COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 146

EFFECTS OF DOMESTIC SEWAGE SLUDGE, CONIFER BARK ASH AND WOOD FIBRE WASTE ON SOIL CHARACTERISTICS AND THE GROWTH OF SALIX AQUATICA

ILARI LUMME & OLAVI LAIHO

SELOSTE

ASUTUSJÄTELIETTEEN, HAVUPUUN KUORITUHKAN JA PUUKUITUJÄTTEEN VAIKUTUS MAAPERÄN OMINAISUUKSIIN JA VESIPAJUN KASVUUN

HELSINKI 1988

COMMUNICATIONES INSTITUTI
FORESTALIS FENNIAE

THE FINNISH FOREST RESEARCH INSTITUTE
(METSÄNTUTKIMUSLAITOS)

Unioninkatu 40 A
SF-00170 Helsinki
FINLAND

Director:
Professor Eljas Pohtila

telex: 121298 metli sf

phone: 90-661 401

Distribution and exchange of publications:

The Finnish Forest Research Institute
Library
Unioninkatu 40 A
SF-00170 Helsinki
FINLAND

Publications of the Finnish Forest Research Institute:

— Communicationes Instituti Forestalis Fenniae (Commun. Inst. For. Fenn.)
— Folia Forestalia (Folia For.)
— Metsäntutkimuslaitoksen tiedonantoja

Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

Dear reader of Communicationes Instituti Forestalis Fenniae,

The Finnish Forest Research Institute and the Society of Forestry in Finland have joined forces as publishers: the two series of monographs, Communicationes Instituti Forestalis Fenniae and Acta Forestalia Fennica, have been merged. The joint series carries the title Acta Forestalia Fennica. Thus the present volume, number 146, is the last Communicationes to be published.

In future, the subscribers of Communicationes Instituti Forestalis Fenniae will be sent all numbers of Acta Forestalia Fennica, which is similar in aim and scope to the Communicationes.

We hope that with this co-operation results of Finnish forest research are more efficiently distributed to users throughout the world.

If there are any questions, please write to the editors of the series: The Finnish Forest Research Institute, Tommi Salonen / Seppo Oja, Unioninkatu 40 A, SF-00170 Helsinki, Finland. Phone: +358-0-661401.

Arvoisa Communicationes Instituti Forestalis Fenniae -sarjan lukija

Metsäntutkimuslaitos on tehnyt Suomen Metsätieteellisen Seuran kanssa yhteistyösopimuksen, jonka mukaan sarja yhdistetään Acta Forestalia Fennica -sarjan kanssa. Sopimuksen mukaisesti Communicationes -sarjan numero 146 on viimeinen sarjassa ilmestyvä julkaisu.

Metsäntutkimuslaitos lähettää vastaisuudessa tilaajilleen kaikki Acta Forestalia Fennica -sarjan julkaisut. Sarja vastaa sisällöltään ja rakenteeltaan Communicationes -sarjaa. Yksittäiskappaleita Metsäntutkimuslaitoksen toimittamista Acta -sarjan julkaisuista saa Communicationes -sarjan tapaan Metsäntutkimuslaitoksen kirjastosta.

Toivomme, että yhteisellä sarjalla voimme entistä paremmin välittää metsäntutkimuksen tuloksia tiedon käyttäjille.

Mikäli teillä on epäselvyyksiä järjestelyn suhteen, pyydämme teitä ottamaan yhteyttä sarjojen toimitukseen. (Metsäntutkimuslaitos, Seppo Oja / Tommi Salonen, Unioninkatu 40 A, 00170 Helsinki, puh. 90-661 401).

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE
146

ILARI LUMME & OLAVI LAIHO

EFFECTS OF DOMESTIC SEWAGE SLUDGE, CONIFER BARK ASH AND WOOD FIBRE WASTE ON SOIL CHARACTERISTICS AND THE GROWTH OF SALIX AQUATICA

Approved on 22.7.1988

SELOSTE

ASUTUSJÄTELIETTEEN, HAVUPUUN KUORI-TUHKAN JA PUUKUITUJÄTTEEN VAIKUTUS MAAPERÄN OMINAISUUKSIIN JA VESIPAJUN KASVUUN

HELSINKI 1988

LUMME, I. & LAIHO, O. 1988. Effects of domestic sewage sludge, conifer bark ash and wood fibre waste on soil characteristics and the growth of *Salix Aquatica*. Seloste: Asutusjätelietteen, havupuun kuorituhkan ja puukuitujätteen vaikutus maaperän ominaisuuksiin ja vesipajun pituuskasvuun. Communicationes Instituti Forestalis Fenniae 146. 24 p.

The experiments were established at Häädetjärvi (62°00'N, 22°30'E), in the Parkano Research Area of the Finnish Forest Research Institute, in 1981 and 1982. The limestone sludge caused marked alterations in the chemical, microbiological and physical properties of the soil and changes in the water balance, which were otherwise beneficial except that the low concentration of potassium and high concentration of iron in the sludge evidently restricted the growth of the willows. Total soil nitrogen, soil ammonium, nitrate, soil soluble phosphorus and N and P concentration in the leaves and bark of the willows increased due to the limestone sludge application. Denitrification was at a high level in the limestone sludge treated soil. This slugde enhanced also cellulose decomposition activity in soil during the first growing season. The effects of the chemically treated sludge in soil were marginal due to the low amount applied. Conifer bark ash raised the soil pH and Ca content and soil P, K and Mg concentration. The ash raised the P and K content in the leaves and bark of the willows also. Wood fibre waste was found to be unsuitable for rapidly growing willows.

Asutusjätelietteen, havupuun kuorituhkan ja puukuitujätteen hyödyntämistä selvittävät kokeet perustettiin Metsäntutkimuslaitoksen koe-alueelle Häädetjärvelle Parkanossa (62°00'N, 22°30'E). Kalkkiliete kohotti maan kokonaistypen, ammoniumtypen, nitraattitypen ja liukoisen fosforin pitoisuutta. Kalkkiliete lisäsi myös vesipajun lehtien ja kuoren N ja P konsentraatiota. Denitrifikaatio oli kalkkilietteellä vilkkaampaa kuin nitraattipitoisella keinolannoitteella lannoitetussa maassa. Liete lisäsi maaperän selluloosan hajotusaktiivisuutta ensimmäisellä kasvukaudella. Myös maaperän vedenpidätyskyky ja kationinvaihto-kapasiteetti kohosivat kalkkilietekäsittelyllä. Toisaalta lietteen alhainen kaliumpitoisuus ja korkea rautapitoisuus ilmeisesti rajoittivat vesipajun kasvua. Kemiallinen liete ei aiheuttanut merkittäviä muutoksia maassa, koska lietteen määrä oli liian alhainen. Havupuun kuorituhka kohotti merkittävästi maaperän P-, K-, Mg- ja Ca-pitoisuutta sekä pH:ta. Myös vesipajun lehtien ja kuoren P- ja K-pitoisuus lisääntyi. Toisaalta suuri tuhkamäärä (20 t/ha) vähensi vesipajujen Mg ottoa. Puukuitujäte ei sopinut nopeakasvuisten pajujen viljelyyn.

Key words: sewage sludge, conifer bark ash, wood fibre waste, short-rotation forestry, nitrogen, denitrification
ODC 176.1 *Salix Aquatica* + 237.4 + 114.2 + 238

Authors' addresses: *Lumme, I.* University of Helsinki, Department of Agricultural Chemistry, SF-00710 Helsinki, Finland. *Laiho, O.* The Finnish Forest Research Institute, Parkano Research Station, SF-39700 Parkano, Finland.

ISBN 951-40-1016-7
ISSN 0358-9609

Helsinki 1988. Valtion Painatuskeskus

CONTENTS

1. INTRODUCTION

11. Short-rotation cultivation of willows

One consequence of the fuel crisis of 1973 was the stimulation of research in Finland into the cultivation of fast-growing woody plants for fuel purpose. This was followed around 1980 by a research initiative in the chemicals industry directed towards the use of plants of this kind for the production of certain chemicals. One alternative for short-rotation cultivation under Finnish conditions may be the fast-growing willow (*Salix* spp.) species, and experiments on the use of such species, chiefly of Southern Swedish, Danish and Dutch provenances have been in progress since 1975. The most extensively studied species are the common osier, *Salix viminalis* (L.), *Salix Aquatica* and a hybrid *Salix* × *dasyclados* (Wimm.). The high productive capacity of these species is due to their adaptation to habitats with an abundance of light, heat, moisture and nutrients (Kaunisto 1983, Siren 1983, Pelkonen 1984, Saarsalmi 1984). They are propagated from cuttings and are thus easy to clone and to produce in sufficient numbers to meet the needs of extensive cultivation. Willow plantations can be coppiced at relatively frequent intervals (2–6 years) and their rootstock lives for an estimated 20–40 years (Siren 1983).

12. Sewage sludge, conifer bark ash and wood fibre waste

Consideration of possible practical uses for the sludge produced in the purification of domestic waste water and sewage has become a matter of urgency with the recent increases in the amounts of waste to be processed and advances in purification methods. Considerable amounts of nutrients are lost annually by placing these type of wastes into dumps. The transportation itself is expensive and the dumps cause a risk to the environment. The use of wastes in forestry is less problematic than in agriculture due to the high hygiene and quality requirements for the foodstuffs produced in the latter sector.

There were 560 domestic sewage purification plants in operation in Finland by December 1981, processing waste from the homes of some 3 million people and generating sludge equivalent to around 150 000 metric tonnes of dry matter every year. This figure is expected to rise to 210 000 t by 1990 (Ympäristöministeriö 1983).

The extent to which domestic sewage sludge can be utilized in farming and forestry depends essentially upon its chemical and biological properties, the most important of which in this sense are its nitrogen, phosphorus and potassium concentrations and its effect on soil pH and microbiological activity. The concentrations of the main nutrients are dependent upon the purification process used (Riiheläinen 1975). Thus total nitrogen can vary between 0.1 % and 18 % (Ympäristöministeriö 1983), total phosphorus between 0.1 % and 5 % (Mitchell et al. 1977) and potassium between 0.02 % and 0.5 %. Domestic sewage sludge contains an average of 2 % calcium, but the figure can be very much higher than this if limestone is used in the purification plant for stabilization and precipitation purposes. The mean magnesium content is 1 % (Ympäristöministeriö 1983). The proportion of organic matter is between 30 % and 80 % and the microbiological activity is high (Huhta et al. 1978 and Hsieh et al. 1981a).

It has been estimated that a total of 600 000–700 000 t of ash (dry weight) was produced in Finland in 1984–85, the majority of which, 67 %, arose from the burning of coal and the remainder, 33 %, from peat (20 %), sulphite liquor (8 %), bark and other forms of wood (4 %) and oil and rubbish (1 %) (Energiataloudellinen yhdistys 1985).

The suitability of ash for fertilization and soil amelioration depends mainly on its nutrient and Ca content, the proportions of the nutrients and the extent to which they are present in soluble form and on the content of harmful compounds in the ash.

The most suitable for this purpose is the light, powdery grade of ash, in which 50 % of the inorganic compounds consist of various silicon oxides and the remainder of metals, non-metallic oxides and carbonates, in proportions determined by the source (Keppo and Ylinen 1980). In the case of wood, bark and peat, tree species and peat type will affect the nutrient content of the ash (Hakkila and Kalaja 1983). A great deal of research has been done into the effects of wood ash on growth in forest trees, the earliest experiments being from around 1940 (Karsisto 1979, Paavilainen 1980, Merisaari 1981, Silfverberg and Huikari 1985).

The paper and cardboard industry in Finland produces wood fibre waste in connection with the purification of its waste liquor which amounts to some 150 000–250 000 t of dry matter per year. Attempts have been made to find some economic use for this, but so far the problem has not been solved.

13. The aim of the study

The aim of the present study was to assess the effects of domestic sewage sludge, conifer bark ash and wood fibre waste on soil chemical, microbiological and physical characteristics and the growth of *Salix Aquatica*.

The emphasis in this study was very much upon soil parameters, however, since these aspects are regarded as being of interest for the cultivation of any species on soil composed partly of waste. The majority of the measurements thus concern the soil nutrient changes brought about by the use of the substances in question.

This study was planned and the field experiments set up in collaboration by the both authors. Ilari Lumme was responsible for the field measurements and microbiological, chemical and physical analysis of the samples collected from the field. The Finnish version has been presented as a part of his licenciate thesis at the Department of Ecology, University of Jyväskylä. The English manuscript was completed by the authors together.

The authors received advice and guidance from Michael Starr, Ph.D., Hannu Raitio, M.Sc., of the Parkano Research Station and Dr. Pertti Uomala, of the Department of General Microbiology, University of Helsinki. Professor Jaakko Paasivirta of the Department of Chemistry, University of Jyväskylä, kindly allowed the use of equipment at the department for denitrification measurements. This manuscript was translated into English by Malcolm Hicks, M.A. at Oulu Technology Centre. Kristina Palmgren, M.Sc., of the Department of Soils and Professor Erkki Lähde of the Department of Silviculture of the Finnish Forest Research Institute, Dr. Pertti Martikainen, Ph.D., of the Department of Environmental Hygiene and Toxicology in the National Health Institute, Kuopio, Assoc. Professor Veikko Huhta and Professor Mikko Raatikainen of the Department of Ecology, University of Jyväskylä, greatly assisted in completion of this paper by making valuable corrections to the manuscript. The figures were drawn by Mrs Tiina Luoto. The authors wish to thank all the above persons and all those who helped with this work in various ways.

2. MATERIALS AND METHODS

21. The sewage sludges, conifer bark ash and wood fibre waste used in the experiments

A. Limestone sludge from the local authority domestic sewage purification plant at Hämeenkyrö. This plant employs a biological purification process combined with ferrous sulphate precipitation to remove phosphorus. The sludge is then stabilized with limestone.

B. Sludge formed in the chemical purification process used at the Parkano municipal domestic sewage purification plant, which uses ferrous sulphate to precipitate phosphorus. This is referred to below as chemical sludge.

C. Conifer bark ash (70 % spruce bark, 30 % pine bark) from the power plant of Oy Kyro Ab at Hämeenkyrö.

D. Wood fibre waste from the mechanical waste water purification plant of Oy Kyro Ab, containing the fibre fraction of spruce wood not utilized for paper and cardboard production.

The sludges examined had a high concentration of total nitrogen and ammonium nitrogen (Table 1), but were low in nitrate. They also contained little potassium but large amounts of iron. The greatest differences in nutrients between the sludges and the bark ash lay in the low nitrogen content and high potassium, magnesium and calcium (except in the limestone sludge) in the latter. Both the sludges and the ash had a high phosphorus content. The wood fibre waste contained little available plant nutrients, while total carbon and the C:N ratio were high.

The effects of the sludges, conifer bark ash and wood fibre waste were compared with N-rich chemical fertilizer and dolomite lime. The N-rich fertilizer used had a chemical composition of 20 % N (8 % NO_3), 4.4 % P, 8.3 % K, 1 % Mg, 0.05 % B and 4 % S, so that the application of 1.5 metric tonnes/ha of this fertilizer implied an administration of 300 kg/ha of N, 66 kg/ha P and 125 kg/ha of K. The available nitrogen given in the N-rich fertilizer was estimated to be the same as given by an application of 75 metric tonnes of limestone sludge/ha. Similarly the amount of dolomite lime given with the N-rich chemical fertilizer was estimated to be the same as in the limestone sludge.

22. Field experiments

The field experiments were set up in 1981 and 1982 at the Häädetjärvi site (62°00'N, 22°30'E) belonging to the Parkano Research Area of the Finnish Forest Research Institute. The area was originally a cultivated mire, but had been abandoned in 1978. The soil was poor in potassium, calcium and magnesium, but the other nutrient parameters were satisfactory (Table 2).

At first the soil was ploughed to a depth of 50 cm in order to mix the organic layer and the underlying mineral soil together and then harrowed to a depth of 30 cm using a farm tractor. The area was then divided into 65 quadrats of 50 m^2 in 1981, with a further 30 quadrats of 20 m^2 set up in 1982 (Table 3). The dosage of the chemical sludge was clearly lower than that of the limestone sludge due to the high moisture content of the latter. It was not possible to spread much of the chemical sludge without loosing some of the slurry outside the quadrats. After application of the waste materials, N-rich chemical fertilizer and lime the experimental quadrats were harrowed to a depth of 30 cm using farm tractor.

Following these soil treatments 20 cm long cuttings of *Salix Aquatica* clone V769 were planted in 09.06.1981 and 03.06.1982 on the quadrats at a density of 20 000 cuttings/ha.

Table 1. Chemical and physical properties of the limestone sludge, chemical sludge, conifer bark ash and wood fibre waste (per dry matter).

Taulukko 1. Kalkkilietteen, kemiallisen lietteen, havupuun kuorituhkan ja puukuitujätteen kemiallisia ja fysikaalisia ominaisuuksia (kuiva-aineena).

Parameter *Tunnus*	Limestone sludge *Kalkki-liete*	Chemical sludge *Kemialli-nen liete*	Bark ash *Kuori-tuhka*	Wood fibre *Puu-kuitu*
pH	8.0	5.5	10.5	5.0
Total nitrogen % *Kokonaistyppi*	2.1	3.5	0.0	0.3
Ammonium % of tot N *Ammoniumtyppi % kok N*	19.6	14.4	0.0	0.0
Nitrate % of tot N *Nitraattityppi % kok N*	0.3	0.1	0.0	0.0
Soluble phosphorus g/kg *Liukoinen fosfori*	17.9	16.6	15.1	1.2
Exchang. potassium g/kg *Vaihtuva kalium*	0.8	2.3	32.6	0.3
Exchang. magnesium g/kg *Vaihtuva magnesium*	3.5	3.4	27.9	0.3
Exchang. calcium g/kg *Vaihtuva kalsium*	60.2	9.1	310.0	0.4
Soluble iron g/kg *Liukoinen rauta*	116.0	97.6	13.1	0.0
Organic matter % *Orgaaninen aines*	55.2	46.3	2.1	80.3
Dry matter content % *Kuiva-ainepitoisuus*	20.0	5.0	70.0	22.9
C:N ratio *C:N-suhde*	15:1	8:1		155:1

23. Parameters analysed

Soil samples from a depth of 0–20 cm were taken at random from all the quadrats on five occasions in 1981 for nitrogen and pH determinations and the other chemical and physical soil analysis were performed from three of these. In 1982 soil samples were taken on four occasions during the growing season. Each sample from one quadrat was a combination of ten subsamples which were mixed together before analysis. The following chemical and microbiological determinations were carried out on the soil samples:

- pH(H_2O 1:4)
- organic matter and cation exchange capacity (CEC)
- total nitrogen and C:N ratio
- ammonium and nitrate nitrogen content
- denitrification (N_2O production)
- AAAc soluble phosphorus
- exchangeable potassium, magnesium, calcium and soluble iron
- cellulose decomposition activity

Table 2. Chemical and physical properties of the soil at the Häädetjärvi experimental site.
Taulukko 2. Maaperän kemiallisia ja fysikaalisia ominaisuuksia Häädetjärven koealueella.

Parameter – *Tunnus*	Value – *Arvo*
pH	5.1
Total nitrogen % – *Kokonaistyppi*	2.3
Ammonium mg/l – *Ammoniumtyppi*	4.8
Nitrate mg/l – *Nitraattityppi*	5.5
Soluble phosphorus mg/l – *Liukoinen fosfori*	3.9
Exchang. potassium mg/l – *Vaihtuva kalium*	64
Exchang. magnesium mg/l – *Vaihtuva magnesium*	63
Exchang. calcium mg/l – *Vaihtuva kalsium*	774
Soluble iron mg/l – *Liukoinen rauta*	26
Cation exchange capacity meq/100 g – *Vaihtokapasiteetti*	11
Humus content % – *Humuspitoisuus*	10
Soil type – *Maalaji*	Sandy moraine *Hiekkamoreeni*

All the analyses were performed at Parkano Forest Research Station except for gas chromatographic N_2O measurements which were performed at the Department of Chemistry, University of Jyväskylä.

Cellulose decomposition activity in the soil was assessed by placing ten 3 cm × 10 cm strips of birch cellulose vertically in the ground in each quadrat at a depth of 0–10 cm in 12.06.1981 and 27.05.1982. Five of the replicate strips were removed in mid-July for determination of weight loss, and the remainder in 10.09.1981 and 12.09.1982. Soil water tension was measured with tensiometers, with the sensor at a depth of 15 cm.

Cation exchange capacity was assessed by extracting the soil samples with 1 N ammonium acetate (AAAc, pH 4.65 and 7.00) in order to saturate the exchange nodes with ammonium ions. The samples were then filtered and the soil retained on the filter paper extracted with 80 % ethanol to remove the excess ammonium and then with 2 M potassium chloride to remove that contained in the soil exchange complex. Exchange capacity in meg/100 g was calculated by determining the ammonium released in the potassium chloride extraction.

Ammonium, nitrate, total nitrogen, AAAc soluble phosphorus and exchangeable potassium, calcium, magnesium and soluble iron in the soil samples were analyzed according to Matt 1970 and Halonen et al. 1983.

The denitrification measurements carried out in 1982 employed a laboratory incubation test and an in situ field method, both based on acetylene inhibition of the enzyme systems of the denitrification bacteria, preventing the formation of gaseous nitrogen and generating nitrous oxide (N_2O) as a reaction product. The laboratory incubation started out with a fresh soil sample, which was placed in a sterilized incubation flask to which water was added to 200 % of the water retention capacity of the soil. The flask was then closed and a vacuum created inside. Nitrogen gas was introduced to replace the air, followed by 10 % acetylene gas by volume. The nitrous oxide formed after 7 days' incubation at +20°C was measured by Carlo Erba 4200 gas chromatography using an electron capture detector. A Porapak Q 80/100 2 m aluminium column was used with a N_2 carrier gas and a gas flow of 25 ml/min. The detector, injector and oven temper-

Table 3. Dosages of the sludges, conifer bark ash, wood fibre waste and chemical fertilizer (dry matter) and the amount of replicates in the experiments in 1981 and 1982.
Taulukko 3. Lietteiden, havupuun kuorituhkan, puukuitujätteen ja keinolannoitteen levitysmäärät (kuiva-aineena) ja toistojen lukumäärä vuosina 1981 ja 1982.

Treatment *Käsittely*	Dosage metric t/ha *Annostus*	Replicates – *Toistot* 1981	1982
Control (ploughing & harrowing) – *Kontrolli (kyntö ja äestys)*		10	10
Chemical sludge – *Kemiallinen liete*	14.4	10	
Limestone sludge – *Kalkkiliete*	75.0	10	10
N-rich fertilizer – *Typpirikas Y*	1.5	10	5
N-rich fertilizer – *Typpirikas Y*	1.5		
+ limestone – *+ kalkitus*	5.0		5
Bark ash – *Kuorituhka*	5.0	5	
Bark ash – *Kuorituhka*	20.0	10	
Fibre waste – *Kuitujäte*	23.0		
+ bark ash – *+ kuorituhka*	10.0	10	

atures were 250, 150 and 50°C, respectively (Kaspar and Tiedje 1981).

The field measurements were performed by pressing PVC tubes 20 cm long and 25 mm in diameter into the ground to a depth of 15 cm, closing the top end with a septum cork and injecting acetylene gas through this to a proportion of 10 % of the tube by volume. After 7 days' incubation the tubes were removed from the ground and closed at the bottom end and nitrous oxide measured by gas chromatography as mentioned earlier (Kaspar and Tiedje 1981).

The survival and height increment (from the base of the cutting to the tip of the shoot) of all the cuttings of the *Salix Aquatica* clone V769 in every experimental quadrat were evaluated on 10.9.1981 and 9.9.1982. Nitrogen, phosphorus, potassium, magnesium, calcium and iron content in the leaves and bark of the shoots were analysed from samples taken on 12.9.1981 and 11.9.1982 by removing all the shoots from a randomly selected 10 % of the cuttings in each quadrat and taking all their leaves and bark for the nutrient analysis according to Halonen et al. 1983.

The results were analysed statistically using one-way and two-way analyses of variance, t-test and regression analysis. The symbols (*) used in Tables from 5 to 12 indicate the following levels of statistical significance for the differences between the treatments used: * = $p<0.05$, ** = $p<0.01$ and *** = $p<0.001$.

24. Weather conditions at Häädetjärvi in 1981 and 1982

The effective temperature sum (dd°C) recorded at the nearby Alkkia meteorological station in both years was somewhat below the long-term mean (Table 4), as also were the mean monthly temperatures with the exception of May 1981. May and June of 1982 were exceptionally cold months. Precipitation sums for the months in question were above the long-term mean in 1981 and below it in 1982 (Ilmatieteen laitos 1981, 1982).

Table 4. Effective temperature sum (> +5 °C), mean monthly temperatures, and precipitation at Alkkia metereological station in 1981 and 1982 with corresponding long-term means.

Taulukko 4. Tehoisan lämpötilan summa (> +5 °C), kuukauden keskilämpötila ja sademäärä Alkkian sääasemalla vuosina 1981 ja 1982 sekä vastaavat pitkänaikavälin keskiarvot.

Month – *Kuukausi*	1981	1982	1961 – 1980
Temperature sum dd°C – *Lämpösumma*			
May – *Touko*	183	83	122
June – *Kesä*	197	158	263
July – *Heinä*	333	328	304
August – *Elo*	213	284	264
Sept. – *Syys*	105	99	121
October – *Loka*	20	19	33
Total – *Yhteensä*	1062	973	1115
Mean temperature °C – *Keskilämpötila*			
May – *Touko*	10.2	7.3	8.8
June – *Kesä*	11.6	10.2	14.0
July – *Heinä*	15.8	15.6	16.3
August – *Elo*	11.9	14.2	14.8
Sept. – *Syys*	8.1	8.2	9.9
Precipitation mm – *Sademäärä*			
May – *Touko*	10	44	35
June – *Kesä*	108	20	44
July – *Heinä*	68	31	69
August – *Elo*	113	93	73
Sept. – *Syys*	29	78	60
Total – *Yhteensä*	329	269	281

3. RESULTS

31. Soil organic matter and cation exchange capacity

A positive correlation was noted between soil organic matter and CEC (r = 0.930**), and both parameters were increased markedly by the limestone sludge and the wood fibre waste + bark ash applications ($p < 0.01$). The 20 metric tonnes/ha bark ash dosage reduced the soil CEC compared with the control ($p < 0.05$) (Table 5).

32. Soil pH

The limestone sludge application led to a marked increase in the soil pH ($p < 0.01$), but pH then decreased in the course of both growing seasons (Table 6). Bark ash enhanced the soil pH more markedly and more permanently. The 5 t/ha ash dosage raised the pH to 6.5 – 7.0 ($p < 0.01$), the 20 t/ha dosage to pH 7.5 – 8.2 ($p < 0.001$) and the wood fibre waste + bark ash application to pH 7.3 – 7.6 ($p < 0.01$). The N-rich chemical fertilizer gave a soil pH which remained slightly below that of the control throughout the period studied, being in the range pH 4.3 – 4.7, whereas N-rich fertilizer + limestone raised the pH to 6.0 – 6.5 ($p < 0.01$) and caused it to remain higher for longer than with limestone sludge.

33. Nitrogen balance in soil

331. Total nitrogen and C:N ratio

The limestone sludge enhanced the total soil nitrogen content and caused a marked

Table 5. Soil organic matter content (%) and cation exchange capasity (CEC) in 1981 and 1982.
Taulukko 5. Maaperän orgaanisen aineen pitoisuus (%) ja vaihtokapasiteetti (CEC) vuosina 1981 ja 1982.

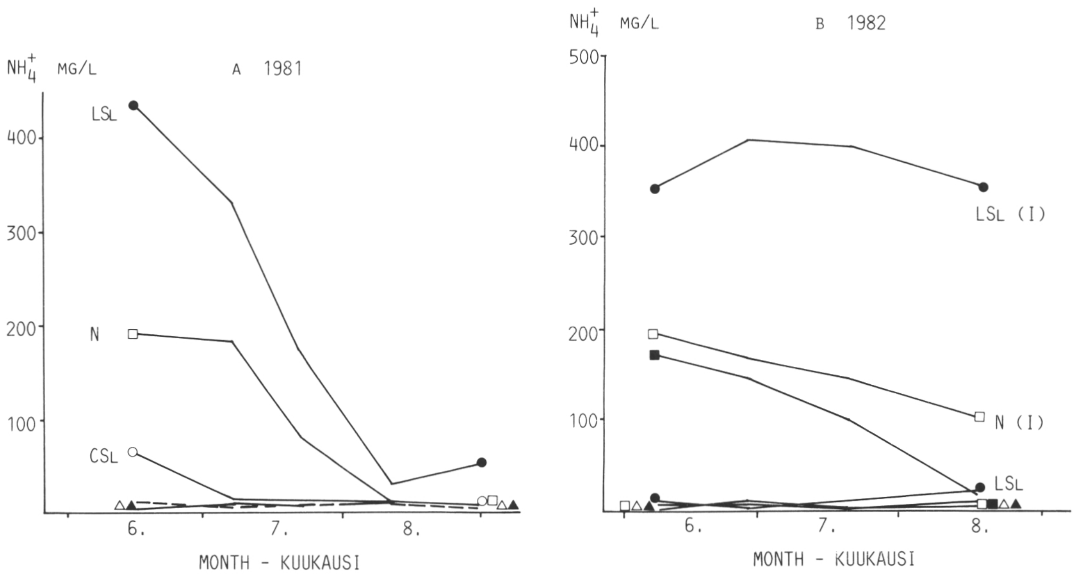
Treatment *Käsittely*	Organic matter % – *Orgaaninen aines* 1981	 1982	CEC meq/100 g 1981	 1982
Control – *Kontrolli*	10.4	10.6	10.5	11.0
Chemical sludge – *Kemiallinen liete*	12.5	12.0	13.1	12.4
Limestone sludge-81 – *Kalkkiliete-81*	14.2**	11.4	20.3**	19.9**
Limestone sludge-82 – *Kalkkiliete-82*		16.5**		20.7**
N-rich fertilizer – *Typpirikas Y*	10.9	11.8	11.2	11.4
Bark ash 5 – *Kuorituhka 5*	9.6		9.1	
Bark ash 20 – *Kuorituhka 20*	9.7	8.4	7.6*	8.1*
Fibre waste + ash – *Kuitujäte + tuhka*	16.1**	15.4**	15.8*	15.1*

Table 6. Soil pH (H_2O) in 1981 and 1982.
Taulukko 6. Maaperän pH (H_2O) vuosina 1981 ja 1982.

Treatment *Käsittely*	pH 06.1981	 08.1981	 06.1982	 08.1982
Control – *Kontrolli*	5.2	5.1	5.0	5.1
Chemical sludge – *Kemiallinen liete*	5.7	5.2	5.2	4.9
Limestone sludge-81 – *Kalkkiliete-81*	7.0**	5.8	5.3	4.9
Limestone sludge-82 – *Kalkkiliete-82*			6.5*	5.1
N-rich fertilizer – *Typpirikas Y*	5.4	4.7	4.6	4.4
N-r. fertilizer + lime – *Typpirikas Y + kalkitus*			6.5*	6.0
Bark ash 5 – *Kuorituhka 5*	6.8*	6.5*	7.0**	6.9*
Bark ash 20 – *Kuorituhka 20*	8.2***	7.6**	7.5**	7.6**
Fibre waste + ash – *Kuitujäte + tuhka*	7.6**	7.3**	7.3**	7.4**

Table 7. Total soil nitrogen content (% of soil organic matter) and C:N ratio in 1981 and 1982.
Taulukko 7. Maaperän kokonaistypen määrä (% maan orgaanisesta aineesta) ja C:N-suhde vuosina 1981 ja 1982.

Treatment *Käsittely*	Total N % *Kokonaistyppi* 1981	1982	C:N *C:N -suhde* 1981	1982
Control — *Kontrolli*	2.1	2.4	27:1	25:1
Chemical sludge — *Kemiallinen liete*	2.0	2.3	27:1	24:1
Limestone sludge-81 — *Kalkkiliete-81*	3.4**	3.2**	16:1**	15:1**
Limestone sludge-82 — *Kalkkiliete-82*		3.4**		18:1**
N-rich fertilizer — *Typpirikas Y*	2.4	2.6	22:1	20:1
Bark ash 5 — *Kuorituhka 5*	1.8	1.7	29:1	29:1
Bark ash 20 — *Kuorituhka 20*	1.9	1.8	27:1	27:1
Fibre waste + ash — *Kuitujäte + tuhka*	1.2*	1.5*	57:1**	35:1**



Symbols — *Merkinnät*

- - - - - - - Control — *Kontrolli*
○———○ CSL Chemical sludge — *Kemiallinen liete*
●———● LSL (I) Limestone sludge (first year) — *Kalkkiliete (ensimmäinen vuosi)*
□———□ N (I) N-rich fertilizer (first year) — *Typpirikas Y (ensimmäinen vuosi)*
■———■ N + L N-rich fertilizer + lime — *Typpirikas Y + kalkitus*
△———△ AS (20) Bark ash metric t/ha — *Kuorituhka t/ha*
▲———▲ F + A Fiber waste + bark ash — *Kuitujäte + kuorituhka*

Figure 1. Soil ammonium concentration (mg/l) in 1981 (A, first year) and 1982 (B, second year if not otherwise indicated).
Kuva 1. Maan ammoniumpitoisuus (mg/l) vuosina 1981 (A, ensimmäinen vuosi) ja 1982 (B, toinen vuosi ellei toisin osoiteta).

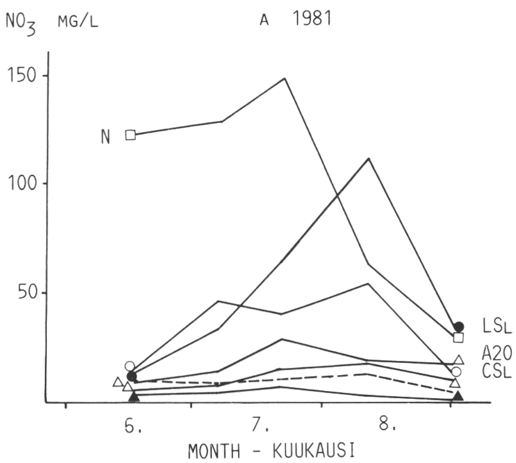
decrease in the C:N ratio ($p < 0.01$) (Table 7). The wood fibre waste + bark ash application reduced the total nitrogen content and increased the C:N ratio ($p < 0.01$) during the first growing season, but the C:N ratio decreased markedly in 1982.

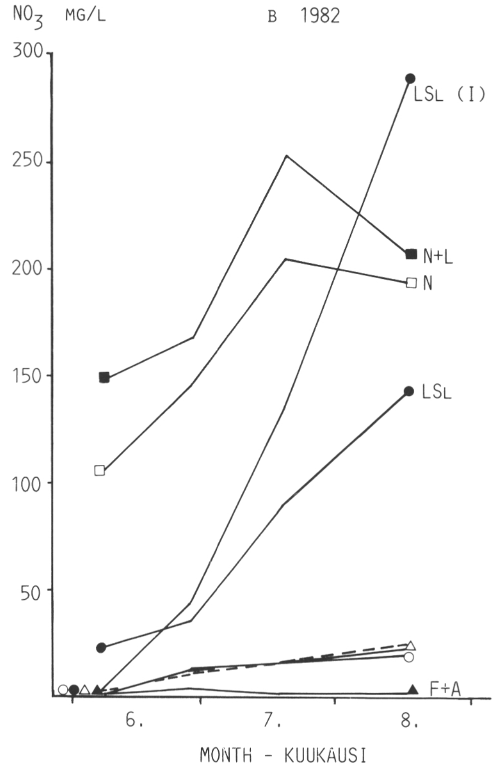
332. Ammonium and nitrate

Soil ammonium concentration was higher in the limestone sludge quadrats than in any other treatment at the beginning of the growing season (440 mg/l) in 1981, diminishing sharply to a level as low as 29 mg/l by August (Fig. 1A). Ammonium content in the limestone sludge quadrats set up in 1982 remained high throughout the grow-

Figure 2. Soil nitrate concentration (mg/l) in 1981 (A, first year) and 1982 (B, second year if not otherwise indicated). Symbols as in Fig. 1.

Kuva 2. Maan nitraattipitoisuus (mg/l) vuosina 1981 (A, ensimmäinen vuosi) ja 1982 (B, toinen vuosi ellei toisin osoiteta). Merkinnät ks. kuva 1.





ing season ($p < 0.001$), however, being in the range 356–406 mg/l (Fig. 1B). The ammonium concentration in the chemical sludge quadrats was slightly above that of the control values at the start of the season in 1981, but it fell during the growing season and remained low throughout the season in 1982, whereas that in the bark ash quadrats was close to the control level in both years. The lowest soil ammonium concentrations were found in the fibre waste + bark ash quadrats (Fig. 1A,B).

The limestone sludge application increased soil nitrate concentration markedly during the growing season in the experiments set up in 1981 and 1982 ($p < 0.001$); from 12 mg/l to 112 mg/l in 1981 (Fig. 2A) and from 23 mg/l to 143 mg/l in 1982 in the experiments set up in 1981 (Fig. 2B), the corresponding increase in the sludge quadrats set up in 1982 being from 3 mg/l to 288 mg/l. In the case of the chemical sludge the nitrate concentration also increased markedly in 1981 ($p < 0.01$) (Fig. 2A). Soil nitrate concentration decreased markedly by the end of the season in 1981, however, both in the limestone quadrats and in the chemical sludge quadrats.

The 5 t/ha and the 20 t/ha bark ash dosages did not alter soil nitrate concentration, but the wood fibre waste + bark ash application gave lower nitrate concentrations than was found in the control, (range 0–5 mg/l) in the course of both growing seasons ($p < 0.05$) (Fig. 2A,B).

333. Denitrification

The laboratory tests showed a clear increase in denitrification in the course of the season in the limestone sludge quadrats, nitrous oxide concentrations rising from 23 µl/ml to 103 µl/ml in the quadrats set up in 1981 and from 1 µl/ml to 241 µl/ml in those set up in 1982 (Fig. 3A). In situ measurements in the field in the quadrats set up in 1981 showed an increase in N_2O concentration from 12 µl/ml to 38 µl/ml during June and July, but the level de-

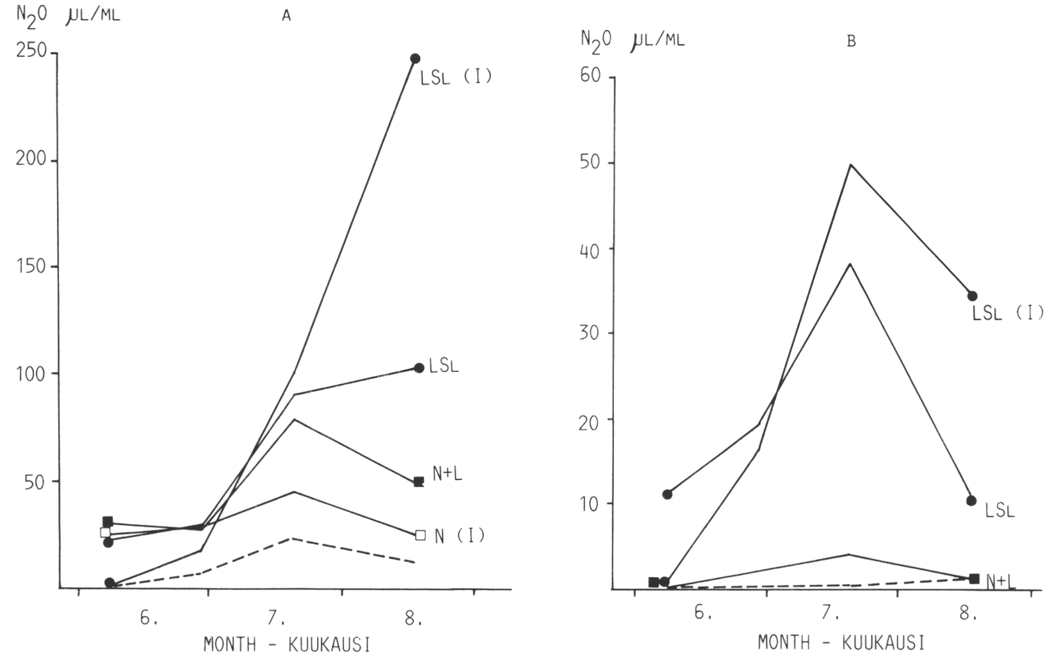


Figure 3. Nitrous oxide production (µl/ml) in the soil as measured in the laboratory (A) and in the field (B) in 1982 (second year if not otherwise indicated). Symbols as in Fig. 1.
Kuva 3. Typpioksiduulin muodostuminen (µl/ml) maassa vuonna 1982 (toinen vuosi ellei toisin osoiteta) mitattuna laboratoriossa (A) ja kentällä (B). Merkinnät ks. kuva 1.

creased to 11 µl/ml in August (Fig. 3B). The corresponding N_2O values in the quadrats set up in 1982 rose from 0.1 µl/ml to 50 µl/ml during June and July but again decreased in August to 35 µl/ml. Even so, a higher denitrification rate was obtained with the limestone sludge application than with the other treatment ($p < 0.001$).

34. Soil soluble phosphorus and exchangeable potassium, magnesium, calcium and soluble iron

The limestone sludge application in 1981 increased soil AAAc soluble phosphorus concentration over that of the control at the beginning of the growing season (45 mg/l) ($p < 0.001$), but it declined in the course of the season to 11 mg/l (Table 8). AAAc soluble P concentration in the limestone sludge quadrats set up in 1982 was 57 mg/l ($p < 0.001$) at first, but it also declined (25 mg/l) during July and August. The overall P level in the limestone sludge quadrats was above that resulting from the N-rich chemical fertilizer ($p < 0.05$). Soluble P concentration at the chemical sludge application remained at the level of the control throughout the both growing seasons.

Soil AAAc soluble P concentrations varied only in the range 7—11 mg/l in 1981 with 5 t/ha and 20 t/ha of bark ash. In 1982 the concentrations in both dosages had clearly increased and were higher than in the control ranging with 5 t of ash/ha between 21—44 mg/l and between 52—66 mg/l with 20 t of ash/ha ($p < 0.001$). Wood fibre waste + bark ash application gave P concentration of 7—8 mg/l during the first growing season and between 29 and 51 mg/l during the second season ($p < 0.01$) (Table 8).

Limestone and chemical sludge did not alter the concentration of soil exchangeable potassium compared with the control and the concentrations were below the values obtained with the N-rich chemical fertilizer ($p < 0.01$). The range was 85—103 mg/l (Table 9).

Table 8. Soil AAAc soluble phosphorus (mg/l) in 1981 and 1982.
Taulukko 8. Maaperän AAAc:hen uuttuvan fosforin pitoisuus (mg/l) vuosina 1981 ja 1982.

Treatment *Käsittely*	06.1981	08.1981	06.1982	08.1982
		P mg/l		
Control – *Kontrolli*	4.5	2.5	3.2	2.0
Chemical sludge – *Kemiallinen liete*	7.0	3.0	4.5	2.1
Limestone sludge-81 – *Kalkkiliete-81*	45.1***	11.0*	54.2***	34.0***
Limestone sludge-82 – *Kalkkiliete-82*			57.1***	25.2***
N-rich fertilizer – *Typpirikas Y*	24.6**	5.0	45.3***	18.1**
N-r. fertilizer + lime – *Typpirikas Y + kalkitus*			44.8***	12.3*
Bark ash 5 – *Kuorituhka 5*	8.0	7.3	43.7***	21.4**
Bark ash 20 – *Kuorituhka 20*	9.5	10.5*	65.5***	52.2***
Fibre waste + ash – *Kuitujäte + tuhka*	8.1	7.5	51.2***	29.4***

Table 9. Soil exchangeable potassium, magnesium and calsium concentrations (mg/l) in 1981 and 1982.
Taulukko 9. Maaperän vaihtuvan kaliumin, magnesiumin ja kalsiumin pitoisuudet (mg/l) vuosina 1981 ja 1982.

Treatment *Käsittely*	1981 K	1981 Mg	1981 Ca	1982 K	1982 Mg	1982 Ca
			mg/l			
Control – *Kontrolli*	60	60	691	68	65	857
Chemical sludge – *Kemiallinen liete*	82	73	815	95	80	1167
Limestone sludge-81 – *Kalkkiliete-81*	103	102	2087**	85	50	1272
Limestone sludge-82 – *Kalkkiliete-82*				95	102	2280**
N-rich fertilizer – *Typpirikas Y*	151*	87	662	203**	75	990
N-r. fertilizer + lime – *Typpirikas Y + kalkitus*				201**	270**	2645**
Bark ash 5 – *Kuorituhka 5*	100	97	1301*	228**	214**	1987*
Bark ash 20 – *Kuorituhka 20*	249**	450***	5418***	550***	874***	6863***
Fibre waste + ash – *Kuitujäte + tuhka*	150*	250**	2990**	309***	343***	3567**

The 5 t/ha bark ash dosage did not increase the exchangeable K concentration in 1981 (100 mg/l), but it had increased by the second year to 228 mg/l ($p < 0.01$). The 20 t/ha ash application led to a sharp increase compared with the control in 1981, the concentration being 249 mg/l ($p < 0.01$). These effects were also retained into the second year, when values were well above the control level ($p < 0.001$) and still higher than in 1981, i.e. 550 mg/l. The combination of fibre waste and bark ash gave an exchangeable K concentration of 150 mg/l ($p < 0.05$) in 1981, rising to 309 mg/l in 1982 ($p < 0.001$) (Table 9).

Limestone sludge, chemical sludge and N-rich fertilizer did not cause any changes in the soil exchangeable magnesium concentration (Table 9). However, N-rich fertilizer + limestone enhanced soil magnesium level ($p < 0.01$). No increase was obtained with 5 t/ha bark ash dosage during the first growing season, but a sharp increase to a level of 450 mg/l was noticed at 20 t/ha ($p < 0.001$). Both ash applications led to still higher values in the second growing season, reaching 214 mg/l with 5 t/ha ($p < 0.01$) and 874 mg/l with 20 t/ha ($p < 0.001$). The wood fibre + bark ash application increased exchangeable Mg concentration to 250 mg/l in 1981 ($p < 0.01$). Again a marked rise was noted in the second year, i.e. to 343 mg/l ($p < 0.001$).

Limestone sludge, the 5 t/ha and the 20 t/ha bark ash dosages, fibre waste + bark ash mixture and chemical fertilizer + limestone, all yielded marked increases in soil exchangeable calcium concentrations ($p < 0.05$) (Table 9).

Soil soluble iron concentrations were considerably higher with the limestone sludge application than with any of the other treatments ($p < 0.001$) (Fig. 4). Concentrations increased markedly towards the end of the growing season in 1981, with values of 311–339 mg/l recorded in June and July but results as high as 698 mg/l in mid-August. The limestone sludge quadrats set up in 1982, however, showed the highest Fe concentration immediately after spreading of the sludge (801 mg/l), a figure which then dropped during June and settled at a level of about 500 mg/l for the rest of the season (Fig. 4).

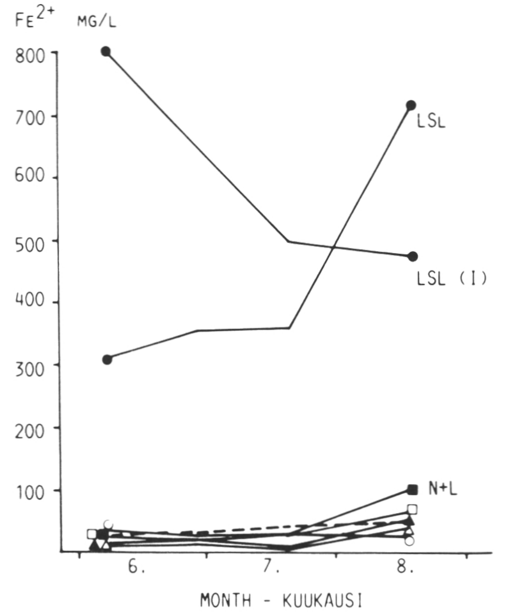


Figure 4. Soil soluble iron concentration (mg/l) in 1982 (second year if not otherwise indicated). Symbols as in Fig. 1.

Kuva 4. Maan liukoisen raudan pitoisuus (mg/l) vuonna 1982 (toinen vuosi ellei toisin osoiteta). Merkinnät ks. kuva 1.

35. Cellulose decomposition in soil

Limestone sludge increased cellulose decomposition activity in soil in the first year more than did any other treatment ($p < 0.01$), but a distinct drop in the activity was noted in the second year (Fig. 5A,B). The cellulose decomposition activity remained close to the control levels with the 20 t/ha bark ash application. Wood fibre waste + bark ash resulted in lower decomposition activity than with any other treatment in 1981, but in 1982 decomposition was markedly enhanced ($p < 0.001$), exceeding the results of all other treatments except for the limestone sludge application of that year.

36. Moisture balance in soil

Soil water tension was low in 1981 as a result of the rainy summer and no differences were discernible between the control, chemical sludge, N-rich chemical fertilizer

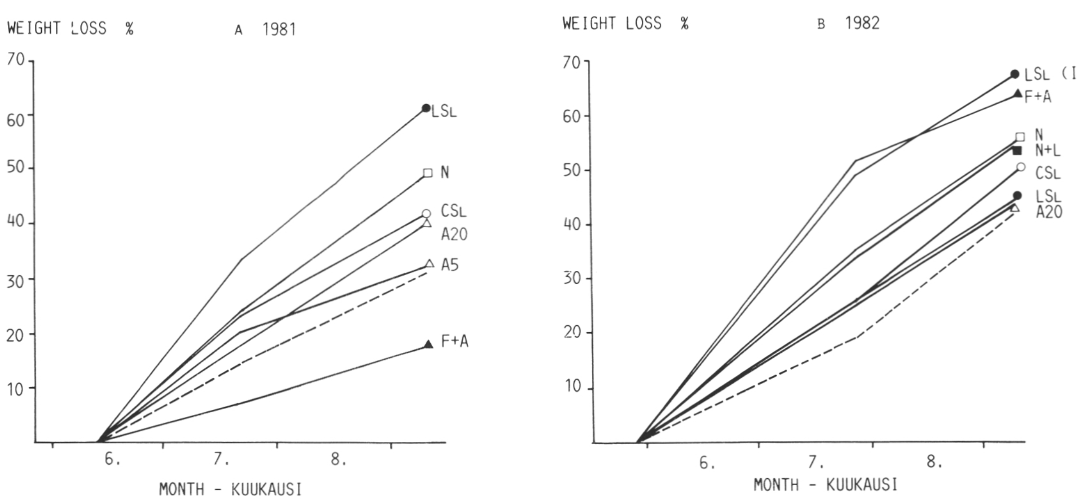


Figure 5. Cellulose decomposition (% weight loss) in the soil in 1981 (A, first year) and 1982 (B, second year if not otherwise indicated). Symbols as in Fig. 1.

Kuva 5. Selluloosan hajoaminen (painonvähennys, %) maassa vuosina 1981 (A, ensimmäinen vuosi) ja 1982 (B, toinen vuosi ellei toisin osoiteta). Merkinnät ks. kuva 1.

Table 10. Nitrogen, phosphorus and potassium concentrations (mg/g) in the leaves and bark of clone V769 of *Salix Aquatica* in 1981 and 1982.
Taulukko 10. Vesipajun kloonin V769 lehtien ja kuoren typen, fosforin ja kaliumin pitoisuudet (mg/g) vuosina 1981 ja 1982.

Treatment *Käsittely*	1981 N %	 P mg/g	 K mg/g	1982 N %	 P mg/g	 K mg/g
Control — *Kontrolli*	2.06	2.18	16.6	2.36	2.23	16.1
Chemical sludge — *Kemiallinen liete*	2.32	2.41	16.4	2.77	2.39	16.2
Limestone sludge-81 — *Kalkkiliete-81*	3.09**	2.62*	14.1*	3.20**	3.06*	14.5*
Limestone sludge-82 — *Kalkkiliete-82*				3.49**	2.96*	14.7*
N-rich fertilizer — *Typpirikas Y*	2.82**	2.59*	17.9*	3.29**	2.97*	18.1*
N-r. fertilizer + lime — *Typpirikas Y + kalkitus*				3.33**	3.05*	15.8
Bark ash 5 — *Kuorituhka 5*	1.57	1.71	17.7*	2.09	2.77*	17.9*
Bark ash 20 — *Kuorituhka 20*	2.24	2.62*	18.1*	2.75	2.95*	19.5*
Fibre waste + ash — *Kuitujäte + tuhka*	1.66	1.97	15.8	2.63	2.61	16.8

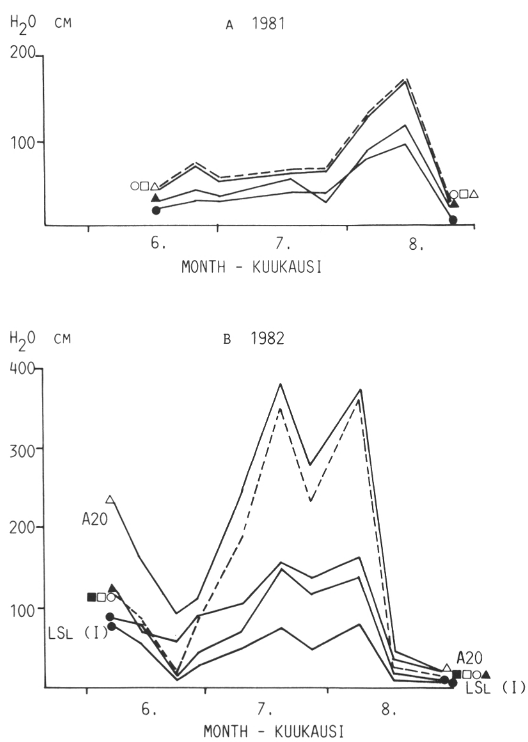


Figure 6. Soil water tension (cm H_2O) at a depth of 15 cm in 1981 (A, first year) and 1982 (B, second year if not otherwise indicated). Symbols as in Fig. 1.
Kuva 6. Maaveden jännitys (cm H_2O) 15 cm syvyydessä vuosina 1981 (A, ensimmäinen vuosi) ja 1982 (B, toinen vuosi ellei toisin osoiteta). Merkinnät ks. kuva 1.

and bark ash quadrats (175 cm H_2O or pF 2.24 during dry spells) (Fig. 6A). Lower values ($p < 0.05$) were recorded, however, with the limestone sludge and the wood fibre waste + bark ash applications (96 – 110 cm H_2O or pF 1.98 – 2.04 during dry spells). Once the soil became damper towards the end of the season the differences between the treatments disappeared.

Soil water tension varied much more in 1982 than in 1981, due to the lower summer rainfall, but in other respects the results were similar to those for the previous year (Fig. 6B). The readings for the limestone sludge application in both years and for the wood fibre waste + bark ash application were lower than elsewhere ($p < 0.01$). Soil water tension in the control quadrats during dry spells in 1982 was 350 cm H_2O, or pF 2.52. The soil of the limestone sludge quadrats set up in 1981 reached a value of 140 cm H_2O, or pF 2.15, during dry weather, that for the corresponding 1982 quadrats being 82 cm H_2O, or pF 1.91. Thus soil water tension in the former quadrats increased only slightly in spite of the drier summer and the quadrats from both years were close to their field capacity throughout the growing season.

37. Nutrient concentrations in the leaves and the bark of the willows

371. Nitrogen, phosphorus and potassium

Limestone sludge increased the nitrogen content of the leaves and bark of the willows with respect to the control values ($p < 0.01$) (Table 10). Same level was also achieved using N-rich chemical fertilizer. The same treatments similarly enhanced the phosphorus content of the plants in both years, as also did the 20 t/ha bark ash dosage ($p < 0.05$), while the 5 t/ha dosage increased the P content of

Table 11. Magnesium, calsium and iron concentrations (mg/g) in the leaves and bark of clone V769 of *Salix Aquatica* in 1981 and 1982.
Taulukko 11. Vesipajun kloonin V769 lehtien ja kuoren magnesiumin, kalsiumin ja raudan pitoisuudet (mg/g) vuosina 1981 ja 1982.

Treatment *Käsittely*	1981 Mg	 Ca	 Fe	1982 Mg	 Ca	 Fe
	mg/g					
Control — *Kontrolli*	1.68	8.20	67.3	1.17	8.10	78.5
Chemical sludge — *Kemiallinen liete*	1.81	8.75	65.9	1.31	7.78	74.7
Limestone sludge-81 — *Kalkkiliete-81*	1.85	9.75*	84.2*	1.41	9.89*	98.6**
Limestone sludge-82 — *Kalkkiliete-82*				1.27	9.72*	105.9**
N-rich fertilizer — *Typpirikas Y*	1.80	8.36	64.6	1.29	8.19	79.4
N-r. fertilizer + lime — *Typpirikas Y + kalkitus*				2.49*	10.50*	80.3
Bark ash 5 — *Kuorituhka 5*	1.90	9.80*	72.6	2.10**	10.20*	80.8
Bark ash 20 — *Kuorituhka 20*	1.44	8.68	71.8	0.94	7.50	78.9
Fibre waste + ash — *Kuitujäte + tuhka*	1.91	8.84	71.9	1.32	7.00	80.4

Table 12. Survival and height increment in clone V769 of *Salix Aquatica* in 1981 and 1982.
Taulukko 12. Vesipajun kloonin V769 kasvuunlähtö ja pituuskasvu vuosina 1981 ja 1982.

Treatment *Käsittely*	Survival % *Kasvuunlähtö* 1981	 1982	Height increment cm *Pituuskasvu* 1981	 1982
Control — *Kontrolli*	88.3	78.6	90	85
Chemical sludge — *Kemiallinen liete*	88.1		110	55
Limestone sludge-81 — *Kalkkiliete-81*	86.7		125	90
Limestone sludge-82 — *Kalkkiliete-82*		77.2		125
N-rich fertilizer — *Typpirikas Y*	88.6	79.1	150*	140*
N-r. fertilizer + lime — *Typpirikas Y + kalkitus*		78.6		130*
Bark ash 5 — *Kuorituhka 5*	85.4		95	30
Bark ash 20 — *Kuorituhka 20*	87.5		105	45
Fibre waste + ash — *Kuitujäte + tuhka*	85.1		55	20

the willows only during the second growing season ($p < 0.05$).

The limestone sludge application reduced the potassium concentration in the leaves and bark ($p < 0.05$), however, whereas the 5 t/ha and 20 t/ha bark ash applications and the chemical fertilizer increased it in relation both to the control and to the limestone sludge values ($p < 0.05$). The K concentration in the willows receiving N-rich chemical fertilizer + limestone was at the control level in 1982, however, as also was those receiving wood fibre waste + bark ash (Table 10).

372. Magnesium, calcium and iron

N-rich fertilizer + lime and the 5 t/ha bark ash dosage enhanced magnesium concentration in the leaves and bark of the willows ($p < 0.05$), whereas the 20 t/ha ash application gave a Mg concentration at the control level (Table 11).

Limestone sludge, N-rich fertilizer + lime and the 5 t/ha ash dosage gave higher calcium concentration in the willows than was found in the control ($p < 0.05$) (Table 11). The 20 t/ha bark ash application, in spite of its high Ca content, did not have any marked effect. The limestone sludge application led to increased iron concentration in the willows compared with the control ($p < 0.01$).

38. Survival and height increment of the willows

Survival of the willows was similar in all the treatments in 1981, as also in 1982, although at a lower level than in 1981 (Table 12). This difference was probably due to the low temperatures in June 1982. The survival may be regarded as satisfactory in 1981 but poor in 1982. Height increment in 1981 was greater in the quadrats receiving N-rich chemical fertilizer than elsewhere ($p < 0.05$) (Table 12). The willows grew also well in the control, however, considering that the prevailing soil conditions were not assumed to be favourable for willow cultivation. The limestone sludge did not markedly increase growth as compared with the controls. Height increment in the cuttings planted in 1982 was somewhat poorer than in those planted in the previous year, again due to the lower temperature, but the results pointed in much the same direction. Again the limestone sludge did not cause any improvement in growth but good results were achieved with the N-rich chemical fertilizer alone ($p < 0.05$).

4. DISCUSSION

41. Sewage sludges

According to Ericsson and Lindsjö (1981) the liming effect and rise in soil pH achieved in this study by application of limestone sludge at 75 metric tonnes/ha was adequate for willows at first, but the pH buffer capacity against a pronounced increase in soil nitrate concentration was low and consequently the pH fell below the optimum for willow growth. Obviously the high soil pH at the early stages was also due to the high ammonium concentration in the sludge. Although the results do not tell us whether the prevailing pH in itself had any crucial effect on the growth of the willows, the poor pH buffer capacity of the limestone sludge argues for avoidance of its use on highly acid soils.

Limestone sludge caused a pronounced increase in the nitrogen content of both the soil and the *Salix Aquatica* willows. In a fresh domestic sewage sludge 5—50 % of the total N content is usually in the form of ammonium and nitrate, 90—99 % of this being ammonium (Beauchamp et al. 1979), and the same was true of the limestone sludge tested here. Ammonification has been observed to be fairly pronounced in domestic sludges, with between 15 and 50 % of the organic N in crude, active and composted sludge being ammonified within 3—5 months of spreading (Ryan et al. 1973, Kelling et al. 1977, Epstein et al. 1978, Hsieh et al. 1981b). The high ammonium concentration indicated that ammonification activity in the limestone sludge had been high at the sewage works. The results suggest also, that it remained high in the soil only during the first growing season, however.

The marked decline in soil ammonium concentration observed with the limestone sludge application in the course of the growing season in 1981 was probably caused by evaporation of ammonia into the atmosphere at the beginning of the growing season and by nitrification and ammonium uptake by the willows later in the summer. Formation of gaseous ammonia from ammonium ions takes place in the pH range 6.5—12 and is stimulated by increasing temperature within this pH range (Terry et al. 1978). The limestone and ammonium ions in the sludge caused the soil pH to rise to critical values only at the start of the growing season. According to King and Morris (1974) between 10 and 60 % of the ammonium in waste sludge mixed with soil can be lost through evaporation.

A marked increase in soil nitrate concentration, an obvious result of high nitrification activity, was noted 3—4 weeks after the application of limestone stabilized sludge in 1981 and 1982. In the case of the limestone sludge applied in 1981, the nitrate concentration increased markedly during the second growing season in 1982 also. This is an important observation, because the majority of plants use nitrate as a major source of N. According to King (1972), Ryan et al. (1973) and Beauchamp et al. (1979) 15—50 % of the ammonium in crude, active and composted sludge is nitrified to nitrate within 1—4 months of application. Nitrate concentrations were higher in the limestone sludge than in the chemical sludge, obviously on account of the greater ammonium concentration in the former. In addition, the limestone sludge raised the pH of the soil to a more favourable level for nitrification (Alexander 1982).

Limestone sludge markedly increased the denitrification activity (N_2O production) of the soil, as measured in the laboratory, with rising nitrate concentrations in the course of the growing season. In the field measurements, however, an enhancement of N_2O production was obtained during the first half of the growing season only, after which a clear decrease was noted.

Experiments on denitrification in sewage sludges indicate a positive correlation between N_2O production and the amount of soluble organic carbon compounds, the oxygen (moisture) content and the nitrate concentration of the sludge (Burford and Bremner 1975, Jacobson and Alexander 1980). The limits for the commencement of denitrification as far as oxygen concentration is concerned have been set at a soil water tension value of pF 2.0 and redox potential values of +200 – +300 mV (Hsieh et al. 1981b, Letey et al. 1981). Since the soil water tension readings in the limestone sludge quadrats in both research years were almost continuously <pF 2.0, conditions were favourable for denitrification in this respect and thus the process seems to have been regulated by the other factors mentioned. The decrease in denitrification noted in the field may have been caused by a decline in the soluble organic carbon content of the soil due to high microbiological activity.

Results obtained both in the laboratory and in field analysis showed a marked difference in denitrification between the soil treated with microbiologically active limestone sludge and with the N-rich chemical fertilizer. According to King (1972) and Kaspar and Tiedje (1981), between 16 % and 40 % of the nitrate formed in crude and active sludges may be denitrified.

As for the other macro nutrients, the limestone sludge applications added enough AAAc soluble phosphorus to the soil, but the concentration declined fairly markedly in both years. This was partly due to P uptake by the willows, as the P content of the willows increased at the same time, and perhaps to precipitation of P by ferric compounds. 80 – 85 % of total P in the sludges is in inorganic form (Beek et al. 1977), a considerable proportion of the P being bound by Al, Ca and Fe compounds used for P precipitation in the purification processes. Fe-bound P cannot be utilized by plants at all, and only a part of the Al and Ca bound P is utilizable (Raitio 1983). The binding of P to these metals is dependent on their concentrations and on the soil pH; Al and Fe binding P under acid conditions and Ca under neutral or alkaline conditions. The limestone sludge tested contained high quantities of both Fe and Ca. The decline in the pH of the soil in the course of the growing season obviously increased the solubility of the Fe of the limestone sludge. Consequently more Fe-bound P may have been obtained towards the end of the season.

The results indicate that the soil potassium concentration, following the limestone sludge applications was too low in relation to soil N and P. This becomes evident by comparing the K:N ratios in the leaves and bark of the willows in the control, 0.81, with that in the limestone sludge quadrats, 0.42, in 1981, and 0.77 in the controls and 0.42 – 0.46 with limestone sludge in 1982. The K concentrations in the leaves and bark of the willows fertilized with N-rich chemical fertilizer + limestone were nevertheless lower than in the willows receiving chemical fertilizer alone, and even slightly lower than the control values. This may be due to the retarding effect of Ca ions on K uptake in willows (Soon et al. 1978 and Raitio 1983), and would suggest that the low K concentrations observed in the willows were not caused entirely by the low K content of the limestone sludge.

Domestic sewage sludges commonly have low concentrations of available K, since it is readily soluble and easily passes through the sewage purification processes. In addition, according to Dunigan and Dick (1980), only 10 – 20 % of the total K in sludges is usually in exchangeable form. The additional potassium requirement may be estimated from the K:N ratio in the sludge, a value of 0.9 being needed to ensure an adequate K supply for the plants. If the figure is lower than this, additional K should be provided (Palazzo and Jenkins 1979). The K:N ratio in the limestone sludge employed here was 0.4.

In addition to the retarding effect on the solubility of P in the soil, the Al and Fe compounds used in the sewage purification process can inhibit plant growth. Their solubility is dependent on the pH and oxygen content of the soil, with increasing solubility under acidic (pH < 5.5) and anaerobic conditions (Raitio 1983). The limestone sludge tested contained high concentration of Fe. According to the increased Fe concentrations in the willows and the soil analysis, the solubility of the sludge Fe increased towards the end of the second growing season, presumably due to the decline in soil pH and in oxygen content (caused by increased rainfall). The toxic effects of Fe may have reduced the growth stimulation achieved by the high N and P content of the sludge. Even though no visible symptoms were apparent, growth was comparable to that in the controls. Siira et al. (1984) found that domestic sewage sludge disturbed growth of *Salix Aquatica* due to high Al content in the sludge.

The limestone sludge markedly increased cellulose decomposition in the soil during the first growing season. Due to high microbiological activity in the sludge, a substantial proportion of the organic matter was obviously decomposed already during the first growing season. Therefore a marked decline in cellulose decomposition activity was noted in the second growing season. This result is consistent with other observations showing that 20—46 % of the organic carbon contained in sludges is oxidized within 2—12 months of application (Epstein et al. 1978 and Hsieh et al. 1981a).

The limestone sludge was found to improve the water balance in the soil, an effect which was particularly obvious during spells of dry weather. *Salix Aquatica* has been shown to consume a lot of water, as much as 300—350 litres/kg of dry matter produced (Kaunisto 1983 and Saarsalmi 1984) and therefore the use of this kind of sludge would seem to help to maintain growth under extremely dry conditions. This was evidently due to the increased organic matter content of the soil, which also led to an improved CEC, thus enhancing the soil's potential for binding the increased total nutrient concentration.

These results suggest that major changes in the chemical, microbiological and physical properties of soil can be achieved using sludge from domestic waste. The limestone-stabilized sludge used at Häädetjärvi may, when supplemented with potassium, be regarded as suitable for the fertilization of rapidly growing plants, as a substitute for lime and N and P fertilization. The high Fe content of this sludge may retard plant growth, however, especially if the sludge is applied at frequent intervals in the same areas.

42. Conifer bark ash

The conifer bark ash tested at Häädetjärvi was found to be a useful P, K and Mg fertilizer and liming material for the cultivation of fast-growing plant species. The P, K and Mg contained in it were shown to be less readily soluble than those in chemical fertilizer, obviously giving bark ash a long-term effect, as reflected in a greater release of these nutrients in the second growing season than in the first. Such conclusions are also supported by the results from other ash experiments in which the effects become apparent only after a few years' delay but may last as long as 20—40 years (Merisaari 1981, Silfverberg and Huikari 1985). The P, K and Mg in the bark ash produced by combustion occure as oxides and carbonates, which dissolve much more slowly than the phosphoric acid and K and Mg chlorides present in chemical fertilizers. The results of the 5 t/ha bark ash application indicate that the nutrients may dissolve too slowly during the first growing season to meet the needs of rapidly growing plants. The Ca in the bark ash used was evidently in an easily soluble form, since the 5 t/ha dosage raised the soil pH markedly already during the first growing season.

The stimulus in growth noted after the application of bark ash even at a high level (20 t/ha), was poor. The reason must be that no N fertilizer was supplied and no substantial increase in the mineralization of organic N in the soil (2 % total N) was recorded during the two growing seasons studied. Both bark ash treatments did cause an increase in K and P content of the willows, however (and Mg with 5 t of ash/ha). Wood ash applications of 10 t/ha on N-rich mire soils have been reported to achieve 7—20 fold increases in growth compared with control plots (Paavilainen 1980).

Application of wood and bark ash to soil has been shown in earlier experiments to increase soil microbiological activity, cellulose decomposition activity and ammonification in peat soils and nitrification in heath soils (Karsisto 1979 and Martikainen 1986). The present bark ash experiments lasting for two growing seasons did not show any significant increase in microbiological activity as measured in terms of cellulose decomposition. According to Alexander (1982) the soil pH at the 20 t/ha ash dosage may have been too high for the soil microflora.

Ash fertilization experiments with rapidly growing plants have often resulted in disturbances in nutrient uptake on account of the high concentrations of trace elements in the ash (Adriano et al. 1980). The present results similarly indicate a disturbance in Mg uptake in the willows with the 20 t/ha ash dosage. According to Raitio (1983) this was probably due to the inhibition of Mg uptake by manganese in the ash. It is not clear, however, whether this had any significant effect on the growth of the willows. In addition, the Ca content of the soil increased to 6 800 mg/l with the 20 t/ha ash application and the soil pH rose to 8.2. The osmotic pressure in the rooting zone of the willows may therefore have been too high. The 20 t/ha ash dosage reduced the CEC of the soil, but it was not found to alter the water balance in the soil. This is consistent with results presented by Chang et al. (1977).

The results obtained suggest, that conifer bark dosages from 5 to approximately 10 t/ha similar to the one tested here, is enough to cause beneficial effects in the soil nutrient status and pH under soil conditions similar to those in the Häädetjärvi area. Conifer bark ash applications > 10–20 t/ha are likely to interfere with the nutrient uptake of the plants.

43. Wood fibre waste

The use of wood fibre waste in conjunction with bark ash was not found to be advantageous for fast-growing willows. Due to the high C:N ratio (> 100:1) of the fibre waste, most of the available nitrogen, especially nitrate, was immobilized by the microorganisms in the soil. The C:N ratio decreased markedly after the first growing season, however, obviously due to increased decomposition activity in the soil. It is obvious that a large cellulose degrading microflora had developed in the cellulose-rich fibre waste during the second growing season. In addition, the 10 t/ha ash dosage markedly inreased the pH and P, K and Mg concentrations in the soil and thus may have enhanced the overall soil microbial activity. Wood fibre waste also caused an increase in available water in the soil.

REFERENCES

Adriano, D., Page, A., Elseewi, A., Chang, A. & Straughan, J. 1980. Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems; a review. Journal of Environmental Quality 9:333–343.

Alexander, M. 1982. Introduction to soil microbiology. John Wiley. New York. 573 p.

Beauchamp, E., Soon, Y. & Moyer, J. 1979. Nitrate production from chemically treated sewage sludge in soil. Journal of Environmental Quality 8:557–560.

Beek, J., Haan, F. & Riemsdijk, W. 1977. Phosphates in soils treated with sewage water 2. Fractionation of accumulated phosphates. Journal of Environmental Quality 6:7–11.

Burford, J. & Bremner, J. 1975. Relationships between the denitrification capacities of soils and total, water soluble and readily decomposable soil organic matter. Soil Biology and Biochemistry 7:389–394.

Chang, A., Lund, L., Page, A. & Warneke, J. 1977. Physical properties of fly ash amended soils. Journal of Environmental Quality 6:267–270.

Dunigan, E. & Dick, R. 1980. Nutrient and coliform losses in runoff from fertilized and sewage sludge treated soil. Journal of Environmental Quality 9:243–250.

Energiataloudellinen yhdistys 1985. Turve- ja seostuhkan hyötykäyttö. Väliraportti. Ekono Oy. 67 p.

Epstein, E., Keany, D., Meisinger, J. & Legg, J. 1978. Mineralization of nitrogen from sewage sludge and sludge compost. Journal of Environmental Quality 7:217–221.

Ericsson, T. & Lindsjö, I. 1981. Tillväxtens pH-beroende hos några energiskogsarter. Sveriges Lantbruksuniversitet. Projekt Energiskogsodling. Teknisk Rapport 11. 7 p.

Hakkila, P. & Kalaja, H. 1983. Puu- ja kuorituhkan palauttamisen tekniikka. Summary: The technique of recycling wood and bark ash. Folia Forestalia 552. 37 p.

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. Metsäntutkimuslaitoksen tiedonantoja 121. 28 p.

Hsieh, Y., Lowell, A. & Motto, H. 1981a. Modelling sewage sludge decomposition in soil 1. Organic carbon transformation. Journal of Environmental Quality 10:54–58.

– , Lowell, A. & Motto, H. 1981b. Modelling sewage sludge decomposition in soil 2. Nitrogen transformations. Journal of Environmental Quality 10:59–63.

Huhta, V., Sundman, V., Ikonen, E., Sivelä, S., Wartiovaara, T. & Vilkamaa, P. 1978. Jäteliete-kuorirouhe-seosten maatumisen biologia. Jyväskylän yliopiston biologian laitoksen tiedonantoja 11. 126 p.

Jacobson, S. & Alexander, M. 1980. Nitrate loss from soil in relation to temperature, carbon source and denitrifier populations. Soil Biology and Biochemistry 12:501–505.

Karsisto, M. 1979. Maanparannustoimenpiteiden vaikutus orgaanista ainetta hajottavien mikrobien aktiivisuuteen suometsissä. 2. Tuhkalannoituksen vaikutus. Summary: Effect of forest improvement measures on activity of organic matter decomposing micro-organisms in forested peatland. 2. Effect of ash fertilization. Suo 30:81–91.

Kaspar, H. & Tiedje, J. 1981. Denitrification and dissimilatory nitrate reduction to ammonium in digested sewage sludge. Canadian Journal of Microbiology 27:878–885.

Kaunisto, S. 1983. Koripajun (Salix viminalis) biomassatuotos sekä ravinteiden ja veden käyttö eri tavoin lannoitetuilla turpeilla kasvihuoneessa. Summary: Biomass production of Salix viminalis and its nutrient and water consumption on differently fertilized peats in greenhouse. Folia Forestalia 551. 34 p.

Kelling, K., Walsh, L., Keeney, D., Ryan, J. & Peterson, A. 1977. A field study of the agricultural use of sewage sludge 2. Effect on soil nitrogen and phosphorus. Journal of Environmental Quality 6:345–351.

Keppo, M. & Ylinen, P. 1980. Voimalaitostuhkat ja niiden hyväksikäyttö 1. Suomessa muodostuvat tuhkat ja niiden laatu. Valtion teknillinen tutkimuskeskus. Tiedonanto 61. 63 p.

King, L. 1972. Land disposal of liquid sewage sludge 3. The effect on soil nitrate. Journal of Environmental Quality 1:442–446.

– & Morris, H. 1974. Nitrogen moving resulting from surface application of liquid sewage sludge. Journal of Environmental Quality 3:238–242.

Kuukausikatsaus Suomen ilmastoon, vuosikerrat 1981–1982. Ilmatieteen laitoksen julkaisuja. Helsinki.

Letey, J., Valoras, N., Focht, D. & Ryden, J. 1981. Nitrous oxide production and reduction during denitrification as affected by redox potential. Soil Science Society of American Journal 45: 727–730.

Martikainen, P. 1986. Nitrification in two fertilized pine forest soils. Academic Dissertation. University of Helsinki. 77 p.

Matt, J. 1970. Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. Soil Science 109: 216–220.

Merisaari, H. 1981. Tuhkalannoituksen kesto eräillä vanhoilla tuhkakokeilla. Metsäntutkimuslaitoksen tiedonantoja 13. 69 p.

Mitchell, M., Mulligan, R., Hartenstein, R. & Nauhauser, E. 1977. Conservation of sludges into topsoils by earthworms. Compost Science 18:28–32.

Paavilainen, E. 1980. Tuloksia vanhoista tuhkalannoituskokeista. Tuhka metsänlannoitteena. Metsäntutkimuslaitoksen tiedonantoja 20:22–23.

Palazzo, A. & Jenkins, T. 1979. Land application of waste water, effect on soil and plant potassium. Journal of Environmental Quality 8:309–311.

Pelkonen, P. 1984. Carbon dioxide exchange in willow clones. In: Perttu, K. (ed.) Ecology and management of forest biomass production systems. Swedish University of Agricultural Sciences, Department of Ecology and Environmental Research, Report 15. Uppsala. p. 187–196.

Raitio, H. (ed.) 1983. Metsäpuiden fysiologiaa 1. Ravinnetalouden perusteita. Helsingin Yliopiston metsänhoitotieteen laitoksen tiedonantoja 39. Helsinki. 200 p.

Riiheläinen, T. 1975. Lietteen kemialliset ominaisuudet. Vesipäivät 3.–4.4.1975. Lietteen käyttö ja sijoitus. Vesiyhdistys ry. p. 46–56.

Ryan, J., Keeney, D. & Walsh, L. 1973. Nitrogen transformations and availability of an anaerobically digested sewage sludge in soil. Journal of Environmental Quality 2:489–492.

Saarsalmi, A. 1984. Vesipajun biomassan tuotos sekä ravinteiden ja vedenkäyttö. Summary: Biomass production and nutrient and water consumption in Salix 'Aquatica gigantea' plantation. Folia Forestalia 602. 27 p.

Siira, J., Heikkinen, Y. & Viljanen, M-L. 1984. Lietelannoituksen vaikutus vesipajun *(Salix* cv. *aquatica)* ja rauduskoivun *(Betula pendula)* kasvuun ja kemialliseen koostumukseen. In: Siira, J. & Tahvanainen, J. (eds.) Lietelannoitus energiapuun kasvatuksessa. Metsäntutkimuslaitoksen tiedonantoja 138:7–18.

Silfverberg, K. & Huikari, O. 1985. Tuhkalannoitus metsäojitetuilla turvemailla. Abstract: Wood-ash fertilization on drained peatlands. Folia Forestalia 633. 25 p.

Siren, G. 1983. Energiskogsodling. NE 11. Sveriges lantbruksuniversitet. Institutionen för ekologi och miljövård. Stockholm. 350 p.

Soon, Y., Bates, T. & Moyer, J. 1978. Land application of chemically treated sewage sludge 2. Effects on plant and soil phosphorus, potassium, calcium and magnesium and soil pH. Journal of Environmental Quality 7:269–273.

Terry, R., Nelson, D., Sommers, L. & Meyer, G. 1978. Ammonia volatilization from wastewater sludge applied to soils. Journal of Water Pollution and Conservation Federation 50:2657–2665.

Ympäristöministeriö 1983. Taustamuistio jätteiden määrästä ja hyödyntämisestä sekä tuotteiden käyttöiän pidentämisestä. Jätehuollon neuvottelukunta. 150 p.

Total of 42 references

SELOSTE

Asutusjätelietteen, havupuun kuorituhkan ja puukuitujätteen vaikutus maaperän ominaisuuksiin ja vesipajun kasvuun

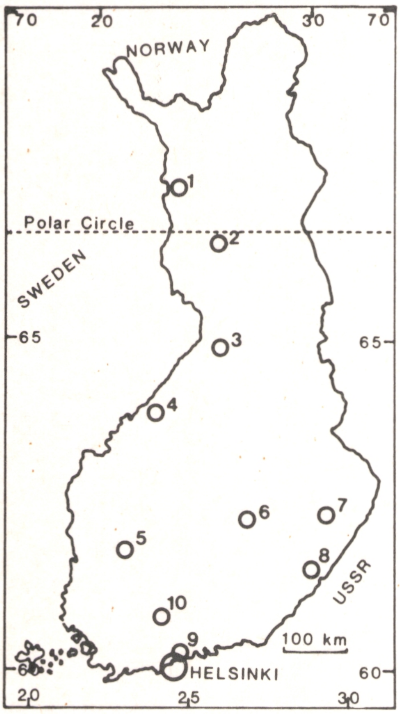
Asutusjätelietteiden, havupuun kuorituhkan ja puukuitujätteen hyödyntämistä selvittävät kokeet perustettiin Metsäntutkimuslaitoksen koealueelle Häädetjärvelle Parkanossa (62°00'N, 22°30'E). Kenttäkokeissa, joita seurattiin kaksi kasvukautta, käytettiin kalkkistabiloitua (75 t/ha) ja kemiallisesti käsiteltyä (14,4 t/ha) lietettä, havupuun kuorituhkaa (5 ja 20 t/ha) sekä paperiteollisuudessa syntyvää puukuitujätettä (23 t/ha), johon sekoitettiin havupuun kuorituhkaa (10 t/ha). Tuhkalannoituksen yhteydessä ei annettu typpeä. Vertailuna olivat käsittelemättömät kontrollit, runsastyppinen Y-lannos ja runsastyppinen Y + dolomiittikalkki. Kokeille istutettiin vesipajun (Salix Aquatica) kloonin V769 pistokkaita (pituus 20 cm) 20 000 kpl/ha.

Kalkkiliete muutti maaperän mikrobiologisia, kemiallisia ja fysikaalisia ominaisuuksia selvästi sekä kontrolliin että keinolannoitekäsittelyihin verrattuna. Kemiallinen liete ei aiheuttanut merkittäviä muutoksia maassa, kohonnutta nitraattipitoisuutta lukuunottamatta (ensimmäisellä kasvukaudella), koska lietteen määrä oli ilmeisesti liian alhainen. Maan kokonaistypen ja ammonium-typen pitoisuudet kohosivat merkittävästi kalkkilietteellä käsitellyissä koeruuduissa. Nitraatti-typen pitoisuus oli kasvukauden alussa alhainen, mutta se kohosi voimakkaasti 3—4 viikkoa lietteen levityksestä. Maaperän kohonnut typpipitoisuus heijastui myös vesipajun lehtien ja kuoren N-pitoisuuden kohoamisena. Toisaalta denitrifikaatio oli kalkkilietteellä selvästi vilkkaampaa kuin nitraattipitoisella keinolannoitteella lannoitetuissa koeruuduissa. Kalkkiliete lisäsi maaperän liukoisen fosforin pitoisuutta ja vesipajun lehtien ja kuoren P-konsentraatiota vaikka osa fosfaateista lienee sitoutunut lietteen sisältämään rautaan ja kalkkiin. Maaperän kalkkipitoisuus ja pH kohosivat kalkkilietteellä, mutta maan lisääntyneen nitrifikaatioaktiivisuuden vuoksi pH aleni jo ensimmäisen kasvukauden aikana kontrollin tasolle. Kalkkiliete lisäsi ensimmäisen kasvukauden aikana maaperän selluloosan hajotusaktiivisuutta merkittävästi, mutta hajotusaktiivisuus aleni jo toisena kasvukautena. Myös maaperän vedenpidätyskyky ja kationinvaihtokapasiteetti paranivat kalkkilietteellä. Toisaalta lietteen alhainen kaliumpitoisuus ja korkea rautapitoisuus todennäköisesti rajoittivat vesipajun kasvua. Pajun pituuskasvu lisääntyi merkittävästi vain runsastyppisellä keinolannoitteella.

Havupuun kuorituhkalannoitus kohotti selvästi maaperän P-, K-, Mg- ja Ca-pitoisuutta sekä pH:ta. Myös vesipajun lehtien ja kuoren P- ja K-pitoisuus lisääntyi. Tuhkakäsittely 5 t/ha lisäsi vesipajun Mg-pitoisuutta mutta 20 t/ha käsittely alensi sitä. Tämä johtui ilmeisesti tuhkan sisältämän mangaanin pajun Mg ottoa inhiboivasta vaikutuksesta. P, K ja Mg olivat tuhkassa hidasliukoisessa muodossa, joten tuhkalla on ilmeisesti pitempi lannoitusvaikutus kuin keinolannoitteella. Toisaalta tuhkan ravinteet saattavat olla liian hidasliukoisia nopeakasvuisten kasvien kannalta viljelyn alkuvaiheessa. Koealueen maaperä oli typpipitoista (2 % tot N), mutta tuhkan ei havaittu lisänneen merkittävästi orgaanisen typen mobilisaatiota maassa kahtena seurantavuotena. Tästä syystä tuhkan aiheuttama kasvureaktio vesipajussa oli heikko. Tuhka ei muuttanut maaperän vesitaloutta, mutta tuhkakäsittely 20 t/ha alensi maan kationinvaihtokapasiteettia.

Puukuitujätteen ja havupuun kuorituhkan sekoittaminen maahan ei lisännyt vesipajun kasvua kuitujätteen ja tuhkan alhaisen typpipitoisuuden vuoksi. Puukuitujätteen korkean C:N-suhteen vuoksi typpilannoituksen pitäisi olla voimakas kasvureaktioiden aikaansaamiseksi. Toisaalta mikrobiologinen aktiivisuus (selluloosan hajotus) kuitujätteessä lisääntyi voimakkaasti toisena kasvukautena. Sen seurauksena C:N-suhde aleni selvästi edelliseen kasvukauteen verrattuna. Lisäksi puukuitujäte paransi maaperän vesitaloutta.

Lumme, I. & Laiho, O. 1988. Effects of domestic sewage sludge, conifer bark ash and wood fibre waste on soil characteristics and the growth of Salix Aquatica. Seloste: Asutusjätelietteen, havupuun kuorituhkan ja puukuitujätteen vaikutus maaperän ominaisuuksiin ja vesipajun kasvuun. Communicationes Instituti Forestalis Fenniae 146. 24 p.



THE FINNISH FOREST RESEARCH INSTITUTE

DEPARTMENTS (Helsinki)

Administration Dept.
Information Office
Research Area Office
Dept. of Soil Science
Dept. of Peatland Forestry
Dept. of Silviculture
Dept. of Forest Genetics
Dept. of Forest Protection
Dept. of Forest Technology
Dept. of Forest Inventory and Yield
Dept. of Forest Economics
Dept. of Mathematics

RESEARCH STATIONS

1 Kolari
2 Rovaniemi
3 Muhos
4 Kannus
5 Parkano
6 Suonenjoki
7 Joensuu
8 Punkaharju
9 Ruotsinkylä
10 Ojajoki

FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

Communicationes Instituti Forestalis Fenniae

141 Ahti, E. Water balance of drained peatlands on the basis of water table simulation during the snowless period. Seloste: Ojitettujen soiden vesitaseen arvioiminen lumettomana aikana pohjavesipinnan simulointimallin avulla.

142 Hokkanen, T., Heliövaara, K. & Väisänen, R. Control of *Aradus cinnamomeus* (Heteroptera, Aradidae) with special reference to pine stand condition. Seloste: Punalatikan torjunta erityisesti metsänhoidollisin menetelmin.

143 Juslin, H. & Tarkkanen, T. Marketing strategies of the Finnish forest industries. Seloste: Suomalaisen metsäteollisuuden markkinointistrategiat.

144 Korhonen, K.-M. Damage caused by the root vole *(Microtus oeconomus)* to Scots pine in man-made habitats in northern Finland. Seloste: Lapinmyyrä metsätuholaisena Pohjois-Suomessa.

145 Kaunisto, S. & Paavilainen, E. Nutrient stores in old drainage areas and growth of stands. Seloste: Turpeen ravinnevarat vanhoilla ojitusalueilla ja puuston kasvu.

146 Lumme, I. & Laiho, O. Effects of domestic sewage sludge, conifer bark ash and wood fibre waste on soil characteristics and the growth of Salix Aquatica. Seloste: Asutusjätelietteen, havupuun kuorituhkan ja puukuitujätteen vaikutus maaperän ominaisuuksiin ja vesipajun kasvuun.

ISBN 951-40-1016-7
ISSN 0358-9609