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RESPONSE OF SOIL FAUNA TO FERTILIZATION AND MANIPULATION OF pH IN CONIFEROUS FORESTS

LANNOITUKSEN JA pH-MUUTOKSEN VAIKUTUS KANGASMETSÄN MAAPERÄELÄIMISTÖÖN

Veikko Huhta, Riitta Hyvönen, Antti Koskenniemi, Pekka Vilkamaa, Paula Kaasalainen & Minna Sulander

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Seloste

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HELSINKI 1986

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The effects of different fertilizer treatments on the invertebrate fauna of coniferous forest soil were investigated during the years 1979–83 both in field and in laboratory experiments. Fertilizers tested were urea (both alone and added with P and K), ammonium nitrate and ashes. Ash-treatment was also controlled by raising the pH at the same level with $Ca(OH)_2$. Both ashes and urea resulted in considerable changes in the soil fauna. Nematodes, especially bacterial feeders, increased temporarily. Some families of *Coleoptera* invaded the urea-treated plots. Enchytraeid worms and several microarthropod species decreased, as well as the total animal biomass. Ash-treatment influenced more slowly than did urea-fertilizing, but it caused more permanent changes. Ammonium nitrate with lime had little influence in the field. All fertilizers affected more strongly when mixed with soil in laboratory. pH alone proved to explain most of the changes observed, but nitrogen as a nutrient also plays role independently of acidity.

Erilaisten lannoituskäsittelyjen vaikutuksia kangasmetsän maaperän selkärangattomiin tutkittiin vuosina 1979–83 sekä kenttä- että laboratoriokokeissa. Tutkitut lannoitteet olivat urea (sekä yksin että yhdessä apatiitin ja biotiitin kanssa), oulunsalpietari ja tuhka. Tuhkakäsittelyn kontrollina käytettiin myös maata, jonka pH oli nostettu samaksi $Ca(OH)_2$:n avulla. Sekä tuhka että urea aiheuttivat huomattavia muutoksia maaperäeläimistössä. Sukkulamadot, erityisesti bakteereja syövät lajit, lisääntyivät ohimenevästi. Eräiden kovakuoriaisheimojen lajit lisääntyivät urealannoitetuissa koeruuduissa. Änkyrimadot ja useat mikroniveljalkaislajit vähenivät, samoin kuin eläinten kokonaisbiomassa. Tuhka vaikutti hitaammin kuin urea, mutta sen vaikutukset jäivät pitkäaikaisemmiksi. Oulunsalpietari vaikutti kenttäkokeissa vain änkyrimatoihin. Laboratoriossa, missä lannoitteet sekoitettiin maahan, kaikki käsittelyt vaikuttivat voimakkaammin kuin kentällä. pH yksinään selitti useimmat todetuista muutoksista, mutta myös typellä ravinteena oli vaikutusta happamuudesta riippumatta.

Keywords: Invertebrates, Soil ecology, Nematoda, Enchytraeidae, Microarthropods, Macroarthropods, Lumbricidae
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PREFACE

This work has been part of an inofficial research project "Effect of fertilizing on the forest ecosystem". It was supported by the National Research Council for Sciences, Academy of Finland, and carried out at the Department of Zoology, University of Helsinki, and Department of Biology, University of Jyväskylä. The main experimental fields were established by Kemira Oy, a company that also kindly offered help in the coordination between different subprojects. Several persons have been involved in the practical work and offered technical assistance in sampling, extraction, counting, drawing etc. We wish to express our best thanks to all of them.

The study was conducted by the first author, and responsibility for identification and treatment of the main animal groups was shared by the authors as follows: Huhta: *Enchytraeidae, Lumbricidae, Mesostigmata;* Hyvönen: *Nematoda;* Koskenniemi: *Oribatida* excl. Saarijärvi; Vilkamaa: *Collembola;* Kaasalainen: macroarthropods; Sulander: *Oribatida,* Saarijärvi.

1. INTRODUCTION

Soil invertebrates form an essential part of the decomposer food web which, in complex interaction with microbes, is responsible for the breakdown of forest litter into humus and mineral components. The process of decomposition is regulated by a multiplicity of factors that can be divided into climatic, edaphic and substrate quality (type of litter) factors. Coniferous forest soil is characterized by raw humus of low pH, slow decomposition rate and scarcity of large decomposer organisms like millipeds and earthworms (Swift et al. 1979).

Fertilization is a common practice used to increase the productivity in coniferous forests. Area treated annually with fertilizers has fluctuated widely in Finland during the last decades, the maximum being ca. 240 000 ha, and the minimum less than 100 000 ha (Yearbook of Forest Statistics 1984). Now it is essentially smaller than in the 1970's, but the recent forestry program "Metsä 2000" forecasts a twofold increase in the use of fertilizers by the end of century (Forest 2000 Programme 1986).

Little is known about how fertilization affects the decomposer system. Substrate of high C/N ratio is considered to be nutrient-limited (Swift et al. 1979), thus addition of nutrients can be expected to accelerate decomposition. However, other factors are also involved. Fertilization should not be studied separately from pH, since different fertilizers either differ in acidity, or may result in different reactions in the soil pH, like urea during its hydrolysis (Roberge & Knowles 1966). The potential use of ashes for fertilizing has arosen in connection with increased production of ashes when peat, wood chips and wood industry wastes are increasingly burned for energy. Ashes have been shown to exert a long-lasting beneficial influence on tree growth (Merisaari 1981). It has been shown e.g. by Schalin (1967) that pH is an essential factor to explain the reactions of soil microbes to fertilizers, and by Bååth et al. (1980), Hågvar & Abrahamsen (1980), Hågvar & Amundsen (1981) and Hågvar & Kjøndal (1981a, b), that experimental manipulation of pH exerts influence on soil invertebrates. The role of pH in the soil processes has connections with the problem of acid precipitation (e.g. Huhta et al. 1967, 1969, Marshall 1974, Lohm et al. 1977, Behan et al. 1978, Abrahamsen & Thompson 1979, Sohlenius & Wasilewska 1984).

Effects of forest fertilization upon soil invertebrates have been dealt with in several studies, but most of them suffer from one or more drawbacks: data have been collected during a limited period, number of replicate samples is insufficient, the investigation does not cover all animal groups, species have not been identified and/or biomasses have not been estimated. Our research group has recently finished a comprehensive study, the results of which, dealing with each animal group separately, have appeared or will be published (Huhta et al. 1983, Huhta 1984, Vilkamaa & Huhta 1986, Koskenniemi & Huhta 1986, Hyvönen in prep.). A preliminary report in Finnish was published by Huhta et al. (1984). In these papers emphasis has been paid to communities and populations of individual species.

In the present work we concentrate to summarize the results bearing in mind the soil animal community as a whole. The treatise is mainly based on biomass data, which were only cursorily noted in the previous papers. General responses of the main animal taxa to nitrogen and ash-fertilizers are compared, and an effort is made to separate the role of pH from that of nutrients.

2. MATERIAL AND METHODS

21. Field experiments

Site 1, Saarijärvi, central Finland (62° 40' N, 25° 15' E). A Norway spruce stand of *Myrtillus*-type, aged about 40 years at the beginning of survey. *Vaccinium myrtillus* dominates the field layer vegetation, which is rather sparse and patchy, leaving an almost continuous carpet of common forest mosses to cover the soil. The thickness of humus layer varies between 3 and 5 cm, locally up to 7 cm. The stand was thinned and the slash removed before the treatment.

This site was designed for studying the effects of different nitrogenous fertilizers applied in quantities normally used in forestry. 40×40 m test plots were set up in an area of ca. 2 ha. These were randomized for four different treatments, two replicates for each, i.e.

- C: Control, unfertilized.
- U: Urea (H_2NCONH_2) 432 kg ha^{-1}, i.e. 200 kg N ha^{-1}.
- AN: Ammonium nitrate with lime (Kemira Oy), 727 kg ha^{-1}, i.e. 200 kg N ha^{-1}. (Later referred to as ammonium nitrate).
- U+PK: Urea (200 kg N ha^{-1}) plus phosphorus and potassium in form of apatite (200 kg ha^{-1}) and biotite (1560 kg ha^{-1}), i.e. ca. 100 kg P_2O_5 (44 kg P) and 100 kg K_2O (83 kg K) ha^{-1}.

The fertilizers were spread at the end of May 1979. In each main plot, a subplot of 10×10 m was set up for soil zoological studies. One duplicate of the U+PK treatment was later considered unrepresentative on the basis of botanical survey, and both subplots were taken from opposite sides of the same main plot.

Site 2, Tammela, southern Finland (60° 40' N, 23° 50' E): A Scots pine stand of the *Calluna*-type, ca. 50 years at the start of survey. *Calluna vulgaris* dominates the field vegetation, otherwise it is similar to Site 1.

The experimental design was the same as at the study site 1. In addition, smaller plots (10×10 m) were established for fertilization with ash:

- C: Control, unfertilized.
- A: Ashes, 7000 kg ha^{-1} (fly ash from a power plant of a timber factory).
- A+P: The same as A added with apatite, ca. 44 kg P ha^{-1}.
- U+PK: Urea, apatite and biotite, same amounts as at Site 1.

The U+PK treatment was done in October 1978, while the ashes were spred in May 1979.

Site 3, Ruotsinkylä (Tuusula) (60° 25 N, 24° 50 E). A young (ca. 30 years) *Calluna*-type Scots pine stand, thinned in the previous year. *Calluna vulgaris* strongly dominates the field vegetation.

Ten 4×4 m test plots were selected from as homogeneous places as possible, most of them with a young pine in the centre. Slash, if present, was removed from the plots. Each plot was further divided into four subplots, and these were randomized for different treatments.

Fertilizers were spread on the plots at a 19 days' interval (13 May and 1 June 1981; the second treatment was not done before there had been rain). The treatments were:

- C: Control, unfertilized.
- A+P: 2×3 350 kg ha^{-1} (dry mass) bark ash + 2×500 kg ha^{-1} commercial superphosphate equivalent to 88 kg P ha^{-1} (total).
- L: Slaked lime, $Ca(OH)_2$, 2×2 000 kg ha^{-1}.
- 2×U: Urea, 2×230 kg N ha^{-1}.

At Saarijärvi and Tammela the amounts of fertilizers were those used in practical forestry. At Ruotsinkylä we used double dosages of urea, $Ca(OH)_2$ instead of crushed limestone, and phosphorus as superphosphate instead of apatite, in order to reveal the possible effects more rapidly and distinctly. Chemical composition of the ashes is given in Table 1.

Table 1. Chemical composition of ashes used for the experiments. n.d. = not determined.
Taulukko 1. Kokeisiin käytetyn tuhkan kemiallinen koostumus. n.d. = ei määritetty.

	Fly ash used at Tammela *Tammelassa käytetty lentotuhka* (Enso-Gutzeit Oy)	Softwood bark ash used at Ruotsinkylä *Ruotsinkylässä käytetty kuorituhka* (Viljavuus-palvelu Oy)	Birch ash used for lab. experiment *Laboratoriokokeessa käytetty koivutuhka* (Viljavuus-palvelu Oy)
Loss on ignition, % *Hehkutushäviö, %*	20	22	n.d.
% soluble *% liukoista*	48	n.d.	96.0
pH	11.1	12.7	12.7
P g kg^{-1}	9	7	23
K g kg^{-1}	38	15	98
Ca g kg^{-1}	134	151	283
Mg g kg^{-1}	15	113	40
S g kg^{-1}	15	3	n.d.
Fe g kg^{-1}	12	n.d.	n.d.
Na g kg^{-1}	5	n.d.	n.d.
Mn g kg^{-1}	8	n.d.	n.d.

22. Laboratory experiments

Laboratory tests were designed to separate the effects of pH from those caused by addition of nutrients. Because in undisturbed soil it was not possible to produce similar vertical pH gradients with ash and lime, the materials were mixed homogeneously with soil. A preliminary test was first made to find out what amounts of ash or lime were needed to produce a desired rise of pH.

Intact blocks of soil (all the organic layer including vegetation) were taken from the study site 3 (see above), and placed into six plastic boxes measuring 40×60 cm, 11 cm depth. Before insertion, ca. 1 cm of mineral soil was taken from immediately under each plot and spread on the bottom of the box. Organic soil from the same site was brought into the laboratory and sieved through a 10 mm mesh, forcing by hand most of the dead organic matter through the sieve. The soil so treated was mixed and divided for different treatments. The minerals to be tested were weighed and mixed thoroughly with this soil.

Equal portions of these test materials (soil with or without minerals) were weighed and placed into small baskets made of plastic mesh (∅ 4 cm, height 8 cm, mesh 1.5 mm). When loose at the beginning, the samples made about 100 cm^3 in volume. Holes of corresponding size were bored into the soil in the boxes. Each box had 54 holes and received 18 replicates of three test materials. The order of the samples was random-systematical: each row of six holes received two replicates of each test material, the position of which in the row was randomized. The boxes were covered with perforated plastic to reduce evaporation, and incubated in clima chambers in 12 + 12 h daily cycles of +20 and +15°C (light off at night).

The soil in the boxes was kept moderately moist by watering at times with distilled water. Winter conditions were simulated during the experiments by lowering the temperature weekly by steps of 5°C, until it was close to zero under 24 hour dark conditions for 2 or 3 weeks. Summer conditions were then re-established by a reverse procedure. The order of the shelves of the two chambers was changed weekly.

Experiment 1 was started on 13 August 1981 and kept till 18 May 1982 ("winter" between 1 Dec. and 2 Febr., lowest temperature +3 ±1°C). The test materials were:

- C: Control, mixed soil with no addition.
- A: 9.7 g (d.m.) birch ashes and 1.4 g superphosphate kg^{-1} (f.m.) of soil, equivalent to 1.75 g ashes and 2.2 kg P m^{-2}.
- L: Slaked lime, $Ca(OH)_2$, the same amount as ashes in A.

Both ash and lime were sieved before weighing through 0.57 mm mesh. Superphosphate was pulverized in a mortar. The portions of test materials weighed 33 g (fresh mass), corresponding to 18.2 cm^2 *in situ*. Chemical composition of the ashes is shown in Table 1.

Experiment 2 was started on 25 May and kept until 7 December 1982 ("winter" between 10 Sept. and 5 Nov., lowest temperature +2 ±1°C in chamber 1, and 0 ± 1°C in chamber 2.) The test materials were:

C: Control.
U: Urea, 2.6 g kg $^{-1}$ of soil, (fresh mass; water content 56 %), equivalent to 15 g N m^{-2}.
AN: Ammonium nitrate, 3.4 g kg^{-1}, which makes the same amount of nitrogen as in U.

The chemicals were in pulverized form for analytical purposes. The weight of samples (25.1 g f.m.) corresponds to 20 cm^2 *in situ*.

The same symbols of the treatments are used in the text later.

23. Sampling and sample treatment

In each field plot at the study sites 1 and 2, 5 permanent points were marked (ten on plots A and A+P at Tammela) on homogeneous places. Succeeding samples were taken as close to these points as possible, yet from undisturbed places and at a minimum distance of 10 cm from previous samples. This procedure was thought to minimize accidental variation between sampling dates in comparison with strictly random sampling. At the study site 3, samples were taken from random points of each subplot. Thus a total of 10 sample units were taken each time from each treatment.

Sampling was performed during snow-free periods, usually monthly from May to September. Separate samples were taken with cylindrical steel corers for nematodes, enchytraeids and microarthropods, down to a depth of 6 cm. The soil cores (= sample units), 9.4 or 25 cm^2 in area according to animal group, were divided into layers of 0 to 3 and 3 to 6 cm. Samples for macroarthropods were 25 × 25 cm quadrats, taken with a special spade down to the surface of the mineral soil.

Unfortunately we were unable to follow the same sampling scheme for all groups of animals. Table 2 gives a summary of samples treated.

For pH measurements, 5 similar units from each plot were taken with a 9.4 cm^2 corer, pooled and mixed well. A subsample of ca. 5 g was mixed into 60 ml distilled water, and pH was recorded after 1 hour's incubation (overnight for 1980 samples from Saarijärvi).

Table 2. Sampling scheme for different animal groups, years and treatments (Tammela) in the field experiments. The figures indicate numbers of samples (10 units each) taken during a given season. At Saarijärvi and Ruotsinkylä all treatments were sampled. In addition, enchytraeids were collected at Saarijärvi and Tammela in 1981 and 1982. Abbreviations: see p. 6.

Taulukko 2. Näytteenottokaavio eri eläinryhmille, vuosille ja käsittelyille (Tammela) kenttäkokeissa. Luvut osoittavat ko. vuonna otettujen näytteiden määrän (kukin 10 yksikköä). Saarijärvellä ja Ruotsinkylässä näytteitä otettiin kaikista käsittelyistä. Lisäksi änkyrimatoja kerättiin Saarijärvellä ja Tammelassa 1981 ja 1982. Lyhenteet ks. s. 6.

	Site 1 Saarijärvi		Site 2 Tammela			Site 3 Ruotsinkylä		
	1979	1980	1980			1981	1982	1983
Growing period after treatment / *Kasvukausi käsittelyn jälkeen*	1	2	2			1	2	3
			A	A+P	U+PK			
Nematoda	–	–	5	5	5	5	–	–
Enchytraeidae	4	5	5	5	–	3	3	–
Collembola	–	–	5	5	–	1	2	1
Oribatida	5	5	5	–	–	1	2	1
Mesostigmata	–	5	5	5	–	1	2	1
Macroarthropoda	1	3	3	3	–	1	–	–

From the laboratory experiments, one unit of each treatment (all from the same randomly chosen row), together with its mesh-basket, was removed at selected intervals from each of the six boxes, and extracted immediately. pH was measured from two separate samples, pooled from 3 units each.

Results of the pH measurements from both field and laboratory experiments are presented in Table 3. Separate sets of laboratory samples were weighed at the end of the experiments to reveal differences in mass loss (Table 4.)

Animals were extracted from the samples with appropriate techniques: standard wet funnels (O'Connor 1962) for enchytraeids, Oostenbrinks's (1960) filtration as modified by Huhta & Koskenniemi (1975) or modified wet funnels (Sohlenius 1979) for nematodes, Macfadyen's (1961) high gradient canister extractor (modified) for microarthropods, and large Tullgren funnels (Huhta 1972) for macroarthropods. The samples for nematodes were homogenized and sub-sampled (1/5) before extraction. More details are given by Huhta et al. (in press).

Separate samples for earthworms were not taken because of very sparse populations at the study sites. Earthworms were counted from the large funnel samples, and the figures so obtained are certainly underestimates.

All animal groups were identified to species as far as possible. Nematodes could be identified only to genera of subfamilies, and larval *Diptera* and *Coleoptera* to families.

Table 3. Results of pH measurements. Each number is a mean of two measurements made from separate pooled samples. 1 = Measured from total organic horizon. 2 = One measurement only. Symbols: see pp. 6–8.

Taulukko 3. pH-mittausten tulokset. Kukin luku on kahden erillisen yhdistetyn näytteen keskiarvo. 1) Mitattu koko orgaanisesta kerroksesta. 2) Vain yksi mittaus. Lyhenteet: s. 6–8.

Saarijärvi

	Layer / *Kerros*	1980 V	VI	VII	VIII	IX	1982 VI	VII	IX
C	0 – 3	4.3	5.1	4.1	4.2	3.8	4.4	4.7	4.2
	3 – 6	4.0	5.1	3.9	4.1	4.0	4.3	4.4	4.3
U	0 – 3	5.9	6.2	5.5	5.1	4.6	4.5	4.8	4.3
	3 – 6	4.8	5.4	4.3	4.9	4.2	4.4	4.6	4.3
U+PK	0 – 3	5.6	5.8	5.0	4.6	4.5	–	–	–
	3 – 6	4.7	5.3	4.2	4.2	4.1	–	–	–
AN	0 – 3	4.5	5.3	4.2	4.5	4.1	4.5	4.8	4.3
	3 – 6	4.1	5.0	4.0	4.2	3.9	4.4	4.6	4.3

Tammela

	Layer / *Kerros*	1979[1)] VI	IX	1980[1)] VI	1980 VII	IX
C	0 – 3	4.1	4.0	3.7	4.3	4.3
	3 – 6				4.3	4.3
A	0 – 3	4.8	5.6	6.0	6.0	6.0
	3 – 6				5.1	5.5
A + P	0 – 3	4.8	6.3	5.9	5.2	5.8
	3 – 6				4.7	5.5

Ruotsinkylä

	Layer / *Kerros*	1981 VI	VIII	1982 V	VII	1983 V
C	0 – 3	4.5	4.0	4.3	–	4.7
	3 – 6	4.4	4.3	4.5[2)]	4.7	4.7
A + P	0 – 3	7.4	6.5	6.7	7.0	7.2
	3 – 6	5.7	4.5	4.6[2)]	6.0	4.7
L	0 – 3	7.4	6.6	7.3	7.0	7.7
	3 – 6	4.6	4.4	4.8[2)]	6.2	4.9
2 × U	0 – 3	–	6.0	5.7	5.2	4.9
	3 – 6	–	5.1	5.0[2)]	5.2	4.7

Laboratory experiments – *Laboratoriokokeet*

1	30.VIII	5.X	1.XI	9.III	18.V
C	4.5	4.4	5.0	5.0	4.8
A + P	6.9	6.7	6.6	6.3	5.4
L	7.0	6.6	6.6	6.5	5.5

2	20.V	2.VI	15.VI	5.VII	27.III	7.IX
C	4.4	4.3	4.3	4.7	4.7	4.9
U	6.5	6.4	5.8	6.0	5.9	6.1
AN	3.8	4.1	4.1	4.9	4.9	5.0

Table 4. Mean dry mass ± SD (g) of the soil samples at the end of the laboratory experiments. Significant differences between treated soil and control indicated with asterisks (Student's t-test). Symbols: see pp. 7–8.

Taulukko 4. Maanäytteiden keskimääräinen kuivamassa ± hajonta (g) laboratoriokokeiden lopussa. Merkitsevät erot käsittelyjen ja kontrollin välillä osoitettu tähdillä. Lyhenteet ks. s. 7–8.

Experiment 1: *Koe 1*	C	A + P	L
(n = 12)	15.42±1.37	13.69±1.16**	13.21±1.36**
Experiment 2: *Koe 2*	C	U	AN
(n = 6)	10.18±0.22	9.82±0.32*	10.28±0.16

24. Estimation of biomasses

Nematoda. The biomass of nematodes was estimated by taking randomly 30 to 60 specimens of each taxon from samples taken from untreated plots. These were measured and their average weights were determined according to Andrassy (1959). Final values were obtained after multiplying the individual weights by the numbers counted from each sample.

Enchytraeidae. The animals were measured into size classes as in Huhta & Koskenniemi (1975). A length-weight regression was calculated according to Abrahamsen (1973) after measuring individually a sample of preserved specimens, representing different sizes. This was done separately for *Cognettia sphagnetorum* and *Mesenchytraeus* + *Bryodrilus* (the latter genera were found only sporadically). Using a dry mass/wet mass ratio 0.16 (Persson et al. 1980) average dry masses were obtained for each size class; these were then multiplied by numbers in the sample to calculate the biomass.

Collembola. Simultaneously with identification, all specimens were placed into size classes at intervals of 0.1 mm (up to 1.2 mm) or 0.2 mm. Biomasses were calculated separately for all species with the aid of regression formulae given by Tanaka (1970) and Petersen (1975). For species not found in these, regressions for species of similar body shape were used.

Oribatida and *Prostigmata*. Average weights of adult individuals for each oribatid species were picked from the table given by Luxton (1975). For some infrequent species not found therein, weights of species of similar size and shape were taken instead. Juvenile oribatids as well as all prostigmatids were measured into size classes, and their weights were calculated from the regressions of Huhta & Koskenniemi (1975). For estimating dry weights, dry mass/wet mass ratio was assumed to be 0.4 (Persson & Lohm 1977).

Mesostigmata. Weights for the most abundant species were obtained by weighing 10 to 30 specimens with a microbalance. Otherwise, a few representatives of each species and developmental stage were measured under microscope, and weights were calculated from length/breadth/weight regression by Persson & Lohm (1977), after some corrections described by Huhta et al. (1979).

Macroarthropoda and *Lumbricidae*. After counting and identifying, each taxon from each sample unit was dried at +80°C and weighed separately. The balance used had an accuracy of only 0.1 mg; weights of samples below this limit were estimated by using average weights of individuals of similar size, obtained from larger samples. Weight loss during preservation was corrected for lumbricids by multiplying the figures by 1.3, while no correction was made for arthropods.

All biomasses are expressed in dry weights per square metre. Statistical treatments were not performed with biomass figures, because, apart from those obtained by direct weighing, they themselves are estimates based on numbers, involving unknown sources of error. For the same reason no confidence limits are presented in figures and tables. The standard errors for numbers generally varied between 10 and 20 % of the mean values.

3. RESULTS

31. Nitrogen fertilizers

Urea was used in different experiments either alone or added with apatite and biotite as sources of P and K. Both of these are slowly soluble, while urea is hydrolyzed within a few days in the soil (Overrein 1968), becomes dissolved in the soil water and also results in a reaction in pH. The possible influences of P and K, if any, are probable masked by the strong impact of urea. Therefore we here regard the U+PK-treatment merely as a nitrogen fertilizing, without trying to analyze the potential roles of P and K.

311. Nematoda

Nematodes were included in two field experiments, at Tammela with urea+PK, sampled during the second summer after fertilizing, and at Ruotsinkylä with a double dosage of urea (460 kg N ha^{-1}), sampled during the first growing period.

Nematodes increased strongly during the first two months; in two samples taken in June and July their numbers exceeded those of the control plots about fourfold (Fig. 1). Towards the end of season they decreased again in relation to the control, but remained still at a higher level. There was a similar peak in the second summer at Tammela, although it was of shorter duration, and the mean value of 5 samples remained relatively lower in comparison with Ruotsinkylä. The peak occurrence in both cases took place during the summer minimum in the unfertilized plots.

The increase of nematodes in the fertilized soils was principally due to reproduction of bacterial-feeding species. Their average share in total biomass was 67 % (Ruotsinkylä 1981) or 44 % (Tammela 1980) in the treated soils, while it was 44 % or 22 % in the controls, respectively (Table 5). The difference was severalfold during the peak occurrence (more details in Hyvönen in prep.).

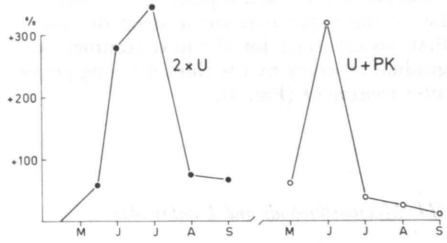

Fig. 1. Numbers of *Nematoda* after urea fertilization in relation to control (difference in %) at Ruotsinkylä (2×U) during the first growing season, and at Tammela (U+PK) during the second season.

Kuva 1. Sukkulamatojen yksilömäärä urealannoituksen jälkeen suhteessa kontrolliin (erotus prosentteina) Ruotsinkylässä (2×U) ensimmäisenä kasvukautena, ja Tammelassa (U+PK) toisena kasvukautena.

Table 5. Estimated mean biomass of the main feeding groups of *Nematoda* after urea fertilization; at Ruotsinkylä during the first growing season, and at Tammela during the second season. Symbols: see p. 6.

Taulukko 5. Sukkulamatojen ravintobiologisten ryhmien arvioitu keskibiomassa urealannoituksen jälkeen Ruotsinkylässä ensimmäisenä kasvukautena, ja Tammelassa toisena kasvukautena. Lyhenteet: ks. s. 6.

	Ruotsinkylä		Tammela	
	C	2×U	C	U+PK
	mg/m²			
Root/fungal feeders				
Juurten ja sienten syöjät	5.8	7.1	4.2	4.2
Bacterial feeders				
Bakteerien syöjät	20.5	59.4	15.1	35.3
Miscellaneous feeders				
Sekaravinnon syöjät	17.8	19.0	48.8	39.8
Predators				
Pedot	2.1	2.9	0.0	1.3
Total				
Yhteensä	46.2	88.4	68.1	80.6

312. Enchytraeidae

Enchytraeid worms were sampled at all study sites, and their development was also monitored longer than that of any other group. This group reacted strongly and rapidly (within a few weeks), and similarly to all nitrogen treatments (Fig. 2). The mean biomass during the first summer varied between 36 to 47 % of that in control plots, depending on the experiment. It remained roughly on the same relative level for the next two years; one experiment (U+PK, Saarijärvi) showed some recovery during the third year, while a double dosage of urea (Ruotsinkylä) caused a continued decrease in the second summer. It was not until the fourth year after fertilization, when the populations recovered to the control level or even above it (urea, but not NH_4NO_3 with lime). This result is in accordance with previous studies (Huhta et al. 1967, 1969, Abrahamsen & Thompson 1979).

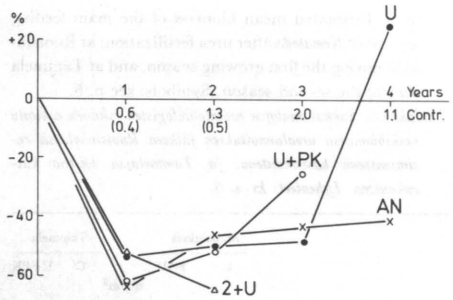

Fig. 2. Biomass of *Enchytraeidae* after nitrogen fertilization in relation to control (difference in %) at Saarijärvi (U, U+PK, AN) and at Ruotsinkylä (2×U). Figures above the zero line show years after fertilizing, and those below the line actual biomasses in the controls ($g \cdot m^{-2}$; in parentheses for 2×U). Samples for each year have been combined. Symbols: see p. 6.

Kuva 2. Änkyrimatojen biomassa typpilannoituksen jälkeen suhteessa kontrolliin (erotus prosentteina) Saarijärvellä (U, U+PK, AN) ja Ruotsinkylässä (2×U). Luvut nollaviivan yllä osoittavat vuosia käsittelyn jälkeen, ja luvut sen alla kontrolliruutujen todellisia biomassoja ($g \cdot m^{-2}$; Ruotsinkylän arvot suluissa). Kunkin vuoden näytteet on yhdistetty. Lyhenteet: ks. s. 6.

313. Microarthropods

Mites (*Acari*) did not show significant reactions to any treatment in which nitrogen fertilizers were spread in quantities 200 kg N ha^{-1}. The same probably holds true for *Collembola*, although these were studied only at Ruotsinkylä with a double dosage of urea. Even here there were only few significant reactions, and the responses of different species compensated each other, resulting in no change in total numbers or biomass (Vilkamaa & Huhta 1986). One species of mesostigmatid mites, *Saprosecans baloghi* Karg, formed and exception: it appeared in rather high numbers in plots treated with urea (Saarijärvi and Ruotsinkylä). This is a predatory mite which is probably distributed phoretically with flying insects (see Chapter 314).

A double fertilizing with urea (Ruotsinkylä) resulted in significant changes in the mite community (Table 6). *Prostigmata* and *Oribatida* reacted markedly, while only few mesostigmatid mites showed significant changes, (for details, see Koskenniemi & Huhta 1986). All changes recorded in populations of individual oribatid species were negative. *Prostigmata* decreased abruptly at first, but recovered later so that they were finally more abundant than in the control plots. A similar trend was seen in juvenile oribatids, although they just reached the control level by the end of survey (2 years). Because of the dominating share of adult oribatids in the total biomass of microarhtropods, these both followed the same pattern: a steep decline at first, steady state for the next summer, and gradual recovery by the third growing period after treatment (Fig. 3).

314. Macroarthropods and Lumbricidae

Because macroarthropods are not treated in more detail elsewhere, we present our numerical data in this paper (Tables 7 and 8). Groups of minor importance and with no significant reactions have been omitted. Selected coleopteran families are included in addition to total numbers of *Coleoptera*, *Diptera* and *Araneae*.

Table 6. Biomass (mg/m^2) of microarthropods at the study site Ruotsinkylä.
Taulukko 6. Mikroniveljalkaisten biomassa (mg/m^2) Ruotsinkylän kokeessa.

	Control – *Kontrolli*					Urea				
	IX 1981	V 1982	VII 1982	V 1983	$\bar{x}$	IX 1981	V 1982	VII 1982	V 1983	$\bar{x}$
Collembola	97	117	77	75	92	112	61	103	79	89
Oribatida ad.	279	224	328	194	257	101	103	118	173	127
" juv.	46	29	23	25	31	21	19	19	22	20
Mesostigmata	120	55	61	35	67	97	29	53	15	48
Prostigmata	8	13	7	10	9	3	10	10	14	10
Total – *Yhteensä*	550	438	496	339	456	334	222	303	303	294

	Ash+P – *Tuhka+P*					$Ca(OH)_2$				
	IX 1981	V 1982	VII 1982	V 1983	$\bar{x}$	IX 1981	V 1982	VII 1982	V 1983	$\bar{x}$
Collembola	143	119	109	58	108	132	104	11	96	111
Oribatida ad.	208	158	266	161	198	274	242	220	145	217
" juv.	43	36	55	24	39	29	41	26	23	29
Mesostigmata	121	51	66	24	65	108	75	50	26	65
Prostigmata	5	19	11	22	15	5	13	10	13	10
Total – *Yhteensä*	520	383	507	289	425	548	475	417	303	432

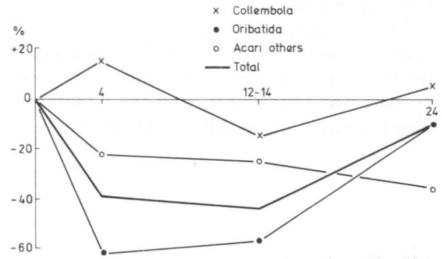

Fig. 3. Relative biomass of microarthropods (difference in % of control) after urea fertilization at Ruotsinkylä (2×U). Time scale: months after treatment; the two samples of the second year have been pooled.

Kuva 3. Mikroniveljalkaisten suhteellinen biomassa (erotus % kontrollista) urealannoituksen jälkeen Ruotsinkylässä (2×U). Aika-akseli: kuukausia käsittelystä; toisen vuoden kaksi näytettä on yhdistetty.

The only taxon showing a significant response to ammonium nitrate with lime was elaterid larvae (Table 7). Two families of *Coleoptera* increased strongly after urea fertilization: *Staphylinidae* and *Ptiliidae*. Numbers of adult and larval staphylinids at Saarijärvi were about threefold in comparison with control three and four months after the treatment, and one year later still twofold. A real mass invasion was made by *Ptiliidae:* hundreds of specimens per square metre were counted in the two first samples, while only scattered individuals were found in unfertilized soil (Table 7). At Ruotsinkylä, *Staphylinidae* were scarce and showed no response to urea, while the mass occurrence of *Ptiliidae* was even more marked than at Saarijärvi.

The total biomass of macroarthropods did not change significantly after fertilization (Saarijärvi). There is enourmous size variation among species of macroarthropods, and *Staphylinidae* and *Ptiliidae* do not contribute

Table 7. Numbers and total biomass of macroarthropods at the study site Saarijärvi. Significant differences from the control indicated with asterisks (* = P<0.05, ** = P<0.01; Student's t-test after logarithmic transformation).

Taulukko 7. Makroniveljalkaisten yksilömäärä ja kokonaisbiomassa Saarijärven kokeessa. Merkitsevät erot kontrolliin osoitettu tähdillä.

	VIII-IX 1979	16.V 1980	14.VII 1980	8.IX 1980	$\bar{x}$
Staphylinidae ad.	ind./m² – *kpl/m²*				
Control *Kontrolli*	67	107	88	88	88
Urea	186**	214**	93	155*	162
NH_4NO_3	94	118	115	78	102
Ptiliidae ad.					
Control	5	5	0	2	3
Urea	259**	464**	50**	85**	214
NH_4NO_3	19	11	0	6	9
Total *Coleoptera* ad.					
Control	118	150	122	117	127
Urea	464**	739**	179	302**	421
NH_4NO_3	134	147	166	131	145
Staphylinidae larvae					
Control	72	46	83	75	69
Urea	219*	110*	229*	155	178
NH_4NO_3	67	45	50	91	63
Cantharidae larvae					
Control	296	221	323	888	432
Urea	326	250	174*	579	333
NH_4NO_3	274	381	237	550	360
Elateridae larvae					
Control	130	91	72	86	96
Urea	62	40	34	78	54
NH_4NO_3	67	54	46	21*	48
Total *Coleoptera* larvae					
Control	544	382	501	1081	627
Urea	335	448	446	854	521
NH_4NO_3	475	517	378	693	516
Diptera larvae					
Control	218	171	26	397	203
Urea	178	239	53	355	206
NH_4NO_3	248	133	18	570	242
Araneae					
Control	549	360	589	867	591
Urea	453	386	350	648	459
NH_4NO_3	526	506	448	576	514
Total biomass					
Kokonaisbiomassa		mg/m²			
Control	513	409	376	469	441
Urea	424	412	269	481	396
NH_4NO_3	248	479	279	516	373

Table 8. Numbers and total biomass of macroarthropods at the study site Ruotsinkylä in September 1981. Significant differences from the control indicated with asterisks. Symbols, see p. 6.

Taulukko 8. Makroniveljalkaisten lukumäärä ja kokonaisbiomassa Ruotsinkylän kokeessa syyskuussa 1981. Merkitsevät erot kontrolliin osoitettu tähdillä. Lyhenteet ks. s. 6.

	C	U	A+P	L
	ind/m²–*kpl/m²*			
Staphylinidae	27	27	6	14
Ptiliidae ad.	0	942**	3	0
Total *Coleoptera* adults	42	981**	26	24
Staphylinidae larvae	6	19	14	8
Cantharidae larvae	141	109	323	534*
Elateridae larvae	54	24	11	11
Total *Coleoptera* larvae	206	179	355	555
Cecidomyiidae larvae	153	129	61	96
Total *Diptera* larvae	347	274	163	227
Araneae	210	312	197	282
Total biomass		mg/m²		
Kokonaisbiomassa	346	184	82	164

essentially to the biomass because of their small size (*Ptiliidae* in particular). At Ruotsinkylä, the macroarthropod biomass was considerably smaller in the fertilized plots than in the controls (Table 8), but nothing can be concluded about its significancy on the basis of one sample.

Only scattered specimens of earthworms (*Lumbricidae*) were found in the samples. No trend to either direction (increase or decrease) was observable, and their biomasses also remained negligible (30 to 120 mg m^{-2}).

315. Total biomass

Data about changes in total biomass of soil fauna are only available from experiments and years when all groups were studied simultaneously. As to nitrogen fertilizing, this was in fact done only at Ruotsinkylä in September 1981. In this case, the total biomass was 1.27 g m^{-2} in the control plots, and 0.8 g m^{-2} in the treated plots, meaning a reduction of biomass by 37 %. Taking into consideration that the contribution of *Nematoda* is insignificant, and that there is no proof whether the decrease recorded in the macroarthropod biomass in 1981 was real and/or persistent, it is possible to follow the development of the bulk biomass (summed biomass of microarthropods and enchytraeids) for a time span of two years. This was 46 % lower in the urea-fertilized soil (mean for the whole period, Fig. 9). Although the microarthropod biomass was recovering towards the end of the survey, that of *Enchytraeidae* was not. So, in May 1983 the total biomass of these groups was still 36 % lower in the treated plots. If average values are taken for macroarthropods and nematodes, the difference would be of the order of 25 %.

A related calculation can be made for the nitrogen treatments at Saarijärvi in 1980 (second summer), if missing values for *Collembola* are substituted with the average value at the two other sites (no changes due to fertilization assumed). On this basis, a total biomass of 2.75 g m^{-2} is obtained for untreated soil, and 2.07 g for fertilized soil, which means a reduction by 25 %, exactly the same estimate as for the 2×U-treatment at Ruotsinkylä. In this case, however, the difference is almost exclusively attributable to *Enchytraeidae,* a dominating group in the biomass and clearly suffering from the treatment (640 vs. 1286 mg m^{-2}). The nematodes can be omitted because of their negligible contribution to total biomass.

There was virtually no change in the vertical distribution of animal biomass due to urea fertilizing (Fig. 9).

316. Laboratory experiment

Addition of urea into the soil in laboraroty resulted in similar reactions in all soil animal groups as it did in the field (Fig. 4). However, the response was stronger in laboratory. Excluding nematodes that increased temporarily after the treatment (Huhta et al.1983), most groups suffered from the fertilizer. Especially the population of *Enchytraeidae* was decimated. Many species of microarthropods which showed no reaction in the field, did so in laboratory; in fact all significant changes were negative (Vilkamaa & Huhta 1986, Koskenniemi & Huhta in press). As a result, the total biomass of the groups studied dropped roughly to half of that in untreated soil, and remained so until the end of experiment (Fig. 4).

However, there was one notable exception: A few earthworms, a group not studied intensively, were obtained together with enchytraeids in the wet funnel extraction. All of them were found in urea-treated soil. Because of their large size, they made up a considerable biomass, so that in all samples in which even one specimen was present, the total biomass exceeded that in the control two- to fourfold. Statistically the variation in these samples was enormous, but the observation should not be left without attention. The species in question was *Dendrobaena octaedra* Sav., the only species of earthworms found in dry pine forests.

Ammonium nitrate proved to be harmful or even toxic to soil animals. Enchytraeids were either killed, destroyed immediately ("zero-samples" one day after application, Huhta 1984), and nematodes and springtails were either killed, repelled or prevented from reproduction by the chemical (Huhta et al. 1983, Vilkamaa & Huhta 1986). Oribatid mites were the only group that seemed not to suffer; their numbers remained at the same level as after urea treatment, and reactions of individual species were also similar (Koskenniemi & Huhta 1986). Other groups recovered gradually, the total biomass reached the level of urea treatment (without earthworms) in two months, and that of the control by the last sampling (Fig. 4).

32. Ash-fertilizing and liming

Ashes used for the experiments were added with phosphorus (apatite at Tammela, superphosphate at Ruotsinkylä and in laboratory), because ash is rather poor in P, and the aim was to give a complete non-nitrogen fertilizing for forestry purposes. Ashes have a strong neutralizing effect on soil, and the faunal

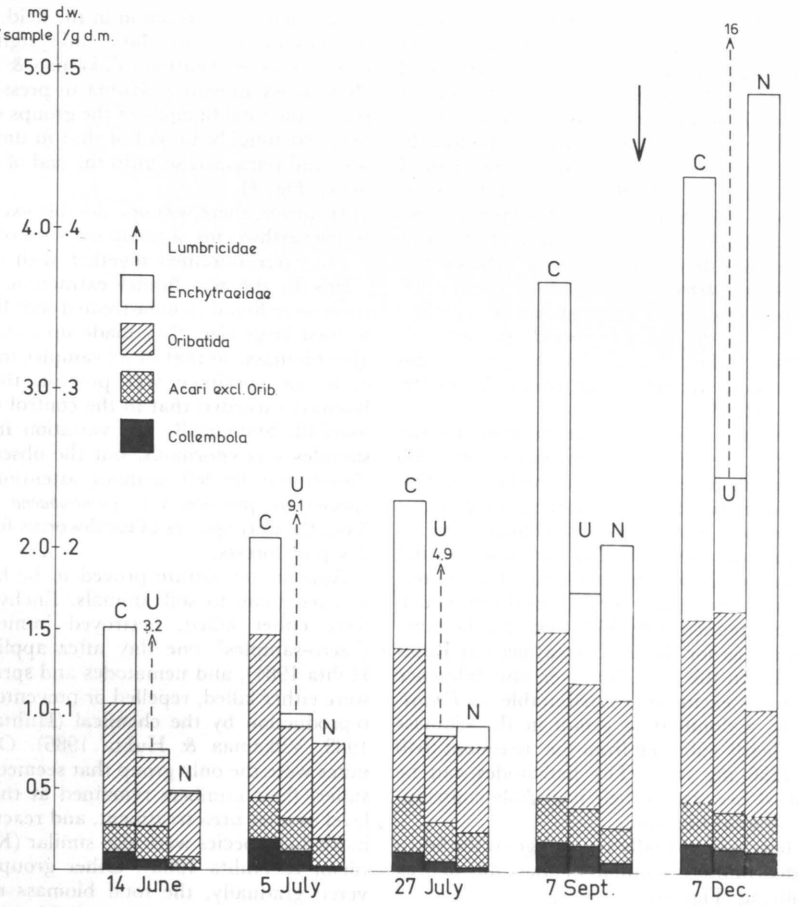

Fig 4. Biomass of *Oligochaeta* and microarthropods in the laboratory experiment 2 (started on 25 May 1982). The arrow shows between which samples artificial winter took place. C = control, U = urea, AN = ammonium nitrate.

Kuva 4. Harvasukamatojen ja mikroniveljalkaisten biomassa näytettä (vasen asteikko) ja sen kuivapainogrammaa kohti laboratoriokokeessa 2 (perustettu 25. 5. 1982). Nuoli osoittaa keinotekoisen talven ajankohdan. C = kontrolli, U = urea, AN = NH_4NO_3.

response (enchytraeids and nematodes) was similar to ash alone and to ash+P (Tammela). Therefore, data from A and A+P (if both were studied, see Table 2) have been combined and mean values presented here for simplicity.

321. Nematoda

Nematodes were sampled during the first growing period after ash-treatment and liming at Ruotsinkylä, and during the second summer after ash-fertilizing at Tammela.

Table 9. Estimated mean biomass of the main feeding groups of *Nematoda* after liming and ash-fertilizing; at Ruotsinkylä during the first growing season, and at Tammela during the second season. Symbols: see p. 6.

Taulukko 9. Sukkulamatojen ravintobiologisten ryhmien arvioidut keskibiomassat kalkituksen ja tuhkalannoituksen jälkeen Ruotsinkylässä ensimmäisenä ja Tammelassa toisena kasvukautena. Lyhenteet: ks. s. 6.

	Ruotsinkylä			Tammela		
	C	A+P	L	C	A	A+P
	mg/m²					
Root/fungal feeders						
Juurten ja sienten syöjät	5.8	5.3	5.8	4.2	5.6	3.3
Bacterial feeders						
Bakteerien syöjät	20.5	24.0	22.7	15.1	28.8	33.5
Miscellaneous feeders						
Sekaravinnon syöjät	17.8	17.5	7.0	48.8	53.8	45.1
Predators						
Pedot	2.1	1.6	2.2	0.0	1.3	3.3
Total						
Yhteensä	46.2	48.4	37.7	68.1	89.5	85.2

The initial response of nematodes to both ash-treatment and liming seemed to be negative, but soon thereafter an increase above the control level took place (Fig. 5). However, the difference between treatment and control was not significant in any sample, and the apparent changes in relative numbers can be explained by stronger fluctuations (deeper summer minimum) in the untreated plots. Mean values of the first year were virtually the same in treated and untreated plots. The proportion of bacterial feeders increased later.

At Tammela (second summer) the mean numbers in both treatments (A, A+P) were ca. 60 % higher than those of the control. The increase was mainly caused by bacterial feeders (Table 9); thus the average picture was rather similar to that after fertilizing with urea. However, the annual fluctuation was different: the relative peak during the summer minimum in the control plots was only moderate, after which the reproduction was more rapid in ash-treated soil, resulting in another peak in September (Fig. 5). (More details in Hyvönen, in prep.).

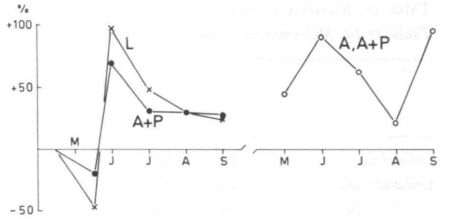

Fig. 5. Relative numbers of *Nematoda* (difference in % of control) after ash-treatment and liming at Ruotsinkylä (L, A+P) during the first growing season, and at Tammela (A, A+P combined) during the second season. Symbols: see p. 6.

Kuva 5. Sukkulamatojen suhteellinen yksilömäärä (erotus % kontrollista) tuhkalannoituksen ja kalkituksen jälkeen Ruotsinkylässä (L, A+AP) ensimmäisenä kasvukautena, ja Tammelassa (A ja A+P yhdistetty) toisena kasvukautena. Lyhenteet: ks. s. 6.

322. Enchytraeidae

Ash-treatments were as destructive to enchytraeid populations as were nitrogen fertilizers, but the rapidity of reactions and duration of effects were essentially different. While urea affected almost immediately and populations started to recover after some years, there was a slow but continuous decline in ash-fertilized plots (Fig. 6). Four years after treatment (Tammela) the mean biomass was only 22 % of that in control soil, without any signs of recovery. The effects of liming did not become evident before the second summer, when the trend was strongly decreasing, indicating that the impact of lime is similar to that of ashes in the long run.

323. Microarthropods

Many species of microarthropods, especially oribatid mites, reacted negatively to ashes and/or liming. The initial reaction of *Prostigmata* (first samples) was also negative, but later they increased considerably above the control level in the ash-treated soil (Ruotsinkylä). Because of their small size, however, they did not compensate for losses in the total mite biomass. Among *Collembola*, both posi-

Table 10. Monthly biomass (mg/m²) of microarthropods at the study site Tammela in 1980.
Taulukko 10. Mikroniveljalkaisten kuukausittainen biomassa vuonna 1980 Tammelan kokeessa.

	Control – *Kontrolli*						Ash, Ash+P – *Tuhka, Tuhka+P*					
	V	VI	VII	VIII	IX	x̄	V	VI	VII	VIII	IX	x̄
Collembola	193	89	77	135	110	121	132	73	128	160	205	140
Oribatida ad.	1100	457	648	563	1089	777	481	327	321	312	864	446
" juv.	63	34	25	32	82	48	14	9	13	26	85	28
Mesostigmata	114	122	165	108	220	146	56	70	102	115	149	98
Prostigmata	24	20	15	24	25	22	16	16	24	35	56	29
Astigmata	5	3	2	3	2	3	3	1	2	2	4	2
Total – *Yhteensä*	1499	725	930	867	1528	1117	702	496	590	650	1363	743

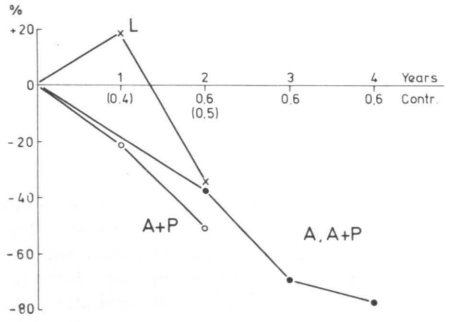

Fig. 6. Relative biomass of *Enchytraeidae* (difference in % of control) after ash-treatment and liming at Tammela (A and A+P combined) and at Ruotsinkylä (L, A+P). Figures above the zero line show years after the treatments, and those below the line actual biomasses in the controls (g·m⁻²; in parentheses for Ruotsinkylä). Samples for each year have been combined. Symbols: see p. 6.

Kuva 6. Änkyrimatojen suhteellinen biomassa (erotus % kontrollista) tuhkalannoituksen ja kalkituksen jälkeen Tammelassa (A ja A+P yhdistetty) ja Ruotsinkylässä (L, A+P). Luvut nollaviivan yllä osoittavat vuosia käsittelyn jälkeen, ja luvut sen alla kontrolliruutujen todellisia biomassoja g·m⁻², Ruotsinkylän arvot suluissa). Kunkin vuoden näytteet on yhdistetty. Lyhenteet: ks. s. 6.

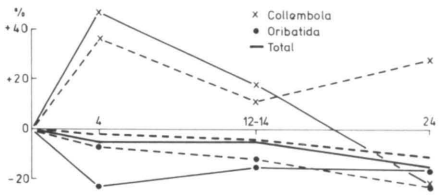

Fig. 7. Relative biomass of microarthropods (difference in % of control) after ash-treatment and liming (dashed lines) at Ruotsinkylä. Time scale: months after treatment; the two samples of the second year have been pooled.

Kuva 7. Mikroniveljalkaisten suhteellinen biomassa (erotus % kontrollista) tuhkalannoituksen ja kalkituksen (katkoviiva) jälkeen Ruotsinkylässä. Aika-asteikko; kuukausia käsittelystä; toisen vuoden kaksi näytettä yhdistetty.

tive and negative effects were recorded; their summed biomass increased at first but decreased later in relation to control. The trend in the total biomass of microarthropods was gradually declining at Ruotsinkylä (Fig. 7). Liming resulted in a similar pattern as did ash-treatment (exception: *Collembola* at the last sampling), but the changes were somewhat slower and less marked (Table 6, Fig. 7).

At Tammela, the mean microarthropod biomass was 33 % lower in the ash-treated plots than in the control. Only Collembola had a higher average biomass in the treated soil (Table 10). During the summer all microarthropod groups showed similar annual trends (increase) in relation to control (Fig. 8). The available data do not allow conclusion whether this indicates a recovery from the negative effects of the treatment, or whether the same pattern would be repeated in succeeding years. The midpoint in the time scale of Fig. 7 corresponds to May–July in Fig. 8, and the decreasing trend continued at Ruotsinkylä by the following May.

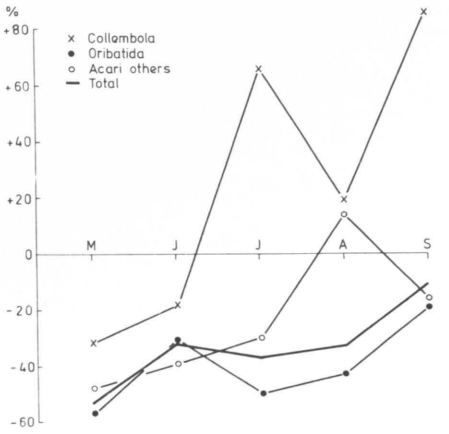

Fig. 8. Relative biomass of microarthropods (difference in % of control) in the second growing period after ash-treatment at Tammela (A and A+P combined).

Kuva 8. Mikroniveljalkaisten suhteellinen biomassa toisena kasvukautena tuhkalannoituksen jälkeen Tammelassa (A ja A+P yhdistetty).

324. Macroarthropods and Lumbricidae

Only few significant changes in the major macroarthropod taxa were recorded after ash-treatments or liming (Tables 8 and 11). The most noteworthy of these was the increase of cecidomyiid larvae at Tammela. All significant differences were found in the last samples, 1.5 years after fertilizing, which indicates that a prolonged monitoring could have revealed more changes in macroarthropod communities.

Table 11. Numbers and total biomass of macroarthropods at the study site Tammela. Significant differences from the control indicated with asterisks (* = P<0.05, ** = P<0.01; Student's t-test after logarithmic transformation). x = sample missing.

Taulukko 11. Makroniveljalkaisten yksilömäärä ja kokonaisbiomassa Tammelan kokeessa. Merkitsevät erot kontrolliin osoitettu tähdillä. x = näyte puuttuu.

	10.V	14.VII	13.IX	x̄
Staphylinidae ad.		ind./m²–*kpl/m²*		
Control *Kontrolli*	18	7	14	13
Ash *Tuhka*	27	21	21	23
Ash + P	27	23	14	21
Total *Coleoptera* adults				
Control	45	11	26	27
Ash	61	37	59	52
Ash + P	49	34	46	43
Staphylinidae larvae				
Control	5	21	18	14
Ash	x	34	11	15
Ash + P	3	24	13	13
Cantharidae larvae				
Control	262	136	290	229
Ash	x	171	195	182
Ash + P	230	198	491	333
Elateridae larvae				
Control	40	43	19	34
Ash	x	29	34	31
Ash + P	42	40	85	55
Total *Coleoptera* larvae				
Control	309	205	352	288
Ash	x	246	246	246
Ash + P	357	269	608	411
Cecidomyiidae larvae				
Control	160	11	15	62
Ash	154	49	270**	158
Ash + P	179	51	89**	106
Total *Diptera* larvae				
Control	328	70	80	159
Ash	285	138	480*	301
Ash + P	346	139	200**	228
Araneae				
Control	227	246	195	239
Ash	235	131	278	215
Ash + P	298	278	466*	347
Total biomass		mg/m²		
Kokonaisbiomassa				
Control	356	261	321	313
Ash	x	242	373	275
Ash + P	308	286	424	318

The populations of earthworms at the study sites were extremely sparse. However, even the small difference between treatments and control at Tammela was significant: not a single specimen was found in the control plots (3 samples), while 9 worms were obtained from the 6 samples taken from the treated plots. Their contribution to biomass was negligible.

325. Total biomass and vertical distribution

Because several animal groups decreased in numbers and biomass after ash-treatment, and only a few increased, the trend in the total biomass was negative (Fig. 9). Including macroarthropods and nematodes, the average biomass at Tammela was 2.15 g m^{-2} in the control, and 1.65 g in the ash-treated soil (difference 23 %). At Ruotsinkylä, ash-treatment decreased the total biomass by 35 %, and the difference between liming and control was ca. 20 %. The main groups responsible for the overall decrease were enchytraeids and oribatid mites.

Both treatments also resulted in an average movement of the animal biomass into deeper soil horizons. At Tammela, 41 % of the total biomass (0–6 cm) of microarthropods and enchytraeids in the ash-treated plots was estimated to be in the 3 to 6 cm layer, while it was 30 % in the control plots (Fig. 9). At Ruotsinkylä the corresponding figures were: Ash 37 %, Lime 42 %, Control 23 %.

326. Laboratory experiment

Similarly to the experiment with nitrogen fertilizers, both ash and lime resulted in a stronger response in the laboratory than they did in the field. The results were generally in good accordance with those obtained in the field experiments, except that more species showed significant reactions in the laboratory. The changes caused by ash and lime were almost identical with each other, while lime affected more slowly in the field.

Bacterial feeding nematodes increased strongly within three weeks, but their peak occurrence remained transitory. Eight weeks from the start of the experiments, and in all later samples, there were less nematodes in treated soil than in control. Most other groups and species suffered from the treatment, only in *Collembola* there were two species that increased in numbers. As a result, the total biomass remained considerably lower in the treated soil, particularly due to strong decrease of biomass of *Oribatida* and *Enchytraeidae* (Fig. 10). The situation remained as such through the duration of the experiment, as far as only these groups are considered. However, casual appearance of earthworms (*Dendrobaena octaedra*) in enchytraeid samples "confused" the picture even in this experiment (cf. p. 15). Twelve specimens were found altogether, and 10 of them in treated soil. When they are counted (estimation of biomass based on Huhta & Koskenniemi 1975), on 8 March there was much more biomass in the ash- and lime-treated samples than in the control ones (Fig. 10).

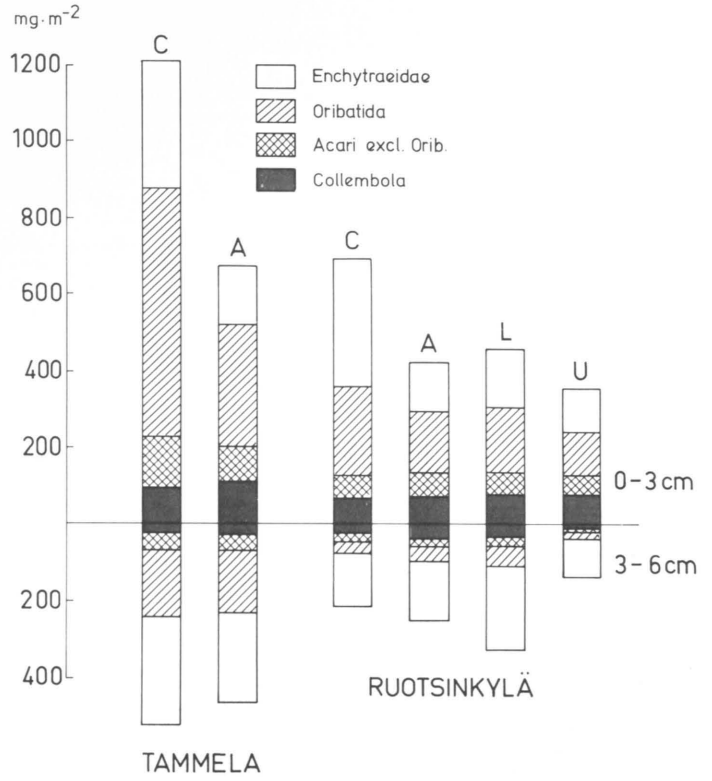

Fig. 9. Biomass of enchytraeids and microarthropods in the field experiments at Tammela (1980) and at Ruotsinkylä (means of all samples). Columns above the base line show biomasses in 0 to 3 cm, and those below in 3 to 6 cm. C = control, A = ash, L = lime, U = urea (see p. 6 for details).

Kuva 9. Änkyrimatojen ja mikroniveljalkaisten biomassa kenttäkokeissa Tammelassa v. 1980 ja Ruotsinkylässä (kaikkien näytteiden keskiarvot). Perusviivan yläpuoliset pylväät: biomassa 0–3 cm kerroksessa, alapuoliset: biomassa 3–6 cm kerroksessa. C = kontrolli, A = tuhka, L = kalkki, U = urea (lähemmin ks. s. 6).

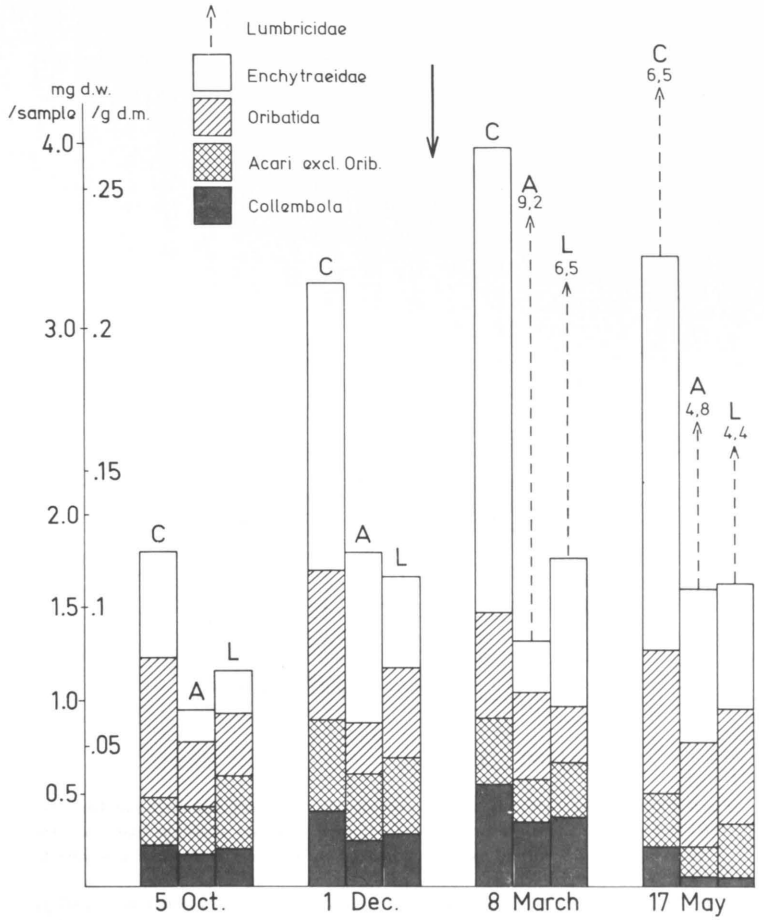

Fig. 10. Biomass of *Oligochaeta* and microarthropods in the laboratory experiment 1 (started on 13 Aug. 1981). The arrow shows the timing of the artificial winter. C = control, A = ash, L = lime.

Kuva 10. Harvasukamatojen ja mikroniveljalkaisten biomassa laboratoriokokeessa 1 (perustettu 13. 8. 1981). Nuoli osoittaa keinotekoisen talven ajankohdan. C = kontrolli, A = tuhka, L = kalkki.

4. CONCLUSIONS AND DISCUSSION

41. Nitrogen fertilizers

The effect of fertilizing depends largely on the amount and chemical form of the nitrogen applied. In dosages normally used in forestry (150 to 200 kg N ha^{-1}) significant responses were recorded after urea treatment in *Nematoda, Enchytraeidae* and some families of *Coleoptera*. When the dosage was increased to 460 kg N ha^{-1} (as urea), microarthropods started to react in addition to these groups. This is in accordance with the results of Lohm et al. (1977). They observed significant changes in microarthropod populations after three repeated applications (one per year) of NH_4NO_3, whereby the amount of N rose to 480 kg ha^{-1}. A similar trend could be seen even at smaller dosages (total 160 kg N ha^{-1}), but this was not demonstrated statistically. A single application of urea or ammonium nitrate (150 kg N) did not result in any reactions in microarthropods, even not in enchytraeids. Abrahamsen & Thompson (1979) showed that decrease in enchytraeid populations is the more marked, the higher is the dosage of urea. Duration of the response was accordingly longer at high dosages, but after several years an even more marked increase above the control took place.

The faunal response was more marked in the laboratory experiment in spite of the smaller amount of N applied when calculated per unit area. This is understandable because in this case the chemicals were mixed with the soil. In the field they are spread on the soil surface, where they are gradually dissolved by rain, and possibly also partially volatilized as ammonia (Overrein 1968).

Most of the reactions observed after nitrogen fertilizing were negative. The most noteworthy exceptions were certain insects (*Coleoptera*: *Ptiliidae* and *Staphylinidae*) invading the urea treated plots, and nematodes, among them bacterial feeders especially, which temporarily increased manyfold above the control level. In the laboratory experiment, earthworms were found only in urea-treated soil, which was probably due to gathering of worms from the surrounding soil rather than to reproduction. This would not be possible in the field where large areas are generally treated simultaneously. On the other hand, invasion by flying insects was prevented in the laboratory.

The influence of urea was more or less transitory, depending on group or species. The peak occurrence of nematodes lasted only for ca. two months, although their average numbers still remained above control level, and there was another peak in the second summer at Tammela. In the laboratory, nematodes showed hardly any peak at all. Many microarthropod species that suffered from the treatment were recovering after two years, while some others still remained sparse. Juvenile oribatids had already reached the control level, which indicates that reproduction had started, and "normal" situation was soon expected also in adult populations. This agrees well with the average generation time in oribatids, which may be about one year at these latitudes (Wallwork 1970). A trend towards control level can also be seen in *Staphylinidae* and *Ptiliidae* during the second summer at Saarijärvi. Enchytraeids took the longest time to recover, but even they exceeded the control populations in the fourth growing season.

Ammonium nitrate is undoubtedly harmful to soil animals, although the field experiment did not reveal negative changes in other groups but enchytraeids. Repeated application of ammonium nitrate in Scots pine stands has been shown to decrease total numbers of *Nematoda* (Sohlenius & Wasilewska 1984), *Enchytraeidae, Collembola* and *Oribatida* (Lohm et al. 1977). In our laboratory experiment NH_4NO_3 decimated the populations of most species, but a recovery took place in ca. 6 months.

42. Ash-fertilizing and liming

Fertilization with ashes resulted in rather similar changes in the soil community as did nitrogen-fertilizing: most species that suffered from urea, decreased also after ash-treatment and vice versa (microarthropods particularly in the laboratory experiments). However, there were essential differences in rapidity and duration of the responses. The effect of ashes was more gradual but more long-lasting. Enchytraeids that were monitored longer than other groups showed no sign of recovery even four years after application. The first significant changes in macroarthropods were not recorded until 1.5 years after treatment. Nematodes did not react significantly before the second summer (Tammela). In laboratory their reaction was more rapid, but the peak occurrence was of very short duration.

Liming affected still more slowly in the field, but finally caused a similar response. The difference can be explained by the lower solubility of $Ca(OH)_2$ than at least of some components of ashes. Actually lime could be seen on the soil surface still in the following year. In laboratory, where pulverized $Ca(OH)_2$ was mixed with soil, it caused an almost identical response with ash.

Unfortunately, earthworms were so sparse at our study sites that no conclusions can be drawn about how the treatments would affect this group. The laboratory experiment 1 indicates that *Dendrobaena octaedra* benefits from both ash and lime. Huhta (1979) has earlier shown that numbers and biomass of *Lumbricidae* increase manyfold after liming in a spruce stand. However, species other than *D. octaedra* were more favoured by the measure.

43. Role of pH versus nutrients

Ashes have a strong and long-lasting neutralizing effect on soil. The pH in the topmost soil layer rises in a short time even by three units, and a difference of ca. two units persists for more than three years. Urea results in a rapid rise of pH by ca. two units, the difference levelling out gradually during two years (Table 3). Many species of soil invertebrates have been shown to respond to experimental manipulation of pH (Bååth et al. 1980, Hågvar & Abrahamsen 1980, Hågvar & Amundsen 1981, Hågvar & Kjøndal 1981a, b, Hågvar 1984a, b).

The lime treatments in the field (Ruotsinkylä) and the laboratory (Exp. 1) were planned to control whether the effects of ashes are explained by changes in pH rather than by addition of nutrients. In the laboratory experiment the soil pH was almost identical in both treatments (Table 3), and so were the changes in animal populations. The slower impact of liming in the field experiment can also be explained by pH: there was a time lag before lime started to influence in deeper soil layers, while the first pH recording showed that the most easily soluble components of ash had temporarily raised the pH in the 3 to 6 cm layer in one month. In the second year the pH was about the same in both treatments, and there was a convergent development in animal populations.

On the basis of these observations it seems plausible that the decrease of acidity alone is enough to explain the changes observed in soil fauna. If so, the nutrients present in ashes either play no role or their impact is masked by the pH (Chapter 32, Figs. 5, 6, 7, 10).

Changes in the faunal biomass after urea fertilizing run rather parallel to those in pH: a rapid change followed by gradual return to original level. It is therefore tempting to conclude that even this reaction is principally caused by the rise in pH rather than by addition of nitrogen. The second laboratory experiment was designed to separate these two factors. Ammonium nitrate caused a slightly acid initial reaction, after which the pH did not differ from that of untreated soil more than 0.2 units. Instead, there was a considerable difference between urea-treated soil and control (Table 3).

The interpretation was hampered by the fact that ammonium nitrate was harmful or even toxic to soil animals. Gradually the populations recovered; probably microbes had transformed and assimilated the initial compounds. When numbers of animals now increased, it could also be because resources were available, the use of which was previously prevented by the toxic chemical. However, oribatid mites did not suffer from NH_4NO_3, at least no more than from urea. In spite of some significant differences, the general response of oribatids was similar in both nitrogen treatments, and their communities in the treated soils were clearly more similar to each other than to the control. So it can be concluded that nitrogen as a nutrient plays a regulating role independently of acidity.

44. Ultimate causes of the changes

Although it has been shown that at least earthworms can respond directly to pH (Laverack 1961), and that reproductive success of some *Collembola* may be regulated by pH (Ashraf 1969, Hutson 1978), it is more probable that the effects of pH and nutrients on soil animals are principally indirect. Hågvar (1984b) has given a thorough discussion about potential mechanisms explaining the impact of acidity on microarthropods, but more questions than answers were found. Naturally, more than one mechanism are involved also in this case when effects of different treatments upon very different animal species are considered.

Because our study did not cover *Protozoa*, bacterial feeding nematodes were the only group of distinct bacterial consumers included. These were among the first animals to respond after different treatments and also one of the few groups showing positive reactions. This indicates an increased bacterial activity which is supported by several previous studies (Mayer-Krapoll 1963, Schalin 1967, Weber et al. 1985). Bacterial feeding nematodes, especially *Rhabditis* species, have a short generation time and high reproductive capacity, which makes them capable to take advantage from enhanced bacterial production (Sohlenius 1973). According to Schalin (1967), urea results in a rapid and strong increase of bacteria even in a quantity of 100 kg N ha^{-1} (plate count method). Similar results have been obtained with direct count techniques. The peak in the microbial biomass starts to disappear in ca. one year after urea-fertilization, and two years later the response turns to negative. Ammonium nitrate has been reported to have negative influence on microbes (review by Söderström 1984).

There is little direct evidence about the influence of ash-fertilizing and liming on bacteria (Bååth et al. 1980), but respiration rate is generally considered to correlate with microbial activity. For instance Lohm et al. (1984) have reported an increased respiration rate after liming (see also Söderström 1984).

Accelerated respiration in turn indicates enhanced decomposition. Respiration was not measured in our study, but there was in fact more weight loss during the laboratory experiments in samples treated with ash, lime and urea, but not in those with NH_4NO_3 (Table 4). Abrahamsen & Thompson (1979) also observed an increase of decomposition in their field experiments with urea.

On the basis of these observations there is reason to conclude that the peak occurrences of bacterial feeding nematodes after ash- and urea-treatments were caused by transitory flush in bacterial activity. This in turn was resulted by the rise of pH, either alone (ash) or in combination with nitrogen (urea). Nitrogen is considered to be the limiting nutrient in coniferous forest soil. However, decomposition rate and microbial activity are also regulated by available resources (decomposable organic matter), hence the transitory nature of the flush in the bacteria-nematode food chain can be explained by exhaustion of resources. The peak was especially short in laboratory, where the bulk of the raw humus was very recalcitrant to decomposition, no living roots were present and no organic matter was added. Living roots stimulate the growth of bacteria and, consequently, reproduction of *Nematoda* (Trofymow & Coleman 1982). Wiggins et al. (1979) observed that there were many times more springtails in the rhizosphere than farther in the soil.

The other non-predatory animal groups treated in our study feed mainly on fungi, dead organic matter or both (Petersen 1971, Luxton 1972, Latter & Howson 1978, etc.). Groups that particularly suffered from fertilization are among the most typical inhabitants of raw humus soil: oribatid mites and the enchytraeid *Cognettia sphagnetorum*. It remains unanswered whether their decrease can be attributed to food shortage because of shift in microflora from fungal-dominated towards a bacterial-dominated one. The balance in the microflora is greatly influenced by acidity, either alone or in combination with fertilizing (Schalin 1967). Bååth et al. (1980) have demonstrated an increase in total fungal

biomass in soil after experimental acidification, although that of active hyphae decreased. However, the diet of these animals is so variable and poorly known, that attempts to explain their occurrence on nutritional basis have failed so far (Anderson & Healey 1972, Latter 1977, Springett & Latter 1977, Latter & Howson 1978, Hågvar & Kjøndal 1981b, Hågvar 1984b).

Apart from *Nematoda*, some effects of ash-treatment seem to remain permanent at least at the time span of the present study, but probably even longer. These must, by some means, be related with the long-lasting decrease of acidity. The enchytraeid *Cognettia sphagnetorum* continues to suffer, while the available evidence indicates that the earthworm *Dendrobaena octaedra* increases instead. In moister forest types other earthworm species probably also benefit. Enchytraeids and earthworms are related families, and may at least partially occupy similar niches. Interspecific interactions between an earthworm and an enchytraeid living in composts have been demonstrated by Haukka (in press). Preliminary observations by Hågvar (1984b) also indicate that competitive interactions may play role in microarthropods.

One effect of urea fertilization must still be mentioned. Urea causes death of mosses, which get brownish in colour already during the first summer. This means an extra source of decomposable matter and possibly contributes to increased numbers of nematodes.

Flying insects are capable to colonize appropriate substrates from distances, and certain coleopteran families did invade the test plots. A predatory mite *Saprosecans baloghi* was probably transported by these insects because it appeared (and vanished) coincidently.

The time of application of the fertilizers is also of importance, not only from the viewpoint of biological response of soil, but also from that of practical forestry (Päivinen & Salonen 1981, Salonen & Päivinen 1983). If spread in late fall, winter and melting snow may considerably decrease the burning effect of urea, while the same amount of fertilizer spread in spring results in a great concentration of it in dry soil in case of low precipitation.

LITERATURE

Abrahamsen, G. 1973. Studies on body-volume, body-surface area, density and live weight of Enchytraeidae (Oligochaeta). Pedobiologia 13: 6–15.

— & Thompson, W. N. 1979. A long term study of the enchytraeid (Oligochaeta) fauna of a mixed coniferous forest and the effects of urea fertilization. Oikos 32: 318–327.

Anderson, J. M. & Healey, I. N. 1972. Seasonal and inter-specific variation in major components of the gut contents of some woodland Collembola. J. Anim. Ecol. 41: 359–368.

Andrassy, I. 1956: Die Rauminhalts- und Gewichtsbestimmung der Fadenwürmer (Nematoden). Acta Zool. Acad. Sci. Hung. 11: 1–15.

Ashraf, M. 1969. Studies on the biology of Collembola. Rev. Ecol. Biol. Sol. 6: 337–347.

Bååth, E., Berg, B., Lohm, U., Lundgren, B., Lundkvist, H., Rosswall, T., Söderström, B. & Wiren, A. 1980. Effects of experimental acidification and liming on soil organisms and decomposition in a Scots pine forest. Pedobiologia 20: 85–100.

Behan, V. M., Hill, S. B. & Kevan, D. K. M. 1978. Effects of nitrogen fertilizers, as urea, on Acarina and other arthropods in Quebec black spruce humus. Pedobiologia 18: 249–263.

Forest 2000 Programme. Silva Fenn. 20: 35–44.

Hågvar, S. 1984a. Effects of liming and artificial acid rain on Collembola and Protura in coniferous forest. Pedobiologia 27: 314–354.

— 1984b. Ecological studies of microarthropods in forest, with emphasis on relations to soil acidity. Dissertation, University of Oslo. 36 pp.

— & Abrahamsen, G.. 1980. Colonisation by Enchytraeidae, Collembola and Acari in sterile soil samples with adjusted pH levels. Oikos 34: 245–258.

— & Amundsen, T. 1981. Effects of liming and artificial acid rain on the mite (Acari) fauna in coniferous forest. Oikos 37: 7–20.

— & Kjøndal, B. R. 1981a. Succession, diversity and feeding habits of microarthropods in decomposing birch leaves. Pedobiologia 22: 385–408.

— & Kjøndal, B. R. 1981b. Effects of artificial acid rain on the microarthropod fauna in decomposing birch leaves. Pedobiologia 22: 409–422.

Haukka, J. (in prep.): Growth and mortality of Eisenia fetida (Sav.) (Oligochaeta: Lumbricidae) in relation to temperature, moisture, and presence of Enchytraeus albidus (Henle) (Enchytraeidae). Biol. Fert. Soils.

Huhta, V. 1972. Efficiency of different dry funnel techniques in extracting Arthropoda from raw humus forest soil. Ann. Zool. Fennici 9: 42–48.

— 1979. Effects of liming and deciduous litter on earthworm (Lumbricidae) populations in a spruce forest, with an inoculation experiment on Allolobophora caliginosa. Pedobiologia 19: 340–345.

— 1984. Response of Cognettia sphagnetorum (Enchytraeidae) to manipulation of pH and nutrient status in coniferous forest soil. Pedobiologia 27: 245–260.

— & Koskenniemi, A. 1975. Numbers, biomass and community respiration of soil invertebrates in spruce forests at two latitudes in Finland. Ann. Zool. Fennici 12: 164–182.

— , Karppinen, E., Nurminen, M. & Valpas, A. 1967. Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous forest soil. Ann. Zool. Fennici 4: 87–143.

— , Nurminen, M. & Valpas, A. 1969. Further notes on the effect of silvicultural practices upon the fauna of coniferous forest soil. Ann. Zool. Fennici 6: 327–334.

— , Ikonen, E. & Vilkamaa, P. 1979. Succession of invertebrate populations in artificial soil made of sewage sludge and crushed bark. Ann. Zool. Fennici 16: 223–270.

— , Hyvönen, R., Koskenniemi, A. & Vilkamaa, P. 1983. Role of pH in the effect of fertilization on Nematoda, Oligochaeta and microarthropods. In: Lebrun, Ph. et al. (eds.), New trends in soil biology. Proc. VIII Int. Coll. Soil Zoology, Louvain-la-Neuve 1982: 61–73.

— , Hyvönen, R., Koskenniemi, A., Vilkamaa, P., Kaasalainen, P. & Sulander, M. 1984: Metsänlannoituksen ja pH:n vaikutus maaperäeläimistöön. Jyväskylän yliopiston biologian laitoksen tiedonantoja 36: 1–35.

— , Hyvönen, R., Kaasalainen, P., Muona, J., Mäkelä, I., Sulander, M. & Vilkamaa, P. (in prep.). Soil fauna in Finnish coniferous forests. Ann. Zool. Fennici 23.

Hyvönen, R. (in prep.): Effects of urea, lime and ash on nematode populations in two Finnish Scots pine forests.

Hutson, B. R. 1978. Influence of pH, temperature and salinity on the fecundity and longevity of four species of Collembola. Pedobiologia 18: 163–179.

Koskenniemi, A. & Huhta, V. 1986. Effects of fertilization and manipulation of pH on mite (Acari) populations of coniferous forest soil. Rev. Ecol. Biol. Sol. 23: 271–286.

Latter, P. M. 1977. Decomposition of a moorland litter, in relation to Marasmius androsaceus and soil fauna. Pedobiologia 17: 418–427.

— & Howson, G. 1978. Studies on the microfauna of blanket bog with particular reference to Enchytraeidae II. Growth and survival of Cognettia sphagnetorum on various substrates. J. Anim. Ecol. 47: 425–448.

Laverack, M. S. 1961. Tactile and chemical perception in earthworms. – II. Responses to acid pH solutions. Comp. Biochem. Physiol. 2: 22–34.

Lohm, U., Lundkvist, H., Persson, T. & Wiren, A. 1977. Effects of nitrogen fertilization on the abundance of enchytraeids and microarthropods in Scots pine forests. Studia For. Suec. 140: 1–23.

— , Larsson, K. & Nömmik, H. 1984. Acidification and liming of coniferous forest soil: long-term

effects on turn-over rates of carbon and nitrogen during an incubation experiment. Soil. Biol. Biochem. 16: 343–346.
Luxton, M. 1972. Studies on the oribatid mites of a Danish beech wood soil. Pedobiologia 12: 434–463.
— 1975. Studies on the oribatid mites of a Danish beech wood soil. II. Biomass, calorimetry, and respirometry. Pedobiologia 15: 161–200.
Macfadyen, A. 1961. Improved funnel-type extractors for soil arthropods. J. Anim. Ecol. 30: 171–184.
Marshall, V. G. 1974. Seasonal and vertical distribution of soil fauna in a thinned and urea fertilized Douglas fir forest. Can. J. Soil Sci. 54: 491–500.
Mayer-Krapoll, H. 1963. Der Einfluss einer Düngung mit Handelsdüngemitteln auf die Kleinlebewelt forstlich genutzter Böden. Die Phosphorsäure 23: 179–205.
Merisaari, H. 1981. Tuhkalannoituksen vaikutuksen kesto eräillä vanhoilla kokeilla. Metsäntutkimuslaitoksen tiedonantoja 13: 1–69.
O'Connor, F. B. 1962. The extraction of Enchytraeidae from soil. In: Murphy, P. W. (ed.), Progress in soil zoology: 279–385. London.
Oostenbrink, M. 1960. Estimating nematode populations by some selected methods. In: Sasser, J. N. & Jenkins, W. R. (eds.), Nematology: 85–102. Durham.
Overrein, L. N. 1968. Lysimeter studies on tracer nitrogen in forest soil: I. Nitrogen losses by leaching and volatilization after addition of urea – N^{15}. Soil Sci. 106: 280–290.
Persson, T. & Lohm, U. 1977. Energetical significance of the annelids and arthropods in a Swedish grassland soil. Ecol. Bull. 23: 3–211.
— , Bååth, E., Clarholm, M., Lundkvist, H., Söderström, B. E. & Sohlenius, B. 1980. Trophic structure, biomass dynamics and carbon metabolism of soil organisms in a Scots pine forest. In: Persson, T. (ed.), Structure and function of northern coniferous forests – an ecosystem study. Ecol. Bull. 32: 419–459.
Petersen, H. 1971. Collembolernes ernaeringsbiologi og dennes ökologiske betydning. Entomol. Meddel. 39: 97–118.
— 1975. Estimation of dry weight, fresh weight, and calorific content of various Collembolan species. Pedobiologia 15: 222–243.
Päivinen, L. & Salonen, K. 1981. Urea- ja ammoniumnitraattitypen levitysajan vaikutuksesta puiden kasvuun kangasmailla. Metsätutkimuksia. Kemira Oy 1/1981, 4 pp.
Roberge, M. R. & Knowles, R. 1966. Ureolysis, immobilization, and nitrification in black spruce (Picea mariana Mill.) humus. Soil Sci. Soc. Amer. Proc. 30: 201–204.
Salonen, K. & Päivinen, L. 1983. Erilaisten typpilannoitteiden vaikutus nuorissa männiköissä kevät- ja syyslevityksissä. Metsätutkimuksia. Kemira Oy. 3/1983. 4 pp.
Schalin, I. 1967. On the effect of nitrogen fertilization on the bacteria and microfungi in humus layer. Silva Fenn. 1: 1–11.
Sohlenius, B. 1973. Structure and dynamics in populations of Rhabditis (Nematoda: Rhabditidae) from forest soil. Pedobiologia 13: 368–375.
— 1979. A carbon budget for nematodes, rotifers and tardigrades in a Swedish coniferous forest soil. Holarctic Ecology 2: 30–40.
— & Wasilewska, L. 1984. Influence of irrigation and fertilization on the nematode community in a Swedish pine forest soil. J. Appl. Ecol. 21: 327–342.
Springett, J. A. & Latter, P. M. 1977. Studies on the microfauna of blanket bog with particular reference to Enchytraeidae. I. Field and laboratory tests of micro-organisms as food. J. Anim. Ecol. 46: 959–974.
Swift, M. J., Heal, O. W. & Anderson, J. M. 1979. Decomposition in terrestrial ecosystems. Studies in Ecology 5. 372 pp. London.
Söderström, B. 1984. Some microbial data on acidification and liming of forest soils. Statens Naturvårdsverk. PM 1860. 15 pp.
Tanaka, M. 1970. Ecological studies on communities of soil Collembola in Mt. Sobo, southwest Japan. Japanese J. Ecology 20: 102–110.
Trofymow, J. A. & Coleman, D. C. 1982. The role of bacterivorous and fungivorous nematodes in cellulose and chitin decomposition in the context of a root/rhizosphere/soil conceptual model. In: Freckman, D. (ed.) Nematodes in soil ecosystems: 117–138. Austin.
Vilkamaa, P. & Huhta, V. 1986. Effects of fertilization and pH on communities of Collembola in pine forest soil. Ann. Zool. Fennici 23: 167–174.
Wallwork, J. A. 1970. Ecology of soil animals. 283 pp. London.
Weber, A., Karsisto, M., Leppänen, R., Sundman, V. & Skujinš, J. 1985. Microbial activities in a histosol: Effects of wood ash and NPK fertilizers. Soil Biol. Biochem. 17: 291–296.
Wiggins, E. A., Curl, E. A. & Harper, J. D. 1979. Effects of soil fertility and cotton rhizosphere on populations of Collembola. Pedobiologia 19: 75–82.
Yearbook of forest statistics 1984. Folia For. 620. (1985). 232 pp.

Total of 63 references

SELOSTE

LANNOITUKSEN JA pH:N VAIKUTUS KANGASMETSÄN MAAPERÄELÄIMISTÖÖN

Johdanto

Lannoituksen vaikutuksia metsämaan eläimistöön on tarkasteltu lukuisissa tutkimuksissa. Kuitenkin kuva erilaisten ravinnelisäysten vaikutuksista kangasmetsän maaperäeläimistöön kokonaisuutena on jäänyt monelta osin puutteelliseksi. Useimmissa töissä eläimet on määritetty ainoastaan pääryhmittäin, mikään tutkimus ei kata kaikkia eläinryhmiä, eikä vaikutuksia biomassoihin ole selvitetty. Monissa vanhemmissa tutkimuksissa koejärjestely on ollut puutteellinen tai näytemäärä riittämätön. Useimmissa kenttätutkimuksissa ei ole otettu huomioon, että monet lannoitteet muuttavat maan happamuutta, minkä tiedetään vaikuttavan mikrobistoon ja sitä kautta epäilemättä myös eläimiin. Urealannoitus nostaa happaman kangashumuksen pH:ta ja vaikutus voi kestää kaksikin vuotta. Vielä voimakkaampi ja pitkäaikaisempi neutraloiva vaikutus on tuhkalla. Monissa viimeaikaisissa laboratoriotutkimuksissa on osoitettu, että maaperäeläimet reagoivat happamuuden kokeelliseen muuttamiseen.

Kirjoittajat ovat äskettäin saaneet päätökseen laajahkon tutkimuksen typpi- ja tuhkalannoituksen sekä pH-muutoksen vaikutuksista maaperäeläimiin. Tulokset on julkaistu tai lähetetty painettavaksi eläinryhmäkohtaisesti erillisinä artikkeleina, joiden pääpaino on kokonaisyksilömäärien ja eri lajien populaatioiden reaktioissa eri käsittelyihin. Tässä työssä keskitytään luomaan kokonaiskuva käsittelyjen vaikutuksista maaperäeläimistöön. Tarkastelun pohjana ovat ensi sijassa biomassa-arviot, jotka ryhmäkohtaisissa artikkeleissa on mainittu vain lyhyesti ja ilman kommentteja.

Aineisto ja menetelmät

Tutkimuksen kohteena oli kaksi kenttäkoetta, joissa lannoitteita käytettiin metsänhoidollisten ohjeiden mukaiset määrät. Mustikkatyypin kuusikossa Saarijärvellä tutkittiin erityisesti typpilannoitteden vaikutuksia, ja kanervatyypin männikössä Tammelassa tuhkalannoitusta. Kolmas koekenttä perustettiin Tuusulaan (Ruotsinkylä), missä tutkittiin tuhkalannoituksen ja kaksinkertaisen urealannoituksen vaikutuksia. Maanäytteitä otettiin yleensä kuukausittain yhden tai useamman kasvukauden aikana käsittelyn jälkeen. Tuhkan, urean ja ammoniumnitraatin vaikutuksia tutkittiin lisäksi laboratoriokokeissa, joissa lannoitteet sekoitettiin punnittuihin määriin kangashumusta ja inkuboitiin kasvatuskaapeissa. Tuhkakäsittelyä verrattiin sekä kentällä että laboratoriossa toisaalta käsittelemättömään maahan ja toisaalta maahan, jonka pH oli nostettu samaksi Ca $(OH)_2$:n avulla. Toisessa laboratoriokokeessa annettiin sama määrä typpeä ureana ja ammoniumnitraattina. Eri eläinryhmiä varten otettiin erilliset näytteet, joista eläimet eroteltiin asianomaisilla menetelmillä, laskettiin, ja määritettiin mikäli mahdollista lajilleen. Samalla arvioitiin niiden biomassa.

Tulokset ja päätelmät

Metsänhoidossa yleisesti käytetyillä typpilannoitemäärillä (200 kg N/ha) todettiin merkitseviä vaikutuksia vain joihinkin eläinryhmiin. Sukkulamadot lisääntyivät aluksi voimakkaasti; vaikutus kesti 1–2 kasvukautta. Eräitä kovakuoriaislajeja tuli suurina määrinä urealannoitettuihin koeruutuihin. Änkyrimadot vähenivät jyrkästi ja runsastuivat vasta neljäntenä kasvukautena ureakäsittelyn jälkeen. Kaksinkertainen urealannoitus vaikutti edellisten lisäksi useisiin mikroniveljalkaislajeihin; monien lajien populaatiot vähenivät, samoin kokonaismäärät ja biomassa. Palautumista tapahtui kolmanteen kasvukauteen mennessä. Maaperäeläinten kokonaisbiomassa oli 6–24 kk aikana keskimäärin 25 % kontrollia alempi. Oulunsalpietari vähensi kentällä vain änkyrimatojen määrää.

Tuhkalannoitus vaikutti hitaammin kuin urea, mutta vaikutus jäi pitkäaikaiseksi. Vaikutus oli kokonaisuutena ottaen saman suuntainen kuin urean. Erityisesti vähenivät änkyrimadot, jotka eivät osoittaneet palautumisen merkkejä vielä neljäntenä kesänä käsittelystä. Myös kangasmetsän maaperässä runsaslukuiset punkkilajit vähenivät. Sukkulamatoja esiintyi erityisesti toisena kasvukautena kontrollia runsaammin. Maaperäeläinten kokonaisbiomassaan myös tuhkan vaikutus oli negatiivinen. Käsittely vaikutti voimakkaammin lähellä maanpintaa, joten tuhkalannoitetussa maassa suhteellisesti suurempi osa biomassasta oli 3–6 cm syvyydessä.

Laboratoriossa sekä typpi- että tuhkalannoituksen vaikutus oli voimakkaampi kuin kentällä, vaikka lannoitteita käytettiin pinta-alayksikköä kohti laskettuna vähemmän. Laboratoriokokeissa monet sellaiset lajit reagoivat, joihin kentällä ei todettu vaikutusta. Useimmat lajit reagoivat negatiivisesti, mutta lieroja kertyi tuhkalla ja urealla käsiteltyihin näytteisiin niin, että kokonaisbiomassa nousi kontrollia suuremmaksi. Kenttäolosuhteissa lierot todennäköisesti hyötyvät tuhkalannoituksesta, mutta tutkituilla koekentillä lieroja oli niin vähän, että vaikutus jäi näyttämättä toteen.

Kalkin ja tuhkan vaikutukset olivat lähes identtiset sekä laboratorio- että kenttäkokeen perusteella, edellyttäen että ne aiheuttivat samansuuruisen pH:n muutoksen. Näin ollen tuhkan vaikutus selittyy pelkästään happamuuden muutoksella, ja ravinteiden mahdolliset vaikutukset peittyvät pH:n vaikutuksen alle. Myös ureakäsittelyn vaikutus perustunee osittain happamuuden vähenemiseen, mutta laboratoriokokeen perusteella pääteltiin, että myös typellä ravinteena on vaikutusta pH:sta riippumatta. Ammoniumnitraatti oli maaperäeläimille aluksi myrkyllistä, mutta kokeen jatkuessa sen aikaansaamat muutokset olivat samankaltaisia kuin ureakäsittelyn jälkeen, vaikka se ei juuri vaikuttanut happamuuteen.

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180 Simula, M. 1983. Productivity differentials in the Finnish forest industry. Seloste: Tuottavuuden vaihtelu Suomen metsäteollisuudessa.
181 Pohtila, E. & Pohjola, T. 1983. Lehvästöruiskutuksen ajoitus kasvukauden aikana. Summary: The timing of foliage spraying during the growing season.
182 Kilkki, P. 1983. Sample trees in timber volume estimation. Seloste: Koepuut puuston tilavuuden estimoinnissa.
183 Mikkonen, E. 1983. Eräiden matemaattisen ohjelmoinnin menetelmien käyttö puunkorjuun ja kuljetuksen sekä tehdaskäsittelyn menetelmävalinnan apuvälineenä. Abstract: The usefulness of some techniques of the mathematical programming as a tool for the choice of timber harvesting system.
184 Westman, C. J. 1983. Taimitarhamaiden fysikaalisia ja kemiallisia ominaisuuksia sekä niiden suhde orgaanisen aineen määrään. Summary: Physical and physico-chemical properties of forest tree nursery soils and their relation to the amount of organic matter.
185 Kauppi, P. 1984. Stress, strain, and injury: Scots pine transplants from lifting to acclimation on the planting site. Tiivistelmä: Metsänviljelytaimien vaurioituminen noston ja istutuksen välillä.
186 Henttonen, H. 1984. The dependence of annual ring indices on some climatic factors. Seloste: Vuosilustoindeksien riippuvuus ilmastotekijöistä.
187 Smolander, H. 1984. Measurement of fluctuating irradiance in field studies of photosynthesis. Seloste: Säteilyn vaihtelun mittaaminen fotosynteesin maastotutkimuksissa.
188 Pulkki, R. 1984. A spatial database – heuristic programming system for aiding decisionmaking in long-distance transport of wood. Seloste: Sijaintitietokanta – heuristinen ohjelmointijärjestelmä puutavaran kaukokuljetuksen päätöksenteossa.
189 Heliövaara, K. & Väisänen, R. 1984. Effects of modern forestry on northwestern European forest invertebrates: a synthesis. Seloste: Nykyaikaisen metsänkäsittelyn vaikutukset luoteiseurooppalaisen metsän selkärangattomiin: synteesi.
190 Suomen Metsätieteellinen Seura 75 vuotta. The Society of Forestry in Finland – 75 years. 1984.
191 Silvola, J., Välijoki, J. & Aaltonen, H. 1985. Effect of draining and fertilization on soil respiration at three ameliorated peatland sites. Seloste: Ojituksen ja lannoituksen vaikutus maahengitykseen kolmella suomuuttumalla.
192 Kuusipalo, J. 1985. An ecological study of upland forest site classification in southern Finland. Seloste: Ekologinen tutkimus Etelä-Suomen kangasmetsien kasvupaikkaluokituksesta.
193 Keltikangas, M., Laine, J., Puttonen, P. & Seppälä, K. 1986. Vuosina 1930–1978 metsäojitetut suot: Ojitusalueiden inventoinnin tuloksia. Summary: Peatlands drained for forestry in 1930–1978: Results from field surveys of drained areas.
194 Vehkamäki, S. 1986. The economic basis of forest policy. A study on the goals and means of forest policy. Seloste: Metsäpolitiikan taloudelliset perusteet. Tutkimus metsäpolitiikan tavoitteista ja keinoista.
195 Huhta, V., Hyvönen R., Koskenniemi A., Vilkamaa P., Kaasalainen P. & Sulander M. 1986. Response of soil fauna to fertilization and manipulation of pH in coniferous forests. Seloste: Lannoituksen ja pH-muutoksen vaikutus kangasmetsän maaperäeläimistöön.

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