ACTA FORESTALIA FENNICA

Vol. 139, 1974

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Juhani Päivänen

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Publications of the Society of Forestry in Finland

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NUTRIENT REMOVAL FROM SCOTS PINE CANOPY ON DRAINED PEATLAND BY RAIN

JUHANI PÄIVÄNEN

SELOSTE:

RAVINTEIDEN SIIRTYMINEN SADEVEDEN MUKANA LATVUSTOSTA MAAHAN TURVEMAAN MÄNNIKÖSSÄ

HELSINKI 1974

ISBN 951-651-014-0

Hämeenlinna 1974, Arvi A. Karisto Osakeyhtiön kirjapaino

PREFACE

In the Department of Peatland Forestry, University of Helsinki, forest hydrological studies have been carried out on drained peatlands over a period covering several years. One of the problems studied is the effect of various silvicultural measures on throughfall. Apart from quantitative investigations it seemed reasonable to analyze the chemical properties of the water reaching the ground in the form either of throughfall or of stemflow. Such studies have not been carried out previously in Finland.

The apparatus used for collecting throughfall water was constructed by the author in collaboration with Mr. Eino Mälkönen, Lic. For., who also, in addition to Prof. Leo Heikurainen and Acting Prof. Kustaa Seppälä, read the manuscript. All these persons made valuable suggestions to improve the manuscript. Financial support for the study was obtained from the National Research Council for Agriculture and Forestry. The manuscript was translated from Finnish into English by Mr. Karl-Johan Ahlsved, B.Sc. (For.). I wish to express my sincerest thanks to all the persons and institutions mentioned in the foregoing.

Helsinki, January 1974

Juhani Päivänen

CONTENTS

1. INTRODUCTION

Precipitation brings appreciable quantities of nutrients to the ground (Feilitzen and Lugner 1910, Finnberg 1923, Hansen 1931, Viro 1953, Buch 1960, Haapala 1972). Usually rainwater becomes enriched with nutrients as it penetrates the forest canopy. Nutrients are both leached from the canopy and washed from the surface of leaves and branches (Nihlgård 1970). Eaton *et al.* (1973) use the term net removal to describe the nutrients which are leached from the canopy plus those washed from the surface of leaves, i.e., the net removal = nutrients leached + nutrients washed − nutrients in precipitation. On the other hand, it has been indicated that nutrients can be absorbed into the leaves from intercepted water or taken up by epiphytes on the surface of leaves and branches (Ingham 1950; Tukey *et al.* 1958; Carlisle *et al.* 1966, 1967 a, 1967 b).

Nutrient removal from the canopy of Scots pine (*Pinus silvestris* L.) has been mentioned only briefly in a few papers (Tamm 1951, 1953). In the case of pine stands growing on peat, no information has been published previously on the proportional share of leaching in the nutrient cyclus.

The aim of the present study was to assess the quantity of nutrients reaching the ground, on the one hand, in gross precipitation, and on the other hand, in throughfall and stemflow in pine stands growing on peat. Another aim of the study was to find out whether forest fertilization increases nutrient leaching.

2. COLLECTION AND HANDLING OF DATA

21. Study area and sample plots

The study was carried out in a stand of Scots pine (*Pinus silvestris* L.) in Central Finland (61° 50' N; 24° 20' E). The study area has an altitude of about 150 m above sea level. Annual precipitation averages 600 mm, one half of which is received during the summer months (June-September).

Results from previous studies in the same experimental area have been presented concerning the effect of different silvicultural measures (thinning, clear cutting, fertilizer application) on throughfall, depth of the ground-water table, relative runoff and snow conditions (HEIKURAINEN and PÄIVÄNEN 1970; PÄIVÄNEN 1972, 1973). The study area is located in the central parts of a large forest area, the distance to the nearest human habitations being more than 3 km. There are no public roads in the vicinity, only a forest truck road which ends about 200 m from the study area and which is used primarily by research workers. No aerial fertilization was carried out in the region during the period of the study. Consequently, it may be supposed that no air pollution was brought about during the study period in the vicinity of the area concerned.

The quantities of nutrients brought to the ground with rainwater were studied during the period June 4 – October 4, 1971. Determinations were performed on one unfertilized (sample plot 1) and two fertilized (sample plots 2 and 7; see HEIKURAINEN and PÄIVÄNEN 1970, p. 6, Fig. 1) plots as well as in the open. The area concerned was originally drained in 1912, and drainage has been completed later. The fertilizer, 600 kg/ha of a compound fertilizer containing N, P_2O_5 and K_2O (14–18–10), was applied in 1968 immediately after the snow had melted. The pine stand in which the study was performed is even-aged, and relatively even in structure, too. The volume of the control plot was about 110 m^3/ha at the time of the study, and that of the fertilized plots about 100 (sample plot 2) and 90 m^3/ha (sample plot 7).

Needle samples were collected in late August 1969 and 1971 from five medium-sized trees in each sample plot. The needles were systematically collected from the southern side of the crown from the same whorl of branches. The results from the needle-length determinations performed have been published previously (PÄIVÄNEN 1972, p. 471). The needles collected from the fertilized sample plots were 6–13 mm longer than those from the unfertilized plot. The nutrient contents of the needles will be dealt with later in this paper.

22. Methods of study

In each sample plot, twenty vessels were installed in a systematical pattern for collection of the rainwater to be analyzed. Each collector consisted of a 2-l bottle to which a polyethylene funnel had been attached which had a diameter of 165 mm, or a collecting surface of 214 cm^2 (Fig. 1). A polyethylene net with a mesh size of 1.5 mm was attached to the upper part of the funnel, and a filter socket (Extraktions-Hülse Nr 603, Carl Schleicher & Schüll) was placed in its tapering part. The location of the collectors in relation to the tree crowns and the canopy coverage were determined using Cajanus' tube (see SARVAS 1953).

	Number of collectors within	at the edge of	outside crown projection	Canopy coverage %
Sample plot 1	5	10	5	56
» » 2	6	8	6	55
» » 7	7	8	5	61

The funnels used in the collectors were of different color depending on the location in relation to the crown projection (within the area covered by the crown projection, at the edge of the crown projection, under openings in the canopy). The collectors were emptied and the quantities of rainwater measured every rainy day. The water which had been collected from sampling points representing each of the three locations in relation to the crown projection was stored separately into 20-l polyethylene containers. 10 ml of toluene was added to each container in order to inhibit microbial action (cf. TARRANT *et al.* 1968 a). Moreover, the containers were kept in holes in the peat soil of the sample plots during the summer in order to keep the temperature of the sampled water at a low level.

Stemflow was measured on three stems in each sample plot. The trees were selected so as to represent different size categories (dbh = 10, 13 and 19 cm). The stemflow was led into glass flasks by means of polyethylene collars and polyethylene tubes (Fig. 2). Polyethylene cement was used to make the collar tight. The stemflow, too, was filtered through a filter socket which had been attached to the lower end of the polyethylene tube. Stemflow was measured every rainy day, and it was stored in the same way as the throughfall water.

Precipitation was sampled in an open locality in the vicinity of the sample stands using similar collectors as those used for throughfall sampling. Determinations were based on three replications. The collectors were also checked in the open area, the results showing no statistically significant differences between them and the Lambrecht rain gauge used for comparison.

The water samples were sent for analysis in five portions. Each sampling gave four samples per plot (from under the crown, from the edge of the crown projection, from the canopy opening and on the stemflow) and three samples from the open site. Thus, the number of samples to be analyzed at one time was fifteen. The analyses performed were representative of the following periods of time and gross precipitation values:

Fig. 1. Apparatus for collecting throughfall water for chemical analysis. — *Analysoitavan sadeveden keräämiseen käytetty laite.*

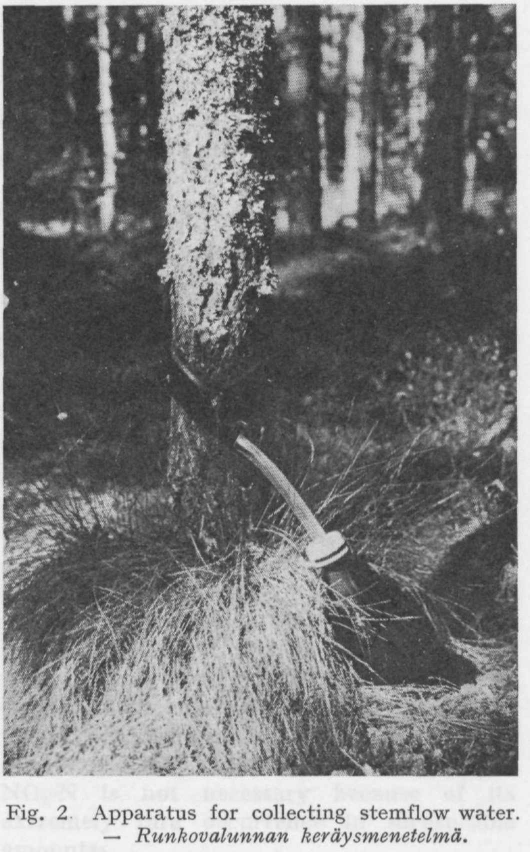

Fig. 2. Apparatus for collecting stemflow water. — *Runkovalunnan keräysmenetelmä.*

Sampling period, 1971	Gross precipitation, mm
June 4 — July 1	23.0
July 2 — Aug. 1	52,6
Aug. 2 — Aug. 24	84,7
Aug. 25 — Sep. 13	55 3
Sep. 14 — Oct. 4	22.4
	238.0

The average precipitation values of the summer months during the period 1931—60 are as follows for the study area: June, 53 mm; July, 77 mm; August, 79 mm; September, 65 mm. Only in the case of the month of August, the study period was more rainy than on average; during the rest of it the precipitation values obtained were below the average. As a whole, precipitation was about 13 % lower during the study period than the average used for comparison.

After each period of sampling, when the collectors were emptied, the vessels were washed using distilled water, and the filter sockets were changed. Likewise, the containers in which the samples had been stored were carefully washed. Litter which had fallen on the nets covering the funnels was removed almost daily.

The water samples were analyzed in the laboratory of Viljavuuspalvelu Oy for the contents of K, P, NH_4-N, NO_3-N and NO_2-N using traditional methods of determination.

3. RESULTS AND DISCUSSION

31. Nutrient contents of gross precipitation

Table 1 shows the average nutrient contents of the rainwater collected from the open area during the study period as three replications.

The average potassium content in the precipitation was slightly smaller than that recorded during the summer months of the same year by the National Board of Waters some 20 km from our study area (cf. HAAPALA 1972, p. 44) and somewhat higher than the average recorded for snow samples collected in 1952 and 1953 from open localities (VIRO 1953, p. 36) Particular attention is drawn by the high potassium content in the precipitation of the month of July in the study area. The potassium content in the precipitation seems to be about one third of that recorded for the water discharged from the Kokemäki watershed area (see LAAKSONEN 1970, p. 22).

The average phosphorus and NO_3-N contents of the summer months were somewhat lower than those recorded by HAAPALA (op. cit.). The differences may be due, however, to the fact that the research station of the National Board of Waters is located in an agricultural area.

Table 1. Average nutrient contents of precipitation at the 5 % risk level for the sampling periods of the study and the means for the whole study period as weighted by the amounts of water collected.
Taulukko 1. Aukean sadannan keskimääräiset ravinnepitoisuudet 95 %:n luotettavuusrajoineen eri keräysjaksoina sekä kerätyillä vesimäärillä punnitut koko tutkimuskauden keskiarvot.

Sampling period *Keräysajanjakso*	K	P mg/l	NH_4-N	NO_3-N
June 4 — July 1 *Kesäk. 4 — Heinäk. 1*	0.77 ± 0.09	0.036 ± 0.030	0.71 ± 0.11	1.12 ± 0.32
July 2 — Aug. 1 *Heinäk. 2 — Elok. 1*	1.73 ± 0.27	0.063 ± 0.060	0.23 ± 0.26	0.37 ± 0.09
Aug. 2 — Aug. 24 *Elok. 2 — Elok. 24*	0.10 ± 0.00	0.043 ± 0.034	0.20 ± 0.00	0.23 ± 0.09
Aug. 25 — Sep. 13 *Elok. 25 — Syysk. 13*	0.05 ± 0.06	0.051 ± 0.048	0.66 ± 0.24	0.13 ± 0.09
Sep. 14 — Oct. 4 *Syysk. 14 — Lokak. 4*	0.11 ± 0.01	0.010 ± 0.000	0.16 ± 0.18	0.27 ± 0.09
Average — *Keskimäärin*	0.55	0.045	0.35	0.33

Apart from the studies mentioned in the foregoing, only few results from nutrient analyses of rainwater have been published in Finland. According to FINNBERG (1923), the ammonia content of rainwater is 0.43 mg/l. BUCH (1960) presents the quantities of nutrients reaching the ground in precipitation in terms of kilograms per hectare of deposited substance, and his findings will be dealt with later in this paper. Studies carried out in Scandinavia show a variation in the nutrient contents of precipitation within more or less the same limits as according to the results of the present study (FEILITZEN and LUGNER 1910; HANSEN 1931; TAMM 1951, 1953).

In a maritime climate, such as that of the western coast of the USA, the content of inorganic nitrogen in precipitation have shown to be extremely small (TARRANT *et al.* 1968 a, 1968 b). In the mountains of the eastern coast, on the other hand, contents of NO_3-N of as much as 1.31 mg/l have been recorded (LIKENS *et al.* 1969, p. 556).

The contents of NO_2-N recorded in the present study were usually smaller than the degree of precision (0.01 mg/l) applied to the determinations. According to TARRANT *et al.* (1968 a, p. 6), too, »determination of NO_2-N is not necessary because of its extremely rare occurrence in measurable amounts».

32. Nutrient contents of throughfall and stemflow

Fig. 3 shows the means as weighted by the quantities of collected water of the nutrient contents in stemflow, in throughfall in different places under the canopy of forest crops and in the precipitation reaching the ground. In the case of potassium, the results obtained are completely clear. The highest potassium contents were obtained for the stemflow, and there was a consistent decrease when moving from under the crowns over the edge of the crown projection into openings in the canopy. The horizontal broken line in the figure indicates the average potassium content in precipitation; it was smaller in every instance than the values obtained for water that reaches the ground in the forest. It seems also that fertilizer application affects the potassium contents of stemflow and throughfall. In the fertilized plots the potassium contents of stemflow and throughfall were more than twofold as compared with the values recorded for the unfertilized plot.

In the case of phosphorus, the contents recorded for stemflow were more than twofold those obtained for throughfall. A decrease of similar regularity as in the case of potassium could not be observed, however, when moving from under the crowns into openings in the canopy and to the open area. The effect of fertilization on the phosphorus contents of stemflow and throughfall was not very distinct either, although the contents were consistently higher in the fertilized plots than in the unfertilized plot.

Tamm (1951, 1953), in the case of Norway spruce (*Picea abies*), has also observed that the contents of potassium and phosphorus in the throughfall increase when moving from open areas and openings in the forest to under the crowns. Other research workers have drawn attention in particular to the liability of potassium to be leached from the canopy (e.g. Will 1955). Studies carried out concerning the nutrient contents of stemflow have usually produced markedly high potassium contents in the case both of conifers and of hardwoods (Mina 1965, Ulrich 1969, Gersper and Holowaychuk 1971, Eaton *et al.* 1973). The corresponding results obtained for phosphorus usually show a much greater variation. Generally speaking, it has been observed that phosphorus is leached much more difficultly than potassium (cf., e.g., Eaton *et al.* 1973).

There was a large variation in the contents of inorganic nitrogen both in stemflow and in throughfall as measured in different places under the canopy. In all sample plots studied NO_3-N was lower in stemflow than in throughfall, and even lower than in precipitation in the open (Fig. 3). This might indicate that nitrogen, particularly NO_3-N, is absorbed by the needles, or taken up by epiphytes living on the boles of trees. Particularly in the case of sessile oak *(Quercus petraea)* it has been established that the amounts of inorganic nitrogen both in stemflow and in throughfall are smaller altogether than in precipitation (Carlisle *et al.* 1966, 1967 a, 1967 b). This indicates that the trees might take up inorganic nitrogen directly through their leaves. In other connections, too, it has been pointed out that above-ground plant parts should be considered as being organs of both uptake and loss of nutrients (Ingham 1950, Tukey *et al.* 1958).

Fig. 3 shows that the content of NH_4-N in throughfall is almost twofold that of NO_3-N and that, in the case of precipitation, the former is somewhat higher than the latter. Similar results have been obtained by Gubareva (1970). On the average, NH_4-N contents were higher in stemflow and throughfall in all sample plots than in precipitation in the open. This result is in agreement with those obtained for black spruce *(Picea mariana)* by Mahendrappa and Ogden (1973). Fertilization showed no clear influence on the NH_4-N content; likewise, there seemed to be no variation depending on the place of sampling under the canopy.

According to the results obtained in this study, the potassium contents both of stemflow and of throughfall were higher during the months of June and July than later during the summer and autumn. In the northern hardwood forests of the USA *(Fagus grandifolia* and *Acer saccharum)* it has been established that the susceptibility of potassium to be leached increases toward the autumn (Eaton *et al.* 1973). On the

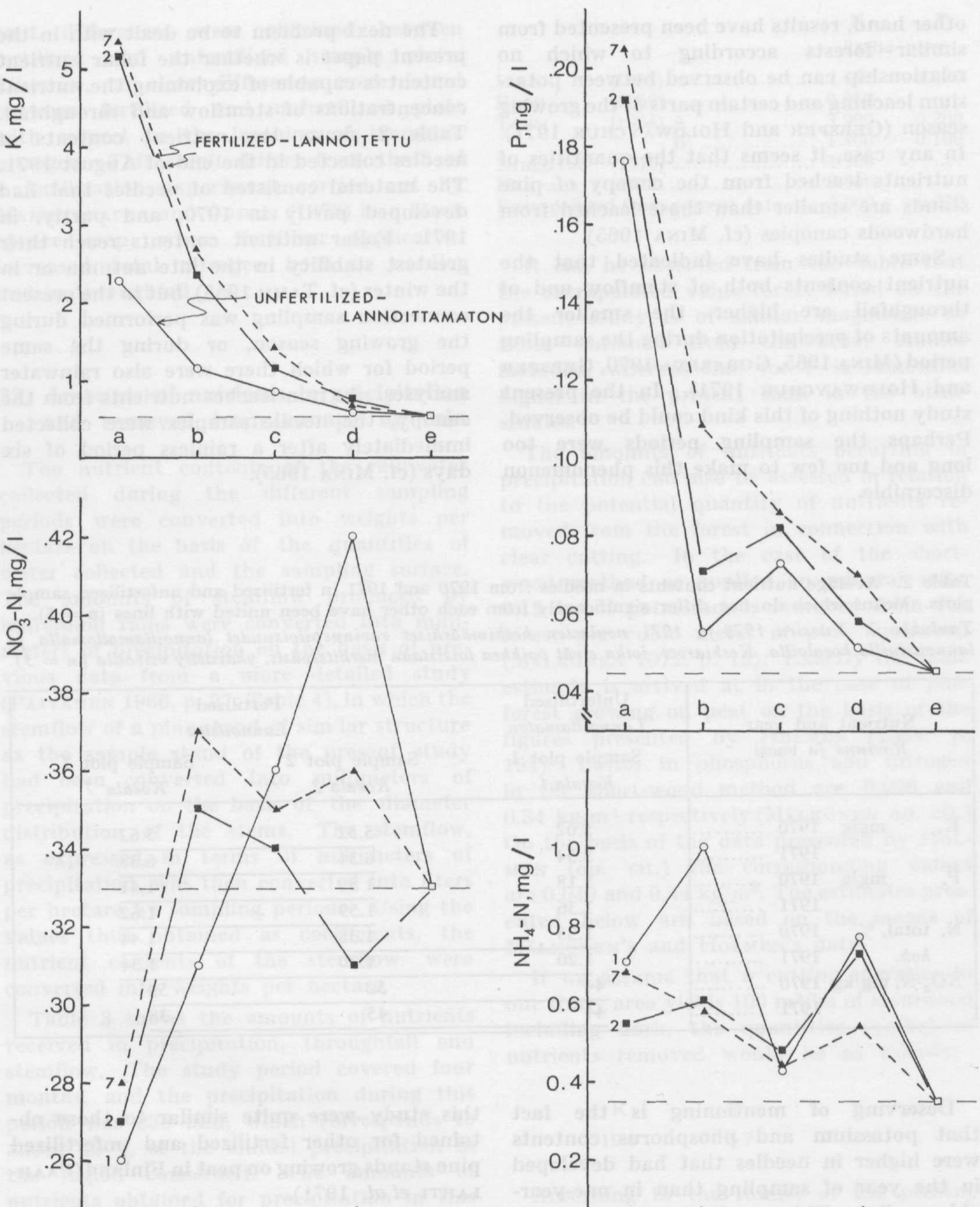

Fig. 3. Average contents of K, P, NO_3-N and, NH_4-N during the period June 4 — Oct. 4, 1971, in stemflow (a), throughfall (b = under crown, c = at the edge of crown projection, d = under canopy opening) and precipitation (e) as weighted by the volumes of the water samples. — *Runkovalunnan (a) metsikkösadannan (b = latvuksen alla, c = latvusprojektion rajalla, d = latvusaukossa) ja vapaan sadannan (e) vesimäärillä punnitut keskimääräiset K:n, P:n, NO_3-N:n ja NH_4-N:n pitoisuudet, mg/l, 4/6 — 4/10 1971 välisenä aikana.*

other hand, results have been presented from similar forests according to which no relationship can be observed between potassium leaching and certain parts of the growing season (Gersper and Holowaychuk 1971). In any case, it seems that the quantities of nutrients leached from the canopy of pine stands are smaller than those leached from hardwoods canopies (cf. Mina 1965).

Some studies have indicated that the nutrient contents both of stemflow and of throughfall are higher, the smaller the amounts of precipitation during the sampling period (Mina 1965, Gubareva 1970, Gersper and Holowaychuk 1971). In the present study nothing of this kind could be observed. Perhaps the sampling periods were too long and too few to make this phenomenon discernible.

The next problem to be dealt with in the present paper is whether the foliar nutrient content is capable of explaining the nutrient concentrations of stemflow and throughfall. Table 2 shows the nutrient contents of needles collected in the end of August 1971. The material consisted of needles that had developed partly in 1970, and partly, in 1971. Foliar nutrient contents reach their greatest stability in the late autumn or in the winter (cf. Tamm 1955), but in the present connection sampling was performed during the growing season, or during the same period for which there were also rainwater analyses. As rain leaches nutrients from the canopy, the needle samples were collected immediately after a rainless period of six days (cf. Mina 1965).

Table 2. Average nutrient contents in needles from 1970 and 1971 in fertilized and unfertilized sample plots. Means which do not differ significantly from each other have been united with lines (n = 5).

Taulukko 2. Vuosien 1970 ja 1971 neulasten keskimääräiset ravinnepitoisuudet lannoittamattomalla ja lannoitetuilla koealoilla. Keskiarvot, jotka eivät poikkea toisistaan merkitsevästi, yhdistetty viivoilla (n = 5).

Nutrient and year *Ravinne ja vuosi*		Unfertilized *Lannoittamaton* Sample plot 1 *Koeala 1*	Fertilized *Lannoitettu* Sample plot 2 *Koeala 2*	 Sample plot 7 *Koeala 7*
K, mg/g	1970	5.02	5.52	5.62
	1971	5.54	6.34	6.38
P, mg/g	1970	1.18	1.39	1.41
	1971	1.36	1.59	1.62
N, total, %	1970	1.35	1.38	1.44
kok.	1971	1.20	1.20	1.34
NO_3-N, mg/kg	1970	44	52	59
	1971	44	45	38

Deserving of mentioning is the fact that potassium and phosphorus contents were higher in needles that had developed in the year of sampling than in one-year-old needles. This result is in conformity with those presented by Tamm (1955), although Tamm's figures are higher on average than those obtained in the present study. This, however, is due to the fact that the former were obtained from a pine stand growing on mineral soil. Foliar nutrient contents in the pine stands used in this study were quite similar to those obtained for other fertilized and unfertilized pine stands growing on peat in Finland (Paarlahti *et al.* 1971).

Fertilization led to a statistically significant increase in foliar potassium and phosphorus. No significant differences could be observed in this respect between the fertilized plots. The result supports those obtained from studies concerning the leaching of fertilizers (see Fig. 3). In the case of foliar NO_3-N and total nitrogen, no significant differences were obtained between fertilized and unfertilized sample plots. Likewise, no clear differences were found between fertilized and unfertilized plots with respect to the leaching of inorganic nitrogen. This result differs from those of a fertilization experiment carried out by MAHENDRAPPA and OGDEN (1973) in a black spruce crop, where fertilizer application increased total nitrogen both in needles and in throughfall.

33. Amounts of nutrients in precipitation and removed from canopy by rain

The nutrient contents of the rainwater collected during the different sampling periods were converted into weights per hectare on the basis of the quantities of water collected and the sampling surface. The amounts of stemflow produced by individual rains were converted into millimeters of precipitation on the basis of previous data from a more detailed study (PÄIVÄNEN 1966, p. 27, Table 4), in which the stemflow of a pine stand of similar structure as the sample stand of the present study had been converted into millimeters of precipitation on the basis of the diameter distribution of the stems. The stemflow, as expressed in terms of millimeters of precipitation, was then converted into liters per hectare by sampling periods. Using the values thus obtained as coefficients, the nutrient contents of the stemflow were converted into weights per hectare.

Table 3 shows the amounts of nutrients received in precipitation, throughfall and stemflow. The study period covered four months, and the precipitation during this period was 238 mm, which corresponds to about 40 % of the annual precipitation in the region concerned. The amounts of nutrients obtained for precipitation in this study were extrapolated so as to represent the whole year by multiplying them by 2.5. On the basis of the results of the present study and of some other investigations carried out in the Nordic countries, the following table was compiled concerning the annual amounts of K and P reaching open ground:

		K	P
		kg/ha year	
VIRO	(1953)	2.450	0.086
BUCH	(1960)	0.960	...
TAMM	(1964) A	3.900	0.200
	B	1.400	0.100
NIHLGÅRD	(1970)	1.900	...
HAAPALA	(1972)	3.600	...
Extrapolated from present data		3.000	0.270

It can be observed from the table that the extrapolated value for K based on the present study is of similar magnitude as those obtained from the other studies included, whereas that for P is somewhat higher in the present than in the other studies.

The amounts of nutrients occurring in precipitation can also be assessed in relation to the potential quantity of nutrients removed from the forest in connection with clear cutting. In the case of the short-wood method as applied on mineral soils, 0.19 kg of potassium is removed from the forest per cubic meter of pine stemwood (MÄLKÖNEN 1972, p. 12). Exactly the same estimate is arrived at in the case of pine forest growing on peat on the basis of the figures presented by HOLMEN (1964, p. 194). Losses in phosphorus and nitrogen in the short-wood method are 0.026 and 0.34 kg/m³ respectively (MÄLKÖNEN op. cit.) On the basis of the data presented by HOLMEN (op. cit.) the corresponding values are 0.049 and 0.44 kg/m³. The estimates presented below are based on the means of MÄLKÖNEN's and HOLMEN's data.

If we assume that a cutting operation in our study area yields 100 m³/ha of stemwood including bark, the quantities (kg/ha) of nutrients removed would be as follows:

K	P	N
19.0	3.7	39 0

According to the results of the present study, the quantities of nutrients brought to the ground by gross precipitation during the course of one year are as follows: 3 kg/ha of potassium, 0.27 kg/ha of phosphorus and 4.1 kg/ha of inorganic nitrogen. Thus, the quantities of nutrients removed in connection with the short-wood system would be compensated for through precipitation during periods of the following lengths as expressed in terms of years:

K	P	N
6.3	13.7	9.5

The above simplified example is based on many assumptions and estimations. Thus, for example, the amounts of nutrients possibly transferred from forest drainage areas with discharging water have been disregarded. Due to the trap ditches surrounding drained peatlands, water from adjacent mineral soils cannot enter the peat. The purpose of the example is only to indicate the magnitude of the importance of nutrients brought to the ground by rains for the nutrient balance of forest crops (cf. Carlisle *et al.* 1967 b, p. 147).

According to Table 3, the unfertilized sample plot received a quantity of potassium through stemflow and throughfall which was almost 1.5-fold that contained in precipitation. Furthermore, the table shows that the fertilized plots received quantities of potassium which are 1.5—1.8-fold in comparison with that received by the unfertilized plot. In the case of the other nutrients studied, the results obtained are not as clear as for potassium. Fertilization may increase leaching of phosphorus from the canopy, but the results of the present study showed a large difference even between the fertilized plots. The quantities of inorganic nitrogen reaching open places as well as unfertilized and fertilized pine forest are all of similar magnitude.

Sample plot 7 received a quantity of potassium almost 3-fold that in precipitation. From the literature we find that the quantities of potassium reaching the ground under tree crops with water are 3—13-fold

Table 3. Amounts of nutrients in precipitation and in its components reaching the ground in fertilized and unfertilized pine crops during the period June 4 — Oct. 4, 1971.

Taulukko 3. Sadeveden mukana maahan tulleet ravinnemäärät aukealla sekä lannoittamattomassa että lannoitetussa mäntymetsikössä 4/6—4/10 1971 välisenä aikana.

Nutrient and component of precipitation *Ravinne ja sadannan osa*	Open *Aukea*	Unfertilized *Lannoittamaton* Sample plot 1 *Koeala 1*	Fertilized *Lannoitettu* Sample plot 2 *Koeala 2*	Sample plot 7 *Koeala 7*
		g/ha		
K, precipitation/throughfall *vapaa sadanta/metsikkösandanta*	1191	1599	2320	2820
stemflow *runkovalunta*	—	142	218	254
Total — *Yht.*	1191	1741	2538	3074
P, precipitation/throughfall *vapaa sadanta/metsikkösadanta*	108	119	124	277
stemflow *runkovalunta*	—	6	8	8
Total — *Yht.*	108	125	132	285
NH_4-N, precipitation/throughfall *vapaa sadanta/metsikkösadanta*	884	1229	1046	923
stemflow *runkovalunta*	—	42	34	135
Total — *Yht.*	884	1271	1080	1058
NO_3-N, precipitation/throughfall *vapaa sadanta / metsikkösadanta*	769	664	585	651
stemflow *runkovalunta*	—	15	14	56
Total — *Yht.*	769	679	599	707
Inorganic N, *Epäorganinen N,* Total — *Yht.*	1653	1950	1679	1765

that in precipitation (e.g., TAMM 1951; MADGWICK and OVINGTON 1959; WILL 1959; CARLISLE *et al.* 1966, 1967 a, 1967 b; GUBAREVA 1970; NIHLGÅRD 1970; YAWNEY *et al.* 1970). Even 80-fold values have been presented (EATON *et al.* 1973). The differences are of course due to variations in site, tree species, stand density, annual precipitation, distribution of the rains over the year, etc. In the case of cereals, too, potassium has showed to be the nutrient which is most exposed to leaching from the above-ground parts of the plants in question (MAYBORODA 1971).

It has been indicated in other studies, too, that phosphorus is rather poorly leached from forest canopies. The amounts of P collected from under the canopy are usually 1—3-fold that collected from the open (cf. TAMM 1951; CARLISLE *et al.* 1967 a, 1967 b; GUBAREVA 1970; YAWNEY *et al.* 1970).

As, in the case of pine crops, the percentage throughfall increases when moving from close to the stems toward openings in the canopy (PÄIVÄNEN 1966, p. 20), it seems feasible to assess, at least for potassium, whether indeed more of the nutrient in question is received per unit area under the crown of trees than at the edge of the crown projection and in canopy openings, as can be assumed on the basis of the content values obtained (see Fig. 3). The calculations carried out to shed light on this problem gave the following results for the whole study period:

Sample plot no.	Under canopy	Edge of canopy projection	Canopy opening
		K kg/ha	
1	1.89	1.60	1.31
2	3.57	2.04	1 44
7	3.76	2.85	1.46

During the whole study period 1.19 kg/ha of potassium was brought to the ground with precipitation. Despite the fact that the amounts of rainwater reaching the ground under forest canopy, is smaller than in openings, the quantity of potassium reaching the ground per unit area increased when moving from canopy openings to under the crowns in the pine crops studied. Similar results have been obtained by TAMM (1951) for Norway spruce. It is difficult to estimate the area of the ground affected by stemflow. According to MINA (1967), it is 4—5 % of the total area in the case of mature pine stands. In young pine crops it probably is still smaller. As the area affected by stemflow is so small, the amounts of nutrients per unit area received with stemflow are still greater than those reaching the soil under the canopy with throughfall. The nutrients reaching the ground in stemflow and, on the other hand, in throughfall lead consequently to systematic differences in the chemical properties of the soil under tree crops. The phenomenon can be called »biohydrologic factor» (GERSPER and HOLOWAYCHUK 1971).

As was mentioned in the introduction, nutrients are both leached and washed from the canopy of tree crops by rainwater. In the vicinity of the present study area there were no dust sources deserving of mentioning. As fertilization increased the potassium contents both of the needles and of the stemflow + throughfall, we may indirectly draw the conclusion that most of the potassium comes from the cell sap. Obviously only a small part of the nutrients reaching the ground with stemflow and throughfall, if any at all, comes from aerosols which, in a dry state, have settled on the surface of needles. This has also been indicated by NIHLGÅRD (1970) in the case of beech and spruce stands in southern Sweden. Consequently, the nutrients which are brought back to the soil with rainwater are mainly soluble in water, and this means that they can be reused by the vegetation at a faster rate than those contained, for example, by litter.

The quantities of nutrients leached from the canopy were not extrapolated so as to correspond to the whole year because we do not know whether snow is capable of bringing nutrients from the canopy during the period of dormancy of trees.

4. SUMMARY

The aim of the study was to assess the contents and quantities of macronutrients reaching the ground with precipitation, stemflow and throughfall in pine stands growing on drained peatland, one of which was unfertilized and two of which had been fertilized three growing seasons before measurements were carried out. On the basis of the results obtained from the study, the following conclusions can be drawn:

— The quantities of nutrients reaching the ground with precipitation are relatively large as compared, for example, with those removed with the stemwood carried away from the forest in logging.

— The nutrient which is most exposed to leaching from the canopy is potassium. Both the content of potassium in rainwater penetrating the canopy and the quantities reaching the ground are highest in stemflow, decreasing when moving from under the tree crowns toward the edge of the crown projection and into openings in the canopy.

— In the case of phosphorus, the results obtained were of a similar kind although they were not as clear as for potassium.

— The contents of NO_3-N were smaller in stemflow than in precipitation. Otherwise the results did not support assumptions according to which nitrate nitrogen is leached from the canopy or is taken up by the canopy from precipitation. In the case both of precipitation and of throughfall and stemflow, the quantities of nitrite nitrogen recorded were smaller than the degree of precision applied in the determinations carried out (0.01 mg/l). The contents of NH_4-N were on average higher in stemflow and throughfall than in precipitation.

— Fertilizer application (600 kg/ha of N-P_2O_5-K_2O, 14—18—10) increased the contents particularly of potassium in stemflow and throughfall. A slight increase in phosphorus was also observed. Leaching of inorganic nitrogen was not affected by fertilization.

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Seloste:

RAVINTEIDEN SIIRTYMINEN SADEVEDEN MUKANA LATVUSTOSTA MAAHAN TURVEMAAN MÄNNIKÖSSÄ

Jo vapaassa sadannassa tulee huomattavia määriä ravinteita maahan. Tavallisesti sadevesi rikastuu ravinteista lävistäessään latvuston. Ravinteita sekä huuhtoutuu latvustosta että peseytyy neulasten, lehtien ja oksien pinnalta. Toisaalta on voitu osoittaa, että lehdet ja neulaset saattavat absorboida ja puilla elävät epifyytit käyttää latvustoon pidättyneen sadeveden sisältämiä ravinteita. Tässä tutkimuksessa on pyritty selvittämään, paljonko ravinteita tulee toisaalta vapaassa sadannassa ja toisaalta turvemaan männikön runkovalunnassa ja metsikkösadannassa maahan. Edelleen on ollut tarkoituksena selvittää, lisääkö metsänlannoitus ravinteiden huuhtoutumista latvustosta.

Tutkimus on suoritettu ojitetun turvemaan männikössä Keski-Suomessa (61°50' N, 24°20' E). Samalta koekentältä on aikaisemmin julkaistu tutkimustuloksia metsänhoidollisten toimenpiteiden vaikutuksesta ojitetun suon hydrologiaan (Heikurainen ja Päivänen 1970, Päivänen 1972, 1973). Sadeveden mukana maahan tulevia ravinnemääriä selvitettiin 4. 6. — 4. 10. 1971 välisenä aikana lannoittamattomalla ja kahdella lannoitetulla koealalla sekä aukealla. Lannoitukset oli suoritettu huhti—toukokuun vaihteessa 1968, jolloin levitettiin 600 kg/ha suomaiden Y lannosta ($N - P_2O_5 - K_2O$, 14—18—10).

Kullekin koealalle asennettiin systemaattisesti kaksikymmentä ja aukealle kolme keräysastiaa (kuva 1). Runkovalunnan mittauksia suoritettiin kolmesta puusta kullakin koealalla (kuva 2). Keräysajanjaksot käyvät ilmi taulukosta 1. Vesinäytteistä analysoitiin Viljavuuspalvelu Oy:n laboratoriossa K:n, P:n, NH_4-N:n, NO_3-N:n ja NO_2-N:n pitoisuudet tavanomaisin menetelmin.

Vapaan sadannan ravinnepitoisuudet on esitetty taulukossa 1 ja pinta-alayksikölle tulleet ravinnemäärät taulukossa 3. Näillä ravinnemäärillä on merkittävä osuus metsikön ravinnetaseessa.

Herkimmin näyttää latvustosta huuhtoutuvan kaliumia. Sekä kaliumin pitoisuus että pinta-alayksikölle tulevan kaliumin määrä oli suurin runkovalunnassa ja pieneni siirryttäessä latvuston alta latvusprojektion rajalle, latvusaukkoon ja aukealle (kuva 3, asetelma s. 15). Fosforin kohdalla tulokset olivat samansuuntaisia. Nitraattitypen pitoisuus oli pienempi runkovalunnassa kuin vapaassa sadannassa. Muutoin tulokset eivät selvästi tukeneet käsityksiä nitraattitypen huuhtoutumisesta sen paremmin kuin vapaassa sadannassa tulevan sitoutumisestakaan latvustoon. Nitriittitypen määrä oli sekä vapaassa sadannassa, metsikkösadannassa että runkovalunnassa alle määritystarkkuuden (0.01 mg/l). Ammoniumtypen pitoisuus oli keskimäärin suurempi runkovalunnassa ja metsikkösadannassa kuin vapaassa sadannassa. Metsänlannoitus lisäsi sekä neulasten (taulukko 2) että runkovalunnan ja metsikkösadannan kalium- ja fosforipitoisuutta (kuva 3). Epäorgaanisen typen huuhtoutumiseen lannoituksella ei ollut vaikutusta.

On ilmeistä, että pääosa sadeveden mukana latvustosta siirtyvistä ravinteista on peräisin nimenomaan solunesteestä. Sadeveden mukana palautuvat ravinteet ovat siten pääosin vesiliukoisia ja nopeammin kuin esim. karikkeissa olevat ravinteet kasvien uudelleen käytettävissä. Runkovalunnassa ja metsikkösadannassa tulevat ravinteet aiheuttanevat myös puiden sijainnin suhteen systemaattisia eroja metsikön maan kemiallisiin ominaisuuksiin.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 116.11

1974. Nutrient removal from Scots pine canopy on drained peatland by rain. ACTA FORESTALIA FENNICA 139. 19 p.

The study deals with the quantity of nutrients reaching the ground, on the one hand, in gross precipitation, and on the other hand, in throughfall and stemflow in Scots pine *(Pinus silvestris* L.) stands growing on peat. Nutrient leaching from the canopy and washing from the surface of needles and branches are discussed. Another aim of the study is to find out whether forest fertilization increases nutrient leaching.

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ISBN 951-651-014-0