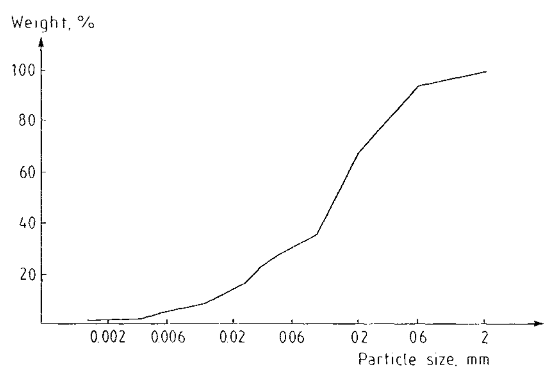

Fig. 1. Cumulative particle size distribution.

core sampler of known volume whereby it was possible to determine the total amount of different elements per m^2. The chemical analyses carried out were pH in H_2O, total organic carbon (wet combustion according to Nömmik, 1971), total nitrogen (Kjeldahl), total phosphorus in organic horizons (wet combustion in sulphuric acid followed by colorimetric determination), phosphorus and potassium soluble in ammonium lactate (P-AL, K-AL) and in hydrochloric acid (P-HCl, K-HCl) according to Kungl. Lantbruksstyrelsens Kungörelser (1965) and cation exchange capacity at pH 7.0, including titratable acidity and exchangeable bases (Nömmik, 1973).

Thin section preparations of the humus layer were produced (Avery & Bascomb, 1974). This process involves resin impregnation of freeze-dried samples extracted carefully with a core sampler, 69 mm in diameter and 70 mm in height. After hardening, the central part of each sample was mounted on a glass slide and finally ground and polished to a thickness of about 20 µm. Thus, this technique makes it possible to analyse micromorphological properties in "undisturbed" soil with its structural elements mainly preserved.

As the pore system in this type of soil is of a continuous type with voids branching and connecting with each other in all directions, it is not possible to frame and quantify individual voids. Thus, indirect quantifications of void size distribution were performed on the basis of intercept measurements. The void intercept length is defined as the distance from one side of a void to the other. Thus, in the thin sections prepared, a great number of lines in vertical and horizontal directions were analysed. Void orientation was quantified by comparing mean intercept length in vertical and in horizontal directions. Porosity was calculated as total intercept length over the total measured line length. Intercepts smaller than 20 µm could not be measured. The proportion of plant remains with visible cell structure to fine organic matter without any visible structure at a magnification of 200 times was measured by point counting.

Results

Morphological properties

The macromorphological properties are given in Table 1. The humus form at the unlimed site was characterized by the occurrence of O horizons (FAO-Unesco, 1974), equivalent to F horizon according to Hesselman (1926), consisting of relatively fresh organic residues in which original structures were discernible. None of the observed O horizons was composed of predominantly fine organic substances, i.e., no H horizon (Hesselman, 1926) occurred. This indicated that mixing of organic matter into the mineral soil was slow enough to give rise to a F horizon but, on the other hand, too fast to result in any H horizon. In addition, the humus content of the underlying mineral soil was high. This distribution of horizons is characteristic of a mull-like moder.

The humus form at the limed site differed mainly by having an appreciably thinner O horizon and being strongly aggregated. The aggregates were extremely rich in organic matter, especially leaf fragments with preserved cell structure. This indicates a more intensive mixing process in comparison with the unlimed site. The humus form is designated as a mull.

The micromorphological analysis of unlimed soil revealed that the organic horizons were generally predominated by leaf remnants with well-preserved tissue structures. This is illustrated by Figs. 2 and 3. The structure was single particle and aggregated granular. The pore system consisted of simple packed voids which were continuous, connecting each other and branching in all directions although, in similarity with the leaves, they were mainly horizontally orientated. There were, however, gradual changes from the O1 to the O3 horizon. Thus, pore volume decreased with depth whereas the proportion of fine organic matter, i.e. material with no visible tissue structures at a magnification of 200 times, increased with depth. In principal no mineral matter was present in the organic horizons, i.e., O1–O3, although in the lower one some mineral grains occasionally occurred.

Faecal droppings indicated the presence of faunal activity. Large droppings, about 200 µm in diameter, occasionally occurred in all holorganic horizons between the leaf remains. The droppings were characterised by their composition of tissue remains with well-preserved cell structure and by the absence of mineral grains (Fig. 4). Small egg-shaped droppings, probably from mites, sometimes occurred in cavities in the leaf remains (Fig. 5). Clusters of dark fine organic matter were present between the leaves on the leaf surfaces (Fig. 6), probably being droppings from enchytraeids.

In the lowest organic horizon, the O3 horizon, a large

Table 1. *Morphological description of the humus form*

Horizon	Not limed	Limed
L (fresh litter)	A loose horizon of mainly beech leaves.	A loose horizon of mainly beech leaves.
O1 (upper F horizon)	A 2 cm thick horizon of matted dark brown beech leaves with no or only small quantities of fine material between the leaves.	A 1 cm thick horizon of matted dark brown beech leaves with no or only small quantities of fine material between the leaves. Aggregates consisting of a mixture of organic and inorganic matter occurred (earthworm excrements).
O2 (middle F horizon)	A 2 cm thick horizon of partially fragmented beech leaves with white to brown colour. Rich occurrence of hyphae. About 25% of the material consisted of fine organic matter.	A 1 cm thick, partially missing, horizon of beech leaves, heavily fragmented and with white to brown colour. About 25% of the material consisted of fine organic matter. Aggregates consisting of a mixture of organic and inorganic matter occurred (earthworm excrements).
O3 (lower F horizon)	A 1 cm thick horizon of heavily fragmented plant remains. About 50% of the material consisted of fine organic matter.	Completely missing.
Ah1	A 2 cm thick horizon with humus rich mineral soil. A combination of single particle structure and a weakly developed aggregated crumb structure.	A 2 cm thick horizon with humus rich mineral soil. Strongly developed crumb structure. Leaf fragments occurred.
Ah2–Ah3	Totally 4 cm thick horizons with humus rich mineral soil. Single particle structure.	Totally 4 cm thick horizons with humus rich mineral soil. Moderately developed crumb structure.

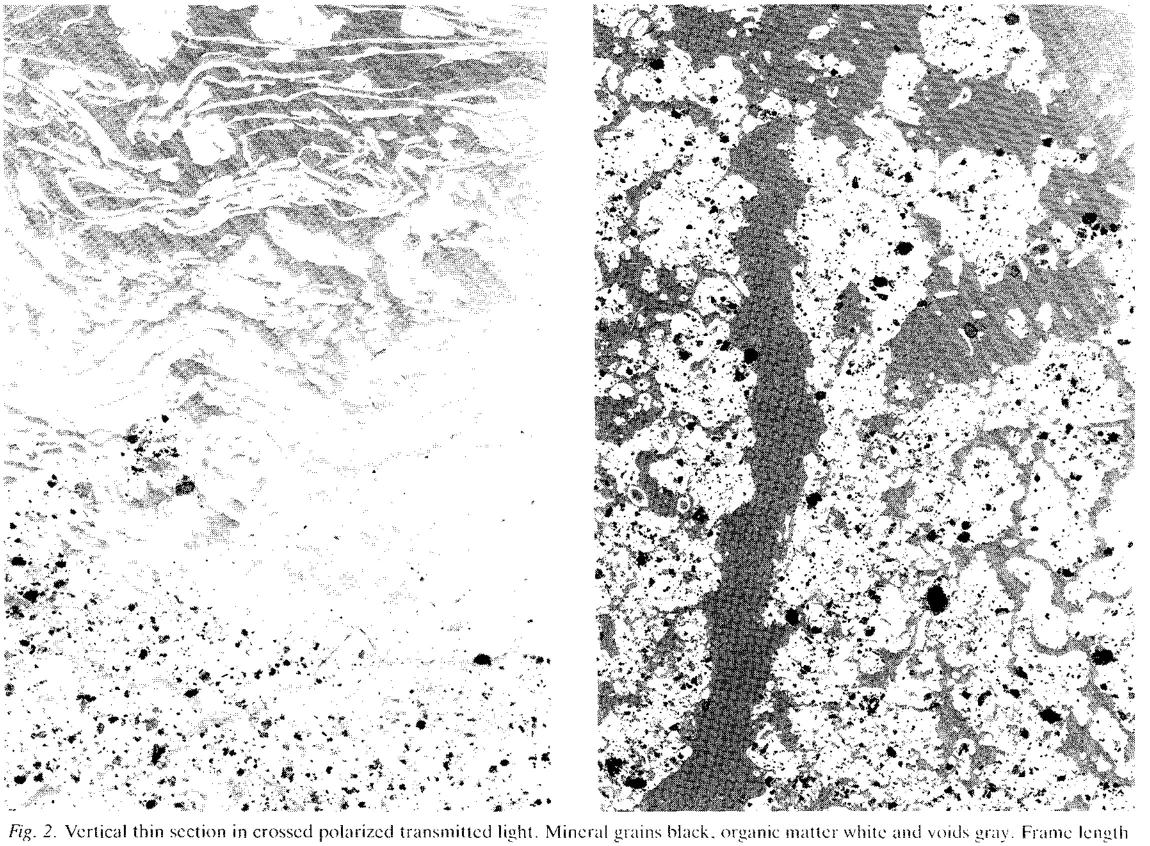

Fig. 2. Vertical thin section in crossed polarized transmitted light. Mineral grains black, organic matter white and voids gray. Frame length 20 mm. Left, not limed soil. Right, limed soil.

Fig. 3. Horizontally orientated and partially degraded beech leaves in the O1 horizon at unlimed site. Thin section in plain transmitted light. Frame size 1 mm.

Fig. 4. Large arthropod excrement in the O2 horizon at unlimed site. Thin section in plain transmitted light. Frame size 2.5 mm.

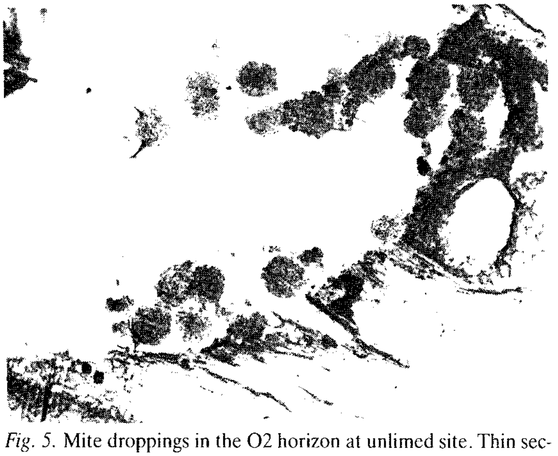

Fig. 5. Mite droppings in the O2 horizon at unlimed site. Thin section in plain transmitted light. Frame size 1 mm.

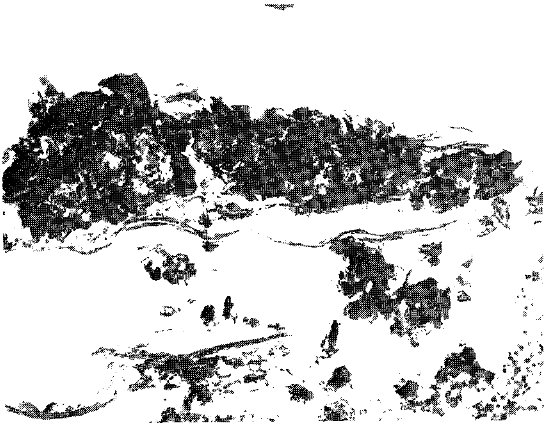

Fig. 6. Enchytraeid droppings in the O2 horizon at unlimed site. Thin section in plain transmitted light. Frame size 1 mm.

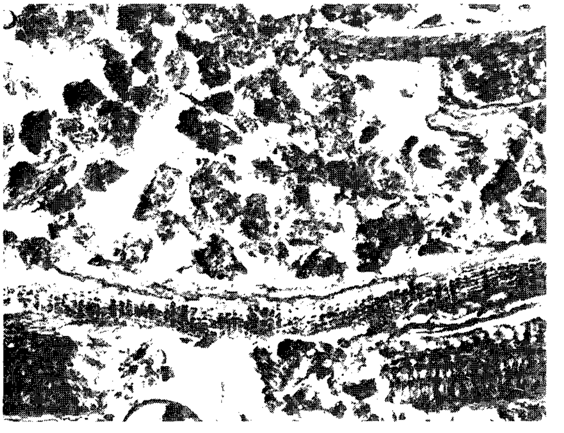

Fig. 7. Granular structure in the O3 horizon at unlimed site. Thin section in plain transmitted light. Frame size 1 mm.

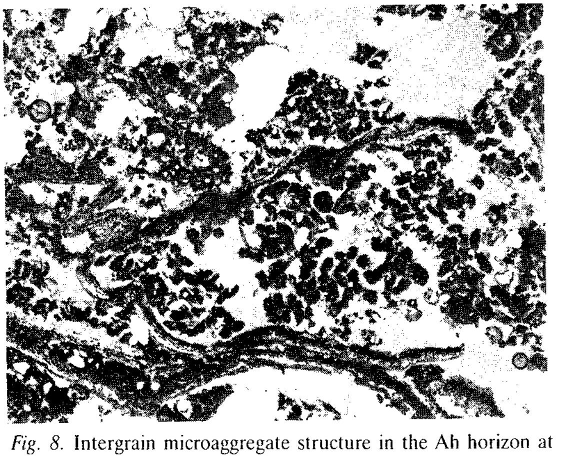

Fig. 8. Intergrain microaggregate structure in the Ah horizon at unlimed site. Thin section in transmitted light and crossed polarizers. Frame size 2.5 mm.

amount of dark-brown rounded aggregates of fine organic matter was present between the plant remains (Fig. 7). They might be aged enchytraeid droppings or aggregates of protein-tannin complexes. Their presence could be followed into the Ah horizons where they constituted the dominating group of organic matter.

At the limed site, the organic horizons differed from those at the unlimed site mainly with respect to thickness and the presence of large organo-mineral excrements from earthworms.

The most noticeable differences between limed and unlimed soil were found in the Ah1 horizon. In the unlimed soil the structure in this horizon chiefly was an intergrain microaggregate structure in combination with coated and bridged grains (Fig. 8). Large organo-mineral aggregates rarely occurred. They were characterized by their organic part only containing fine organic matter and no recognizable tissue remnants and were probably earthworm excrements. The pore system consisted chiefly of simple packed voids which were continuous, connecting with each other and branching in all directions.

In the limed soil the Ah1 horizon was characterized by a crumb structure with embedded grains. The pore system was a combination of simple packed and compound packed voids with channels and chambers. The structure was interpreted as a result of earthworm activity. In contrast to the unlimed soil, the aggregates frequently contained leaf remains (Fig. 9), indicating that the animals fragmented and consumed leaves on the soil surface and transferred them into deeper horizons. The differences between limed and unlimed soil gradually ceased in deeper horizons. Intercept measurements revealed that porosity (calculated on the basis of intercepts >20µm) in the Ah1 horizon was about 30% in unlimed soil but 50% in limed soil (Fig. 10). If the measurements were restricted to intercepts longer than 300 µm the differences were still larger, i.e., a porosity of 10% in unlimed soil and 45% in limed soil (Fig. 10).

In conclusion, although lime affected small voids to a minor extent its main impact was the formation of large so-called structural voids.

All intercepts in the Ah1 horizon larger than 20µm were of equal length in horizontal and in vertical direction in limed as well as in unlimed soil (Fig. 11). Hence, liming did not affect the orientation of the small voids. In contrast, intercepts larger than 300 µm showed different orientation in the limed and unlimed sites. In the latter case, the mean horizontal intercept length exceeded the vertical intercept length, probably due to a slight natural compaction by the weight of the trees. At the limed site the opposite situation was observed, i.e. the mean vertical intercept was larger than the horizontal intercept, probably due to the occurrence of earthworm channels.

Fig. 9. Earthworm excrement in the Ah1 horizon at limed site. Thin section in transmitted light and crossed polarizers. Frame size 2.5 mm.

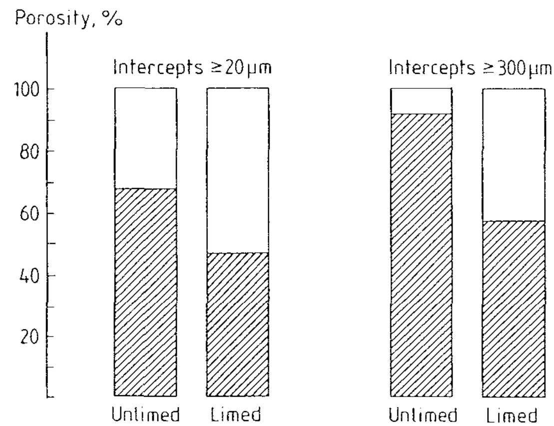

Fig. 10. Porosity in the Ah1 horizon on basis of intercept measurements. Solid material is dark. Porosity is light.

An additional contrast between the Ah1 horizon in limed and unlimed soil was the different occurrence of mineral grains and fine organic matter vis-à-vis plant remains with preserved cell structure. Liming resulted in a lower proportion of mineral grains and a higher proportion of plant remains (Fig. 12). These effects are considered as a result of the earthworms introducing leaf fragments into this horizon.

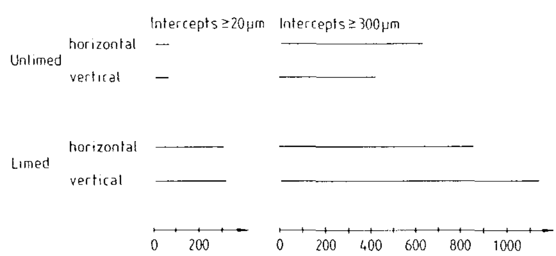

Fig. 11. Void intercept length in horizontal and vertical direction.

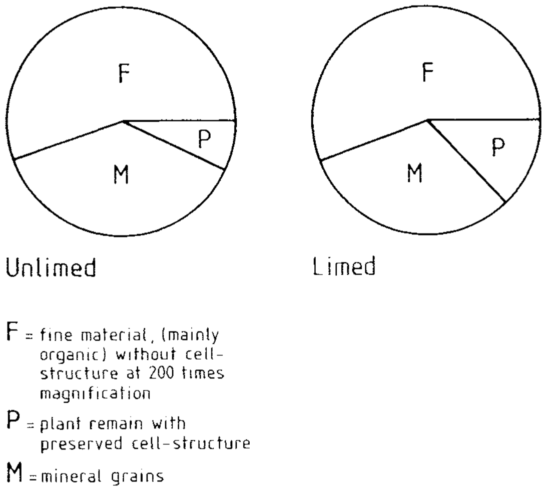

Fig. 12. Relative proportions of different kinds of material in the Ah1 horizon.

Chemical characterization

Despite the long period since lime application there were obvious differences in pH and base saturation between unlimed and limed soil (Table 2). Thus, the largest difference occurred in the Ah horizons where pH in limed soil exceeded pH in unlimed soil by 1.2 units. In the fresh litter the differences were considerably lower, about 0.3 units. The results were similar as regards base saturation, i.e., the differences were large in the Ah horizon whereas they were much smaller in the fresh litter. The impact of lime gradually ceased in the mineral soil, resulting in only small differences in the Bw horizon. The interpretation of this is that lime distribution reflected the zone in which earthworms mixed the soil.

As regards carbon and CEC, the differences between the unlimed and limed sites were small (Table 2). The general trend was an obvious decrease in carbon and CEC with depth due to decreasing humus content. However, in the limed soil the carbon concentration in the upper part of the profile was low compared to the unlimed soil. The difference in distribution pattern was mainly due to the activity of soil animals and their mixing of the soil.

An important fact was the lower nitrogen concentration and the higher carbon/nitrogen ratio in O and Ah1 horizons in limed soil (Table 2). In deeper horizons the differences were not significant.

Liming decreased the amount of soluble phosphorus in the upper part of the profile (Table 3). On the other hand, soluble phosphorus increased in the Bw horizon. Concentrations of potassium were lower at the limed site than at the unlimed site (Table 3), possibly owing to the exchange of potassium with calcium. The differences were not significant for single horizons owing to high standard deviations. However, taking the equal discrepancies in several horizons in consideration, the tendency appears obvious.

Although liming resulted in a redistribution of some elements within the profile, the differences in total amounts

Table 2. *Chemical data. Mean and SD L, O1, O2: 24 samples; O3, Ah1, Ah2: 8 bulk samples composited of 8 subsamples; Ah3, Bw: 10 bulk samples composited of 4 subsamples*

Horizon	CEC, me $\times 100\,g^{-1}$	Base saturation, %	pH(H_2O)	Corg, %	Ntot, %	C/N
Not limed						
L	62.2±7.3	55.0±3.9	5.10±0.09	44.9±0.8	1.05±0.08	42.8±3.2
O1	73.0±11.7	31.5±10.6	4.73±0.23	43.9±1.5	1.73±0.14	25.4±2.4
O2	70.6±6.5	28.6±14.0	4.58±0.21	43.5±1.8	2.05±0.16	21.2±1.2
O3	71.3±3.0	6.1±2.0	4.28±0.07	40.0±1.8	1.59±0.45	25.1±7.5
Ah1	17.2±2.8	10.2±12.4	4.31±0.18	7.3±1.8	0.42±0.12	17.4±2.5
Ah2	10.0±1.6	5.6±2.7	4.43±0.10	4.7±1.3	0.25±0.09	18.8±1.9
Ah3	8.8±1.6	4.1±0.8	4.57±0.07	4.1±0.7	0.22±0.05	18.6±2.0
Bw1	6.4±0.9	3.0±0.3	4.63±0.06	3.1±0.4	0.15±0.02	20.7±1.5
Bw2	5.5±0.5	2.7±0.2	4.71±0.03	2.7±0.4	0.14±0.02	19.3±2.5
Bw3	4.6±1.2	2.9±1.0	4.77±0.08	1.9±0.8	0.11±0.03	17.3±3.1
Limed						
L1	61.1±2.9	70.2±2.5	5.41±0.12	44.1±0.9	0.90±0.04	49.0±2.6
O1	57.0±17.9	67.4±5.3	5.45±0.16	42.6±2.5	1.25±0.10	34.4±2.4
O2	72.7±20.0	69.3±24.2	5.47±0.13	37.0±3.3	1.24±0.11	29.8±1.9
O3	–	–	–	–	–	–
Ah1	15.8±1.2	46.0±10.6	5.54±0.19	6.7±1.1	0.35±0.08	19.1±5.7
Ah2	11.1±1.5	41.9±17.8	5.54±0.25	5.1±0.7	0.27±0.05	18.8±3.1
Ah3	11.4±2.4	40.5±16.2	5.29±0.27	4.0±0.7	0.23±0.02	17.4±2.9
Bw1	8.0±1.8	32.7±15.8	5.29±0.21	3.1±0.4	0.16±0.02	19.4±1.8
Bw2	5.5±0.7	9.7±8.0	5.06±0.15	2.6±0.3	0.14±0.02	18.6±1.0
Bw3	4.6±0.9	5.2±2.8	5.01±0.18	2.1±0.7	0.11±0.03	19.1±2.4

Table 3. *Phosphorus and potassium concentrations. Mean and SD (n: see Table 2)*

Horizon	P-AL, ppm	P-HCl, ppm	K-AL, ppm	K-HCl, ppm
Not limed				
L	91.7±11.6	192±31	260±126	1 389±360
O1	122.2±28.7	375±36	265±68	996±183
O2	105.2±37.1	336±50	170±106	641±1 980
O3	60.8±15.5	307±29	79.3±68.9	440±109
Ah1	12.2±4.0	135±29	17.4±15.3	190±75
Ah2	8.8±3.3	92±24	7.1±5.5	158±69
Ah3	5.2±0.9	106±19	4.4±0.8	250±19
Bw1	4.6±0.9	139±48	2.7±0.3	262±36
Bw2	8.1±1.7	294±81	2.2±0.2	300±59
Bw3	11.4±5.7	378±115	1.9±0.4	313±81
Limed				
L	82.7±15.0	182±20	234±62	1 165±223
O1	81.1±13.6	238±43	292±60	907±174
O2	75.2±16.5	255±34	237±49	727±131
O3	–	–	–	–
Ah1	7.5±1.6	101±20	9.9±2.5	128±33
Ah2	4.3±1.3	89±18	5.5±4.9	91±28
Ah3	4.3±1.0	105±19	3.8±0.3	231±24
Bw1	4.0±1.9	158±48	2.3±0.3	226±26
Bw2	9.0±1.7	318±56	1.7±0.3	244±45
Bw3	15.0±3.5	466±67	1.7±0.4	280±29

per m^2 were usually not large (Fig. 13); in the L, O, Ah, and Bw horizons total carbon abounted to 9 900 g × m^{-2} in unlimed soil and 9 500 g × m^{-2} in limed soil. The exception was potassium which showed a decreased amount in limed soil.

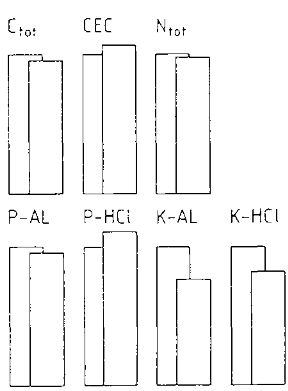

Fig. 13. Relative amounts of nutrients within the total examined profile, i.e., to a depth of approximately 40 cm. For each of the elements the right column indicates the amount at the limed site in relation to the unlimed site, i.e., the left column.

Litter turnover

Based on the amount and chemical composition of the leaf fraction in L, O1 and O2 horizons, some estimations of turnover rate and mean ages of organic matter might be made. The amounts of different elements in the leaf fraction are presented in Table 4. The nitrogen in fresh litter at the unlimed site amounted to 3.3 g × m^{-2} whereas in the O1 horizon it was 8.1 g × m^{-2}. As both these horizons represented very early stages in litter decomposition and since the carbon/nitrogen ratio was quite high, significant changes in nitrogen content probably did not take place. Consequently, O1 was calculated to consist of 2.4 years accumulation of litter. This was also indicated by the amounts of phosphorus.

With reference to this accumulation period, the carbon contents measured in these two horizons corresponded to an annual mean loss of carbon of approximately 30%. The amount of accumulated carbon in the O2 horizon indicates that decomposition could not possibly continue at such a high rate after 2.4 years.

At the limed site, the amounts of nitrogen, as well as phosphorus, did not increase from fresh litter to O1 as was the case in the unlimed soil but, in contrast, decreased from 3.0 to 2.2 g nitrogen × m^{-2}. The residence time of litter in the O1 horizon was assumed to be approximately equal to that in the unlimed soil or slightly shorter, i.e., 2 years. This assumption is supported by two facts. Firstly, the morphological properties of this horizon were the same in limed and in unlimed soil, and secondly, the carbon/nitrogen ratio was somewhat higher at the limed site. Under the assumption that the residence time was 2 years, the decreased amount of nitrogen in the O1 horizon indicated that 50% of the litter, including nitrogen, annually

Table 4. *Bioelements in leaf-litter remains in the upper part of the humus form. Mean and SD (n: see Table 2)*

Horizon	Ntot, $g \times m^{-2}$	Ptot, $mg \times m^{-2}$	Corg, $g \times m^{-2}$	C/N
Not limed				
L	3.34±0.54	174±33	135±21	40.5±3.0
O1	8.13±4.80	404±255	175±96	22.2±2.1
O2	9.78±2.47	499±135	194±47	19.9±1.2
Limed				
L	3.03±1.38	167±93	133±61	43.6±2.3
O1	2.23±1.06	117±56	58±26	26.5±1.8
O2	2.08±1.27	121±74	52±31	25.1±1.6

was transferred into the mineral soil. This estimation is based on the assumption that no significant nitrogen leaching occurred during this early stage of decomposition.

The large drop in carbon content from fresh litter to the O1 horizon, i.e. 133 to 58 $g \times m^{-2}$, must foremost be a result of the earthworms annually introducing 50% into the mineral soil, together with an annual carbon mineralization of 35%. The figures obtained on decomposition rate are minimum values. If the residence time in O1 was substantially shorter than 2 years, then earthworm activity was lower, whereas decomposition was higher.

Annual growth of standing volume

The annual increments of the growing stock are given in Table 5. The increments were somewhat smaller at the limed site than at the unlimed site.

At the 1981 revision the site index was H100=30.1 m in the limed stand but 30.5 in the unlimed site. In 1955 the figures were 13.5 and 13.0 m, respectively. The total production up to 1981 was 419 m^3 per ha in the limed stand compared to 420 m^3 per ha in the unlimed. In 1955 corresponding figures were 113 and 112 m^3 per ha respectively. Considering the slight difference in production and the absence of replications, the difference must be regarded as insignificant. The figures do not support the theory that lime should improve long-term production.

Table 5. *Annual growth*

	$m^3 x year^{-1} x ha^{-1}$		Per cent	
	Not limed	Limed	Not limed	Limed
1959	12.3	12.9	11.1	11.2
1964	12.2	11.6	8.6	7.8
1970	11.1	11.0	6.3	6.2
1975	11.9	10.9	6.0	5.6
1981	13.2	12.8	5.6	5.6

Discussion

The three main results from this investigation were that lime application (1) led to intensified earthworm activity which in turn changed the soil structure, (2) did not generally cause a change in the amount of the nutrients within the profile but did cause a change of their distribution pattern and (3) did not result in an increase of the long-term growth of the beech stand. The latter result is surprising since the change to the humus form mull is generally considered to improve soil condition. However, it must be borne in mind that the soil was a rathe coarse textured till with a clay content less than 5%. This, in combination with mesic moisture conditions, implies that the soil originally was well-drained, well-aerated and that it provided an excellent substrate for root development. Moreover, the root penetration was not impeded by the occurrence of any dense horizons such as iron pans or fragipans. The soil thus originally had favourable physical conditions. The beneficial effects arising from the change to mull were, consequently, marginal.

The small physical improvement might, on the other hand have been counteracted by some unfavourable impacts of lime. Thus, the redistribution of the nutrients to deeper levels in the soil might have been a disadvantage with respect to the large proportion of fine roots close to the soil surface. In the humus form at the limed site the nitrogen concentrations were decreased and the carbon/nitrogen ratios were increased. This might result in less available nitrogen. Lime and increased pH in the soil might also have impeded mycorrhiza activity and consequently decreased the plant's nitrogen supply. Although application of lime favours biological activity in soil and increases the rate of litter decomposition, the long-term impact on humification and nitrogen mineralization might be the reverse. Thus, Duchaufour (1982) referring to Herbauts (1974) and Le Tacon (1976) emphasizes the stabilising effect by calcium carbonate. The protection of organic matter against microbial biodegradation is reflected in the rate of carbon and nitrogen mineralization in calcareous and eutrophic mulls being about half of that in acid mulls.

The production figures reviewed refer to stem production. It cannot be excluded that the total biomass production has increased after liming although it seems rather unlikely with respect to unchanged litter production (Table 4). An additional explanation of the unchanged production after liming might be that too short a period has passed. However, this explanation seems unlikely since the time apparently has been long enough to strongly affect the humus form.

An interesting observation was that nitrogen concentrations were lower and carbon/nitrogen ratios were higher in the upper horizons at the limed site than at the unlimed. This might appear contradictory as lime is considered to increase litter decomposition and thereby decrease the ratio. The prevailing situation might be explained in several ways. The earthworms continuously transferred organic matter into the mineral soil, resulting in a lower mean age and consequently a lower decomposition degree of organic matter remaining on the mineral soil. This is of general interest. In all soil types in which burrowing animals play an important role the carbon/nitrogen ratio will be affected by the animal activity, i.e., even in the case of raised decomposition the ratio might increase. Thus, the ratio is a rather poor index of the degree of decomposition. The increased carbon/nitrogen ratio might also be due to increased mineralization, followed by nitrogen losses through leaching. This is not in accordance with Lundmark & Nömmik (1984) but it should be borne in mind that the carbon/nitrogen ratio might play a decisive role. Thus, in the studied humus form the ratio is lower compared to the mor in coniferous stands.

The figure obtained on carbon mineralization at the unlimed site, 30%, agrees with several othe reports. Berg et al. (1982) calculated the annual decomposition of Scots pine needles to 25%. Bockock & Gilbert (1957) studied the disappearance of leaves from different tree species, reporting 17–23% loss in dry weight during 6 months for oak leaves on moder and 26–29% for birch. Lousier & Parkinson (1976) recorded a weight loss of 26.2% for aspen leaf litter during 12 months.

At the limed site the carbon loss was calculated to at least 35%, i.e., about 17% higher than at the unlimed site. This is in accordance with other reports. Lohm et al. (1983), studied the cumulative amount of CO_2 evolved after 90 days incubation, finding that the amount after lime application was about 40% higher than in a control. This indicates an increased total activity of soil organisms as a result of lime application. It should be stressed that this increase in carbon mineralization also was associated with a decreased net mineralization of nitrogen (Lohm et al., op.cit.).

The calculated residence time of litter remains in different horizons indicates the time required to build up a humus layer. Thus, the figures indicate that 2–3 years are necessary to form the upper part of the O horizon and much more to form the middle and the lower parts. Olsson (1983*b*) found that at least 20 years were required for building up the F horizon but at least 80 years for a H horizon under a coniferous stand.

References

Altemüller, H.-J. 1972. Mikroskopische Merkmale der Boden—stabilisierung mit Kalkhydrat. *Mitteilgn. Dtsch. Bodenkundl. Gesellsch. 15*, 57–63.

Avery, B. W. & Bascomb, C. L. 1974. *Soil survey laboratory methods* (Soil Survey Technical Monograph 6). Harpenden.

Babel, U. 1975. Micromorphology of soil organic matter. In *Soil Components 1. Organic components* (ed. J. E. Gieseking), 369–473. Berlin: Springer Verlag.

Berg, B., Hannus, K., Popoff, T. & Theander, O. 1982. Changes in organic chemical components of needle litter during decomposition. Long-term decomposition. Long-term decomposition in a Scots pine forest. I. *Canadian Journal of Botany 60:* 8, 1310–1319.

Bocock, K. L. & Gilbert, O. J. W. 1957. The disappearance of leaf litter under different woodland conditions. *Plant and Soil 9:* 2, 179–185.

Chauvel, A., Nobrega de, M. T. & Tessier, D. 1983. The effect of compaction and addition of lime on a Latosol. In *Soil Micromorphology 1. Techniques and Applications* (ed. P. Bullock & C. P. Murphy), 237–243. AB Academic Publishers.

Duchaufour, P. 1982. *Pedology.* London: Georg Allen & Unwin. (Translation of Duchaufour, P. 1977. Pédogenèse et classification, vol. 1 Pedologie, by T. R. Paton).

FAO-Unesco 1974. *Soil map of the world I. Legend.* FAO-Unesco, Paris.

Handley, W. R. C. *Mull and mor formation in relation to forest soils.* Forestry Commission, Bulletin 23.

Herbauts, I. 1974. *Evaluation de la disponibilité potentielle en azote minéral dans différents types forestiers lorrains.* D.E.A. Pedologie. Univ. Nancy I.

Hesselman, H. 1926. *Studier över barrskogens humustäcke, dess egenskaper och beroende av skogsvården* (Meddelanden från Statens Skogsförsöksanstalt 22: 5, 169–552).

Hägglund, B. & Lundmark, J.-E. 1977. *Site index estimation by means of site properties, Scots pine and Norway spruce in Sweden* (Studia For. Suec. 138). Swedish College of Forestry, Stockholm.

Kungliga Lantbruksstyrelsens Kungörelser m.m. 1. 1965. Solna.

Ledin, S. 1981. *Physical and micromorphological studies of the effects of lime on clay soil.* Doct. thesis, Swedish Univ. Agr. Sci., Uppsala.

Le Tacon, F. 1976. *La présence de calcaire dans le sol: influence sur le comportement de l'épicéa et du pin noir d'Autriche.* State doct. thesis, Univ. Nancy I.

Lohm, U., Larsson, K. & Nömmik, H. 1984. Acidification and liming of coniferous forest soil: Long term effects on turnover rates of carbon and nitrogen during an incubation experiment. *Soil Biol. Biochem. 16:* 4, 343–346.

Lousier, J. D. & Parkinsson, D. 1975. Litter decomposition in a cool temperate deciduous forest. *Canadian Journal of Botany 54,* 419–436.

Lundmark, J.-E. & Nömmik, H. 1984. *Liming and strong scarification of a clear-felled area—influences on nitrogen mineralization in the soil and growth responses of the young Scots pine plants* (Reports in Forest Ecology and Forest Soils 47, Swedish University Agr. Sci., Uppsala).

Nömmik, H. 1971. A modified procedure for determination of organic carbon in soils by wet combustion. *Soil Sci. 111:* 5, 330–336.

Nömmik, H. 1973. Ammonium chloride-immidazole extraction procedure for determining titratable acidity, exchangeable base cations and cation exchange capacity in soils. *Soil Sci. 118:* 4, 254–262.

Olsson, M. T. 1983*a*. *Long-term effects of methods in forestry on soil processes. A presentation of working and planned projects in Sweden* (Reports in Forest Ecology and Forest Soils 43, Swedish Univ. Agr. Sci., Uppsala).

Olsson, M. 1983*b*. *Morphology and genesis of mor from a pine-heath stand* (Studia For. Suec. 64).

Perman, O. & Manell, E. 1937. Preliminär redogörelse för gödslings-, kalknings- och baljväxtodlingsförsök vid Lanna försöksgård 1929–1936. *Medd. från centralanst. för försöksväsendet på jordbruksområdet 473,* 161–237.

Popović, B. 1967. *Kvävemobiliseringsförsök md humusprov från gödslingsförsöksytor i skogsbestånd på fastmark* (Research Notes 6. Department of Forest Ecology and Forest Soils, Royal College of Forestry, Stockholm).

Popović, B. 1983. Mineralization of carbon and nitrogen in humus from field acidification studies. *Forest Ecology and Management 8,* 81–93.

Popović, B. & Andersson, F. 1984. *Liming and forest production—literature review and revision of Swedish liming experiments* (Statens Naturvårdsverk SNV pm 1792. Stockholm).

Tamm, O. 1934. En snabbmetod för mineralogisk jordartsgranskning. *Svenska Skogsvårdsföreningens Tidskrift I–II,* 231–250.

Tamm, O. 1959. *Studien über die Humidität des Klimas in Schweden* (Bulletin of the Royal School of Forestry 32).

van Breemen, N. & Brinkman, R. 1976. Chemical equilibria and soil formation. In *Soil chemistry, A. Basic elements* (ed. G. H. Bolt & M. G. M. Bruggenwert), 141–170. Elsevier Scientific Publishing Company.

Wiklander, L. 1963. Kalkens betydelse för markens struktur. In *Svenskt jordbruk och skogsbruk 1913–1962.* Minnesskrift, Kungliga Skogs- och Lantbruksakademien, 249–259. Stockholm: Almqvist & Wiksell.