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Eero Kubin

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SELOSTE:

PALJAAKSIHAKKUUN VAIKUTUS KUUSIMETSÄN RAVINNE-TILAAN POHJOIS-SUOMESSA (64° 28' N)

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PREFACE

This report concerns research carried out jointly by the Forest Research Institute research station at Pyhäkoski and Kajaani Oy in conjunction with the Department of Botany at the University of Oulu. In view of the poor results obtained from forest planting in parts of Northern Finland, the Forest Research Institute has undertaken an extensive project aimed at examining the environment into which the seedlings are planted, laying principal emphasis upon the study of the effects achieved by the use of various forest improvement methods. The experimental forest at Kivesvaara, near Paltamo, is used for the study of both the physical properties of the soil and also its nutrient content. As part of the latter topic, the amounts of nutrient present in the wood harvested and in the logging residues before any further treatment of the land were determined. The source material for the figures and tables presented here is to be found in the author's Licenciate thesis lodged at the Department of Botany, University of Oulu.

This research into the effect of cutting on nutrient status was undertaken on the initiative of Dr. Heikki Haapala in spring 1974. The assistance of LuK Ritva Hiltunen was obtained in the measurement of the dry weight of the bole wood and the bark percentages, while Mr. Aaro Kubin helped in the organisation of the material and LuK Martti Löytynoja was responsible for the computer processing of the data. The mineral analyses were carried out at Kajaani Oy under the direction of FM Timo Kopperoinen, and the bole wood volumes were similarly measured by this company. The measurement of the volumes of waste wood and the nutrient analyses were performed by the author himself. Advice on a number of difficult problems was received from MMM Jukka Valtanen. The manuscript was typed by Miss Raija Seppä and translated into English by Mr. Malcolm Hicks. Financial assistance is acknowledged from the Society of Forestry in Finland.

The manuscript has been read through at various stages by Prof. Paavo Havas and Assoc. Prof. Seppo Eurola, of the Department of Botany, University of Oulu, and by Prof. Matti Leikola of the Forest Research Institute, all of whom have contributed large numbers of valuable comments. To all the persons and institutions mentioned above I offer my sincerest thanks, and also to my wife Irmeli Kubin, who has assisted and supported me throughout this work.

Oulu, March 1976

EERO KUBIN

CONTENTS

1. INTRODUCTION

Clear cutting is an operation which has far-reaching consequences for the biology of a forest, for it involves the removal from the area of a considerable proportion of the phytomass and nutrients accounted for by the trees, while some of the nutrients remaining may be subject to rapid mobilization. Run-off from the area increases markedly in the years following the cutting, carrying with it large amounts of soluble nitrogen compounds etc., depending on the type of forest (Borman et al, 1968, Likens et al. 1969 b, Borman and Likens 1969, Tamm et al. 1974, Wiklander 1974), and this leaching affects the stimulatory action of a number of micro-organisms, in particular the nitrification bacteria *Nitrosomonas* and *Nitrobacter* (Likens et al. 1969 a). The changes in litter composition and the rapid extraction of certain nutrients (Viro 1955, Mikola 1955, Nykvist 1959) and also the action of various decomposing and disintegrating agents (Mikola 1957, 1960) obviously serve to promote this overall leaching effect. The nutrients released by decomposition and bacterial action serve to promote seedling growth, so that when whole-tree harvesting is employed less nutrients remain behind, and this obviously leads to a reduction in the growth potential of the seedlings and also in the mobilization of the nutrients.

Approx. 50 mil. m³ (solid measure) of bole wood, including bark, are harvested from the forests of Finland every year, of which spruce accounts for approx. 20 mil. m³ with bark (Metsätilastollinen ... 1973). This annual harvest represents 20 mil. tons of wood (dry weight), a further 13–14 mil. tons (dry weight) being left *in situ* in the form of waste wood, bark and needles, this latter being composed of approx. 15 % bole wood with bark, 55 % branches with bark and needles, and 30 % stumps with bark (Hakkila 1972 b, 1974 b, Hakkila et al. 1975). A large amount of research has gone into the possibility of harvesting this waste material in Finland (Mäkinen 1965, Hakkila 1972 a, 1972 b, 1973, 1974 a, 1975 b, Hakkila and Mäkelä 1973, Hakkila et al. 1975, Mäkelä 1975).

Tamm (1969) has shown that heavy thinning of the forest on soils poor in nutrients may lead to a nutrient loss requiring compensation by fertilization, while with the increasing practice of whole-tree harvesting and the exploitation of logging residues many studies have drawn attention to the nutrient loss involved (Nykvist 1971, 1974, Weetman and Webber 1971, Mälkönen 1972, 1973, 1974 a). The consequences of the harvesting of logging residues have also been examined from a number of other points of view in addition to that of the effect on the nutrient reserves of the forest, including the effect upon the germination and early development of seedlings (Leikola 1974 a), upon the difficulty of reforestation (Appelroth 1974), upon destructive animals (Löyttyniemi 1974) and upon the vital conditions of forest-pathogenic and edible mushrooms (Hintikka 1974). The consequences for the multiple use of forests have also been discussed (Kellomäki 1974).

The present work is an extension of previous research into the nutrient ecology of the soil in the Kivesvaara experimental forest (Kubin 1975). The aim is to obtain an impression of the amounts of nutrients remaining in the experimental plots after cutting, and thus to enable a more accurate interpretation to be made of the results of soil nutrient analyses. Although this work is centred upon the Kivesvaara forest, it may also be seen as a contribution to the discussion of the general problems associated with the effects of whole-tree harvesting upon the nutrient status in forests.

2. THE STUDY AREA

In the phytogeographical zonation of Finland, the experimental forest lies within the Ostrobothnia-Kainuu forest zone (see KALELA 1962, KALLIOLA 1973: 181). The

Table 1. Location and relevant characteristics of the forest studied. Climatic data after KOLKKI (1966) and HELIMÄKI (1967), soil properties from KUBIN (1975).

Taulukko 1. Tutkimusmetsän sijainti ja erityispiirteet. Ilmastotiedot KOLKIN *(1966) ja* HELIMÄEN *(1967), maaperän ominaisuudet* KUBINin *(1975) mukaan.*

VARIABLE — *OMINAISUUS*	VALUE — *ARVO*
GEOGRAPHICAL LOCATION — *SIJAINTI*	
Coordinates — *Koordinaatit:*	N 64° 28′ E 27° 33′
Height above sea level:	200—210 m, supra-aquatic
Korkeus merenpinnasta:	*200—210 m, supra-akvaattinen*
CLIMATE — *ILMASTO*	
Mean annual temperature:	Kajaani 1.9° C, Vaala 2.2° C
Vuoden keskilämpötila:	
Growing season:	149 days at Kajaani and Vaala
Kasvukausi:	*Kajaani ja Vaala 149 vrk*
Effective temperature sum:	Kajaani 1033.0 d.d., Vaala 1050.7 d.d.
Tehoisan lämpötilan summa:	
Rainfall — *Sademäärä:*	Kajaani 564 mm, Vaala 525 mm
SOIL PROPERTIES — *MAAPERÄ*	
Raw humus horizon (mor): *Raaka kangashumuskerros:*	6.7 cm
Eluvial horizon (A_1): *Uutemaakerros (A_1):*	13.0 cm
Illuvial horizon (B): *Rikastumiskerros (B):*	23.7 cm
Mineral substrate:	Fine sandy till
Maalaji:	*Hietainen hiekkamoreeni*
FOREST PROPERTIES — *PUUSTO*	
Age — *Ikä:*	137 yrs — 137 v.
Spruce — *Kuusi:*	110.5 solid m³/ha — *110.5 k-m³/ha* (95.4 %)
Pine — *Mänty:*	4.5 solid m³/ha — *4.5 k-m³/ha* (3.9 %)
Deciduous pulpwood species:	0.8 solid m³/ha (0.7 %)
Lehtipaperipuu:	*0.8 k-m³/ha* (0.7 %)
Average diameter at stump height: *Kannon keskim. halkaisija:*	20.6 cm (n = 79)
Weighted average for diameter at base of stump: *Kannon pohjap.-alalla punnittu keskiarvo:*	22.1 cm (n = 79)
Depth of root penetration: *Juurten esiintymissyvyys:*	0—70 cm

dominant forest type is VMT *(Vaccinium-Myrtillus)*, but with certain features typical of the Peräpohjola forest zone (Kubin 1975), the ecological charcteristics of whose spruce forests have been studied principally by Siren (1955) and Havas (1971). No corresponding research has been carried out on the Kainuu region. The principal data for the Kivesvaara forest are set out in Table 1.

According to Sauramo (1926), the highest shore-line at Kivesvaara runs at 178 m. The differences in climate between this site and the meteorological stations at Kajaani and Vaala are due to its elevation and open hill conditions. Kajaani lies approx. 15 km south of Kivesvaara and Vaala approx. 40 km west. The mean annual temperature for this forest site is lower than at either of the meteorological stations, the snow cover is deeper and it lasts for longer in the spring. The soil at the site is a well-defined, well developed podsol type with underlying till. The forest is approx. 140 years old, and has a growing stock of 115.8 solid m^3/ha, 95.4 % of which is spruce *(Picea abies)*. A figure has been obtained for the diameter at stump height, based on the average for all stumps in a sample area of 10 ares. Hakkila (1972 a) maintains that the diameter at breast height amounts to 0.75 of that at stump height. This would give an average dbh figure of 17 cm. It is estimated that 75 % of the stumps are more than 15 cm across. The Kivesvaara forest has a volume of growing stock above the average for forests of corresponding age in the Kainuu and Northern Ostrobothnia districts (Tiihonen 1966: 24).

3. RESEARCH MATERIAL AND METHODS

3. 1. Fieldwork

The forest was felled during the winter of 1973–74. Estimates of the quantities of the various components of the logging residues were compiled in the summer of 1975, and at the same time samples were taken for the nutrient analyses. In view

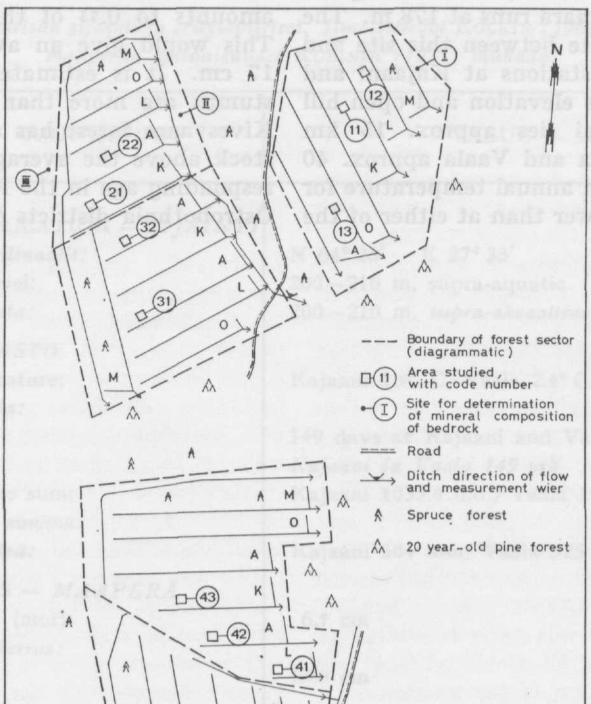

Fig. 1. Location of the plots studied for the determination of logging waste within forest sectors 1–5, and the sites used for the study of the mineral composition of the bedrock. The sectors are divided into strips by ditches, and these strips were treated after cutting according to the following code: M — forested strip, 0 — no treatment after clear cutting, L — scalped strip, A — heavy reforestation plough, K — complete turning of the soil.

Kuva 1. Hakkuujätteen määrittämiseksi tutkittujen näytealojen sijainti lohkoilla 1–5 ja kivilajikoostumuksen tutkimispaikat I–IV. Lohkot ojitettuna koeruutuihin, joiden maankäsittely suoritettiin hakkuujätteen määrän tutkimisen jälkeen. M — metsäruutu, O — paljaaksihakattu käsittelemätön ruutu, L — laikutettu ruutu, A — aurattu ruutu ja K — täysmuokattu ruutu. — — — = metsän raja, □ = tutkittu näyteala, ● = kivilajikoostumuksen näytepiste, ——v——→ = oja, vedenvirtaussuunta ja mittapato, ═══ = tie, ^ = kuusimetsä, ^^ = 20 vuotiasta männikköä.

of the very high proportion of spruce in the forest, attention was concentrated exclusively upon the phytomass and nutrient intake of this species.

The choice of plot for study was made at random at four different size levels. The sectors of the forest were divided into plots, which were numbered in sequence (cf. Fig. 1). Eleven areas of one are each were then chosen from within these, and finally five quadrats of 1 m^2 were selected from each of these. The branches, unmarketable tops of trees and cones were weighed. The dry weight of the branches was determined by dividing the material into three samples and drying each for a minimum of 12 hours at a temperature of 105° C. The quantities of needles and small, broken twigs were estimated from five randomly selected squares of 10 × 10 cm within each quadrat. A specially constructed frame was employed to remove the surface of the moss layer (Fig. 2), from which the needles and twigs were removed after drying. This enabled the dry weight per m^2 to be calculated. The figure obtained for logging waste is thus based on a total of 55 such quadrats, the quantities of twigs and needles being evaluated from 275 squares of 10 × 10 cm.

About half a year had elapsed between cutting and the estimation of the phytomass, and obviously decomposition must have set in during this time, and may even have had a considerable effect on the total weights, especially in the case of the needles. Thus in order to establish the difference in nutrient content between the needles obtained from the waste branches and those on living trees, samples from standing trees were also examined.

The figure for the volume of marketable bole wood, i.e. the timber taken for processing, was obtained directly from Kajaani Oy, expressed in solid cubic metres. No attempt was made to measure the volume accounted for by stumps and roots, but the phytomass involved in these could be estimated from the literature, employing the known volume of stem wood in the experimental plot. The average age of the trees was calculated from the annual rings of the stumps, with the addition of 12 years to each count. The average diameter at stump height is based on the measurement of the stumps in each one are plot studied. The basic density of the wood was determined for the base of the bole wood, at 4 m and at the tree top.

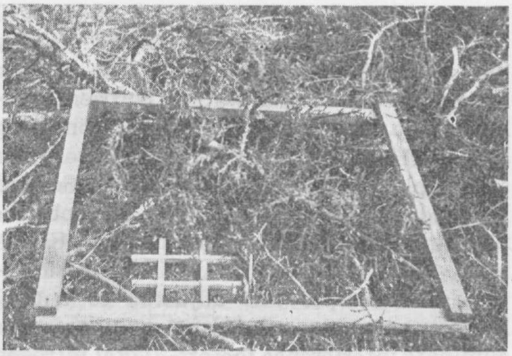

Fig. 2. An experimental plot in the summer following cutting. A 1 m^2 and a 10 × 10 cm quadrat frame are shown. The majority of the needles had fallen during the late winter and early summer. Photograph: Eero Kubin.

Kuva 2. Koekenttää hakkuun jälkeisenä kesänä. Kuvassa näkyy neliömetrin ja 10 × 10 cm:n kehikot. Valtaosa neulasista on varissut kevättalven ja alkukesän aikana. Kuva: Eero Kubin.

Samples from the logging residues were also dried for nutrient analysis, those from the bole wood being taken from the base and from heights of 4 m and 8 m. Samples were also taken from roots of various thicknesses in each sector of the forest. Needle samples were gathered from standing trees at a time corresponding to the felling date during the following winter.

3. 2. Laboratory tests

Nutrient analyses were performed during the winter of 1975 on the material collected the previous summer. These involved evaluations of N, P, K, Ca, Mg, Fe and Mn, and also ash content. Separate analyses were carried out for the bark and the wood proper.

1 g from each oven-dried, finely crushed sample was weighed into a porcelain crucible and burned for 4 hours in a muffle furnace at 450° C. It was then cooled for half an hour in an excicator, and the weight of ash

determined. To this 5 ml of 20 % HCl were added and the sample filtered directly into a 100 ml measuring cylinder, the crucible being rinsed with hot water. Nutrient analyses were carried out on this solution using a PERKIN-ELMER atomic absorption spectrophotometer for K, Ca, Mg, Fe and Mn and a HITACHI MODEL 101 spectrophotometer for P, by colour reaction (KOROLEFF 1968). For the determination of calcium the sample was adjusted to a 1 % lanthanum oxide concentration in order to eliminate interference factors. Total nitrogen was determined from fine material passed through a 0.02 mm mesh sieve after KJELDAHL. Altogether 24 such total nitrogen analyses were performed in the laboratory of the Department of Hydraulic Engineering of the University of Oulu. Each of the other nutrients was studied in 154 experiments in the Department of Botany, University of Oulu. Mineral determinations were carried out on bedrock samples in the laboratories of Kajaani Oy in Kajaani.

The material was compiled by first devising a coding system applicable to the data and then by transfering the data onto coding forms and preparing punched cards. The first stage in the processing of the results was to calculate the statistical distribution of the material. It was after this that the phytomass of the stumps and roots was estimated from references in the literature, and once this and other basic data had been checked it was possible to calculate the total biomass and the nutrients contained in it in kg/ha. A computer was employed for these calculations.

4. RESULTS

4.1. Distribution of dry matter in the spruce

In order to determine the dry matter content a small number of samples were taken for measurement of the basic density of the wood (Table 2). In these calculations the density is expressed as the weight of completely dry material per unit volume, where volume is determined in the fresh state. No significant differences are encountered between the results obtained with the wood in a fresh state and with it in a saturated state (HAKKILA 1966). No account was taken when perfoming these measurements of the distinction between wood samples obtained in the spring and summer, nor of whether the samples originated from the surface or the heart of the tree. A certain optimum growth rate has been noted in conifers, at which the densest wood is formed, while at the same time wood of different densities is to be found at different distances from the heart of the tree (JALAVA 1952).

The density was found to diminish in the present samples from the base of the tree to the top, a result which conforms with those of JALAVA (1952) and HAKKILA (1966). Wood is generally found to be denser in

Table 2. Basic densities of wood and bark in kg/m³, thickness of bark and percentage of total dry weight. The basic densities are based on the averages from two readings.

Taulukko 2. Puun ja kuoren tilavuuspaino kg/m³, kuoren paksuus ja osuus prosentteina kuivapainosta. Tilavuuspaino perustuu kahden määrityksen keskiarvoon.

Component *Komponentti*	Wood — *Puu*		Bark — *Kuoret*		
	Wood with bark kg/m³ *Kuorineen kg/m³*	Wood kg/m³ *Puuaines kg/m³*	kg/m³	As % dry weight *% kuivapainosta*	Thickness cm *Paksuus cm*
Butt wood — *Tyvipuu*	460	460	560	13.4	0.7
Bole wood 4 m .... *Runkopuu 4 m*	430	420	610	10.1	0.3
Bole wood 8 m .... *Runkopuu 8 m*	—	—	—	9.5	0.3
Tree-top waste at lowest point *Latvahukkapuu tyvi*	420	400	600	15.5	0.2
Tree-top waste at diam. 3 cm *Latvahukkapuu halkaisija 3 cm*	—	—	—	21.1	—
Roots at diam. 3 cm .... *Juuret halkaisija 3 cm*	—	—	—	38.9	—
Branches at diam. 2 cm .... *Oksat halkaisija 2 cm*	—	—	—	30.4	—
Average for bole wood .... *Keskiarvo runkopuusta*	440	430	590	13.9	0.4

forests of the MT and VT types, denser in the north than in the south, and denser with increasing age (Lassila 1930, Hakkila 1966, 1968), while that forming in areas of planted forest tends to be lighter (Hakkila and Uusivaara 1968). The figure of 440 kg/solid m^3 obtained for Kivesvaara would thus seem logical, being higher than that obtained by Hakkila in Southern Finland, though even in the latter area about 30 % of cases were of the order of 400—450 kg/solid m^3.

The percentage of bark by weight is a measure of the dry weight of the bark as a percentage of the total dry weight of wood with bark (Hakkila 1967). Hakkila (1967) reports figures of 8.4 % for sawlogs, 10 % for pulpwood and 20.6 % for logging residues from the tree tops in Southern Finland. The sets of results conform well (Table 2), especially when one remembers that the bark of spruce increases in thickness towards the north of the country (Ilvessalo 1965).

4. 1. 1. Aerial phytomass

The aerial phytomass of the tree may be divided into two parts in respect of their commercial value, the marketable bole wood and the waste wood. The conventional harvesting process yields marketable bole wood which includes the whole trunk of the tree with the exception of the tree-top residue. The bole wood from well-developed forests is utilizable commercially for two timber assortments, sawlogs and pulpwood. The waste wood comprises the tops of the trees, the branches, needles and cones. Averages and ranges of variation for the amounts of the various types of logging residue are presented in Table 3.

The branches form the principal component of the logging residue, while approx. three times the amount of needle litter is deposited in the felling area compared with the waste wood from the tree tops. The proportion of cones is the smallest of all, but even so exceeds 600 kg/ha. The uneven distribution of these types of logging waste may be appreciated from the statistical range figures in the Table, there being some places where no logging waste is to be found, and others with large piles of branches.

The distribution of the aerial phytomass between marketable bole wood and waste wood is depicted in Table 4. The aerial harvesting residues amount to 34,748 kg/ha, or 71.5 % of the figure for marketable bole

Table 3. Amounts of logging waste, their statistical range (s), coefficient of variation (C) and number of observations (n). The three different values for branches were obtained using different samples for the dry weight determinations.

Taulukko 3. Hakkuujätteen eri osien määrä, hajonta (s), variaatiokerroin (C) ja havaintojen lukumäärä (n). Oksien kolme erilaista arvoa on saatu kuivapainomäärityksiin käytetyistä erilaatuisista näytteistä.

Componen *Komponentit*	Average kg/ha *Keskiarvo kg/ha*	s	C	n
Bole wood at top — *Latvarunkopuu*	2960	5864	198.1	55
Branches 1 — *Oksat 1*	19878	15818	79.6	55
Branches 2 — *Oksat 2*	20921	16299	77.9	55
Branches 3 — *Oksat 3*	22751	17967	79.0	55
Average br. 1—3 — *Keskiarvo 1—3*	21183	16489	77.8	55
Twigs — *Pikkuoksat*	3042	2241	73.6	55
Needles — *Neulaset*	6888	6226	93.3	55
Cones — *Kävyt*	638	1330	208.6	55
Total — *Yhteensä*	34711	—	—	—

wood. Of the latter, 66 % is accounted for by material suitable for sawlogs and 8 % by bark. Sawlogs and their bark account for 43 % of the aerial phytomass and 34 % of the total phytomass, and are equivalent to 164 % of the underground phytomass. The overall effect of cutting was to remove 46 % of the total phytomass, or 58 % of

Table 4. Distribution of aerial phytomass into marketable bole wood and waste wood. In each case the total is given first and then subdivided into types. The stump is considered underground waste wood.

Taulukko 4. Maanpäällisen fytomassan jakaantuminen hyötyrunkopuun ja jätepuun kesken. Molemmissa on ylinnä esitetty kokonaismäärä ja alla jakautuminen eri osien kesken. Kanto on laskettu maanalaiseen fytomassaan.

Component *Komponentti*	Phytomass kg/ha *Fytomassa kg/ha*	Percentages — *%-osuudet* of total phytomass *Kokonaisfytomassasta*	of aerial phytomass *Maanpäällisestä fytomassasta*	of underground phytomass *Maanalaisesta fytomassasta*	of marketable bole wood *Hyötyrunkopuusta*
Marketable bole wood .... *Hyötyrunkopuu*	48618	46.1	58.3	220.8	100.0
Sawlogs .... *Tukkipuun puuaines*	32150	30.5	38.6	146.0	66.1
Pulpwood .... *Paperipuun puuaines*	10877	10.3	13.1	49.4	22.4
Sawlog bark .... *Tukkipuun kuori*	3973	3.8	4.8	18.0	8.2
Pulpwood bark .... *Paperipuun kuori*	1618	1.5	1.9	7.4	3.3
Waste wood .... *Jätepuu*	34748	31.0	41.7	157.8	71.5
Tree-top waste wood .... *Latvarunkopuun puu*	2305	2.2	2.8	10.5	4.7
Tree-top waste bark .... *Latvarunkopuun kuori*	654	0.6	0.8	3.0	1.4
Branches (wood) .... *Oksien puu*	14743	12.0	17.9	66.9	30.3
Branches (bark) .... *Oksien kuori*	6444	6.1	7.7	29.3	13.3
Twigs with bark .... *Pikkuoksat kuorineen*	3041	2.9	3.7	13.8	6.3
Needles .... *Neulaset*	6888	6.5	8.3	31.3	14.2
Cones .... *Kävyt*	673	0.6	0.8	3.1	1.4

the aerial phytomass, equivalent to double the weight of the root phytomass, or 221 %.

Within the category of logging waste, the branches with their bark accounted for 21,187 kg/ha, or 60 % of total residues. This is equivalent to approx. 20 % of the total phytomass, 25 % of the aerial phytomass, approx. 93 % of the underground phytomass and approx. 44 % of the marketable bole wood. We thus see immediately that the weight of branches remaining as logging residue is equivalent to almost a half (44 %) of the amount of timber harvested. The branches with their needles represent approx. 80 % of the total logging waste, with the remainder made up of approx. 9 % broken-off twigs or small branches a few centimetres in diameter, 8 % tree-top residues and approx. 2 % cones.

To sum up, it is seen that the aerial residues created by cutting and left in the forest constitute 31 % of the total phytomass (the proportion harvested being 46 %) and 42 % of the aerial phytomass. This waste represents approx. 1.5 times the underground phytomass (158 %), while the proportion harvested amounts to approx. twice the underground phytomass, or 221 %.

4. 1. 2. Underground phytomass

An estimate was obtained for the amount of material accounted for in stumps and roots on the basis of data obtained elsewhere and employing the known figure for bole wood at Kivesvaara. Hakkila (1972 a) maintains that the root system of the spruce is more extensive in Northern Finland than in the South, while Kalela (1949) states that the root system of this species exceeds that of pine only in fully mature forests. It has been calculated that 60 % of the length of spruce and pine roots consists of roots of less than 1 mm in diameter, 25 % of 1—2 mm and approx. 15 % of over 2 mm. According to Nykvist (1971) a forest containing twice the phytomass of that at Kivesvaara contains roots of under 0.5 mm equivalent to 2 % of the biomass of the bole wood, while Mälkönen (1974 b) reports that the root system of a 42-year-old pine tree contains roots of less than 1 mm in diameter amounting to 6 % of the dry weight of the trunk.

Roots of diameter over 5 cm represent 29.7 % of the dry weight of the bole wood with bark in Northern Finland (Hakkila 1972 a), 34 % of this figure being accounted for by the stump and 66 % by the roots themselves. Similarly, roots of thickness 1—5 cm account for a third of the total volume of the stump plus roots in the pine (Mälkönen 1972). The latter figure, together with the results of Hakkila (1975 a), enable the amount of roots of thickness 1—5 cm to be determined, the proportion of bark within the dry weight of these being 38.9 % (Table 2). The amount of roots of diameter less than 1 mm is estimated to be equivalent to 2.5 % of the dry weight of the trunk at Kivesvaara. The estimates for the underground phytomass including stump are presented in Table 5.

Up to the present time industrial exploitation of stump and root material has generally only been common practice in the Soviet Union, the United States and Poland, and in these cases it has been largely a matter of the use of old resinous pine stumps for chemical extraction. Advances have been made in Finland during the last few years towards the elimination of the difficulties involved in the commercial exploitation of stump and root material, so that the use of pine and spruce stumps may now be said to be technically and economically feasible (Hakkila 1972 a, 1975 b, Hakkila and Mäkelä 1973). In this case, however, only roots of over 5 cm can be employed. The volume of wood contained in the stump is dependent to a large extent upon the height at which the trees are felled, especially since a half of the volume of wood is contained in the lowermost quarter of the length of the trunk (Laasasenaho 1975). A considerable amount of root material, some several thousands of years old, is to be obtained as a by-product of the exploitation of peat bogs for fuel etc.

The phytomass of the stumps and roots at Kivesvaara amounts to approx. 22,000 kg/ha (Table 5), the proportion accounted for by the stumps being approx. 24 % and that of the exploitable roots of diameter 5—20 + cm almost one half. The stumps

Table 5. Estimated underground phytomass, including stump, and its distribution into components. Corresponding figures for total and aerial phytomass are included.

Taulukko 5. Maanalaisen fytomassan (kanto mukaanlukien) arvioitu määrä ja jakautuminen eri komponenttien kesken. Kokonaisfytomassa ja maanpäällinen fytomassa on myös esitetty.

Component *Komponentti*	Phytomass kg/ha *Fytomassa kg/ha*	Percentages — *%-osuudet*			
		of total phytomass *Kokonais-fytomassasta*	of aerial phytomass *Maanpäällisestä fytomassasta*	of underground phytomass *Maanalaisesta fytomassasta*	of marketable bole wood *Hyötyrunkopuusta*
Stump and root material ...... *Kanto- ja juuripuu*	22000	20.9	26.4	100.0	45.3
Stump wood .... *Kannon puu*	4700	4.5	5.7	21.5	9.7
Roots 5—20 cm (wood) ...... *Juurten 5—20 cm puu*	8800	8.4	10.6	40.0	18.1
Roots 1—5 cm (wood) .... *Juurten 1—5 cm puu*	3300	3.2	4.0	15.1	6.8
Stump bark .... *Kannon kuori*	500	0.5	0.6	2.2	1.0
Roots 5—20 cm (bark) .... *Juurten 5—20 cm kuori*	1300	1.2	1.6	5.9	2.7
Roots 1—5 cm (bark) .... *Juurten 1—5 cm kuori*	2100	2.0	2.5	9.5	4.3
Roots 1 cm with bark .... *Juuret 1 cm kuorineen*	1300	1.2	1.6	5.9	2.7
Aerial phytomass .... *Maanpäällinen fytomassa*	83400	79.1	100.0	378.5	171.5
Underground phytomass .... *Maanalainen fytomassa*	22000	20.9	26.4	100.0	45.3
Total phytomass .... *Kokonaisfytomassa*	105400	100.0	126.4	478.5	216.8

and roots are thus equivalent to approx. 45 % of the marketable bole wood, the stumps alone representing 10 % and the roots of diameter 6—20 + cm 20 %. The stumps and roots comprise approx. one fifth of the total phytomass, equivalent to a quarter of the aerial phytomass. Their inclusion gives a total phytomass figure of 105,400 kg/ha. (Table 5).

4.2. Distribution of nutrients amongst the marketable bole wood, waste wood and roots

The nutrient values were calculated in kg/ha for the same components as were employed in determining the distribution of the phytomass, with the needles and twigs from standing trees being assigned the same phytomass as had been obtained in the calculation of logging waste (see Tables 3 and 4). The nutrient analysis results showed a sizeable statistical spread in the case of certain components, though the coefficient of variation remained below 50 % for the majority of the material. The greatest range was generally found in the case of the wood itself, while the determinations from the root systems also showed major fluctuations. The highest individual coefficient of variation was obtained for magnesium in the wood at the tree top, and the second largest for iron in the bark of roots of thickness 1—5 cm.

Some of this wide fluctuation is obviously due to variations occurring in nature, and some may well be exaggerated on account of the method employed. In the case of certain samples the number of analyses performed is small, which may easily give rise to high coefficients of variation. Also, since the samples were collected during the summer following the cutting, varying degrees of change may have taken place in them which may tend to exaggerate the variations. Nevertheless, it is the average values which are employed in the subsequent calculations, so that the results remain relatively reliable, while at the same time pointing to clear numerical differences between the various components examined (Table 6).

Marketable bole wood occurs in the largest amounts in terms of its phytomass (Table 4), and stump and root material in the smallest amounts (Table 5). The largest amounts of nutrients are to be found in the waste wood, including needles. The amounts of phosphorus and iron contained in the roots are also greater than the corresponding amounts in the marketable bole wood. A total of 1676.9 kg/ha of ash is yielded, 34.4 % of which is accounted for by the nutrients examined here.

4. 2. 1. Nutrient proportions in the aerial phytomass

The aerial phytomass amounted to approx. 83,300 kg/ha, or 78 % of total phytomass. This was composed of 46 % bole wood and 32 % waste wood (Table 4). The distribution of nutrients in the marketable bole wood, waste wood and stump and root material are presented as percentages of aerial phytomass in Fig. 3. 30 % of the ash contained in the aerial phytomass is located in the marketable bole wood, and the remaining 70 % in the waste wood, and the distribution of Ca, Mg, Fe and Mn broadly follows the same pattern. The proportion of potassium in the bole wood is higher, however, whereas the proportions of phosphorus (13 %) and nitrogen (24 %) are considerably lower than those of the other nutrients. The proportions of the nutrients contained in the aerial phytomass accounted for by the marketable bole wood thus range between 13 % (P) and 42 % (K), the vast majority of the nutrients remaining in the felling waste.

Table 6. Ash and nutrient concentrations in kg/ha in the marketable bole wood, waste wood and stump and root material.

Taulukko 6. Tuhka- ja ravinnepitoisuudet kg/ha hyötyrunko- ja jätepuussa sekä kanto- ja juuripuussa.

Component *Komponentti*	Ash *Tuhka*	N	P	K	Ca	Mg	Fe	Mn
Bole wood *Hyötyrunkopuu*	423.2	44.0	3.1	35.0	110.2	8.5	1.0	12.9
Waste wood *Jätepuu*	969.2	132.4	20.5	49.1	226.8	16.0	2.0	21.5
Stumps and roots *Kanto- ja juuripuu*	284.5	30.4	4.2	28.6	58.9	5.4	1.4	4.6

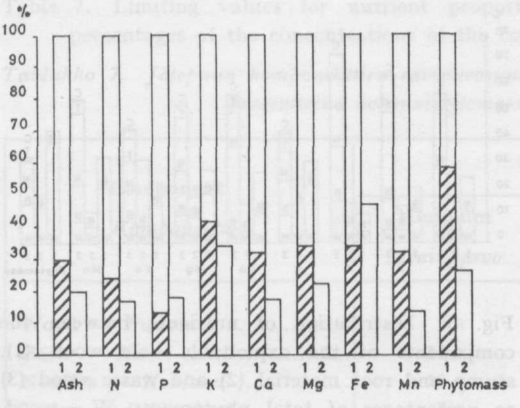

Fig. 3. Distribution of nutrients between the exploitable bole wood and waste wood (1) and the stump and root material (2) as percentages of concentrations in the aerial phytomass. The lower part of column 1 in each case denotes the exploitable bole wood, and the upper part the waste wood. The corresponding distribution of the phytomass is indicated on the right.

Kuva 3. Ravinteiden jakautuma hyötyrunko- ja jätepuun (1) sekä kanto- ja juuripuun (2) kesken prosentteina maanpäällisessä fytomassassa olevasta ravinnemäärästä. Pylvään 1 alaosa on hyötyrunkopuuta, yläosa jätepuuta. Fytomassan vastaava jakautuma myös esitetty.

The phytomass of the stump and root material is equivalent to approx. 26 % of the aerial phytomass (Table 5), whereas the proportions of nutrients, with the exception of potassium and iron, remain below this figure. Thus for the majority of nutrients a relatively lower concentration is to be found in the underground than in the aerial phytomass. Nevertheless, while the stumps and roots possess a phytomass equivalent to approx. 45 % of that of the marketable bole wood (Table 5), the proportions of the nutrients, with the exception of manganese, all exceed this figure, i.e. the stumps and roots possess a relatively higher concentration of nutrients than does the marketable bole wood. and in the case of phosphorus and iron the amounts are greater even in absolute terms (Table 6), even though the phytomass is only 45 % of that of the latter. The proportions of the nutrients contained in the stumps and roots range between 13 % (Mn) and 47 % (Fe) in relation to the nutrients in the aerial phytomass.

4. 2. 2. Nutrient proportions in the underground phytomass

The phytomass of the marketable bole wood is approx. twice that of the stumps and roots, while that of the waste wood is approx. 1 1/2 times the latter (Table 4). Thus if the concentrations of nutrients in the marketable bole wood were comparable with those in the stump and root material they too would be double the latter. In no case is this so, however, and in the case of phosphorus and iron the proportions accounted for by the marketable bole wood are even below those for the root systems (Fig. 4).

In percentage terms the highest proportions are to be found in the waste wood, where over four times the concentrations of phosphorus and nitrogen are to be found compared with those in the stumps and roots, and

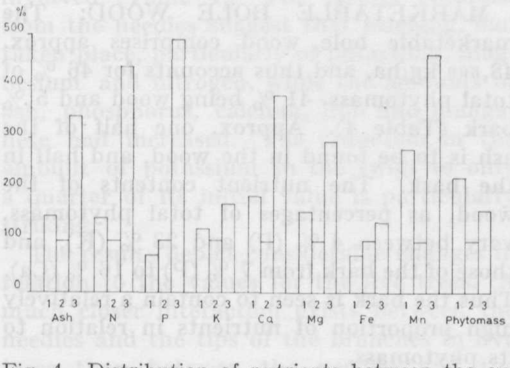

Fig. 4. Distribution of nutrients between the exploitable bole wood (1), stump and root material (2) and waste wood (3) as percentages of concentrations in the stumps and roots. The column for the stump and root material thus represents 100 % throughout. The corresponding distribution of the phytomass is indicated on the right.

Kuva 4. Ravinteiden jakautuma hyötyrunkopuun (1), kanto- ja juuripuun (2) ja jätepuun (3) kesken prosentteina kanto- ja juuripuun ravinnemäärästä. Kanto- ja juuripuun ravinteiden osuudet itsestään 100 %. Fytomassan vastaava jakautuma myös esitetty.

considerable amounts of manganese are also present. On the other hand, lower amounts of iron and potassium than of the other nutrients are present in the waste wood, while the proportions of calcium and magnesium follow closely that of ash. The proportions of all the nutrients are considerably higher than would be expected on the basis of the phytomass of the waste wood. The root systems are thus seen to have performed their function as conveyors of nutrients, and concentrations of these have accumulated in the aerial parts of the organism, in the waste wood and especially in the needles (cf. also Table 6).

4. 2. 3. Nutrient proportions within total phytomass

A tree is composed of its root system, trunk and branches with needles, forming an organic whole. It is therefore reasonable to examine in detail the amounts of the various nutrients in each of its parts in relation to the nutrient content of the total phytomass (Fig. 5).

MARKETABLE BOLE WOOD: The marketable bole wood comprises approx. 48,600 kg/ha, and thus accounts for 46 % of total phytomass, 41 % being wood and 5 % bark (Table 4). Approx. one half of the ash is to be found in the wood, and half in the bark. The nutrient contents of the wood, as percentages of total phytomass, vary between 4 % (P) and 23 % (K), and those of the bark from 7 % (P) to 16 % (Ca). Thus the bark is seen to contain a relatively high proportion of nutrients in relation to its phytomass.

WASTE WOOD: The aerial waste wood phytomass, approx. 34,700 kg/ha, constitutes 31 % of the total phytomass, 15 % of this being accounted for by the wood, 7 % by bark, 7 % by needles, 3 % by twigs recovered from the ground and just under 1 % cones (Table 4).

A large proportion of the nutrients contained in the waste wood are located in the bark and needles. By far the largest nutrient concentration is that of nitrogen in the needles, while similarly the needles contain larger

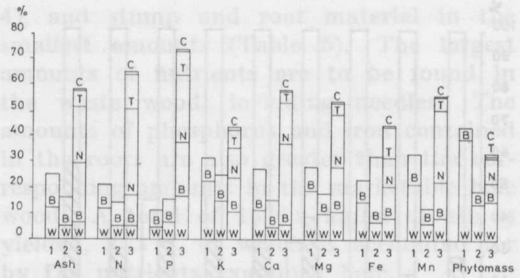

Fig. 5. Distribution of nutrients between the components of the exploitable bole wood (1), stump and root material (2) and waste wood (3) as percentages of total phytomass. W — wood, B — bark, N — needles, T — twigs and C — cones. The corresponding distribution of the phytomass is indicated on the right.

Kuva 5. Ravinteittainen jakautuma hyötyrunkopuun (1), kanto- ja juuripuun (2) ja jätepuun (3) kesken prosentteina kokonaisfytomassan ravinnemäärästä. W — puuaines, B — kuori, N — neulaset, T — pikkuoksat ja C — kävyt. Fytomassan vastaava jakautuma myös esitetty.

amounts of phosphorus, potassium magnesium and manganese than do the other waste wood components. The major concentrations of iron and calcium are to be found in the bark. The minimum and maximum proportions of total phytomass represented by the various nutrients are presented in Table 7.

Of the nutrients determined in the wood component, the concentration of nitrogen is the lowest and that of phosphorus the highest, whereas in the needles and twigs nitrogen had the highest concentration of all the nutrients. Manganese is the least prolific nutrient in the cones and calcium in the twigs. It is in the bark that 30.8 % of total calcium is to be found. The maximum nutrient concentration in the cones is that of potassium, 1.7 %.

STUMPS AND ROOTS: The phytomass of the stumps and roots, approx. 22,000 kg/ha, represents 21 % of total phytomass. Approx. 16 % of this consists of wood of thickness greater than 1 cm and approx. 5 % of bark (Table 5). The corresponding proportions of the nutrients in the wood

Table 7. Limiting values for nutrient proportions in the waste wood components, expressed as percentages of the concentrations of the corresponding nutrients in the total phytomass.

Taulukko 7. Jätepuun komponenttien ravinneosuuksien raja-arvot (minimi- ja maksimiravinteen määrä) prosentteina kokonaisfytomassan vastaavista ravinnemääristä.

Component *Komponentti*	% Minimum *Minimiarvo*	% Maximum *Maksimiarvo*	Minimum nutrient *Minimiravinne*	Maximum nutrient *Maksimiravinne*
Wood — *Puuaines*	5.0	16.6	N	P
Bark — *Kuori*	11.8	30.8	Fe	Ca
Needles — *Neulaset*	11.0	32.4	Fe	N
Twigs — *Pikkuoksat*	3.7	13.8	Ca	N
Cones — *Kävyt*	0.1	1.7	Mn	K

range between 4 % (Ca) and 14 % (K), and in the bark between 4 % (Mn) and 12 % (Fe). Roots of diameter less than 1 cm are not included in these analyses.

The proportions of phosphorus and iron, even in relation to the nutrients contained in the total phytomass, are greater than those to be found in the marketable bole wood (cf. also Fig. 4), while the bark contains well over half of the amount of calcium and iron present in the whole root system, even though its phytomass is only approx. 5 %.

In order to compare the needles contained in the logging waste with those from standing trees, samples of the latter were taken during the following winter at a time corresponding to that of the felling and subjected to similar analyses. The material consisted of needles from the last three years' growing shoots, without further distinction of age. The most recent growths, the 'twigs', were analysed separately (Table 8).

The needles in the logging waste are seen to contain more ash than those from the standing trees, whereas the twigs from the waste wood contain less. In the case of both the needles and the twigs the waste material contained less nitrogen, potassium and magnesium, but more phosphorus, calcium and iron. More manganese was found in the needles of the waste wood than in those of the standing trees, but in the case of the twigs the figures were identical. No attempt has been made to calculate the significances of these differences. The differences for many of the nutrients are smaller in the case of the twigs than in that of the needles, partly due to the lower phytomass involved (Table 4). The results obtained from the needles suggest that leaching, had taken place, particularly of potassium, magnesium and nitrogen, while the amounts of ash, phosphorus, calcium, iron and manganese had increased. The reduction in the amount of potassium in the twigs to only a quarter of its initial value is particularly striking.

The results depict considerable changes in relation to the values for the live trees. A much closer interaction exists between the needles and the tips of the branches in live trees than between the needles and the wood. The samples from the twigs may well have contained some material which had already died on the standing trees before falling to the ground, thus giving rise to discrepancies in the results, involving an element of difference not accountable for by changes occurring in the time elapsing between felling and sampling. Differences may also arise due to variations in soil nutrients, the effects of which may be sufficiently cumulative for quite noticeable discrepancies to appear in the results.

Table 8. Concentrations of ash and nutrients in the needles and twigs in the logging waste (kg/ha) in relation to those in standing trees. The same phytomass figures are assigned to the standing tree components as were found in the case of the logging waste.

Taulukko 8. Hakkuujätteen neulasten ja pikkuoksien ravinteet ja tuhkapitoisuus kg/ha verrattuna pystypuihin. Pystypuun osille annettu sama fytomassa, mikä oli vastaavaa hakkuujätettä.

Sample *Näyte*	Ash *Tuhka*	N	P	K	Ca	Mg	Fe	Mn
Needles on standing trees *Neulaset pystypuusta*	310.9	73.7	55.2	35.8	55.2	7.9	0.3	9.0
Needles in logging waste *Neulaset hakkuujätteestä*	380.7	66.8	63.8	18.0	63.8	5.8	0.5	10.8
Twigs on standing trees *Pikkuoksat pystypuusta*	88.4	28.9	13.3	20.7	13.3	2.8	0.3	1.9
Twigs in logging waste *Pikkuoksat hakkuujätteestä*	85.9	28.5	14.7	5.2	14.7	1.5	0.6	1.9

4.2.4. Nutrient proportions in the harvested bole wood

In addition to the calculations presented above it is possible to study the distribution of nutrients in relation to the harvested bole wood, and thus to obtain an indication of what proportion of nutrients is removed from the forest on harvesting and what proportion remains behind (Fig. 6).

It is always the case that more nutrient remains behind in the waste wood than is removed with the harvested bole wood. This difference is smallest in the case of potassium, though for ash over double the amount removed in the harvested wood remains in the waste and similar proportions are observed in the cases of calcium, magnesium and manganese. Similarly, three times the amount of nitrogen removed by harvesting remains behind in the logging waste, and almost seven times the amount of phosphorus. Particularly large quantities of nutrients, especially of nitrogen and phosphorus, remain in the needles, though this is not the case with iron. Extremely large amounts of nutrients are contained in the bark, especially bearing in mind its low phytomass.

With the exception of nitrogen and phosphorus, the proportions of nutrients contained in the twigs recovered from the ground are of little significance, the proportions contained in the cones are similarly low, and the root systems generally retain less nutrients than are removed in the harvested wood, with exceptions occurring in the case of iron and phosphorus, which exhibit particularly high proportions in the bark of the stumps and roots compared with the other nutrients. Since we are dealing here with elements occurring in extremely small amounts, it is obvious that even a small degree of impurity in the sample may cause erroneous results. The part played by any such impurities would be hard to estimate, however.

4.2.5. Nutrient proportions in relation to soluble soil nutrients

The nutrients present in the phytomass constitute one part of the nutrient potential of the soil as a whole (Table 9), a property which is influenced to a great extent by the local bedrock and its weathering products. A figure of 43 cm has been obtained for the soil depth at Kivesvaara, being the average of the soil depths at the sites studied, and thus obtained in a manner corresponding to that used for the nutrient values themselves (Kubin 1975).

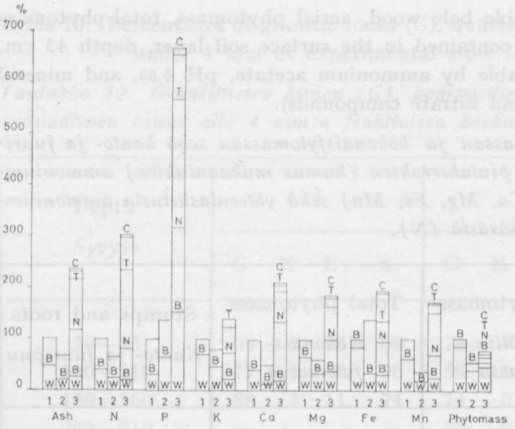

Fig. 6. Nutrients contained in the waste wood and stump and root material in relation to the depletion on harvesting: distribution between exploitable bole wood (1), stump and root material (2) and waste wood (3) as percentages of concentrations in the exploitable bole wood. The column for the bole wood itself thus represents 100 % throughout. W — wood, B — bark, N — needles, T — twigs and C — cones. The corresponding distribution of the phytomass is indicated on the right.

Kuva 6. Maanpäällisen jätepuun sekä kanto- ja juuripuun ravinteet suhteessa poiskorjatun puun ravinteisiin. Jakautuma hyötyrunkopuun (1), kanto- ja juuripuun (2) ja jätepuun (3) kesken prosentteina hyötyrunkopuun ravinnemäärästä. Hyötyrunkopuun ravinteiden osuudet itsestään ovat 100 %. W — puuaines, B — kuori, N — neulaset, T — pikkuoksat ja C — kävyt. Fytomassan vastaava jakautuma myös esitetty.

The harvesting of the bole wood is seen to remove more than three times that amount of nitrogen present in the soil in the form of ammonium and nitrate compounds, but even so over ten times the latter amount remains behind in the waste wood. In the same manner, large amounts of manganese are removed in the bole wood, the amounts of this mineral in the aerial and total phytomass reaching considerable proportions compared with the reserves present in the soil. The proportions of potassium and calcium in the total phytomass, i.e. involved in the nutrient cycle in the spruce forest, are equivalent to a half of the corresponding nutrient supplies in the soil. In each case the amount removed on harvesting was approx. 15 %. The roots contain relatively small proportions of nutrients compared with those present in soluble form in the soil, though even here over twice the concentration of nitrogen is found compared with that in the soil. The overall proportion represented by the nutrients in the exploitable bole wood was 12.4 %, and that in the aerial phytomass 39.7 %, in relation to the nutrients in the soil.

The traditional manner of felling is thus seen to introduce nutrients into the soil to a considerable extent in excess of those it removes (cf. Table 6, for example). This is generally reflected in increased vegetation growth, which at the same time leads to the creation of greater amounts of litter amongst the vegetational cover in the years following cutting. At the same time it marks a stimulation of the nutrient cycle, since the loss in the bole wood is small (cf. Fig. 6, for example) and the gain from the waste wood considerable.

The changeover to whole-tree harvesting with the inclusion of the stumps and roots implies the elimination of this waste wood, whose effect is to stimulate the circulation of nutrients. In this case physical factors such as humidity, temperature and weathering of the bedrock occupy a position of ever-increasing importance. Since the nutrient loss is of the same order as the reserves of available minerals in the soil, or even greater than these, it is the nature of the bedrock and its weathering products, and the mineralization of the nutrient reserves contained in the soil in general, e.g. in the cover of raw humus on firm forest lands, which play a decisive role, for in the final instance it is these factors which determine whether whole-treeh arvesting is in fact detrimental to the soil nutrient reserves.

4. 3. Bedrock composition

The minerals and nutrients contained in the soil are ultimately derived from the bedrock and the loose boulders and stones associated with this, the physical and chemical weathering of the bedrock over many

Table 9. Percentages of nutrients in the marketable bole wood, aerial phytomass, total phytomass and stump and root material in relation to those contained in the surface soil layer, depth 43 cm, including humus (P, K, Ca, Mg, Fe, Mn extractable by ammonium acetate, pH 4.65, and mineral nitrogen in ammonium and nitrate compounds).

Taulukko 9. Hyötyrunkopuun, maanpäällisen fytomassan ja kokonaisfytomassan sekä kanto- ja juuripuun ravinteiden %-osuudet maan 43 cm paksun pintakerroksen (humus mukaanlukien) ammoniumasetaattiin (pH 4.65) uuttuvista ravinteista (P, K, Ca, Mg, Fe, Mn) sekä yhteenlasketusta ammoniumja nitraattitypen määrästä (N).

Nutrient *Ravinne*	Bole wood *Hyötyrunkopuu*	Aerial phytomass *Maanpäällinen fytomassa*	Total phytomass *Kokonais-fytomassa*	Stumps and roots *Kanto- ja juuripuu*
N	344.9	1387.4	1625.2	237.8
P	4.5	34.3	40.5	6.2
K	15.9	38.1	51.5	12.9
Ca	15.7	46.8	55.0	8.2
Mg	8.2	23.7	25.9	5.2
Fe	0.2	0.5	0.8	0.2
Mn	39.2	118.9	133.0	14.1

thousands of years having led to an accumulation of nutrient minerals suitable for absorption by the plants. At the same time the plants themselves are able to achieve an effect similar to weathering through the secretion capacity of their roots. Thus the composition of the bedrock and its susceptibility to weathering are reflected to a great extent in the supply of available nutrients in the soil (Table 10).

In the following discussion the granitic rocks (G) are taken to include granite, granite gneiss, gneiss, veined quartz and grains of feldspar, while the quartizitic group (K) includes quartzite, and the basic rocks and schists (E) the metadiabases, amphibolites, phyllites and vulcanites. The majority of the rocks in the area are of the granitic type, their proportion being greatest at excavation site III and lowest at sites II and IV (Fig. 1). Similarly, the proportion of quartzitic rocks was highest at site III. The basic rocks and schists varied from 15—19 % (I, III) to 25 % (II, IV). The proportion of granitic rocks as a whole was about 70 %, the quartzitic group about 5 % and the basic rocks approx. 25 %. No obvious differences in this distribution were to be found with depth. The low occurrence of the quartzitic group may be due to the small size of the sample fraction taken, less than 4 mm.

The amount of soluble minerals present in the soil water is dependent on the composition of the rocks present and their susceptibility to weathering. Amongst the granitic group feldspar is the principal source of calcium, magnesium and iron. On the other hand quartzite is the most resistent of these rocks to weathering. It is the basic rocks and schists, which account for only about 25 % of the local bedrock (Table 10), which without doubt constitute the principal group affecting the supply of nutrients in the area. Dolomite has even been found in the immediate vicinity (WILKMAN 1931).

The principal micas encountered are generally the potassium micas, from which potassium itself is readily released into solution and absorbed into clays (SAHAMA 1947). Magnesium is also to be derived from the amphibolite and mica groups, although dolomite, (Ca Mg $(CO_3)_2$), is a more

Table 10. Percentages of granitic rocks (G), quartzites (K) and basic rocks and schists (E) in fractions under 4 mm at experimental sites I—IV (Fig. 1). n = number of samples.

Taulukko 10. Graniittisten kivien (G), kvartsiittien (K) ja emäksisten kivien sekä liuskeiden (E) prosentuaalinen osuus alle 4 mm:n fraktioissa koekuopissa I—IV (kuva 1). n = kappalemäärä.

Depth *Syvyys*	I				II				III				IV			
	G	K	E	n	G	K	E	n	G	K	E	n	G	K	E	n
50—55	68	9	23	69	70	4	25	75	66	12	22	109	75	3	21	79
100—110	77	1	22	86	59	11	30	83	78	10	11	99	75	7	18	105
150—160	88	1	11	74	74	0	26	73	67	17	16	103	66	2	32	98
200—210	—	—	—	—	79	0	21	110	74	6	19	99	64	6	30	81
250—260	—	—	—	—	63	13	23	85	78	4	18	77	—	—	—	—
300—310	—	—	—	—	—	—	—	—	80	9	14	55	—	—	—	—
350—360	—	—	—	—	—	—	—	—	86	1	13	176	—	—	—	—
400—410	—	—	—	—	—	—	—	—	86	1	13	142	—	—	—	—
420—430	—	—	—	—	—	—	—	—	74	14	14	491	—	—	—	—
450—460	—	—	—	—	—	—	—	—	75	13	12	89	—	—	—	—
Mean value *Keskiarvo*	77	4	19		69	5	25		76	9	15		70	5	25	

important source. Iron is released from the amphibolites and black micas (biotite) and from the feldspar rocks, and as a closely related element, manganese seems to occur in a similar manner. The main mineral source of phosphorus is apatite, though the majority of the phosphorus present is bound to calcium in the form of phosphates (Sahama 1947).

The proportion of acid granitic rocks at Kivesvaara is extremely high, and large amounts of the essential nutrients may be derived from these by weathering, though an even better source is present in the form of the basic rocks and schists. It is obviously factors such as these which have led to the excellent nutrient status of the area (Kubin 1975) compared with the average fertility of the soils in Southern Finland, for example (Viro 1967). In addition, the extremely high clay content of the soil (Kubin 1975) may well serve to prevent leaching of these minerals to a great extent by binding them to clay particles, and in this way the soil maintains its fertility.

4. 4. Variations between the forest sectors in the nutrient content of their phytomass

The variation between the sectors of forest in terms of their nutrient status was studied first by examining the maximum and minimum nutrient content values, those sectors being recorded in which the samples gave the maximum and minimum values for the concentration of each nutrient. In terms of all the nutrients together, the maximum value for the total phytomass was obtained for sector 1 (code numbers 11 and 12 in Fig. 1) and the minimum values for sectors 3 (code numbers 31 and 32) and 4 (code numbers 41, 42 and 43). For the aerial phytomass alone the results pointed to sectors 1 and 4 respectively, while for the root system nutrients sector 4 gave the maximum values and sector 3 the minimum ones.

The results suggest that sector 1 possesses the best nutrient status, while sectors 3 and 4 are poor in nutrients as far as their aerial phytomass is concerned. Nevertheless these results denote only the maximum and minimum values, and not the actual differences in the nutrients available to the trees at the various sites. In order to gain an insight into the latter, the t test was applied successively to the concentrations of nutrients present in the major forest components in each pair of sectors.

The value of these results is reduced considerably by the small number of analyses performed, but even so certain generalizations can be made on this basis. The t test did not cause any one sector to stand out at all significantly from the remainder, and only a number of non-significant trends could be distinguished. Sector 4 contained lower concentrations of calcium in particular, and also to some extent phosphorus, in the needles than did sectors 1—3, while in the case of the twigs the calcium content in sector 3 was significantly lower than that observed in sector 1 and correspondingly that in sector 4 than that in sector 3.

The comparison largely serves to indicate, however, that the sectors were more or less similar in character, without any major differences. Sector 4 may be somewhat less rich in nutrients than the others, though no really significant differences appeared. It should be noted that the soil analyses from the area around sector 4 also gave lower readings than elsewhere, and the sector possessed a more even vegetation cover than the others (Kubin 1975).

5. DISCUSSION

5.1. Distribution of dry matter

A figure of 105,400 kg/ha was obtained for the total spruce phytomass, of which the aerial phytomass accounted for 83,400 kg/ha (Table 5). The results from Kivesvaara are broadly in conformity with corresponding figures reported from elsewhere (Table 11).

Kivesvaara appears to possess a lower yield of bole wood than the mature HMT spruce forest in Kuusamo studied by Havas (1972). The phytomass of the branches is noticeably larger, however, as is that of the needles to some extent, while the proportion of roots remains slightly lower. The results obtained by Mälkönen (1973) represent a younger spruce forest in a more southerly location. Here the amount of bole wood calculated is greater, while the phytomass of the branches is considerably lower than at Kivesvaara. The proportions of needles and roots are more or less identical. The figure obtained by Nykvist (1971) for bole wood is closely comparable with that of Mälkönen (1973), and that for the branches is also of the same order as in the latter work. His proportion of needles is practically the same as that found at Kivesvaara, but that of the roots is very much lower. The results of Baskerville (1965) from an *Abies balsamea* forest are of the same order as those from Kivesvaara as far as the proportion of bole wood is concerned, though he reports higher proportions of needles and roots, but considerably lower amounts of branches. The highest proportion of bole wood in any of the forests described in this connection is recorded for a *Picea mariana*

Table 11. Distribution of aerial phytomass and proportion of roots as a percentage of aerial phytomass at Kivesvaara and in the results of Havas (1972), Mälkönen (1973), Nykvist (1971), Baskerville (1965), Weetman and Webber (1971) and Heller (1971).

Taulukko 11. Maanpäällisen fytomassan jakaantuminen ja juurten osuus prosentteina maanpäällisestä fytomassasta Kivesvaaralla, Havaksen *(1972),* Mälkösen *(1973),* Nykvist*in (1971),* Baskerville*n (1965),* Weetman *ja* Webber*in (1971) ja* Heller*in (1971) mukaan.*

	Kivesvaara	Havas	Mälkönen	Nykvist	Baskerville	Weetman and Webber		Heller		
Latitude .... *Leveysaste*	64	66	62	60	46	50	47	51	51	51
Age .... *Ikä*	137	220	70	100	42	65	21	43	89	117
Bole wood .... *Runkopuu*	61.7	74.5	76.2	76.3	63.7	78.4	62.7	72.7	78.5	81.0
Branches .... *Oksat*	29.5	18.0	15.9	15.5	17.2	13.8	22.5	16.8	13.4	11.9
Needles .... *Neulaset*	8.3	7.5	7.9	8.2	18.2	7.8	14.8	10.5	8.1	7.1
Roots 5+ cm ... *Juuret 5+ cm*	22.3	25.7	22.2	15.2	28.3	–	16.0			29.3

forest by Weetman and Webber (1971). In this case the proportion of needles corresponds roughly to that found in all the other forests described, but the proportion of branches is lower.

Heller (1971) gives results for *Picea abies* forests of different ages, indicating that the proportion of bole wood increases as the trees become older, and that of branches and needles decreases. He, like the other authors reported here and also Nihlgård (1972), reports generally very much lower values for the proportion of branches in a spruce forest than are obtained from Kivesvaara. Heller (1971) also notes that the amount of roots increases with age, while E. K. Kalela (1949) states that the root system of the spruce continues to grow up to the age of at least 130 years, growth slowing down beyond this point. In this respect the proportion of roots in the 250 year-old spruce forest studied by Havas (1972) is higher than that in the 137 year-old forest at Kivesvaara.

The results from Kivesvaara fit in well at many points with the other reports cited here for comparison. A larger phytomass tends also to produce relatively more bole wood, and the proportion of the latter increases at the expense of the branches and needles as the forest advances in age. The other forests cited may well be pure spruce forests, but at Kivesvaara one finds some pine and birch too, though admittedly in small amounts (Table 1). There is one obvious discrepancy in the Kivesvaara results: the disproportionately high representation of branches. The proportion of small branches and twigs is 3.6 %, which obviously includes large amounts of branch and twig fragments which have been deposited on the ground over the years leading up to cutting. The phytomass figure also contains dead branches which may have formed part of the annual litter before cutting, though the proportion of these is extremely small. This litter which has not yet undergone decomposition may cause a noticeable increase in the figures for the amount of branch material.

The most telling factor involved in the large amount of material from branches is nevertheless obviously the ditching of the forest in strips at a time preceding cutting (Fig. 1). Naturally, no one would fell trees over these ditches, and the estimates of the areas of the sample plots concern only those of the strips between the ditches. This gives an accurate result as far as the distribution of nutrients is concerned, since the aim is to compare the soil nutrients in the different experimental plots. The determination of the phytomass, calculated as a function of area, however, is somewhat misleading, this tending to be emphasized in the case of the branches especially. If we allow a corridor 5 m broad to represent the ditch in each case and calculate an approximate value for the ratio between the strips of forest and the total area under the trees, taking into account the ditches, we obtain a figure of 0.7. This would reduce the value for the proportion of branches in Table 11, for example, to approx. 20 %. On this basis, and taking into account at the same time the relatively large annual volume of litter in a coniferous forest, which was not distinguished separately in this analysis, we are left with results which are very much more clearly comparable with the other material. It is very difficult, however, to obtain a true impression of the extent to which a factor of this sort may be of significance in the case of each forest component separately. One should nevertheless emphasize the overall correctness of the values obtained relative to the areas of the experimental plots, for it is figures of this kind that the work is principally aiming at.

An examination of the distribution of dry matter in the trees in relation to the utilization of the timber yields the following ratio:

Exploitable phytomass	48,600 kg/ha
Unexploitable phytomass ...	56,800 kg/ha
Total	105,400 kg/ha

The unexploitable wood involved here naturally includes a large amount of quite useless material such as part of the stump and the roots (cf. also Tables 4, 5). The mass of wood remaining behind in the forest is altogether quite considerable, however, and a great deal of research has gone into the possibilities of utilizing this (cf. Hakkila 1972 a, 1972 b, 1974 a).

5.2. Distribution of nutrients

The statistical variation in the nutrient figures was extremely large in the case of a number of forest components, and although the size of the total material may be considered reasonable, the number of analyses performed for each component was still too small. There are also two other facts which contribute to this variation. Firstly the *natural fluctuation* between habitats, and secondly the tendency for this effect to be accentuated in a small material. This partly results from the fact that insufficient homogenized material was available when preparing the dried samples. The wood from the top of a tree trunk may well contain very much higher concentrations of nutrients in the area immediately beneath the bark than in the heart of the trunk, and similarly changes may occur in the quality of the wood dependent on whether the tree is entirely healthy or not, and such factors may affect the results of the analyses. Insufficient attention was paid to the homogenization of a large enough sample of phytomass at the preparation stage, nor would such a process have been possible for *technical reasons*. These factors lead to a certain unreliability in the results, but when the subsequent calculations are to be based on average figures, then the differences in nutrient content may be said to be reflected reliably in the results. Special attention obviously needs to be paid to the elimination of the sources of error discussed above when planning any further studies of this kind.

Two facts need to be borne in mind when comparing the proportions of nutrients obtained in this work with those reported elsewhere. Environmentally distinct growing conditions give rise to differences in the utilization of nutrients, while the timing of the experiment may also affect the results. *Secondly, particular features* of the soil status may affect the amounts of nutrients involved in the cycle, even though the plant species involved possesses consistent physiological requirements, and may be reflected in the results. The amounts of nutrients contained in the various components of the phytomass at Kivesvaara and in the material studied by NYKVIST (1971) are depicted in Table 12.

The forest studied by NYKVIST (1971) contains twice the total phytomass of the Kivesvaara forest, so that a direct relationship would presuppose a doubling of the values throughout. The distribution of the phytomass amongst the forest components, however, is by no means identical, the proportion accounted for by the roots being very much greater at Kivesvaara, as is typical of more northerly forests (HAKKILA 1972 a). Since the concentrations of nutrients in the various forest components also differ considerably, this leads to an extremely complex pattern of results.

Table 12. Nutrient concentrations (kg/ha) in the various phytomass components at Kivesvaara and in the material of NYKVIST (1971).

Taulukko 12. Ravinnemäärät kg/ha fytomassan eri osissa Kivesvaaralla ja NYKVISTin (1971) mukaan.

Nutrient *Ravinne*	Bole wood *Runkopuu*		Aerial phytomass *Maanpäällinen fytomassa*		Stumps and roots *Kanto- ja juuripuu*		Total phytomass *Kokonaisfytomassa*	
	Kivesvaara	NYKVIST	Kivesvaara	NYKVIST	Kivesvaara	NYKVIST	Kivesvaara	NYKVIST
N	44	112	176	368	30	42	206.8	427
P	3.1	9.9	23.6	35.0	4.2	4.4	27.8	40.5
K	35.0	57.9	84.1	159.6	28.6	17.5	112.8	190.0
Ca	110	212	337	456	59	31	396	512
Mg	8.5	16.8	24.5	47.6	5.4	4.8	29.9	55.2
Mn	12.9	35.0	39.1	87.6	4.6	4.9	43.8	96.3

The expected occurrence of roughly half the amounts of nutrients at Kivesvaara is most clearly realized in the case of total phytomass, where the amounts of nitrogen and manganese remain below half those in Nykvist's material (1971), but the other nutrients exceed one half. The amounts of nutrients in the stumps and roots are similar at both sites, those of potassium and calcium even being higher at Kivesvaara. High proportions of these nutrients are also found within the bole wood and aerial phytomass. The amount of nitrogen in the aerial phytomass corresponds to a half of that recorded in the comparative material, while that in the bole wood represents a third of this latter figure. Aarnio (1935) maintains that the nitrogen content of the humus in areas of schist-type bedrock is higher than in areas with a basic bedrock-type. One might thus argue that nitrogen would therefore be utilized more intensively in basic bedrock areas. A comparison of the leptite rock of Nykvist's area with the predominance of calcium, magnesium and potassium at Kivesvaara leads us to conclude that the explanation does indeed lie in the nature of the bedrock, and in particular in its mineral composition.

While the proportion of granitic rocks is admittedly high, a considerable amount of basic rocks and schists are also to be found (Table 10), while at the same time the tills of the area posses a high clay content (Kubin 1975). According to Salminen (1931) the concentrations of soluble calcium, magnesium, potassium and phosphorus in clays are higher in areas with a bedrock containing basic rocks and schists than in areas of granitic bedrock.

Relatively smaller concentrations of nutrients are contained in the bole wood than in the other phytomass categories (Table 13). At Kivesvaara the bole wood accounts for 58.3 % of the aerial phytomass and 46.1 % of total phytomass (Table 4). The corresponding figures given by Nykvist (1971) are 76.3 % and 65.0 %, and those of Nihlgård (1972) 86.4 % and 71.3 %. These figures serve to illustrate the lower yield of bole wood at Kivesvaara, even though the forest studied by Nihlgård was a 55-year-old planted spruce forest. In all the works mentioned above, however, the proportions of nutrients in the bole wood are markedly lower than the phytomass proportions represented by this category.

The proportions of nutrients in the bole wood are a few percentage points lower at Kivesvaara than at the sites studied by Nykvist (1971) and Nihlgård (1972), with

Table 13. Nutrient concentrations in the bole wood as percentages of aerial and total phytomass at Kivesvaara and in the work of Nykvist (1971) and Nihlgård (1972).

Taulukko 13. Runkopuun sisältämät ravinnemäärät prosentteina maanpäällisen ja kokonaisfytomassan ravinnemääristä Kivesvaaralla, Nykvistin (1971) ja Nihlgårdin (1972) mukaan.

Nutrient *Ravinne*	Concentration in bole wood as % of that in aerial phytomass *Runkopuun ravinteet %:na maanpäällisen fytomassan ravinteista*			Concentration in bole wood as % of that in total phytomass *Runkopuun ravinteet %:na kokonaisfytomassan ravinteista*		
	Kivesvaara	Nykvist	Nihlgård	Kivesvaara	Nykvist	Nihlgård
N	24.9	30.8	35.1	21.3	26.2	31.3
P	13.0	28.3	32.8	11.0	24.4	30.7
K	41.6	36.2	39.3	31.0	30.5	34.3
Ca	32.7	46.4	61.7	27.8	41.4	56.2
Mg	34.8	35.3	56.2	28.5	30.4	48.8
Mn	33.0	40.0	58.1	29.5	36.3	52.5

the sole exception of potassium. These lower values at Kivesvaara are clearly due to the lower proportion of the biomass entailed in the bole wood, while this fact only serves to emphasize further the high concentration of potassium in the bole wood at Kivesvaara. The proportion of phosphorus at Kivesvaara is extremely low. The figures obtained for the young planted spruce forest (NIHLGÅRD 1972) differ considerably from those for the two older spruce forests.

MÄLKÖNEN (1973) gives a figure of 1.6 for the ratio of the volume of bole wood to that obtained by whole-tree harvesting, and a corresponding figure for Kivesvaara would be 2.0. In terms of nutrient content, the ratios for Kivesvaara and for MÄLKÖNEN'S material (1973) would be the following:

	Kivesvaara	MÄLKÖNEN
N	4.3	3.9
P	8.6	4.8
K	2.9	3.4
Ca	3.3	2.2

The figures are broadly consistent, with the exception of those for phosphorus, the loss of which would be multiplied by a factor of 4.8 in whole-tree harvesting according to MÄLKÖNEN'S figures, but by a factor of 8.6 at Kivesvaara. In the case of the other nutrients, the loss involved in whole-tree harvesting would be 2–4 times as great as that experienced by the conventional methods. Nevertheless the nutrient depletion due to harvesting still remains a relatively minor figure alongside the reserves of soluble nutrients in the soil, the one exception being the case of nitrogen, which occurs in the wood to an extent many times greater than that represented by its combined occurrence in ammonium and nitrate compounds in the soil (Table 9). On the other hand, large quantities of nitrogen are present in the humus layer, but in a form in which the plants are unable to utilize it (HESSELMAN 1926). Considerable ecological significance has been assigned to the various organisms capable of binding nitrogen in humus soils poor in this element (SUNDSTRÖM and HUSS 1975), and the addition of carbohydrates such as cellulose to the soil has been shown to stimulate the activity of such organisms and lead to a quantitative increase in their occurrence (KALININSKAYA 1972). It has also been shown (POPOVIC 1975) that more inorganic nitrogen accumulated in humus material in a clear-cut area than in reference forests. Similarly, algae capable of binding nitrogen have been identified in soil (HENRIKSON et al. 1972). Many factors have been found to lead to a shortage of available nitrogen in the humus layer, one of which is the type of litter present (HESSELMAN 1926). Less attention has been paid, however, to the leaching of nitrogen compounds into the accumulation horizon of a podzol soil, even though TAMM and HOLMEN (1967) suggest that as much as five times the amount of nitrogen may be found in this horizon as in the humus layer. A further cause of the lack of nitrogen in the humus layer may be the apparently rapid leaching of nitrogen compounds into the surface and ground water (TAMM et al. 1974, WIKLANDER 1974). It may also be that some nitrogen is once more bound in a non-available form. It would be an extremely interesting, though difficult, piece of research to study the extent to which the large quantities of nitrogen compounds released by clear cutting, for instance, are bound in the soil, or collect in the accumulation horizon. Other studies have similarly found that an extremely large proportion of the nitrogen is involved in the nutrient cycle (Table 14).

A comparison of these data proves of particular interest, even though it is complicated both by the differences between the areas studied and by the varying depths of the soil horizons analysed. MÄLKÖNEN (1973) claims that whole-tree harvesting removes greater quantities of all the nutrients than are entailed in the exchangeable nutrient potential of the local soil. Thus, whereas the calcium content of the bole wood as a proportion of that of the soil is 16 % at Kivesvaara, MÄLKÖNEN'S figure is 105 %. In the case of calcium WEETMAN and WEBBER (1972) also reach similar results to those of MÄLKÖNEN. In the present work the amounts of nutrient contained in the aerial phytomass are very frequently greater than the corresponding amounts of soluble nutrients in the soil. The soil horizon at Ki-

Table 14. Nutrient concentrations in the bole wood (A) and the aerial phytomass (B) as percentages of exchangeable nutrients in the soil at Kivesvaara and in the work of WEETMAN and WEBBER (1972) and MÄLKÖNEN (1973). Soil nitrogen at Kivesvaara is calculated as the sum of that present in ammonium and nitrate compounds, that reported by WEETMAN and WEBBER as exchangeable NH_4-N.

Taulukko 14. Runkopuun (A) ja maanpäällisen fytomassan (B) ravinteiden prosentuaalinen osuus maan vaihdettavissa olevista ravinteista Kivesvaaralla, WEETMAN *ja* WEBBERin *(1972) ja* MÄLKÖSEN *(1973) mukaan. Maaperän typen määräksi on laskettu Kivesvaaralla ammonium- ja nitraattitypen yhteismäärä,* WEETMAN *ja* WEBBERin *mukaan vaihtokelpoinen ammoniumtyppi*

Source *Tutkimus*	Kivesvaara		WEETMAN and WEBBER				MÄLKÖNEN	
Soil depth *Maanpeite*	43 cm		35 cm		26 cm		Humus and 0—30 cm *ja*	
Nutrient *Ravinne*	A	B	A	B	A	B	A	B
N	345	1387	197	771	558	2724	—	—
P	5	34	39	139	205	940	49	239
K	16	38	19	64	73	246	33	112
Ca	16	47	221	621	128	353	105	234
Mg	8	24	17	55	48	126	—	—

vesvaara was analysed to a depth of 43 cm, which even so is shallower than that encompassed by the root systems as a whole (KUBIN 1975). The nutrient loss entailed in harvesting is thus very much smaller in relation to the reserves of soil nutrients than the figure given here would suggest.

The results as a whole indicate (Table 14) that the proportion of nutrients involved in the nutrient cycle may be higher than that represented by the corresponding nutrient reserves in a relatively deep soil horizon. One should nevertheless ask to what extent the nutrient values obtained in the soil

Table 15. Concentrations of nutrients in bole wood as percentages of dry weight at Kivesvaara and in the work of HAVAS (1972) and REMEZOV & POGREBNYAK (1969).

Taulukko 15. Runkopuun ravinteiden osuus prosentteina kuivapainosta Kivesvaaralla, HAVAKSEN *(1972) ja* REMEZOV *ja* POGREBNYAKin *(1969) mukaan.*

Nutrient *Ravinne*	Kivesvaara	HAVAS	REMEZOV and POGREBNYAK
Ash — *Tuhka*	0.87	1.13	—
N	0.09	0.13	0.07
P	0.01	0.02	0.02
K	0.07	0.07	0.06
Ca	0.23	0.24	0.16
Mg	0.02	0.03	0.02
Fe	0.002	—	0.005
Mn	0.03	—	0.02

analyses correspond to the amounts which the plants are able to utilize in practice.

It is also possible to calculate the nutrient concentrations as proportions of phytomass, in which case the percentages obtained are generally extremely small (Table 15).

The results compared here are to a very great extent in agreement with one another. No major deviations are found between the present results and those of HAVAS (1972), and the only major discrepancy in relation to those of REMZOV and POGREBNYAK (1969) consists of the higher value for calcium at Kivesvaara, which may well be due to the proportion of basic rocks and schists in the local bedrock.

Various approaches have been used above to examine the distribution of nutrients at Kivesvaara in relation to corresponding results obtained elsewhere. In the following a more detailed study will be made of the distribution of nutrients in the needles (Table 16).

The values for P, K and Mg in the litter and felling waste are lower than those for the live trees both at Kivesvaara and in the results presented by NYKVIST (1971). At Kivesvaara the proportion of manganese increases and that of nitrogen falls, though the latter increases in NYKVIST'S results. Noticeably higher values are to be found for ash and calcium both in litter and in felling waste. NYKVIST also provides figures for the fermentation horizon F, and dead needles taken from this layer show a clear drop in calcium values *once* more. The results presented by TAMM (1971) for standing trees are in accord with the Kivesvaara figures as far as nitrogen, phosphorus and magnesium are concerned, whereas the proportions of manganese, potassium and calcium are higher than at Kivesvaara. REMEZOV and POGREBNYAK (1969) provide figures for analyses from different soil types, and the proportions of nutrients reported remain basically similar to those discussed above, though minor variations do occur.

Table 16. Distribution of nutrients in needles as percentages of dry weight at Kivesvaara and in the work of NYKVIST (1971), TAMM (1971), REMEZOV and POGREBNYAK (1969) and HAVAS (1972).

Taulukko 16. Ravinteiden jakautuminen neulasissa prosentteina kuivapainosta Kivesvaaralla, NYKVIST*in (1971),* TAMM*in (1971),* REMEZOV *ja* POGREBNYAK*in (1969) ja* HAVAKSEN *(1972) mukaan.*

Nutrient *Ravinne*	Kivesvaara		NYKVIST			TAMM	REMEZOV and POGREBNYAK		HAVAS
	Needles from live trees *Neulaset elävistä puista*	Needles from waste wood *Neulaset hakkuujätteestä*	Needles from live trees *Neulaset elävistä puista*	Needles in litter *Neulaskarike*	Needles in F horizon *Neulaset F-kerroksesta*	Needles from live trees *Neulaset elävistä puista*	Needles from live trees *Neulaset elävistä puista*		Needles from live trees *Neulaset elävistä puista*
Ash *Tuhka*	4.51	5.53	5.16	7.05	8.02	—	—	—	3.23
N	1.07	0.97	1.04	1.18	1.38	1.15	1.12	1.15	0.90
P	0.15	0.11	0.10	0.09	0.09	0.15	0.21	0.11	0.21
K	0.52	0.26	0.43	0.09	0.07	0.62	0.61	0.55	0.53
Ca	0.80	0.93	0.80	0.89	0.51	0.58	0.34	0.75	0.61
Mg	0.11	0.08	0.10	0.04	0.04	0.10	0.10	0.10	0.08
Fe	0.004	0.01	—	—	—	—	0.01	—	—
Mn	0.13	0.16	0.24	0.15	0.13	0.03	0.12	0.10	—

The results of HAVAS (1972) are comparable with the present ones, with the exception of the lower ash content.

MIKOLA (1955) states that yellow needles still attached to the tree contain only 0.4 % nitrogen by dry weight, but 9.3 % ash, findings which are entirely at variance with those presented above, while VIRO (1955) suggests that magnesium, potassium and phosphorus concentrations decline with age in needles, the nitrogen content remains almost constant and the proportions of calcium and ash increase. AALTONEN (1950) similarly observes an increase in ash and calcium in needles upon ageing, with a corresponding decline in potassium, phosphorus and nitrogen, while the proportion of magnesium remains practically the same. HAVAS (1975) puts forward the idea that the xeromorphic needles of evergreens are low in nitrogen and possess poorer powers of photosynthesis than the more mesomorphic green parts, which are at the same time more sensitive to cold. It thus appears that the capacity of the needles for photosynthesis declines with age as they become more resistent to cold year by year, while at the same time a decline is observed in nitrogen content.

Although the material from Kivesvaara does not include any analyses of needles of differing age, the differences between the standing trees and the felling waste point very much in the same direction as those reported in connection with the age factor. Two reasons may be suggested for this correspondence. Firstly, the litter always contains some needles of greater age, and the proportion of these in the sample may be considerable. Similarly, samples taken cumulatively will contain a greater proportion of older needles. Secondly, it is also possible that the physiological changes taking place in the needles when the tree dies may be accelerated versions of those occurring in standing trees as the needles age, and may exercise a corresponding effect upon the proportions of nutrients. One also finds leaching of both organic and inorganic substances from the needles contained in the forest litter (NYKVIST 1959).

Fungi are at least as important in the decomposition process in firm forest lands as micro-organisms are in herb-rich forests (MIKOLA 1957), and major changes may occur in the pattern of decomposition as a consequence of cutting. The higher temperatures on the open ground, especially where the soil has been turned (LEIKOLA 1974 b) serve to stimulate bacterial action. This is without doubt a decisive factor in the fate of those nutrients which are released rapidly from the needles and are then utilized in the metabolism of the bacteria and saprophytic fungi. When large quantities of these nutrients are available the result is a rapid increase in the bacteria present, and it is through the action of these organisms that the nutrients bound in the wood are released for use by the local vegetation. The result of whole-tree harvesting is that these nutrients are only released from the plant litter, humus and mineral soil, and under these conditions it may be that the rate of mineralization of the nutrient reserves present in the humus layer will be decisive for the early development of the young seedlings.

The distribution of nutrients between the various phytomass categories within the tree is principally a function of the physiological properties and processes operative in the tree itself. Subsidiary factors include those associated with the habitat, e.g. location, topography, climate, humidity, bedrock type or soil structure. It is variations in these factors, together with the age of the forest, which bring about the differences observed in the occurrence of nutrients. Differences were observable in the amounts of nutrient in the different phytomass components (Table 12), the amounts in relation to the nutrients contained in the bole wood (Table 13) and even in the ability to utilize the nutrients (Table 14). The influence of the local bedrock is also clearly distinguishable in the comparison of the nutrients contained in the needles (Table 16).

In view of the distinctions between the habitats examined, these comparisons suggest that the Kivesvaara results may be considered comparable with those reached in other experiments, and this provides the theoretical basis for the examination of the effect of cutting upon the nutrient status of the forest area, though principally only upon the amounts of nutrients present, for it is well-known that changes occur in many physical parameters as a result of cutting, and these may then exercise a considerable influence upon the nutrient status, especially as far as the utilization of the nutrients is concerned.

As was noted at the outset, clear cutting is a procedure which occasions major changes in the ecology of a forest. If one concentrates on the trees alone, it can be seen that the whole nutrient cycle operating in this phytomass is ruptured at the moment of cutting, while at the same time major external changes also take place in the creation of an area of open ground. Thus a major redistribution occurs in the amounts of nutrients contained in the phytomass represented by the forest trees as a result of cutting and the harvesting of the wood (Table 17).

As may be seen from the Table, 214.7 kg/ha of the nutrients studied here are removed from the forest as a result of cutting, while about double this amount remains behind in the surface waste wood, and an amount equivalent to 50 % of the nutrient loss remains in the stump and root material. Thus the total nutrient loss amounts to approx. one fifth of that contained in the phytomass. The loss upon cutting is equivalent to 12.4 % of the soluble nutrient reserves in the soil, or 37.9 % upon the removal of all the aerial phytomass (Table 9). Thus the effect of cutting upon the amounts of nutrient present may be summarized briefly as:

1) a loss of approx. one fifth of the nutrients contained in the phytomass,

2) a nutrient residue in the waste wood and roots which is several times greater than that which is lost in harvesting, and

3) the removal of the total aerial phytomass would deprive the forest of approx. 70 % of its nutrients.

It is very difficult to estimate accurately the extent to which the nutrients contained in the waste wood are released for utilization by the local vegetation and young seedlings, but it may be said to depend essentially upon two factors:

Table 17. Phytomass and nutrients contained in the harvested wood, surface waste wood with needles and stump and root material (kg/ha).

Taulukko 17. Korjatun puun, maanpäällisen jätepuun neulasineen sekä kanto- ja juuripuun fytomassa ja ravinteet (kg/ha).

Nutrient *Ravinne*	Removed in the harvested wood *Poistuma*	Remaining in the waste wood *Jätepuussa*		Total *Yhteensä*
		Aerial waste wood *Maanpäällinen jätepuu*	Stumps and roots *Kanto- ja juuripuu*	
Phytomass .... *Fytomassa*	48618	34748	22000	105366
Ash — *Tuhka*	423.2	969.2	284.5	1676.7
N	44.0	132.4	30.4	206.8
P	3.1	20.5	4.2	27.8
K	35.0	49.1	28.6	112.7
Ca	110.2	226.8	58.9	395.9
Mg	8.5	16.0	5.4	29.9
Fe	1.0	2.0	1.4	4.4
Mn	12.9	21.5	4.6	39.0
N—Mn	214.7	468.3	133.5	816.5

1) the process of decomposition and the organisms which promote this, which are in turn regulated by numerous external factors such as illumination, temperature, the type of waste wood, etc., and

2) leaching of the decomposition products. In addition it should be mentioned that the roots and stumps are slow to decompose, as also is some of the thicker surface waste wood, so that the nutrients in these components are released only after a lengthy time interval.

5. 3. The soil as a source of nutrients

The soil in the area contains relatively large quantities of plant nutrients (Table 19) in comparison with the results reached by Viro (1967) for Southern Finland, for example. The depth of soil analysed, being the average depth of the soil horizon, was 43 cm.

Among the nutrients determined from the phytomass, only nitrogen and manganese in the aerial phytomass exceeded the quantities present in the soil. Three times the amount of nitrogen present in the soil in ammonium and nitrate compounds is removed from the site in the marketable bole wood (Table 9). In the case of the other nutrients greater amounts are always available in the soil than are involved in the nutrient cycle.

Table 18. Plant nutrients present in the 43-cm-thick soil horizon including humus at Kivesvaara in the work of Kubin (1975).

Taulukko 18. Kivesvaaran tutkimusalueen maaperän kasviravinteet Kubin*in (1975) mukaan kg/ha 43 cm paksussa maakerroksessa humus mukaanlukien.*

Nutrient — *Ravinne*	kg/ha
NH_4-N + NO_3-N	12.6
P	68.7
K	224.3
Ca	701.2
Mg	102.8
Fe	588.1
Mn	32.9

The relations between the nutrients utilized by the plants, and also between those stored in the soil, form a complex pattern which constitutes one part of the biological cycle of nutrients. The values obtained by analysis may depart markedly from those amounts which the plant is actually capable of taking up, while in turn the acceptance of nutrients by plants is dependent upon seasonal factors such as illumination and temperature. Thus the mere examination of amounts of nutrient is insufficient even to account for local growing conditions.

In the evaluation of whole-tree harvesting it is the removal of nitrogen and phosphorus which constitutes the most dangerous nutrient depletion factor in areas of low fertility (Weetman and Webber 1971, Mälkönen 1973). A considerable proportion of the nitrogen reserves are bound in inaccessible forms in the raw humus, as was established by Hesselman (1926), while in any case the proportion of nitrogen compounds identified at Kivesvaara was by no means large (Table 18). The proportion of phosphorus at Kivesvaara was low compared with the figures obtained in other studies. This may be partly the result of its precipitation with iron in a practically insoluble form even in the pH 5–6 area (Teuscher et at. 1960), as the pH figure for the accumulation horizon at Kivesvaara was still 5.16 (Kubin 1975). This would indicate that part of the phosphorus originated in the area of the deeper 'extensive root zone' (Ulrich et al. 1971), and thus would be insufficient, since the lower branches of the root systems here extend down to a depth of only 50–70 cm from the surface of the mineral soil. A number of different biological processes may play an important part in the supply of phosphorus, for it is known at least that the concentration of soluble phosphorus increases during the summer months (Kubin 1975).

The relatively high fertility of the soil of this area is due primarily to the mineral content of the bedrock, and to a major extent to the occurrence of basic rocks and schists (Table 10). The nutrients are also relatively evenly distributed throughout the soil, so that no substantial differences are to be found in the nutrient concentrations in the phytomass.

6. SUMMARY

The purpose of this paper was to determine the proportions of nutrients remaining in the forest and removed from the forest as a result of cutting. The surface logging waste was studied in detail in the categories of tree-top waste, branches, twigs, needles and cones. The figures reported for the volumes of harvested bole wood were converted to kilogrammes on the basis of the basic density of the wood, while the amount of stump and root material was estimated from the known amount of bole wood.

The nutrients studied were N, P, K, Ca, Mg, Fe and Mn, and in addition ash content was determined. The proportions contained in the wood and bark were investigated separately. The nutrient content of the needles in the logging waste was compared with figures obtained from needle samples from standing trees. The proportions of nutrients contained in the phytomass of the spruce trees were also examined in relation to those in the soil, and by reference to the mineral composition of the local bedrock.

The conclusions reached were the following:

— Only just under a half of the total phytomass was harvested, while the surface waste wood accounted for a third of the total phytomass and the stump and root material a fifth.

— The nutrients were distributed unevenly within the phytomass, with the needles and bark containing a relatively higher proportion. The needles contained 32 % of the N content of the total phytomass and 26 % of total phosphorus. At the same time the surface waste wood contained more than twice as much nutrient as the harvested bole wood, and more than three times as much as the stump and root material.

— Approx. one fifth of the total nutrients in the phytomass were removed on harvesting. The amount of nutrient remaining in the waste wood and roots was three times this figure.

— The in many ways superior nutrient status of this forest in relation to the results of other investigations, and also the relatively high fertility of the soil, may be explained by the proportions of basic rocks and schists in the mineral composition of the bedrock.

— The amounts of nitrogen involved in the nutrient cycle were many times greater than that contained in the soil in the form of ammonium and nitrate compounds.

The effect of different intensities of harvesting upon the nutrient status of the forest was considered in the Discussion, the chief nutrients which would be removed if the waste wood were harvested being nitrogen and phosphorus. It was also found necessary to discuss those factors which affect the amounts of nutrient released during the decomposition process, and these are found to be largely dependent upon the saprophytic organisms present and the circumstances which regulate their activity. The proportion of the available nutrients which the seedlings and shrub vegetation are able to utilize depends both on their intake capacity and on the extent of leaching.

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SELOSTE:

PALJAAKSIHAKKUUN VAIKUTUS KUUSIMETSÄN RAVINNETILAAN POHJOIS-SUOMESSA (64°28′ N)

Paljaaksihakkuun seurauksena metsikön lukuisat kasvutekijät muuttuvat. Avoalojen metsittäminen kohtaa erityisiä vaikeuksia varsinkin Pohjois-Suomessa, missä äärevien ilmastosuhteiden lisäksi kasvukauden lyhyys huonontaa uudistamistulosta. Metsänviljelyssä on kiinnitetty nykyisin enemmän huomiota maaperän ominaisuuksiin kasvualustana. Kivesvaaran koekentällä tutkitaan erilaisten maanparannusmenetelmien vaikutusta kasvutekijöihin. Työ on metsäntutkimuslaitoksen Pyhäkosken tutkimusaseman ja Kajaani Osakeyhtiön yhteistyötä johon Oulun yliopiston kasvitieteen laitos osallistuu.

Tässä osatutkimuksessa selvitetään hakkuutähteiden eri osien määrää ja niissä olevia ravinteita. Hakkuuta edeltäneiden vuosien karikesatoa ei voida erottaa, mutta kun tarkoitus on selvittää missä määrin kuusen fytomassaa ja ravinteita poistui ja jäi koeruuduille, tästä ei johdu virhettä hakkuutähteen lannoitevaikutusta arvioitaessa. On kuitenkin syytä korostaa, että hakkuuta edeltänyt vielä hajoamaton luontainen karikesato on tässä lisänä varsinaisen hakkuujätteen määrässä. Vaikka tutkimus on Kivesvaaran koekentän mukainen, se on samalla lisä siihen ongelmakenttään jossa tarkastellaan paljaaksihakkuun ja kokopuunkorjuun vaikutusta metsikön ravinnetilaan.

Hakkuujätteen määrä selvitettiin tutkimalla erikseen latvarunkopuun, oksien, pikkuoksien, neulasten ja käpyjen määrät. Aarin näytealoja oli 11. Jokaisesta tutkittiin erikseen viisi yhden neliömetrin alaa (kuva 1). Pikkuoksien ja neulasten määrittämiseksi tutkittiin vielä jokaiselta neliömetrin alalta viisi 10 × 10 cm alaa irroittamalla osa kunttaa erityisen kehikon avulla (kuva 2). Kuivattamisen jälkeen näytteestä erotettiin neulaset ja pikkuoksat. Tutkittuja ravinteita ovat N, P, K, Ca, Mg, Fe ja Mn. Runkopuun määrä saatiin Kajaani Oy:n mittausten mukaan. Kanto- ja juuripuun määrä arvioitiin käyttäen perustana Kivesvaaralta tunnettua runkopuun määrää. Kuusen suuresta osuudesta johtuen (taulukko 1) työssä keskityttiin yksinomaan siihen. Aluskasvillisuuden osuutta ei selvitetty.

Fytomassan määrä ja jakautuminen on esitetty taulukoissa 4 ja 5. Poiskorjattua eli hyötyrunkopuuta oli huomattavin osa kokonaisfytomassasta. Maanpäällistä jätepuuta oli kolmannes, kanto -ja juuripuuta viidennes kokonaisfytomassasta. Maanpäällistä jätepuuta jäi metsään 70 %, kanto ja juuripuuta 45 % poiskorjatun puun määrästä.

Ravinteiden jakautumista suhteessa maanpäällisen fytomassan ravinteisiin on esitetty kuvassa 3 sekä suhteessa kanto- ja juuripuun ravinteisiin kuvassa 4. Hyötyrunkopuun ravinteiden osuus maanpäällisessä fytomassassa olevista ravinteista vaihteli alhaisimmillaan 13 % (P) ja suurimmillaan 42 % (K). Kanto- ja juuripuun sisältämiin ravinteisiin nähden hyötyrunkopuun mukana poistui suurempia ravinnemääriä mitä jäi kanto- ja juuripuuhun. Poikkeuksen tekivät fosfori ja rauta, joita molempia oli kanto- ja juuripuussa määrällisesti enemmän vaikka fytomassan osuus oli vajaa puolet hyötyrunkopuun määrästä.

Ravinteiden yksityiskohtainen jakautuminen kokonaisfytomassassa on esitetty kuvassa 5. Kuori sisälsi yleensä runsaasti eri ravinteita. Hakkuutähteen ravinteista huomattavin osa oli neulasissa jotka ovat kuoren ohella koko fytomassan ravinnerikkain komponentti. Erityisesti typen, fosforin ja mangaanin osuudet neulasissa olivat suuret kalsiumin enemmyyden korostuessa puolestaan kuoressa. Verrattaessa hakkuujätteen ja pystypuiden neulasten ravinteita (taulukko 8), osoittautui että varsinkin typpeä, kaliumia ja mangaania oli hakkuutähteissä vähemmän kuin elävissä neulasissa.

Avoalalle jäävien ravinteiden osuudet puunkorjuussa poistuvista ravinteista on esitetty kuvassa 6. Erityisesti fosforin mutta myös typen osuus hakkuutähteessä oli huomattava neulasten ollessa ravinteisin komponentti. Neulasissa olevan typen osuus oli kokonaisfytomassan typestä 32 %, fosforin 26 %. Perinteisin menetelmin suoritettu puunkorjuu ei muodosta uhkaa metsikön ravinnevaroihin. Siirryttäessä kokopuunkorjuuseen ravinneköyhillä mailla ravinteiden poistuma on ilmeisen pakko korvata lannoituksella. Maaperän laadun ohella mineraalivarojen rapautuminen kasveille käyttökelpoiseen muotoon ratkaisee vasta lopullisesti ravinnepoistuman haitallisuuden. Raakaan kangashumukseen sitoutuneen typen mineralisoitumisella on tässä suhteessa varsin keskeinen merkitys (vrt. taulukko 9). Tutkimusalueen kivistä pääosa oli graniittisia. Emäksisten kivien ja liuskeiden osuus oli myös huomattava (taulukko 10).

Tutkittujen ravinteiden kokonaismääräksi saatiin 817 kg/ha josta maanpäälliseen hakkuutähteeseen jäi 469 kg/ha, kanto- ja juuripuuhun 134 kg/ha. Tuhka-aineen kokonaismäärä oli 1677 kg/ha, josta vastaavasti hakkuutähteeseen jäi 969 kg/ha, kanto- ja juuripuuhun 284 kg/ha (taulukko 17). Tuloksista ilmenee että ravinnejäämä koeruuduille on poistumaan nähden moninkertainen. Kokopuunkorjuu ilman kanto- ja juuripuuta veisi 84 % kuusen koko fytomassaan sisältyvistä tutkituista ravinteista korjatun runkopuun osuuden ollessa vastaavasti vain neljännes. Kokopuunkorjuu vähentäisi siten olennaisesti mahdollista ravinnehuuhtoutumaa pinta- ja pohjavesiin, toisaalta poistuisi se huomattava lannoitevaikutus ja suoja, mikä hakkuutähteillä on taimille.

KUBIN, EERO O.D.C. 114.52: 33

1977. The effect of clear cutting upon the nutrient status of a spruce forest in Northern Finland (64° 28'N). — ACTA FORESTALIA FENNICA Vol. 155, 40 p. Helsinki.

The spruce phytomass remaining after clear cutting is studied in detail in the categories of tree-top waste, branches, twigs, needles and cones. The bole wood, measured in solid cubic metres, is converted to kilogrammes on the basis of relative density determinations, and the amount of stump and root material estimated from the known amount of bole wood and comparable data presented in the literature. The nutrients studied are N (Kjeldahl), P (colour reaction), K, Ca, Mg, Fe and Mn (atomic absorption spectrophotometer). The wood and bark are studied separately throughout. Details of the mineral composition of the bedrock are also presented.
The harvested timber is found to account for 46 % of the total phytomass, or 58 % of the aerial phytomass, while the stump and root material represents one fifth of the total phytomass. The needles and bark are found to contain the highest proportions of the nutrients, especially in the case of nitrogen and phosphorus, the needles containing 32 % of total nitrogen and 26 % of total phosphorus. The surface waste wood contained on average more than double the amount of nutrients compared with the harvested bole wood, including more than six times the amount of phosphorus. Approximately one fifth of the nutrient contained in the total phytomass was removed on cutting. The high proportion of basic rocks in the area is suggested as an explanation of the nutrient status at the site, which is in many ways better than that described in the results of other investigations.

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