

METSÄNTUTKIMUSLAITOKSEN  
TIEDONANTOJA 211



METSÄTEKNOLOGIAN TUTKIMUSOSASTO  
METSÄTYÖTIEEEN TUTKIMUSSUUNTA



PENTTI HAKKILA

RECYCLING OF WOOD AND BARK ASH

A STATE-OF-THE-ART REVIEW FOR PROGRAMME  
GROUP C UNDER THE IEA FOREST ENERGY AGREEMENT

HELSINKI 1986



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## CONTENTS

1. INTRODUCTION .....	3
2. ASH CONTENT OF WOOD AND BARK .....	5
3. COMPOSITION OF PURE ASH .....	9
4. COMPOSITION OF POWER PLANT ASH .....	11
41. Impurities in power plant ash .....	11
42. Nutrient content of power plant ash .....	15
5. POWER PLANT ASH AS A SOIL IMPROVEMENT AGENT .....	19
51. Suitability of ash in agriculture .....	19
52. Suitability of ash in forestry .....	22
6. CONSTRAINTS IN RECYCLING OF ASH .....	27
7. SPREADING TECHNIQUES .....	30
71. Considerations of health .....	30
72. Technical solutions .....	33
8. CONCLUSIONS AND RECOMMENDATIONS .....	39
LITERATURE .....	42

ISBN 951-40-0897-9

ISSN 0358-4283

Helsinki 1986. Valtion painatuskeskus

## 1. INTRODUCTION

Recovery of forest residues for energy results in increasing loss of nutrients from forest soil compared with conventional timber harvesting. When dealing with renewable energy sources, an ecologically sound model must be found to ensure that effective utilization of biomass does not jeopardize the nutrient balance and production capacity of the forest soil. The problem becomes crucial, when branches and foliage are removed from the forest along with the stemwood.

Almost all of the nutrients in biomass, with the exception of nitrogen, remain in the ash after burning. In the future, a growing portion of wood ash and nearly all of the bark and peat ash is created in medium and large size combustion plants. For lack of workable recycling systems, the ash is generally deposited in landfill areas, resulting in extra transportation and dumping costs.

At the landfill area, rainwater passes through the mounds of ash, whereby nutrients and heavy metals may leach into surface and ground water. The possibility of pollution is obvious, even though no clear evidence has been found of ground water contamination by wood and bark ash.

Though biological ash fertilization tests have been carried out for decades, the problem is not sufficiently understood yet. Both lack of information and negative attitudes prevent utilization and practical applications.

Recycling wood and bark ash is still constrained by several ecological, technical and economic factors.

Consequently, the Programme Group on Harvesting, Transport and Processing (PG C) under the IEA forestry energy research agreement decided in 1984 to prepare as a joint action (JAC 19) a state-of-the-art review on recycling of ash. The task was assigned to the Department of Forest Technology at the Finnish Forest Research Institute. Representatives of countries participating in the Programme Group assisted with the literature search.

Since IEA's forestry energy cooperation only extends to forest biomass so far, the review is limited to wood and bark ash and its utilization as soil improvement agent or fertilizer. In addition, however, some comparative data on the composition of peat and straw ash are presented.

Very few research results concerning the ash recycling are available. A significant proportion of them concern peatland forests in Finland and Sweden, but little research has been done on the suitability of ash for mineral soils in forestry and agriculture. Results on the techniques of ash spreading have been published only by the Finnish Forest Research Institute within its ongoing forest energy project (PERA Project). Nevertheless, the author hopes that this review will create interest and stimulate research in the subject matter, and encourage producers and potential users in the participating countries to start pilot experiments for utilization of this natural soil improvement agent.

## 2. ASH CONTENT OF WOOD AND BARK

The root system of a tree takes inorganic minerals or nutrients from the forest soil. The nutrients rise to the stem and crown by sapflow. Some minerals are taken up through the foliage from rain water. The greatest concentration of minerals is in the parts of the tree where the life processes take place.

As wood is burned, the inorganic matter forms ash. The ash content of the biomass varies according to site, tree species, tree size and age, and perhaps to some extent also season. It is generally greater in hardwoods and, on the other hand, in young small-sized trees.

For instance, the ash content of the wood in Central European tree species varies between 0.3 and 1.0 %. In tropical trees, the ash content may rise as high as 4 % (Knigge & Schulz 1966). Kollmann (1951) reports that the ash content of bark-free wood in some German studies has been as follows:

Tree species	Proportion of ash, % of dry matter
<i>Picea abies</i>	0.77
<i>Pinus silvestris</i>	0.39
<i>Betula verrucosa</i>	0.39
<i>Populus tremula</i>	0.32
<i>Fraxinus excelsior</i>	0.43
<i>Tilia parvifolia</i>	0.46
<i>Fagus silvatica</i> (1st study)	0.54
<i>Fagus silvatica</i> (2nd study)	1.17

The Finnish Forest Research Institute has defined the ash content of small-sized fuel chip trees of birch (*Betula*

verrucosa), grey alder (*Alnus incana*), aspen (*Populus tremula*), Scots pine (*Pinus silvestris*) and Norway spruce (*Picea abies*). In bark-free stem wood, the ash content was 0.4 %, while the ash content of the bark was 2 to 4 %, i.e. 5 to 8 times that of stem wood. The ash content of birch, alder, aspen, and spruce foliage was particularly high, as much as 5 to 6 %. The ash content of pine needles was only 2.3 % (Table 1).

Table 1. Proportion of pure ash in the dry matter of newly-felled small-sized trees and in that of the bark of saw timber trees in southern Finland (Hakkila & Kalaja 1983).

Tree part	Birch	Alder	Aspen	Pine	Spruce
-----					
Pure ash, % of dry matter					
-----					
SMALL-SIZED TREES					
Stem wood	0.39	0.43	0.45	0.40	0.63
Stem bark	2.18	3.50	3.40	2.55	3.20
Branches	1.23	1.70	1.75	1.03	1.88
Foliage	5.45	5.45	6.45	2.35	5.13
SAWTIMBER TREES					
Stem bark	1.72	..	..	1.51	3.77

When the proportions of the various tree components are known, the amount of pure ash in chips made from divers kinds of small trees may be calculated by using Table 1. The pure ash content of the above-ground biomass of the Finnish tree species is 0.9 - 1.6 %, if all branches with foliage are included. For instance, by removing the foliage with a flail delimeter before chipping, or after chipping with a sorter, the ash content can be decreased to 0.8 to 1.3 %. If, however, leaves are removed by transpiration drying, a portion of their nutrients is transferred into the branches and stem, resulting in a lesser decrease in ash



content than if foliage is removed while green. There is a significant decrease in ash content if trees are delimited before chipping. In Finnish tree species, the ash content of chips made of delimited trees is 0.7 to 1.0 % (Table 2).

Table 2. The amount of pure ash in fuel chips made from newly-felled small-sized trees in southern Finland (Hakkila and Kalaja 1983).

Raw material of chips	Birch	Alder	Aspen	Pine	Spruce
	Pure ash, % of dry matter				
Delimited stem	0.68	0.92	0.92	0.74	1.04
Whole tree excl. foliage	0.79	1.08	1.09	0.80	1.25
Whole tree incl. foliage	0.98	1.25	1.30	0.86	1.56
	Pure ash, kg/solid m <sup>3</sup> of chips				
Delimited stem	3.1	3.3	3.5	2.7	3.9
Whole tree excl. foliage	3.7	4.0	4.1	3.0	4.9
Whole tree incl. foliage	4.6	4.6	4.9	3.2	6.1

Depending on tree species and degree of delimiting, an average of 3 to 5 kg of pure ash is left from a solid cubic metre of fuel chips under Finnish conditions. In actual fact, the total amount of ash residue is even in complete combustion of course higher, since fuelwood collects sand and other inorganic impurities during logging and transport.

According to a Swedish study, the proportion of pure ash is 1.4 % in undelimited tree sections, and 1.9 % in logging slash. However, impurities collected during harvesting double the total amount of ash residue. When fuel wood is chipped, most of the sand accumulates in the fine fractions (Table 3).

Table 3. Ash content of chips made of various biomass sources in Sweden (Stridsberg 1983).

Source of chips	Fraction of chips		Average
	Under 12 mm	Over 12 mm	
	Total ash content, % of dry matter		
Stem wood	2.0	0.6	0.9
Bark	8.8	2.8	4.4
Tree sections	4.6	1.8	3.0
Logging slash	8.6	1.9	4.6

In northern Europe, fuel wood is generally hauled to the roadside by load-carrying farm or forest tractors. In North America and other countries where off-road haulage on skidders is the norm, the amount of impurities is undoubtedly higher.

Impurities are most abundant in bark residues of the forest industry. If, however, debarking is done in a wetdrum, most of the grit is removed with the washings. The following figures from a large pulp mill in eastern Finland may be cited as examples of the ash content of drum debarking residue: ash residues in Scots pine bark 3.2 to 3.6 %, and Norway spruce bark 3.0 to 3.5 % (Alestalo 1983).

Ash content is relatively low and constant in forest biomass compared with other solid fuels. It is 7 to 15 % in coal, 2 to 8 % in fuel peat, 3 to 10 % in straw, and 2 to 13 % in reed. In fuel oil, however, ash consists only 0.01 to 0.10 % of the total weight (Miljöeffekter ... 1983).

## 3. COMPOSITION OF PURE ASH

Mineral matter in ash is in the form of oxides. Proportional amounts of different elements vary, depending on soil fertility and tree species in particular. Table 4, based on a Russian study, shows the most common elements in pure ash from bark-free hardwood. In this case the calcium-content was exceptionally high.

Table 4. The primary mineral elements in pure ash of bark-free beech, birch and oak wood in the Soviet Union (Naidenow, Koperin and Purim 1982).

Element	Beech	Birch	Oak
Proportion in pure ash, %			
Ca	40.3	41.2	51.8
K	13.6	9.5	8.1
Mg	6.6	4.6	2.4
Na	2.7	5.7	2.9
P	2.4	3.4	2.5
Si	2.6	1.8	1.0
S	0.7	1.5	0.8

With the exception of natrium and silicon, hardly of fertilizing value in either field or forest, the nutrients in Table 4 are of major importance to vegetation. In addition, ash contains small amounts of trace elements, which are also necessary for the well-being of trees. Table 5 shows the proportion of nutrients in the pure ash of the various components of small-sized trees and the bark of saw logs in southern Finland.

Table 5. Proportion of certain elements in pure ash from different components of newly-felled small-sized trees and bark of saw timber trees in southern Finland (Hakkila and Kalaja 1983).

Tree part	Element									
	P	K	Ca	Mg	Mn	Fe	Zn	S	B	Cu
-----										
Proportion in pure ash, %										
SMALL-SIZED TREES										
BIRCH:										
Stem wood	4.6	17.6	19.5	4.4	1.2	0.6	0.5	2.0	0.05	0.04
Stem bark	3.0	10.4	27.9	2.3	0.8	0.6	0.8	0.8	0.06	0.02
Branches	3.3	10.1	26.4	3.3	1.0	0.4	0.5	1.3	0.04	0.02
Leaves	4.6	15.0	22.4	4.4	3.0	0.3	0.6	1.6	0.06	0.01
Whole tree	4.1	15.1	21.9	3.9	1.0	0.6	0.5	1.6	0.05	0.04
ALDER:										
Stem wood	6.0	20.4	17.5	3.1	0.7	0.6	0.3	2.4	0.05	0.06
Stem bark	4.6	13.8	28.5	2.1	0.7	0.3	0.2	1.6	0.07	0.02
Branches	4.8	14.4	26.5	2.9	0.9	0.4	0.3	1.9	0.05	0.04
Leaves	3.8	19.9	19.1	3.4	0.9	0.3	0.1	1.5	0.02	0.03
Whole tree	5.5	18.3	20.6	2.9	0.6	0.6	0.3	2.2	0.05	0.05
ASPEN:										
Stem wood	1.9	23.1	20.1	3.4	0.5	0.4	0.3	2.0	0.06	0.03
Stem bark	1.8	12.5	25.0	2.3	0.4	0.8	0.3	1.0	0.04	0.09
Branches	2.7	16.7	26.6	2.7	0.4	0.1	0.2	1.0	0.05	0.02
Leaves	2.7	25.8	15.8	2.1	0.6	0.1	0.7	1.9	0.03	0.01
Whole tree	2.1	20.7	21.8	3.1	0.5	0.4	0.2	1.6	0.06	0.04
PINE:										
Stem wood	2.1	11.6	21.4	5.4	2.3	0.8	0.2	3.1	0.05	0.03
Stem bark	2.7	11.2	26.3	3.4	0.8	0.2	0.1	1.3	0.04	0.01
Branches	3.1	14.4	22.2	4.5	1.3	0.7	0.2	1.6	0.05	0.03
Needles	6.1	23.5	10.5	3.3	1.5	0.3	0.2	2.2	0.03	0.02
Whole tree	2.5	12.7	21.7	4.9	1.9	0.7	0.2	2.6	0.05	0.03
SPRUCE:										
Stem wood	2.7	13.1	23.3	3.1	3.4	0.8	0.3	1.4	0.05	0.04
Stem bark	2.9	8.4	30.9	2.2	2.6	0.2	0.4	1.0	0.04	0.02
Branches	2.9	10.0	25.0	2.4	2.3	0.7	0.4	1.2	0.04	0.03
Needles	2.6	8.9	16.5	1.6	2.5	0.2	0.2	1.4	0.02	0.01
Whole tree	2.8	11.3	24.0	2.7	3.0	0.7	0.3	1.3	0.05	0.04
BARK OF SAWTIMBER TREES										
Birch bark	2.4	8.0	29.1	3.0	2.6	0.3	1.2	0.8	0.09	0.02
Pine bark	2.5	8.9	26.9	2.7	0.9	0.7	0.2	1.4	0.04	0.02
Spruce bark	1.5	6.0	32.4	2.2	1.7	0.4	0.4	0.6	0.04	0.01

There are notable differences both between tree species themselves, and between various parts of the tree. The calcium content is especially abundant in bark ash. The content of potassium and phosphorus, on the other hand, is higher in wood ash.

#### 4. COMPOSITION OF POWER PLANT ASH

##### 4]. Impurities in power plant ash

In a furnace, the ash falls under the grate, or travels on air currents as fly ash, which is recovered from the combustion air by various types of ash separation equipment. Dynamic separators recover 50 to 90 %, and electric filters 90 to 99 % of the fly ash. Some of the fly ash penetrates through the separation devices and escapes into the outside air. The type of separator affects the properties of the fly ash, since the finest fractions, transported with combustion gases, are important from the point of view of the composition of the ash residues (Keppo and Ylinen 1980).

The proportions of grate or bottom ash and fly ash are dependent on furnace type. For instance, the proportion of fly ash in dust combustion of milled peat in large power plants is about 90 %, while it may be only about 50 % in grate combustion of small chip-fired heating plants (Hyöty 1975). As a rule, sand accumulates in grate ash.

The ash is removed from the furnace manually, by stoker or scraper conveyors, by flushing with water, or pneumatically. If used for soil improvement, ash should be fairly dry. High temperatures and residual charcoal in unquenched ash, however, result in danger of fire unless conveyors and the ash silo are air tight. Handling dry ash also leads to problems with dust.

For these reasons, ash is often extinguished by spraying the conveyor with water or by pouring the ash into a water tank. Slight dampening (10 to 20 %) binds the dust to some extent but does not make spreading more difficult. Wet sludge ash, on the other hand, is useless for spreading. Nutrients also leach out of wet sludge ash.

Avoidance of ash sludging has not always even been considered when constructing chip and bark boilers, as ash recycling has not been intended. In many plants, however, it would be possible to improve ash quality through minor technical changes, if other premises for rational utilization of ash existed.

Residual charcoal in power plant ash not only results in loss of energy, but also makes utilization of the ash more difficult. Transportation and spreading costs, calculated for pure ash, increase with the rise in the amount of charcoal. Charcoal content may be in excess of 50 %.

Table 6 shows average proportions of soluble pure ash, insoluble sand, and unburnt charcoal in ash from various power plants in Finland. The samples were collected from 11 chip fired, 8 bark fired, and 6 milled peat fired power plants. Naturally, the variations between plants and even within a single plant are wide, depending on fuel purity and combustion effectiveness.

Table 6. Proportion of soluble pure ash, insoluble sand and unburnt charcoal in the ash residues from power plants using indigenous fuels in Finland (Hakkila and Kalaja 1983).

Type of ash	Fuel	Charcoal	Sand	Pure ash	Total
Proportion, %					
Bottom ash	Chips	8	25	67	100
Fly ash	Chips	22	19	59	100
Bottom ash	Bark	17	26	57	100
Fly ash	Bark	32	14	54	100
Bottom ash	Peat	28	62	10	100
Fly ash	Peat	7	56	37	100

The mineral compounds of ash melt when exposed to high temperatures and form slag when cooled. Slag formation lowers the value of ash as a fertilizer and causes handling and spreading problems. The degree to which a fuel will slag appears to be dependent primarily on the amount of minerals present and secondarily on the composition of the mineral matter. Fusion temperature decreases with increasing sand content up to about 40 % SiO<sub>2</sub> (Osman and Goss 1983). Because wood fuels are relatively poor in silicone, however, slag formation seldom hampers the recycling of wood and bark ash. The content of silicone is much higher in straw and peat ash.

If wood and bark ash is to be recycled, excessive contents of heavy metals in the ash residues are unacceptable, especially in horticultural and agricultural use. In Finland, for instance, maximum allowable metal content in wastewater sludge is as follows (Ferola et al. 1980).

Element	Maximum allowable content, mg/kg
Cd	30
Cr	1000
Hg	25
Ni	500
Pb	1200

The content of heavy metals in ash residues varies within a wide range, and the variation may be larger within a fuel type than between various biomass fuels. This is mainly due to differences in combustion and gas cleaning efficiency in power plants. Metals often tend to become vapourized in the combustion process and then condense around small particles in the combustion gases. The more effective the filtration of the gases is, the larger is the proportion of heavy metals left in the fly ash (Miljöeffekter ... 1983).

Generally speaking, ash from pure wood-based fuels is harmless as far as heavy metals are concerned, if for instance 5 tons/ha is used. The heavy metal content rises if coal or oil is used for additional fuel. The heavy metal content of ash from the bark fired power plants of the Finnish forest industry is below the limit set for wastewater sludge, as the following data from pulp mill power plants shows (Alestalo 1983): cadmium 5 to 22, chromium 26 to 760, and lead 30 to 90 mg/kg. Table 7 shows the variations in heavy metal content in Swedish analyses.



Table 7. Content of certain heavy metals in wood and peat ash residues in Swedish tests (Miljöeffekter ... 1983).

Element	Wood fuels		Peat fuels	
	Bottom ash	Fly ash	Bottom ash	Fly ash
	mg/kg			
As	0.2- 3	1- 60	0.5- 10	5 - 80
Cd	0.4- 0.7	6- 40	0.0- 7	0.2- 9
Co	0.0- 7	3- 200	3 - 15	15 - 100
Cr	- 60	40- 250	25 -100	40 - 500
Cu	15 - 300	200	15 - 30	60 - 150
Hg	0.0- 0.4	0- 1	0.0- 0.2	0.3- 5
Mn	2500 -5500	6000-9000	500 -800	700 -15000
Ni	40 - 250	20- 100	15 - 70	40 - 260
Pb	15 - 60	40-1000	5 - 40	50 - 400
Se	.	5- 15	0.5- 1.5	3 - 5
V	10 - 120	20- 30	1.5- 90	200 - 300
Zn	15 -1000	40- 700	6- 50	40 - 700

The composition of wood and bark ash is thus dependent on fuel purity. If ash is to be used for soil improvement purposes, fuel should not include materials like impregnated and painted wood, furniture, waste paper or slash from parks and gardens in larger urban areas (Bramryd 1985).

The possible environmental hazards in connection with ash fertilization have not yet been sufficiently studied. Further studies should therefore be performed on the metal uptake in different crops, accumulation of metals in the soil, and leaching (Miljöeffekter ... 1983).

#### 42. Nutrient content of power plant ash

Nutrient content of power plant ash is much lower than that of pure wood and bark ash, as power plant ash contains considerable amounts of impurities, in addition to which

nutrients may leach out in the process of handling and storing wood and bark.

Floating, water storage, and wet drum debarking of timber results in significant leaching of nutrients, which in turn results in a lowered nutrient content of the bark ash in forest industry power plants. Floated wood has a lesser phosphorus content than unfloated (Helander 1918). The major part of the main nutrients in bark, as well as most trace elements, leached out when bark from pulpwood was stored in water for 5 months (Ranua 1977). The order in which nutrients leach out of unbarked wood is potassium, phosphorus, and nitrogen (Pitkänen 1975). Therefore, the most valuable bark ash is produced by forest industry plants that do not store wood in water.

Table 8 shows that power plant wood and bark ash contains phosphorus and particularly potassium in significantly lesser amounts than pure as from freshly-felled, clean wood or bark. The nutrient content in the fly ash from peat fired power plants is considerably below that of chip and bark fired plants partly due to the high amounts of grit in the fuel. Peat ash, on the other hand, is generally rich in silicon, iron and aluminium.

Table 8. The weight proportions of some primary elements in dry ash residues from chip, bark and peat fired power plants (Hakkila and Kalaja 1983).

Fuel	Treatment of ash	P	K	Ca	Mg
-----					
Proportion, %					
Chips	Untreated	1.7	5.3	17.2	2.7
"	Charcoal removed	2.1	6.6	21.2	3.3
"	Sand and charc. rem.	2.7	8.6	27.7	4.3
Bark	Untreated	1.1	3.7	19.6	1.7
"	Charcoal removed	1.5	5.1	27.3	2.4
"	Sand and charc. rem.	1.9	6.9	36.3	3.1
Peat	Untreated	1.1	0.2	6.2	1.0
"	Charcoal removed	1.2	0.2	6.6	1.1
"	Sand and charc. rem.	3.2	0.5	16.7	2.6

For the above reasons, the amounts of trace elements are also less in power plant ash than in pure ash. This is shown by the following figures, which are based on samples collected from six bark fired power plants in Finland (Alestalo 1983).

Element	Content in ash residues from bark-fired power plants		
Ca	134	-288	g/kg
K	16	- 66	"
Mg	14	- 34	"
Mn	8	- 31	"
Fe	11	- 22	"
P	4	- 16	"
Zn	0.3-	6	"
Cu	102	-780	mg/kg
B	67	-358	"
Co	27	- 88	"
V	20	-470	"

Severe leaching of nutrients occurs if power plant ash is cooled with excessive water. As an example, analyses from the largest straw fired heat plant in Denmark show that potassium leaks with percolating water from the ash (Høgsberg and Bisgaard 1985).

In a Danish study, consisting of 47 ash samples from straw fired power plants, a ton of straw produced 30 - 40 kg of ash. The variation in nutrient content between samples was wide, partly due to varying proportions of charcoal. Compared with wood and bark ash, the calcium content was low but that of potassium relatively high (table 9).

Table 9. The weight proportions of some primary elements in dry ash from straw fired power plants in Denmark (Kjellerup 1983).

Element	Barley straw	Wheat straw	Rape straw
	Proportion, %		
N	0.1	0.2	0.1
P	1.4	1.0	1.5
K	15.3	9.2	14.2
Ca	7.6	2.0	17.8
Mg	1.1	0.6	0.9
Na	1.4	0.2	1.8

In a recent Swedish study the contents of phosphorus, potassium and calcium were analyzed from a large number of samples (table 10). The variation was large and erratic. On an average, wood ash was rich in calcium and straw ash in potassium. As expected, peat ash had generally less nutrients compared with wood and peat ash.

Table 10. Contents of phosphorus, potassium and calcium in ash from wood, peat and straw fired power plants in Sweden. Range and (median) values (Scandiaconsult 1985).

Fuel	P	K	Ca
	Proportion, %		
Wood	0.5-3 (1.2)	1.0-12 (5)	9 -60 (30)
Peat	0.1-3 (0.7)	0.1- 9 (1)	0.5-35 (10)
Straw	0.1-3 (1.0)	0.7-30 (15)	3 -23 (6)

## 5. POWER PLANT ASH AS A SOIL IMPROVEMENT AGENT

### 51. Suitability of ash in agriculture

The forest industry is the foremost wood and bark ash producer. Should it so wish, the industry could thus keep the ash for use in its own or its wood suppliers' forests, from whence it originally came. However, for technical and economic reasons spreading is easier to carry out in agriculture, where the need for soil neutralization and trace elements is also better known.

Ash affects soil both as a main and trace element nutrient, and a neutralization or liming agent. Like manure, ash contains a rich variety of trace elements, where nutrients are present almost in natural proportions. It is an unparalleled functional whole, beneficial not only for vegetation but also for animals and humans using the vegetation for food (Jalkanen 1982). In fact, compared with Finnish cereals or timothy, logging slash and bark are richer in many trace elements, such as iron, manganese, zink, cobalt, chromium, selenium, fluorine, molybdenum, cadmium and boron (Alestalo et al. 1980).

In industrialized countries, air pollution causes acidification of the soil. Liming is used in some cases to prevent acidification. In southern Finland, for instance, 90 kg/ha/a of limestone would be needed to compensate oxides of sulphur and nitrogen. Wood and bark ash are also excellent liming agents, particularly since they contain a

sufficient portion of magnesium in addition to calcium. The important Ca/Mg -relationship is a satisfactory 4.5 to 8.5 in small-sized tree ash, while the proportion in bark ash is slightly too high at 10 to 15.

The fly ash of sulphite waste liquor is also a suitable substitute for limestone as a liming agent. No harmful amounts of any element are transferred into the soil, if less than 10 t/ha of ash is spread into a field (Simojoki 1976). The liming effect of peat ash is considerably lower, due to its lesser calcium content.

The calcium content of limestone powder is roughly 35 %. For liming purposes it is generally used at a rate of 5 t/ha. If ash is used instead of lime, the amount applied depends on its calcium and magnesium content. According to laboratory tests of the Finnish Agricultural Research Center, the proportional liming effect of various kinds of ash, calculated chemically and by the rise in the pH value of the soil, was as follows (Saarela 1982):

Liming agent	Proportional liming effect	
	Chemically	By pH value
Limestone powder	100	100
Wood ash	115	106
Bark ash	64	57
Peat ash	13	12
Straw ash	32	..
Coal ash	14	12

Bark ash has been found to significantly improve trefoil growth, particularly on soil poor in trace elements and suffering from acidity (Huokuna 1978). It is also known that ash is very suitable for many vegetables and ornamental

plants, as well as berry bushes and fruit trees. However, potatoes and other plants that prefer acid soil are an exception.

Ash originating largely from fossil fuels should naturally be avoided in agriculture and particularly in gardens, due to the danger of a high heavy metals content. In a Polish green house experiment, high contents of coal ash (5,10 and 15 % of the soil weight in pots) significantly decreased the fresh yield of maize and oats (Nowac and Ciećko 1983).

The traditional practice of coating water yam setts with wood ash before planting was studied in a Nigerian experiment. Wood ash was effective in terms of tuber yield but only slightly so in reducing plant parasitic nematodes. A much better result was achieved with manure (Adesiyan and Adeniji 1976). On the other hand, a widely applied control measure in Nigeria is the spreading of wood ash on stored yams to protect them against termite attacks (Malaka 1972). Another African study in Malawi on protection of stored maize against insect damage found the local habit of admixing ashes from the kitchen fire with grains as effective as a conventional synthetic insecticide. An appropriate ash concentration was 30 % (Golob et al. 1982).

## 52. Suitability of ash in forestry

Utilization of ash in forestry has primarily been studied in the Nordic countries. All of the old experiments were made on peat lands. The early tests were narrow, nor were the properties of the ash used always analyzed. There are no published research results from mineral soils.

The oldest experiments were on a drained open swamp in Hällmyren, Sweden. Ash fertilization of 3.3 tons/ha, carried out in 1918, notably improved birch growth. By 1949, average height of the trees was 3.7 m on an unfertilized plot as against 11.3 m on a fertilized one. By this time, however, the effect of the fertilization had abated considerably. In 1926, another ash fertilization test of 12.5 tons/ha was made. By 1949 height of birch was on an unfertilized plot still under 1 m but on the fertilized plot 11.2 m and growth was still good (Malmström 1952).

An ash fertilization test on very nutrient-poor land was carried out in Åsmyra in southern Norway in the spring of 1944. An older, slowly growing pine stand was removed before fertilization, leaving an ample stock of natural plant growth in the test areas. The effect of ash fertilization became very clear when the length of the pines was measured in the autumn of 1955. Wood ash containing significantly larger amounts of potassium and phosphorus resulted in greater growth than peat ash (Thurmann-Moe 1956):



Ash type	Application, tons/ha	Height of pine trees, m	Ratio %
	0	2.2	100
Peat ash	4	3.2	141
"	7	3.5	156
"	10	3.5	155
Wood ash	4	3.7	166
"	7	3.9	173
"	10	4.3	191

The Finnish Forest Research Institute has carried out several experiments on ash fertilization since 1937. The best known and most successful ash fertilization test field is located in Leppiniemi at Muhos. A nitrogen-rich bog was drained in 1932, planted with pines in 1934 and fertilized with birch ash in 1947. By 1980 the total yield was as follows (Tuhka metsänlannoitteena 1980):

Birch ash tons/ha	Total yield of pine wood, m <sup>3</sup> /ha
0	13
8	252
16	306

The old Finnish experiments on wood ash fertilization on drained peatlands were recently analyzed by Silfverberg and Huikari (1985). The material consisted of 55 ash-fertilized and 24 comparison plots of Scots pine and birch in different parts of Finland. Most of the 25 - 46 year old experiments were situated on rather poor, originally treeless, bogs. The amount of ash applied varied from 1 to 16 tons/ha.

The growth reaction of Scots pine on these relatively poor and open bogs was generally strong. In many cases the

increase in annual growth was  $4 \text{ m}^3/\text{ha}$ , and in one case as much as  $8 \text{ m}^3/\text{ha}$ . In the best stands, with nitrogen content of peat up to 2.5 %, the growth was as fast as in the fertile Oxalis-Myrtillus site type forests in southern Finland. On the other hand, the growth was slow on nitrogen-poor sites where the total nitrogen content in the 20 cm surface layer of peat was only 1,0 %.

Compared with artificial fertilizers, the effect of ash fertilization on nitrogen-rich drained peat lands is more permanent. The following observations have been made (Reinikainen 1980):

- Surface vegetation changes more permanently
- Peat decomposes more quickly and deeper
- Tree growth is less subject to disturbances, no symptoms of deficiencies can be seen
- Growth improvement is of considerably longer duration.

In wood and peat ash potassium is in the form of carbonate ( $\text{K}_2\text{O}_3$ ) while it is as chloride ( $\text{KCl}$ ) or sulphate ( $\text{K}_2\text{SO}_4$ ) in commercial fertilizers. Carbonates give a higher pH value in the soil than chlorides and the leaching of potassium occurs more slowly (Haveraaen and Steenberg, 1967, Haveraaen 1978). In a Norwegian lysimeter experiment, leaching out of phosphorus was reduced when bark ash was also applied in addition to commercial fertilizers (Haveraaen 1981).

Some of the nutrients found in ash are directly utilized by trees. Some, on the other hand, will make microbe activity more vigorous. Ash fertilization in Vilppula, for instance, greatly increased the amounts of molds, yeasts, and bacteria in the surface peat (Huikari 1953). At Muhos, the total amount of bacteria in the top layer of peat rose by a factor of 300 as a result of ash fertilization, and the effect of the ash went to a depth of at least 25 to 30 cm (Karsisto and Leppänen 1980). As a result of activated microbe life, organic nitrogen reserves, not normally available for trees, are mobilized in a usable form. Nitrogen-rich peat containing 1.5 to 2.5 % of pure nitrogen by weight becomes excellent growing ground after ash fertilization.

Trees on drained peatlands are sometimes subject to growth disturbances resulting in short, tapering, crooked, and branched stems. Growth disturbances occur particularly in repeatedly fertilized pine stands. However, disturbances have also been observed on unfertilized land, notably in fertile areas. Lack of boron has been diagnosed as the most common reason for growth disturbances, and traces of copper deficiencies have also been noted (Veijalainen 1980). Peatland forests fertilized by ash generally show no growth disturbances, and ash corrects such disturbances in a short time (Veijalainen 1980). Some trace elements of ash, like boron, are slowly soluble (Silfverberg 1982) and consequently the effect of ash treatment lasts long.

Needle analysis in Silfverberg's and Huikari's (1985) study, however, revealed that a deficiency of phosphorus and potassium may appear in old ash-fertilized stands. No deficiency of boron and other trace elements was recorded. Because availability of phosphorus is thus commonly a limiting growth factor, the amount of wood and bark ash applied per hectare should be determined accordingly, depending on its content of phosphorus. It was also found that large doses of ash not only raised the pH of the surface peat but also converted the vegetation into a more easily decomposing herb- and grassrich type.

If ash is primarily used for phosphorus and potassium fertilization, the amount to be spread is determined primarily by the phosphorus content rather than the potassium content, since the former is lower compared with the needs of the trees. Presently, the recommended amount of phosphorus in fertilizer for peatland forests is 45 to 50 kg per hectare. That means 5 t/ha of ash, if, for instance, its phosphorus content is 1 %. If the content is 2 %, obviously 2.5 t/ha is sufficient.

Paavilainen (1980), Merisaari (1981), and Silfverberg and Huikari (1985) concluded that the effect of ash fertilization on peatlands lasts for 30 to 40 years, while that of artificial fertilizers only lasts for 15 to 20 years.

The report of Silfverberg and Huikari (1985) indicates that wood ash is superior to commercial fertilizers as

regards growth increment in peatland forests. As a result of these encouraging experiences, the Finnish Forest Research Institute has started almost 200 new ash fertilization experiments since the middle of 1970's.

Where ash is available it might also be used to fight acidification of forest soil. Ash in quantities exceeding 10 t/ha has lowered the acidity of surface peat by 1 to 2 pH units for up to 30 to 40 years. The Swedish Environmental Protection Board has recently started a research program on different types of ashes as a liming agent in acidified forests and in damaged spruce and pine stands, but no results have been published yet (Bramryd 1985b).

## 6. CONSTRAINTS IN RECYCLING OF ASH

Tests carried out in many countries have shown that wood and bark ash often promote growth and health of vegetation. The value of ash is commonly acknowledged, and there is much interest in its utilization. In practice, however, many problems concerning ash quality, handling equipment, and spreading technique prevent utilization. Bar a few exceptions, wood and bark ash is still dumped.

The irregular variations in composition render pricing and marketing of ash difficult. In some countries, official permits are needed for marketing and spreading. In Maine, USA, the Board of Environmental Protection requires a site specific review of each area proposed for land application

of "bioash" from a large chip- and bark-fired power plant where 10 % of the fuel consists of coal. The review is similar to that undertaken for municipal sludge application on Maine farm lands. The free evaluation shows the suitability of the site for ash application (Resource Conservation ...).

Ash spreading sends dust whirling into the air, which in turn creates problems. Dust and heavy metal particles that are inhaled or come into contact with skin may be a health hazard, thus preventing manual ash spreading to any practical extent. Mechanized spreading may sensitize the driver if the ash is too dry and if the cabin is not properly insulated. Ash particles in the spreading machinery may result in premature wear and corrosion.

Hot ash is difficult to handle, and constitutes a fire hazard when spread into the forest. To avoid dangers of dust and fire, power plant ash is often water-cooled. To bring down transportation costs and to prevent clumping and freezing, water should be used sparingly. A 10 to 15 % moisture content is enough to prevent dust from escaping into the air during handling (Takalo 1980). Dropping ash directly from a furnace into water is still, however, relatively common. It is hardly technically possible to spread ash in the form of sludge.

Large power plants produce ash year round. A system for ash recycling should, therefore, be practicable at all times of the year. This results in technical problems

particularly where ash spreading onto peatlands is desired, since bogs are accessible by machinery during part of the year only. Ash storage in the power plant area results in hygienic problems and added costs. A reasonable buffer store would, however, facilitate organization of transport and spreading.

As with other fine grained fertilizers, even spreading of ash is difficult. On the other hand, forest fertilization tests at least have shown that the danger for overdosing with ash is slight.

Some of the problems with recycling could be avoided by ash pelleting. Pelleting would bring down the moisture content to an economical level, make storage easier, alleviate problems with dust, make the spreading result more uniform, and reduce clogging of the spreading machinery. Ash pelleting with various bonding agents has been studied in Finland by Kemira Oy (Hörkkö 1975), The Finnish Forest Research Institute (Takalo 1980), the State Technical Research Centre, and A. Ahlström Oy. Pelleting is, however, technically difficult and results in such heavy investment costs as to be economically unfeasible at this time.

Development work is therefore required before wide-spread ash utilization is practicable. In addition to research projects, pilot-scale activity is needed, opening up methods testing and demonstration opportunities for machine constructors.

## 7. SPREADING TECHNIQUES

### 71. Considerations of health

Juntunen (1982 and 1983) at the Finnish Forest Research Institute has studied ash spreading from an occupational health point of view. Ash spreading is a health hazard for the employee, necessitating safety measures. Small particles floating in the air may get into the respiratory system and from there into other organs. Impurities on the skin cause irritation and may even penetrate through the skin.

The principal component in peat and coal ash is silicate ( $\text{SiO}_2$ ). In quartz form it causes silicosis or gritty dust lung disease. The major component of wood and bark ash, on the other hand, is calcium oxide ( $\text{CaO}_2$ ), whose high alkalinity causes irritation of the skin, mucous membranes and respiratory passages. The effect may be aggravated by particles of metal mechanically rubbing the sensitized skin.

Some of the heavy metals that may be present in the ash, such as quicksilver, cadmium, and lead, result in symptoms of poisoning, at least in the long run. Chromium, nickel, and cobalt in their turn result in skin allergies. Wood ash contains these harmful trace elements in considerably lesser quantities than ash from fossile fuels.



Most of the harmful trace elements are found in the finest fractions of the ash. Since the finest ash floats the longest in the air, heavy metals may be a greater health hazard to an employee than the average measured metal content by itself would indicate.

A limit has been set on the maximum content allowable in the air of a place of work. This is also called the "hazardous content". Most people are able to work full time under conditions not exceeding the limit without endangering their health. Sensitive individuals may, however, fall ill after exposure to even lesser amounts. The National Board of Labour Protection in Finland has set maximum limits for some substances, as follows:

	Hazardous content mg/m <sup>3</sup>
Inorganic dust, with slight physiological effect	10.2
Cobalt	0.1
Chromium	0.5
Nickel	0.1
Lead	0.1
Finely fractured quartz	0.2

Juntunen (1982 and 1983) studied employee subjection to ash dust in three tests. Dust samples were collected with a membrane filter from the employees' respiratory area, and as a control measure from outside the machine's cabin.

As a first test, dry ash (moisture content 2 %) was spread. Transportation was by snowmobile and spreading manually with a spade. The dust content of the air around the spreader was 15 to 66 mg/m<sup>3</sup>, depending on winds and

other factors. While the sledge was being loaded, the dust content was even higher. The hazardous limit for inorganic dust with a slight physiological effect was exceeded by such a clear margin, that for reasons of health alone, the spreading of dry ash is impossible by this method at least to any practical extent. The hazardous effect of dust may, naturally, be alleviated by moistening the dust or by pelletizing. However, it is doubtful whether the problem will be entirely avoided even by these measures.

In another test, peat ash (moisture content 10 %) was spread using a prototype centrifugal spreader, fitted onto an old forwarder. The cabin had not been especially insulated against dust. The dust content of the cabin air within the respiratory area of the driver was  $36 \text{ mg/m}^3$  on average, or nearly four times the allowable. Measurements, as well as the symptoms two drivers exhibited, showed that the cabin of an old tractor does not give adequate protection against ash dust without special measures.

The third test consisted of spreading moist bark ash (moisture content 40 %) using equipment fitted onto a terrain truck. The cabin was insulated and pressurized, and all intake air was filtered. The dust content of the air outside the cabin rose to a fairly high level during spreading and particularly during loading. Inside the cabin, within the respiratory area of the driver the air was, however, reasonably low at only  $2 \text{ mg/m}^3$ , i.e. well under the acceptable limit.

The series of tests thus showed that the driver of a spreader is subject to a serious dust hazard in a poorly insulated cabin, but that with certain measures a cabin may be protected against ash dust. It is essential that the cabin is tight and pressurized, and that incoming air is closely filtered. The filter must be changed often enough, and the cabin must be kept neat and clean. The problem of dust may be minimized by adding to the moisture content of the ash. Personal respiratory protectors will not be needed under those conditions. It may, however, be necessary to use them during service and maintenance work.

## 72. Technical solutions

Artificial fertilizer is spread into forests in fairly small amounts of per hectare, making aerial spreading a viable alternative. Ash is used in amounts of 10 or 20 times those of artificial fertilizers per acreage. The labor costs of aerial spreading, roughly US50 per ton in Finland, are therefore prohibitively high for ash. Consequently, ash must be spread from the ground.

The simplest solution is manual spreading. Since it is not economically feasible to sack up ash, transporting it into the forest for manual spreading is difficult. Spreading itself is expensive, and health hazards are not inconsiderable. Therefore, manual spreading can be considered only under exceptional circumstances, as when establishing small-scale test plots for yield studies.

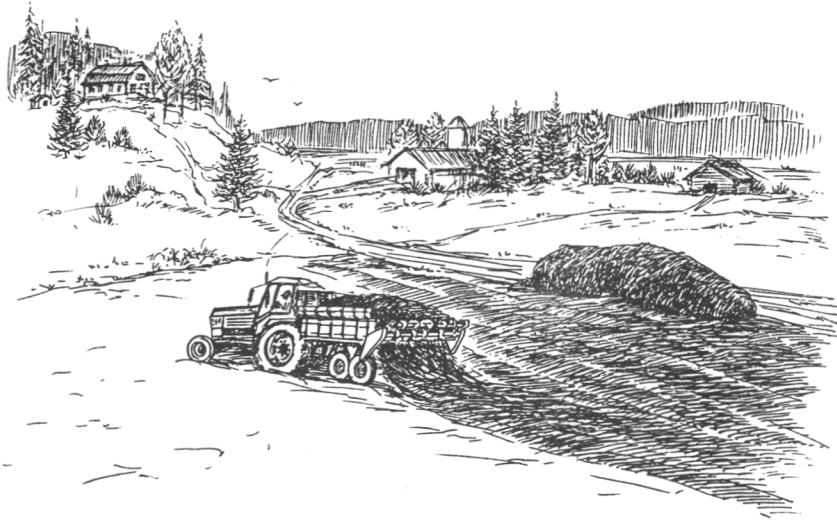


Fig. 1. Conventional manure spreading equipment is a feasible alternative for small farm operations.

Tractor-based spreading equipment seems to be the only feasible alternative for large operations under most conditions.

In agriculture, the work can be done with a machine that drops the ash straight behind, making the width of the spreading swath of little significance. Smaller amounts can be spread with the farm's own conventional manure or lime spreading equipment. In larger farm operations, contractor-owned lime spreading equipment with only minor modifications is generally a more feasible alternative. Loading of ash from storage piles to a tractor-driven spreader can be performed with a front loader or a boom loader with the timber grapple replaced by an ash scoop.

In the forest, the ash spreading machine must be better fitted for the terrain than on a field. Forest improvement must be done without damage to trees, which places specific requirements on the size and maneuverability of the machinery. In addition, the distances from the landing sites to the spreading areas are, on average, greater than in fields.

Furthermore, in the forest ash must be spread from strip roads used for thinning, making it imperative that the ash is spread evenly to a distance of 12 to 15 cm on either side of the machine. As the trees, particularly in spruce stands, further hamper spreading, the demands on the effectiveness of the machine are even more critical in forests.

In these conditions, ash spreading is more practically done with tractor-mounted equipment, making it easier to protect the driver from the dangers of dust. The most natural prime mover is a forwarder. There are at least three tractor-mounted prototype spreaders in Finland.

The first prototype was installed on a Rockums forwarder. Its 10 m<sup>3</sup> ash bin was filled with the forwarder's own loader, whose timber grapple had been replaced by an ash scoop with fixed sides. A screw transporter located on the bottom of the bin transferred the ash to two vertically moving slings that spread the ash onto

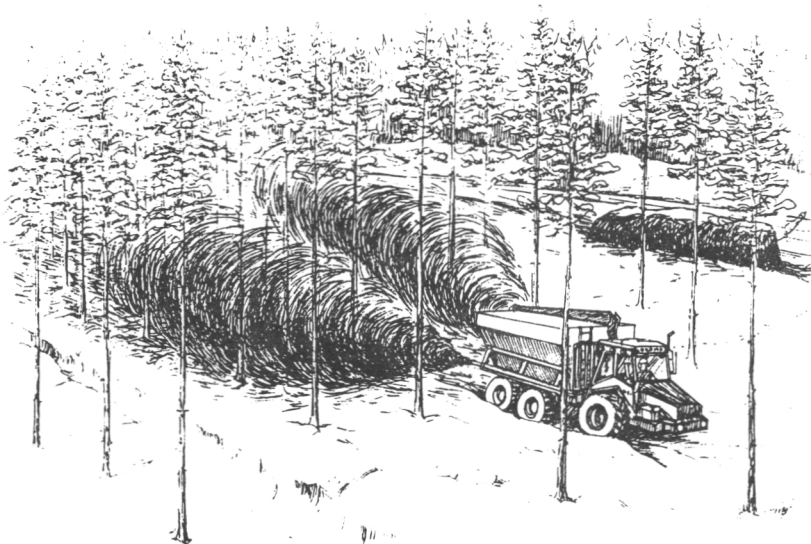


Fig. 2. Forwarder-mounted special equipment is an effective and reliable solution for spreading ash in forests.

both sides of the strip road. In pilot tests, the same wages were paid for spreading a cubic metre of ash as for hauling a solid cubic metre of birch pulpwood to the road side from the same distance.

The second prototype was mounted on a Volvo forwarder. The main difference compared with the first prototype is that the ash is transferred from the bin to the sling using a scraper conveyor. In the winter of 1985 the output per effective hour of the machine was  $22 \text{ m}^3$ , when the forest haulage distance was 300 m. The distribution of effective working time was as follows: loading 43 %, driving loaded 18 %, spreading 23 %, and driving empty 16 %.

The third prototype was installed on a Lokomo 909 forwarder equipped with front and rear tracks. The 12 m<sup>3</sup> ash bin is equipped with a vibrator, and in winter its sides can be heated with exhaust gas to prevent freezing. The ash is transferred by a belt conveyor to slings located at the back. To avoid ash bridging, two horizontal augers rotate above the belt conveyor. The same equipment has also been temporarily installed onto a Meri-Trackmo special peatland tractor equipped with rubber tracks, in order to spread ash onto swamps in summer.

In addition to tractor-mounted equipment, simpler solutions such as placing the spreading equipment on a separate sledge have been tried. A crawler tractor or a conventional farm tractor was used for towing the sledge.

In all the above methods, ash is brought to the site with trucks, using for instance a fuel chip truck. The ash is tipped onto the ground and transferred later into the tractor's bin.

When ash is used in agriculture, trucks can unload directly onto a level field, making it easy to recover it practically all. In the forest the storage areas are often uneven and rocky, resulting in a great deal of ash loss. Ash remaining in the landing area may cause hygienic problems. Stones may also be picked up along with the ash, which again may result in breakage of the transporters and slings of the spreader.



Fig. 3. Terrain truck-mounted equipment can be used for highway transportation as well as for spreading on farm lands and in easily accessible forests. An ash trailer is an essential part of the unit to minimize the costs.

Another alternative is a terrain truck-mounted system which takes care of both highway transportation and spreading. The Algol-Unimog prototype unit was a combination of a Mercedes-Benz Unimog U 1700 L terrain truck as a prime mover, a Silva 5000 ash spreader, and a Multilift HL-C lifting device. With this unit ash was returned from plant to nature using one machine only during the entire work schedule. The system promotes flexible working conditions. Also, no storage at the upper landing is needed. The prime mover, however, does not match up to the performance of a forwarder in difficult forest terrain. Thus the use of this basic machine seems feasible on farm land and in easily accessible forests only.



The prototype is no longer in use, but it offers a starting point for further system development where highway haulage distances are not long and the terrain is easy. It anticipates, however, the use of an additional ash trailer, which should be as big as legally permissible to minimize highway transportation costs. To facilitate the transfer of ash from the trailer to the spreader, the unit has to be equipped with a loading mechanism to avoid health hazards or storage losses.

In New Zealand, a sawmill disposes the fly ash from wood residues and bark by spray irrigation onto pasture land. No scientific studies have been carried out, but the nutrients from ash are considered beneficial to pasture, and the behaviour of stock in the area just irrigated indicates no loss of palatability (Shula 1985).

## 8. CONCLUSIONS AND RECOMMENDATIONS

If the use of ash is to become a permanent practice, an unprejudiced attitude is required on the part of both those producing ash and the potential users. Fortunately, many producer plants, towns, farmers, and forest owners are already showing much interest in the topic of ash recycling. To solve the problems of utilization in an economical way the ash producers should pay attention to the following points:

- Wood and bark ash should be kept separate from fossil fuel ash.
- Wood and bark must be burnt as completely as possible. The charcoal content can be reduced by careful adjustments of the combustion process.
- Cooling of ash and reduction of whirling must be done at the power plant with as little water as possible. When the moisture content exceeds 30 %, applications of ash will be hampered, especially in winter conditions.
- Storage at the plant must be well-arranged to allow easy loading and to avoid a serious dust hazard. The storage capacity should be sufficient for a flexible delivery system.
- In the long run the technology of granulation should be developed.

Ash as a soil improvement agent and a fertilizer is most useful on agricultural lands suffering from acidity and lack of trace elements. Ash is comparable to limestone powder as a neutralizing agent on fields, and spreading is easier and more economical than in forests. The need for additional liming as a result of acid rains is many times that of available amounts of ash.

In forestry, it is most advantageous to spread ash onto nitrogen-rich peatlands. Especially Canada, Finland, Ireland, Norway, and Sweden are countries within the IEA forest energy cooperation where peatland forests are rather common.

Work schedules reported in this review promise a sensible alternative to future development of machinery and methods. In agriculture, methods used for lime and manure spreading may be used as starting points. In forestry, more development of machinery and methods is necessary. The conventional forwarder seems to be the best prime mover.

The problem of recycling ash must be solved in a way that is satisfactory technically and economically, as well as from the health point of view. Development of equipment and methods must continue, in order that functional reliability demanded by year-round practical application may be achieved. At the same time, it is necessary to conduct further experiments to determine the suitability of ash for different applications in both agriculture and forestry. Possible environmental and health hazards in connection with the dumping and/or recycling of wood and bark ash must be carefully examined.

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Helsinki 1986. Valtion painatuskeskus

ISBN 951-40-0897-9  
ISSN 0358-4283