METSÄNTUTKIMUSLAITOKSEN JULKAISUJA

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MITTEILUNGEN DER FORSTLICHEN FORSCHUNGSANSTALT IN FINNLAND
PUBLICATIONS OF THE FINNISH FOREST RESEARCH INSTITUTE
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THE EFFECT OF NITROGEN FERTILIZATION ON THE COMPOSITION AND THE QUANTITY OF VOLATILE OIL IN SCOTS PINE (*PINUS SILVESTRIS* L.)

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INTRODUCTION

It has been observed that forest fertilization affects the occurrence and the harmfulness of many forest insects (e.g. Stark 1965). Many studies have been carried out to determine the role played be the changes in the nutrition on insects as well as in the physiological condition of host trees in this phenomena (Büttner 1961, Merker 1967, Thalenhorst 1972). On the other hand, the influence of changes in the chemical composition of the host trees, resulting from fertilization, on primary attraction does not seem to have earlier been directly studied. According to present knowledge, volatile compounds are the main factors involved in the olfactory orientation of many forest insects, especially in the Scolytidae and in the Curculionidae (e.g. Rudinsky 1966, Kangas et al. 1967, Siegel 1967, Smeljanez 1969, Oksanen et al. 1970, Werner 1971, Selander et al. 1973). However, almost nothing is known about the effect of fertilization on the production and content of volatile oils in host trees (see Otto & Geyer 1970).

The purpose of the present study is to elucidate the effect of nitrogen fertilization on the composition and the quantity of the volatile oil found in Scots pine (*Pinus silvestris* L.). The part of the study concerned with the entomological aspect will be published at a later date.

MATERIAL AND METHODS

Study stand. A pine stand as homogeneous as possible as far as the quality of the standing trees and the soil conditions are concerned was selected for the experiment. The study area is located in the district of Liljendal in southern Finland (Grid 27°E: 6716: 423). The site type was *Vaccinium*-type (medium pine site) and the stand has been naturally regenerated. The characteristics of the stand in fall 1972 were:

average height	17 m
DBH (1.3 m)	16 cm
age class	75 yrs
density	300 trees/ha

Fertilization experiment. The experiments were made by the single-tree-plot method. 30 trees were selected for fertilization from 60 randomly selected trees such that the distance between fertilized and unfertilized trees was at least 15 m. These trees were fertilized by hand in May 1971. Urea fertilizer was used containing 46 % of nitrogen, and was spread within a 5 m radius from each trunk. The amount given is equal to 150 kg nitrogen/ha, which is approximately the same as the presently recommended dosage for Finnish practical forestry (see Viro 1972).

The effect of fertilization upon the radial growth and the size and nitrogen content of the needles after two years, when in general it is at its greatest (cf. Viro 1965, 1970) is presented in Table 1. The radial growth was measured at a height of 1.3 m from the ground (DBH). The sample consisted of 30 fertilized and 30 unfertilized trees. The needle samples representing the growth during summer 1972 were collected from the three highest branch whorls, in this case the sample being 20 plus 20 trees. The total nitrogen contents were determined by the Kjeldahl method.

The effect of fertilization upon the radial growth and needles observed in this experiment is of the same magnitude as that found in comparable conditions by other workers (cf. Tamm 1956, Viro 1965, 1970).

Weather conditions. Since the weather conditions during the growing season effect the biosynthesis of volatile oils (see Juvonen 1966), the temperature and precipitation data from the Lapinjärvi meteorological station situated in the vicinity of the study area are presented in the following tabulation.

1972	April	May	June	July	Aug.	Sept.	Oct.
Average temp., °C	2.2	9.8	17.1	20.1	16.9	10.5	4.7
Precipit., mm	81	20	35	80	169	31	57

The effective temperature sum (d.d. +5° C) during the growing season was 1561. Compared with the averages of the standard period 1931—60 (see Kolkki 1966, Helimäki 1967) the temperature during June—August and the temperature sum of the whole growing season were exceptionally high. During early summer the precipitation was close to the average, but in August higher and in September lower than average.

Samples for analysis. In winter 1973 (January 3rd) 20 fertilized and 20 unfertilized trees were felled for volatile oil analyses. Two 50 cm long sections were cut from each trunk one meter from the base. The phloem layer was removed from every second block (phloem I). The other blocks were left in the study area and in spring 1973 (April 26th) when the first bark beetles had begun to swarm the phloem from these blocks was removed and collected (phloem I, stored). The shoots produced in 1972 were collected from the three highest branch whorls in the crowns, the needles

(needle) and shoot axes (shoot axis) being kept separate. In summer 1973 (June 8th) when the pines began to bloom, the remaining sample of 10 plus 10 trees was cut. A 50 cm long section one meter from the base was also taken from these trunks. The phloem of these blocks was removed (phloem II). At this time the phloem also contained a small amount of soft cambium tissue. The young half-grown shoots of 1973 were collected from the crown, but in this case the needles were not removed from the shoots (shoot —73). All the samples were stored in plastic bags and kept in a deepfreeze until analyzed. During a short storage period the temperature was kept at —5° C, and during the longer periods at —18° C.

The volatile oils. The volatile oils of the phloem samples, needles and shoots were extracted by steam distilling the fresh plant material. The terpenes were analyzed by the same methods and conditions previously described by Juvonen & Hiltunen (1974). Identification of all terpenes was accomplished by comparing relative retention times with those of known compounds analyzed by gas chromatography under the same conditions and compared with values published by Juvonen (1970) and Juvonen & Hiltunen (1974). In addition, some compounds were identified by mass spectrometry.

The percentages of each constituent were calculated from integrator traces for the area under the peaks, compared to the total integrator traces for all terpene peaks.

Statistical analysis was performed at the computer center of the University of Helsinki (Helsingin yliopiston laskentakeskus) using Burroughs B-6700 and Univac-1108 computers.

RESULTS AND DISCUSSION

The composition and quantity of the volatile oils found in Scots pine needles, phloem and xylem is dependent upon plant genotypes as well as upon several nongenetic variables connected with the environment and the processes associated with plant development (Zawarin et al. 1971). Tobolski (1968) showed that several monoterpenes of Scots pine appear to be under simple genetic control, and therefore, are highly variable within a population. He also showed that differences between tissues were significant for all monoterpenes except γ-terpinene. Squillace & Fisher (1966) reported high tree-to-tree variation in monoterpene composition in the stemxylem oleoresin of slash pine (*Pinus elliottii* Engelm.). They also found evidence for strong genetic control of the terpene levels.

On the basis of data from investigations involving Scots pine Tobolski (1968) concluded that the site effects, a source of environ-

mental influences, were minor. Otto & Geyer (1970) investigated the effect of fertilization on the composition of the needle oil of Scots pine. They found no clear differences in the quantity of main compounds between the control trees and the fertilized trees (N, P, K, Ca, Mg -mixture).

The variation in the sesquiterpene composition of pine species has not been recently demonstrated.

In this investigation 60 trees (40 trees during the dormant period and 20 trees during the vegetation period) were randomly selected, 30 (20 + 10) trees of which were fertilized. In the investigated tissues different tissues (needle, phloem I, phloem II, phloem I s, shoot axis and shoot —73) had distinct compositions. The main differences were found in the concentrations of α- and β-pinene, 3-carene, limonene and β-phellandrene. Qualitative differences between different tissues were minor.

Only monoterpenes could be detected in shoot axis tissue. In this tissue (see table 4) the predominant compounds were α-pinene, β-pinene, 3-carene, limonene and β-phellandrene as in all other tissues, together accounting for over 90 percent of the total oil concentration. In the shoot axes, α-pinene ranged from 5 to 37 percent, β-pinene from 1 to 35 percent, 3-carene 8—75 percent and terpinolene from a negligible amount to 4 percent. Limonene and β-phellandrene varied from 1—30 and 1—23 percent respectively in this tissue.

In the needle tissue (see table 2) about 70 percent of the total terpene concentration consisted of monoterpenes. The major constituents of this tissue were α-pinene and 3-carene, together accounting for 50 percent. In this tissue concentrations have been calculated as percentages of the total oil concentration. α-pinene ranged from 14 to 67 percent and 3-carene from 1 to 40 percent. Some sesquiterpene hydrocarbons were detected in the needle tissue. Among these, α-cubebene, β-caryophyllene, β-elemene, α-muurolene and γ- and δ-cadinene were the major constituents. In this tissue about 5 percent of the total terpenes were oxygenated compounds, such as terpinen-4-ol, bornyl acetate, α-terpineol and borneol. The qualitative composition of the phloem samples (see tables 3, 5 and 7) were very similar to needle tissue except that longifolene, β-elemene, methyl chavicol and terpinyl acetate were found in these samples. In addition pinenes and 3-carene varied more in the phloem than in the needle samples. Monoterpene concentrations were higher in the phloem than in the needle tissue (about 85 percent in the phloem).

Tables 6 and 7 give the compositions of the shoot —73 and phloem II tissues. Tissue taken during the vegetation period (shoot —73) was very similar to the shoot axis which was taken during the dormant period. Some sesquiterpene was found in the shoot —73 tissue, since the shoots had not been defoliated and the sesquiterpene concentration was rather high in the

needles (see table 2). Table 5 shows that storing does not change the relative terpene composition in the phloem very much. The concentrations and variations of the individual terpenes were the same in the stored as in the non-stored phloem tissue (see table 3).

Experimental data showed that these tissues are characterized by large tree-to-tree variability for these terpenes. This study together with a recently published investigation (Juvonen & Hiltunen 1974) involving variation in the terpene composition and terpene biosynthesis of Scots pine demonstrated that individual terpenes are under strong gene control. In view of this fact, it is not easy to influence the terpene composition by such factors as fertilization. However, some large differences between control and fertilization samples were found. The concentration of 3-carene increased proportionally from 15 to 18 percent in the needle tissue, from 40 to 46 percent in the shoot axis tissue and in the phloem I tissue from 20 to 30 percent. In the stored phloem tissue this difference was a little smaller. The concentration of α-pinene decreased from 43 to 36 percent in the needles, from 23 to 18 in the shoot axis and from 50 to 45 percent in the phloem I tissue. After storing, no such difference was found. One-way variance analysis showed that these differences were insignificant at the 1 and 5 percent levels. In the phloem I tissue only the concentration of α-terpinene was significantly different (at the 5 percent level) between control and fertilization samples. Again storing reduced the difference to an insignificant level. The concentration of α-terpinene was 50 percent higher in the fertilized phloem I tissue, the α-terpinene level in the needles was significantly lower. Sabinene in the shoot axes increased from 1.9 to 2.7 percent after fertilization. In the needle tissue limonene and δ-cadinene were significantly higher (1 percent level) in the fertilized sample. In this tissue the concentration of α-muurolene increased after fertilization. This difference was significant at the 5 percent level. The concentration of limonene and β-phellandrene decreased in each tissue but only in the case of the needles were the differences significant.

The dry-weight was determined from each sample. On the basis of the data from the dry-weight analyses the absolute total amount of oil for each sample was calculated as microlitres per hundred grams of dry material. The method used in this study for dry-weight determination has been described by Juvonen (1966). Table 8 gives the variation of the total oil concentration between control and fertilization samples in different tissues. In all tissues, except shoot —73, the total oil concentration in the fertilized sample was greater than that in the control sample, although only in the needle and shoot axis tissues were the differences significant. In the phloem I tissue the total oil concentration of the fertilized sample was 33 percent higher but the variation was so large between the samples

that the difference was insignificant. In the stored phloem the total oil concentration was about 20 percent lower than in the non-stored, and no differences were found between samples. In the shoot —73 tissue fertilization had no effect on the total oil concentration.

CONCLUSIONS

This study has given us an insight into environmental variation, especially fertilization depending variation in terpene composition of the needle, phloem and shoot of Scots pine. The results suggest that the total oil concentration could be affected by fertilizing with nitrogen. This effect was also found for some individual terpenes. The fertilization effect was found especially in those tissues which were collected during the dormant period. However, the effect was not so obvious in the tissues which were taken during the vegetation period, due in part perhaps to different rates of various biosynthetic processes, slightly higher tree-to-tree variation and because the sample consisted of only 20 trees. The concentrations of 3-carene, sabinene and terpinolene increased at the same time. These compounds are biosynthetically closely related, and belong to the same biosynthetic family (Juvonen & Hiltunen 1972). It is evident that fertilization affects those chemical reactions which result in a build up of these 3-carene related coumpounds. In the stored phloem the differences in individual terpene levels between control and fertilization samples disappeared. This could be caused by the physical and chemical factors to which the terpenes are subjected during evaporation. In order to be sure of the effect of fertilization further study is needed using a larger sample size (100—200 trees) and attention should be paid to genetic phenomena.

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Table 1. The response of the sample trees of fertilization.

	Radial growth 1972, mm	Needles during winter 1972/73		
		N-content, % d.w.	Length, mm	Weight, g/50 n.
Unfertilized trees	1.08	1.44	54.7	1.95
Fertilized trees	1.29	1.49	60.8	2.32
t-value	6.840***	4.167***	3.267**	2.803**

Table 2. Terpene composition in the needle tissue of Scots pine during the dormant period.

	Range	Control		Fertilized		F-value
		Mean	S.d.	Mean	S.d.	
Tricyclene	0.4— 2.2	1.1	0.4	0.9	0.2	2.36
α-Pinene	14.1—66.5	43.4	14.7	36.2	12.8	2.75
Camphene	1.7— 7.5	4.0	1.4	3.9	1.3	0.07
β-Pinene	0.6— 9.0	2.5	1.9	2.0	0.9	1.28
Sabinene	0.0— 1.6	0.5	0.5	0.7	0.5	1.04
Myrcene		+		+		
3-Carene	1.2—39.9	15.1	11.7	17.8	12.0	0.50
α-Terpinene	0.0— 0.3	0.1	0.1	0.1	0.1	4.61*
Limonene	0.2— 3.5	1.4	1.0	0.7	0.4	8.46**
β-Phellandrene	0.2— 1.2	0.7	0.3	0.5	0.1	7.45**
1.8-Cineol	0.0— 0.1	+		+		
cis-β-Ocimene	0.0— 3.3	1.4	0.9	1.1	0.6	1.70
γ-Terpinene	0.0— 1.2	0.2	0.2	1.2	0.3	0.28
Cymene	0.0— 0.9	0.2	0.2	0.2	0.2	0.02
Terpinolene	0.0— 2.7	0.8	0.8	1.0	0.6	0.77
Total monoterpenes		70.4		66.3		4.11**
β-Caryophyllene	0.2—11.1	6.4	2.8	5.1	2.3	2.56
Sesquiterpene ($C_{15}H_{24}$)	0.5— 9.7	2.8	2.0	3.6	2.0	1.38
ε-Muurolene	0.0— 0.8	0.3	0.2	0.4	0.2	4.59*
γ-Muurolene	0.3— 3.0	0.6	0.4	0.9	0.8	1.81
α-Muurolene	0.4— 8.6	3.8	2.1	5.2	1.6	5.64*
δ-Cadinene	0.4—16.9	6.6	3.3	9.7	3.3	8.55**
γ-Cadinene	0.1— 7.5	2.8	1.7	3.9	1.9	3.40
Total		93.7		95.1		

° Significant at the 10 percent level.
* Significant at the 5 percent level
** Significant at the 1 percent level
*** Significant at the 0.1 percent level.

Table 3. Terpene composition in the phloem tissue of Scots pine during the dormant period (phloem I).

	Range	Control		Fertilized		F-value
		Mean	S.d.	Mean	S.d.	
Tricyclene	0.0— 0.5	0.2	0.1	0.1	0.1	0.04
α-Pinene	3.1—80.8	50.1	24.6	44.5	22.7	0.57
Camphene	0.1— 1.9	0.9	0.5	0.8	0.5	0.09
β-Pinene	0.4—34.7	4.1	7.4	4.5	6.7	0.03
Sabinene	0.0— 0.8	0.1	0.2	0.0	0.1	0.01
Myrcene	0.0— 3.1	0.5	0.9	0.4	0.9	0.08
3-Carene	0.7—76.0	20.7	20.5	30.4	21.2	2.14
α-Terpinene	0.0— 1.0	0.2	0.1	0.3	0.3	4.88*
Limonene	0.7—15.1	3.6	2.5	3.2	3.4	0.24
β-Phellandrene	0.0— 6.2	2.3	1.2	2.2	1.2	0.23
1.8-Cineol		—		—		
cis-β-Ocimene	0.0— 0.2	+		+		1.84
γ-Terpinene	0.0— 1.2	0.3	0.2	0.5	0.3	3.39
Cymene	0.0— 0.8	0.3	0.2	0.4	0.2	1.67
Terpinolene	0.3— 8.5	2.1	1.6	2.8	2.0	1.33
Total monoterpenes		85.4		90.1		
β-Elemene	0.0— 9.6	1.6	2.2	1.2	1.8	0.31
β-Caryophyllene	0.0— 3.2	1.1	1.8	0.6	0.4	1.26
Methyl chavicol	0.0—12.3	1.4	2.7	1.6	1.6	0.06
Sesquiterpene ($C_{15}H_{24}$)	0.0—27.3	3.9	7.0	1.8	1.3	1.71
α-Muurolene	0.0—19.1	3.0	4.8	1.7	1.2	1.32
Total		96.4		97.0		

Table 4. Terpene composition in the shoot axis tissue of Scots pine during the dormant period.

	Range	Control		Fertilized		F-value
		Mean	S.d.	Mean	S.d.	
Tricyclene	0.0— 0.2	0.1	0.1	0.0	0.0	2.84
α-Pinene	5.3—37.5	22.6	9.6	18.1	9.1	2.37
Camphene	0.0— 0.9	0.4	0.2	0.3	0.2	1.87
β-Pinene	1.2—34.8	7.9	7.2	8.0	7.1	0.00
Sabinene	0.0— 6.1	1.9	0.7	2.7	1.3	5.16*
Myrcene	0.0— 3.2	0.8	0.8	0.9	0.5	0.54
3-Carene	7.9—74.1	39.1	19.4	45.7	20.9	1.07
α-Terpinene	0.0— 1.9	0.5	0.5	0.5	0.4	0.03
Limonene	1.1—30.0	13.1	9.6	10.0	8.6	1.11
β-Phellandrene	1.0—22.8	11.2	4.8	10.8	6.1	0.08
1.8-Cineol	0.0— 0.4	0.1	0.1	0.1	0.1	0.51
cis-β-Ocimene	0.0— 1.0	0.3	0.2	0.4	0.2	1.18
γ-Terpinene		+		+		
Cymene	0.1— 1.5	0.5	0.4	0.5	0.0	0.19
Terpinolene	0.0— 4.1	1.5	1.1	2.0	1.2	1.77
Total monoterpenes		100.0		100.0		

Table 5. Terpene composition in the stored phloem tissue of Scots pine (phloem I s).

	Control		Fertilized		F-value
	Mean	S.d.	Mean	S.d.	
Tricyclene	0.5	1.0	0.2	0.6	1.14
α-Pinene	40.6	28.4	40.2	25.2	0.00
Camphene	1.2	0.8	0.8	0.6	2.69
β-Pinene	4.0	8.2	4.2	6.8	0.01
Sabinene	0.4	1.0	0.2	0.6	0.96
Myrcene	1.1	1.3	2.9	7.3	1.16
3-Carene	20.9	22.1	28.8	23.9	1.19
α-Terpinene	0.6	1.0	0.4	0.6	0.65
Limonene	3.3	2.3	2.6	2.2	0.98
β-Phellandrene	1.9	0.9	1.6	0.8	1.15
1.8-Cineol	—		—		
cis-β-Ocimene	0.6	0.9	0.4	0.6	0.92
γ-Terpinene	+		+		
Cymene	0.8	0.9	0.6	0.6	0.33
Terpinolene	2.1	1.5	1.9	1.2	0.16
Total monoterpenes	78.0		84.8		
β-Elemene	2.0	1.9	1.0	0.6	4.46*
β-Caryophyllene	1.0	1.0	0.7	0.7	1.14
Methyl chavicol	1.9	1.6	1.7	1.4	0.13
Sesquiterpene ($C_{15}H_{24}$)	2.7	2.2	2.6	2.4	0.05
α-Muurolene	3.1	2.5	3.3	3.4	0.05
Total	88.7		94.1		

Table 6. Terpene composition in the young shoot tissue of Scots pine (shoot -73).

	Control		Fertilized		F-value
	Mean	S.d.	Mean	S.d.	
Tricyclene	0.1	0.0	0.1	0.1	0.95
α-Pinene	21.5	9.9	18.2	10.4	0.53
Camphene	0.7	0.3	0.6	0.4	0.21
β-Pinene	5.5	3.0	5.4	6.5	0.00
Sabinene	0.2	0.4	0.5	0.5	1.67
Myrcene	0.3	0.4	0.9	1.1	2.18
3-Carene	36.7	17.3	44.1	19.7	0.79
α-Terpinene	0.5	0.2	0.5	0.4	0.01
Limonene	12.1	12.2	8.3	7.4	0.71
β-Phellandrene	12.0	4.7	9.6	4.0	1.46
1.8-Cineol	0.0	0.0	0.0	0.0	—
cis-β-Ocimene	0.6	0.6	0.3	0.6	0.72
γ-Terpinene	1.1	0.5	1.2	0.8	0.07
Cymene	0.5	0.2	0.6	0.3	1.53
Terpinolene	2.7	1.9	2.8	1.8	0.01
Total monoterpenes	94.5		93.1		
β-Caryophyllene	1.1	0.4	1.6	0.8	3.58°
Sesquiterpene ($C_{15}H_{24}$)	0.8	0.4	1.2	0.7	1.49
γ-Muurolene	0.1	0.1	0.1	0.1	0.73
α-Muurolene	0.2	0.1	0.3	0.2	0.32
δ-Cadinene	0.6	0.4	0.7	0.6	0.73
γ-Cadinene	0.1	0.1	0.3	0.2	6.59*
Total	97.4		97.3		

Table 7. Terpene composition in the phloem tissue of Scots pine during the vegetation period (phloem II).

	Control		Fertilized		F-value
	Mean	S.d.	Mean	S.d.	
Tricyclene	0.4	0.8	0.4	0.8	0.00
α-Pinene	48.3	21.1	35.5	22.4	1.72
Camphene	0.9	0.7	0.8	0.7	0.14
β-Pinene	2.0	1.1	6.7	10.9	1.86
Sabinene	0.6	0.8	0.7	0.8	0.03
Myrcene	0.5	0.8	0.7	0.8	0.20
3-Carene	24.5	18.0	32.6	25.3	0.68
α-Terpinene	0.5	0.8	0.6	0.8	0.01
Limonene	2.7	1.8	2.4	1.9	0.14
β-Phellandrene	3.8	5.2	3.2	1.5	0.14
1.8-Cineol	—		—		
cis-β-Ocimene	+		+		
γ-Terpinene	0.6	0.8	0.7	0.8	0.07
Cymene	0.4	0.8	0.6	0.8	0.12
Terpinolene	2.4	1.4	2.8	1.7	0.29
Total monoterpenes	87.6		87.7		
β-Elemene	1.0	0.8	0.4	0.8	1.92
β-Caryophyllene	0.5	0.8	0.5	0.9	0.00
Methyl chavicol	0.7	0.8	0.9	0.8	0.34
Sesquiterpene ($C_{15}H_{24}$)	2.0	1.6	1.5	3.5	0.15
α-Muurolene	1.6	1.6	1.6	2.1	0.00
Total	93.4		92.6		

Table 8. Total oil variation between control and fertilization for each tissue.

		Mean [1]	S.d.	F-value	Risk [2]
Needle	C	1 048	323	5.03	0.03
	F	1 284	344		
Phloem I	C	76	41	1.16	0.29
	F	101	95		
Shoot axis	C	1 670	344	4.40	0.04
	F	1 881	291		
Phloem II	C	43	33	1.08	0.31
	F	82	113		
Phloem I S	C	59	38	0.01	0.94
	F	60	53		
Shoot-73	C	2 015	243	0.33	0.53
	F	1 934	375		

[1]) Mean calculated as microlitres per 100 gram fresh material.
[2]) Risk for rejection the null hypothesis, when true.

C = Control
F = Fertilization

INCIDENCE OF SNOW BLIGHT ON SCOTS PINE AS AFFECTED BY FERTILIZATION AND SOME ENVIRONMENTAL FACTORS

TIMO KURKELA

Seloste

LANNOITUKSEN JA ERÄIDEN YMPÄRISTÖTEKIJÄIN VAIKUTUKSESTA MÄNNYN TAINTEN LUMIKARISTEISUUTEEN

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INTRODUCTION

Snow blight, caused by *Phacidium infestans* Karst., is probably the disease which causes the greatest damage on Scots pine sapling stands in eastern and northern Finland (Liro 1923, Kangas 1937, Rummukainen 1971, Norokorpi 1971). On sapling stands in southern Finland the disease is of minor importance (Kangas 1937, Kujala 1950). Björkman (1948) published a detailed study on the biology of the fungus. Snow blight occurs chronically in pine sapling stands from the initial infection until all the needles remaining under the snow cover are dead. The mycelium of the fungus is able to infect only needles covered by snow. When the leader shoots of the saplings have grown above the snow cover, the disease cannot kill them anymore, even if the lower branches were colonized. Accumulation of snow, early arrival of over-wintering snow, and late melting in the spring increase the danger of snow blight in pine sapling stands (Mattsson Mårn 1944, Björkman 1948, Shtshedrova 1962).

Several methods, including mechanical eradication of diseased saplings and chemical control, have been suggested for the control of snow blight. Of the currently-used methods, the most effective is spraying or powdering with PCNB (pentachloronitrobenzene)-preparations, both in nurseries (Jamalainen 1961) and in sapling stands (Rummukainen 1971). Since spreading of biocides in nature should, in general, be avoided and restricted to a minimum, control of snow blight should preferably be attempted with such reforestation methods and silvicultural measures that the danger of infection in a sapling stand can be avoided. The structure of a pine sapling stand, as affected by various reforestation methods, influences the amount of snow blight (Björkman 1948, Shtshedrova 1962, Kaasa 1971). A stand where the saplings are standing well apart from each other is less susceptible to damage than a stand where the saplings are in dense groups. According to Sjöström (1937), fresh pine slash under the snow may be infected and increase chances of infecting the surrounding saplings. Damage by snow blight possibly may also be reduced by using as resistant planting stock as possible. In Sweden Björkman (1963) showed that, in general, northern provenances were clearly more resistant against snow blight than southern provenances.

With all methods (e.g. soil preparation and fertilization) in which height growth of seedlings is already promoted during the first growing season after reforestation, the period of susceptibility can be reduced (cf. Kaasa 1971). In general, phosphorus and potassium fertilization, and sometimes also nitrogen fertilization, of pine seedlings on peat lands can increase growth considerably (Huikari 1961, Heikurainen 1967, Meshechok 1967, Kaunisto 1972). It also seems possible at times to increase resistance to snow blight by means of fertilization. On peat lands poor in phosphorus and potassium, addition of these nutrients reduces the frequency of snow blight (Kurkela 1965). Due to the considerable growth increase achieved by PK-fertilization, this measure has been accepted as a standard method on peat-land reforestation sites in Finland (cf. Salonen 1967).

There are no observations dealing with the effect of fertilization on snow blight of pines growing on mineral soils. According to Viro (1966), fertilization of young pine sapling stands on mineral soils is not recommended. The seedlings can endure only small amounts of fertilizers when planted on mineral soils; and therefore, the effect of the fertilizer remains for only a short time. Consequently, the treatment may be unprofitable if high survival and fast growth are required. Several observations indicate, however, that also on mineral soils the frequency of snow blight in pine sapling stands could be influenced by regulating the soil nutrients. On dry uplands there usually is more snow blight than on moist uplands (Lindberg 1914, Kujala 1950, Shtshedrova 1962, Kossinskaja 1967, Kaasa 1971). The differences in amount of snow blight may be due to several other causes than fertility of the site, e.g., growth rate of the saplings, density of the sapling stand, quality and amount of other vegetation, microclimatic factors affecting growth of the fungus, etc., as has already been mentioned above (cf. also Kossinskaja 1962, Moros 1964, Kurkela 1969).

Björkman (1967) observed that snow blight caused more damage on rapidly-growing seedlings fertilized with nitrogen in a nursery compared to less vigorous seedlings which received no nitrogen fertilizer. Similarly, he observed that vigorous spruce seedlings fertilized with nitrogen and potassium suffered more from snow mold caused by *Herpotrichia juniperinum* (Duby) Petrak compared to seedlings which had not received these fertilizer treatments. Keller (1970) showed that *Herpotrichia* infection on spruce and respiration correlated positively with the nitrogen content of their needles. Furthermore, he thought that increased respiration caused by lack of potassium and phosphorus or excess fertilization with these elements (e.g. Syrett 1960, Reinken 1963) could also increase the susceptibility of the seedlings to snow mold diseases.

The amounts and proportions of mineral nutrients available in the soil greatly affect the physiological conditions of the plants. It is obvious that

those minerals have a considerable effect on the susceptibility of the plants also. In agriculture, where the use of fertilizers is an important part of modern techniques, several obervations have been made about the relationships between nutrients and plant diseases (Mc New 1960, Krauss 1969, Trolldenier 1969). At the present time observations about the relationships between fertilization and disease are accumulating from reforestation operations, as the use of fertilizers is increasingly becoming more common as a forest improvement method. There are already a few literature reviews about the relationship between forest fertilization and diseases (e.g. Baule and Fricker 1967, Björkman 1967, Foster 1968, Hesterberg and Jurgensen 1972). The effect of forest fertilization on incidence of diseases caused by fungi appears to be a very complicated problem to solve. Different host plants and pathogens react differently to the nutrients of the substrate. Furthermore, the direction and intensity of the reactions appear to be affected by several site factors not related to fertility. In spite of the great uncertainty, the main effects on the relationship between disease and fertilization may be found by examining the diseases according to the physiological basis for their parasitism (Mc New 1960). Obligate parasites, such as the rusts for example, develop best on vigorous and rapidly-growing host plants; however, the facultative parasites cause the greatest damage on hosts previously weakened by some other unfavorable environmental conditions. The snow-blight fungus *P. infestans*, probably belongs to the facultative parasites. It is easy to culture on artificial media (Björkman 1942, Pehrson 1948), but in nature it spreads only in living needles under the snow.

The object of this study was to elucidate effects of different nitrogen, phosphorus, and potassium fertilizers on the resistance of pine to snow blight in experiments established on a nutrient-deficient peat land. In addition to new data, previously published but re-examined data (Kurkela 1965) are presented.

MATERIALS AND METHODS

Fertilization Experiments

The data were collected on the forest fertilization experiment area at Kivisuo (H u i k a r i and P a a r l a h t i 1966, 1973). The Department of Peatland Forestry in the Finnish Forest Research Institute has established several forest fertilization experiments on this area since 1959. In the 1940's peat for fuel use was lifted according to the so-called hydro-peat method. The first experiments were established on the effectively drained fields used for drying of lifted peat. This hydro-peat field, originally a *Sphagnum*-peat bog, was drained with ditches spaced 22 m apart with covered drains between them. When lifting of peat was discontinued, the field remained covered with a 10—15 cm thick layer of homogenized peat. This field was an extremely nutrient-deficient substrate due to the very low nutrient level originally present in the *Sphagnum*-moss and because a considerable portion of the nutrients had been leached away by the large amounts of water repeatedly used to spread a peat slurry on the field.

For the present study the data was collected from Experiments I, V and VI established on the hydro-peat field and from Experiment XI established on the intact *Sphagnum*-moss substrate (H u i k a r i and P a a r l a h t i 1973).

E x p e r i m e n t I. Experiment I was established in May-June 1959 by planting untransplanted two-year-old pine seedlings, using 2 m spacing and applying broadcast fertilization. Two hundred twenty-five seedlings were used per treatment. The experiment contained two factorial, 4^3 series. The fertilizers were calcium ammonium nitrate (25 % N), rock phosphate (33 % P_2O_5), and potassium chloride (50% K_2O). Each fertilizer was used at the following levels:

calcium ammonium nitrate	0, 200, 400, and 800 kg/ha
rock phosphate	0, 200, 400, and 600 kg/ha
potassium choloride	0, 100, 200, and 400 kg/ha

The entire area of Experiment I was poor in phosphorus and potassium before the experiments were established. This is indicated by the results of the analysis of changing mineral nutrients in soil samples collected from the

unfertilized control plots (Table 1). The analyses were made in 1960. Before fertilization, the nutrient conditions were so unfavorable that virtually nothing was growing there.

E x p e r i m e n t V. Experiment V was established in 1959. The levels and kinds of fertilizers were the same as in Experiment I. The fertilizers were applied around the seedlings on a 0.25 m^2 area in amounts (kg/m^2) proportionate to the amounts (kg/ha) given in Experiment I. Consequently, the amount of fertilizers applied around the seedlings was only 1/16 of the corresponding broadcasted application. The experiment included the following combinations: NPK, PK and NP. NK combination was applied on one experimental plot only.

E x p e r i m e n t VI. Experiment VI contains a tree species trial and a patch fertilizer experiment. It was established on May 8- June 3, 1962. Four different species were planted and fertilized in the patch. The pine seedlings were three-year-old transplants (2 + 1). Several different fertilizers were used, including two 3^3 factorial series. In the NPK combination the nitrogen source was calcium ammonium nitrate (25 % N); the phosphorus source was superphosphate (19 % P_2O_5); and the potassium source was potassium chloride (50 % K_2O). The levels were:

calcium ammonium phosphate	0, 200, and 400 kg/ha
superphosphate	0, 350, and 700 kg/ha
potassium choloride	0, 100, and 200 kg/ha

The experiment also included a lime test where, in addition to the NPK-fertilization, 4 000 kg/ha of lime was applied. The NPK levels were:

calcium ammonium phosphate	0 and 400 kg/ha
superphosphate	0 and 700 kg/ha
potassium chloride	0 and 200 kg/ha

The source of lime was ground limestone (49 % CaO).

Table 1. Changing mineral nutrients in soil samples from the unfertilized plots of Experiment I, 1960 (H u i k a r i and P a a r l a h t i 1973).

Taulukko 1. Vaihtuvat mineraaliravinteet lannoittamattomilla koeruuduilla kokeessa I v. 1960 (H u i k a r i ja P a a r l a h t i 1973).

Plot No.	NH_3 mg/100 g	NO_3 mg/100 g	P_2O_5 mg/100 g	K_2O mg/100 g	CaO mg/100 g	pH
14.....	14.0	5.58	2.48	33.4	244.0	4.0
41.....	10.4	4.05	2.33	22.3	210.0	4.0
91.....	15.3	4.46	2.94	21.6	223.0	4.1
122.....	29.0	4.70	7.62	25.8	293.0	4.2
159.....	9.9	2.52	2.17	16.9	189.0	4.1

Experiment XI. Experiment XI was established on May 5—23, 1964 by planting three-year-old pine transplants with spacing 2×2 m and broadcasting the fertilizers. Each plot had about 100 seedlings. The seed was from eastern Häme. The amounts and kinds of fertilizers were the same as in Experiment I. The design here was also a factorial 4^3. The plots were separated by drains about 30 cm deep made by a rotary cutter. The distance between the normal open drains was about 100 m. Before draining, the area was a natural *Sphagnum* bog.

Determination of snow blight frequency

The amount of snow blight was determined by examining all planted trees. If the tree had snow blight, it was marked diseased; if not, it was marked healthy. If completely dead trees still had enough needles attached in order to diagnose snow blight, they were marked as diseased. The total number of seedlings on the plot was the sum of diseased and healthy seedlings. The percentage of diseased trees per plot was determined and transformed by $2 \arcsin \sqrt{x}$ function for statistical analysis.

The amount of snow blight was determined in Experiments I and V during the summer of 1964 and in Experiments VI and XI the summer of 1970.

Measurements and analyses

Size of young trees. It is obvious that the larger the needle canopy, the greater is the probability that the trees may be infected by snow blight. Since the disease can occur only in that part of the needle canopy which is under the snow, an attempt was made to define a variable which would be proportional to the number of needles remaining under the snow. This variable would then be used as a regression variable in examining the relationship between fertilization and incidence of snow blight. The best variable to explain the probability of snow blight infection would, of course, be one that indicates the surface area of the snow-covered needles. This was, however, impossible to determine on the growing saplings. As a variable explaining the probability of infection, the volume of the crown remaining under the snow was chosen. This was determined by the equation for a cone or a truncated cone. Since snow blight occurred on the small trees from the ground up to 80 cm above it, this height was used as the height of a truncated cone. If the height of the small tree was 80 cm or smaller, the volume was calculated according to a full cone.

In Experiments VI and XI, 10 randomly-chosen young trees were measured from each plot. Height and width of the crown at the lowest branches were measured. Since the seedlings had been planted at a 2 × 2 m spacing, even their lowest branches were still alive at age 6—8, and usually the branches were longest at the ground, forming a cone-shaped crown. The width of the crown was always measured in the same direction on all plots regardless of the irregularities of the crown shape.

During the summer of 1964, the size of the young trees was not measured at the time when they were examined. The Department of Peatland Forestry of the Forest Research Institute, which has been in charge of the experiments, has, however, measured the height of the trees annually. Using a transformation, the volume of the crown below 80 cm was calculated. The transformation was made as follows: Using the data from Experiments VI and XI, a polynomial regression was calculated with the height of the young trees as the only variable. The volume of the crown below 80 cm was found by the equation $V = 13.912 - 1.187h + 0.028h^2$ where V = the volume, and h = the height of the young trees. The third degree factor was negligible in the equation. Using the height of the young trees in the fall of 1963 in this equation, a variable was obtained which was used as a regression variable when examining the effect of fertilization on incidence of snow blight.

Snow depth measurements. Snow depth was measured in Experiments VI and XI on March 14, 1971. The measurements were done at three spots on each plot. One spot was located in the center of the plot, and two were at the ends of the plot, 4 m towards the center of the plot from the most peripheral young tree. The information about snow conditions on the plots was valuable since snow depth may have a strong influence upon incidence of snow blight (Mattson Mårn 1944). On the other hand, it must be noted that considerable variation between years may occur in snow depth, drifting and accumulation. The Kivisuo experimental area is even and relatively free of natural vegetation and brush, and thus the most important obstacle affecting snow accumulation is the size of the planted young trees. When examining the effect of snow depth, it also must be noted that the size of the young trees changes each year, and the differences between fast- and slow-growing stands increase year by year.

Needle analysis. In December 1970 needle samples were collected from trees in Experiment VI. The needles were analyzed for amounts of nitrogen, phosphorus, potassium and calcium at the laboratories of Satoturve Oy. The nitrogen was analyzed by the Kjelldahl-method, phosphorus by colorimeter, and potassium and calcium by atomic absorption spectrophotometry. Needle analyses were not made from Experiments I and V, nor on Experiment VI due to the scarcity of plants on some plots.

Statistical treatment of data. The effect of various variables on incidence of snow blight was studied using analyses of variance and covariance. The interpretation of these analyses was complicated by the fact that variables logically affecting the incidence, e.g. volume of crown ($\simeq$ number of needles trapping spores), snow depth, and nutrients in the needles, were dependent on the fertilizer treatments. In general, the basic assumption for using regression variables is that they are not interdependent or dependent on the treatments. The dependence of the regression variables on the fertilizer treatments was studied using analysis of variance. In Experiment XI an additional variable explaining incidence of snow blight was used: the distance from the plot center to the edge of Experiment I. Experiment I was located in relation to Experiment XI so that the prevailing rain-bringing winds brought spores from Experiment I which, already in 1964 when Experiment XI was established, was heavily infected with snow blight (Kurkela 1965).

RESULTS

Interdependence of the variables explaining incidence of snow blight.

Size of saplings

Based on previous investigations (H u i k a r i 1961), it is known that in Experiment I nitrogen somewhat increased the height of the saplings and that phosphorus increased it very significantly. Potassium did not affect height growth of the saplings during the two growing seasons after planting. Later, measurements made by the Department of Peatland Forestry showed that the effect of nitrogen had been reduced to virtually nothing. The effect of phosphorus had continued to be the strongest (Figure 1), but potassium had also increased the height very significantly (Table 2). As with the effect of nitrogen, the effects of potassium and phosphorus decreased year by year. Still in 1965, however, the effects of both phosphorus and potassium on growth were statistically significant (growth from years later than 1965 is not analyzed here).

There was a statistically significant difference in height of saplings between the replicates in Experiment I. This was also evident in the growth of the saplings during 1964.

Table 2. Analysis of variance of the effect of fertilizers on height and height growth of saplings in Experiment I.

Taulukko 2. Varianssianalyysi lannoituksen vaikutuksesta männyn tainten pituuteen ja pituuskasvuun kokeessa I.

		F-values				
		Height of saplings			Height growth	
Treatment	d.f.	1962	1963	1964	1964	1965
N	3	+ 3.203*	0.377	0.550	1.187	1.755
P	3	+116.602***	+93.020***	+83.663***	+8.799***	+36.252***
K	3	+ 16.070***	+12.611***	+10.567***	±3.921*	+ 4.707**
NP	9	1.479	1.213	1.256	0.357	0.954
NK	9	0.980	0.237	0.257	0.858	0.287
PK	9	0.826	1.036	0.445	0.789	0.598
Blocks	1	8.345**	15.729***	8.996**	5.032*	1.360
Error	90					

+ and — indicate the direction of the effect.

* Significant with a 5 per cent level of probability
** » 1 »
*** » 0.1 »

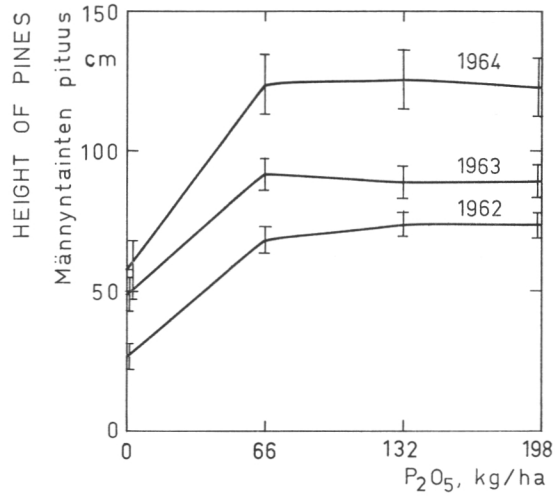

Figure 1. Height of pine saplings on plots fertilized with various amounts of phosphorus in Experiment I at Kivisuo in 1962—1964.

Kuva 1. Männyn tainten pituus erilaisen fosforilannoituksen saaneilla koeruuduilla kokeessa I Kivisuolla vuosina 1962-1964.

In Experiment VI the tallest saplings were found on plots fertilized with phosphorus. In Experiment XI both nitrogen and phosphorus fertilization increased the height very significantly (cf. K a u n i s t o 1972). Fertilization with potassium and lime did not have any statistically significant effect on height (Table 3). Potassium and lime significantly ($P < 1\ \%$) decreased the ratio between height and width of the crown in Experiment VI. The change of this ratio did not have any statistically significant effect on the volume of the crown below 80 cm (Table 3). Fertilization with phosphorus increased this volume in Experiments VI and XI, and in addition, so did

Table 3. The effects of fertilizers on the height and crown volume of saplings in Experiments VI and XI.

Taulukko 3. Lannoituksen vaikutus männyn tainten pituuteen ja latvuston kokoon kokeissa VI ja XI

	Fertilizer	d.f.	F-values		
			Mean height	Height/width	Volume
Exp. VI	Nitrogen	2	0.096	1.740	0.067
	Phosphorus	2	+14.692***	1.362	+9.342***
	Potassium	2	2.067	—5.242**	2.416
	Liming	1	0.006	—7.857**	0.134
	Error	54			
Exp. XI	Nitrogen	3	+16.260***	1.147	+12.238***
	Phosphorus	3	+51.453***	±2.836*	+23.539***
	Potassium	3	0.454	1.117	0.945
	Error	132			

fertilization with nitrogen in Experiment XI. There was no significant interaction between the effect of the fertilizer treatments on height of the saplings or the crown below 80 cm.

Nutrient content of needles

Table 4 presents the analysis of variance of the amounts of minerals in the needles as affected by the fertilizer treatments in Experiment VI. Neither nitrogen- and potassium fertilizers nor lime application had any significant effect on the nitrogen content of the needles. Fertilization with phosphorus reduced very significantly the nitrogen content of the needles as compared to nitrogen content at zero-level phosphorus (Figure 2). On plots

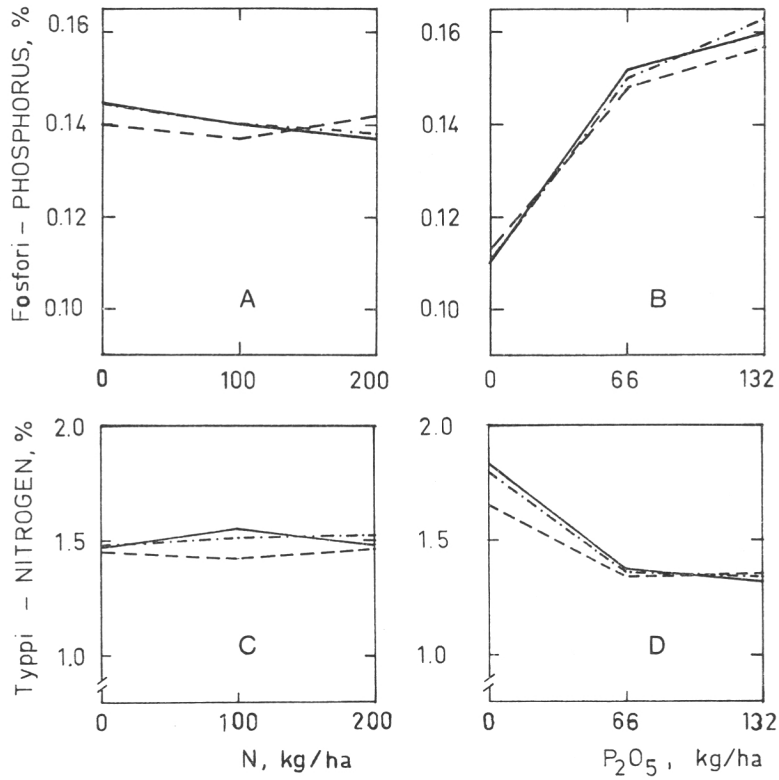

Figure 2. The effects of nitrogen and phosphorus fertilizers on the mineral content of needles in Experiment VI at Kivisuo. Samples for analysis were collected in December 1970. A and C) The effect of nitrogen fertilizer on plots having received various levels of phosphorus, ——— = 0, — — — 66 and —.—.— = 132 kg/ha P_2O_5. B and D) Effect of phosphorus fertilizer on plots having received various levels of nitrogen, ——— = 0 — — — 100 and —.—.— = 200 kg/ha N.

Kuva 2. Typpi- ja fosforilannoituksen vaikutus männyn neulasten typpi- ja fosforipitoisuuksiin kokeessa VI Kivisuolla. Näytteet otettiin joulukuussa 1970. A ja C) Typpilannoituksen vaikutus eri fosforilannoitustasoilla, ——— = 0, — — — = 66 ja —.—.— = 132 kg/ha P_2O_5. B ja D) Fosforilannoituksen vaikutus eri typpilannoitustasoilla, ——— = 0, — — — = 100 ja —.—.— = 200 kg/ha N.

not fertilized with phosphorus, the nitrogen content of the needles varied from 1.49 — 2.03 %, with an average of 1.75 %; and on those plots fertilized with phosphorus, it varied from 1.08 — 1.50 %, with an average of 1.35 %.

Fertilization with phosphorus very significantly increased the phosphorus content of the needles, and nitrogen caused a nearly significant reduction in phosphorus (Table 4, Figure 2). The mean phosphorus content of the needles was 0.11 % on plots not fertilized with phosphorus, compared to those fertilized with phosphorus where the content was 0.16 %. The other fertilizers tested did not affect the phosphorus content of the needles.

Potassium fertilization increased the needle content of that element very significantly, and liming reduced it significantly ($P < 1.0$ %). At the zero-level of potassium the content of that element in the needles was 0.26 %; and on the plots that had received 200 kg/ha potassium choloride, the content was 0.33 %.

Fertilization with phosphorus and liming very significantly increased the calcium content of the needles. Seven hundred kg/ha of superphosphate increased the Ca-content from 0.25 % to 0.30 %, which may have been partly due to the CaO-content (about 28 % CaO) of superphosphate. On plots that had received lime, the average Ca-content of the needles was 0.33 %.

According to Paarlahti et al. (1971), the recommended content (for optimum growth) of elements in the needles of pines on peat land is: N = 1.20—1.30 %, P = 0.14—0.17 %, and K = 0.35—0.40 %. Compared to these figures, the pines in Experiment VI on plots fertilized with phosphorus had nearly the optimum contents of these elements in their needles. On plots not fertilized with phosphorus the content of nitrogen had clearly been abnormally large, and the height growth had been the least of the whole experiment. Such a N/P ratio may be due to several causes. Phosphorus added to the peat substrate may have increased microbial activity, which then has consumed the available nitrogen, causing the low nitrogen contents in the needles of pines on plots fertilized with phosphorus. In such cases, fertilization with phosphorus would have caused lack of nitrogen.

Table 4. The effects of fertilizers on the mineral content of needles in Experiment VI.
Taulukko 4. Lannoituksen vaikutus männyn neulasten ravinnepitoisuuksiin kokeessa VI.

Fertilizer treatment	d.f.	Content of minerals in the needles, % d.w.			
		Nitrogen	Phosphorus	Potassium	Calcium
		F-values			
Nitrogen	2	0.671	— 3.632*	2.223	1.640
Phosphorus	2	—113.709***	+263.439***	1.710	+13.460***
Potassium	2	2.165	0.450	+22.562***	0.309
Liming	1	2.780	0.060	— 7.070**	+20.852***
Error	54				

This could have been corrected by fertilizing with nitrogen. There was, however, no interaction between fertilization with nitrogen and phosphorus. Consequently, this abnormal N/P-ratio may be explained by the marked effect of phosphorus on the energy metabolism of plants (c.f. Bandurski and Ching 1958). It is obvious that the saplings suffering from lack of phosphorus were not able to utilize all the nitrogen absorbed from the substrate, but accumulated it in the needles in unusually large amounts. The accumulation of nitrogen was perhaps even more accentuated since the difference in needle size between poorly- and rapidly-growing saplings was very great, and the content of the elements was determined as a percentage of the dry weight. A corresponding accumulation of nitrogen in leaves of silver birch (*Betula verrucosa* Ehr.) on this experimental area has been reported previously (Kurkela 1973).

Depth of snow cover

The size of the saplings in the experiments varied according to the fertilizer treatment. It was to be expected that there would be a corresponding variation in snow depth according to the size of the saplings. Snow depth was measured on March 14, 1971. The amount of snow during that winter was less than normal. The object of measuring snow depth was to find out the relative differences in amounts of snow (due to drifting and accumulation) on the various plots. During a winter with very little snow, such differences may be small. According to the data collected by the Finnish Meteorological Institute (1963—1972) the maximum average snow cover has been in Leivomäki during the winters 1963—1970 as follows:

1963	76 cm	1967	79 cm
1964	55 cm	1968	64 cm
1965	67 cm	1969	83 cm
1966	97 cm	1970	85 cm

In Experiment VI and XI average snow depth was 49 cm and 44 cm respectively in 1971. Experiment XI was located on a more open area, compared to Experiment VI, which may have resulted in less snow even at the time of snowfall. The difference in average snow depth may also depend on the fact that the wind had carried away some of the snow from the open area of Experiment XI and accumulated it on the edges of the forest surrounding the area. In Experiment VI the depth varied from 28 to 60 cm and in Experiment XI from 26 to 61 cm. Within these limits there was clearly a positive correlation between depth of snow and height

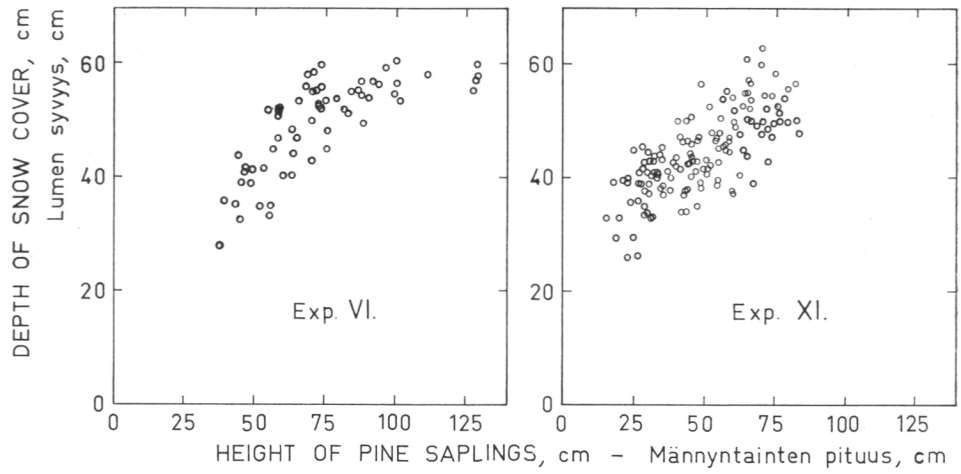

Figure 3. The effect of pine sapling height on accumulation of drifting snow on the plots in Experiments VI and XI during the winter of 1971.

Kuva 3. Männyn tainten pituuden vaikutus tuulen kuljettaman lumen kasautumiseen koeruuduille kokeissa VI ja XI talvella 1971.

of saplings (Figure 3). The snow had drifted away from plots with small saplings and accumulated at those with large saplings. Since the largest saplings were on plots fertilized with phosphorus, the snow depth was indirectly dependent on the fertilizer treatment.

Incidence of snow blight

Effect of crown volume

It was to be expected that the crown volume of the saplings (from ground level up to 80 cm) would explain much of the incidence of snow blight on the plots, since more spores of the pathogen would be trapped on a larger number of needles. Only in Experiment XI, however, did the crown volume have a statistically significant effect, according to an analysis of covariance, on the amount of snow blight (Table 5). The same method of analysis was applied to the data from Experiments I and VI. According to regression analysis, the effect of crown volume on incidence of snow blight was very significant in Experiments VI and XI. In addition to crown volume, the following independent variables were used: In Experiment VI snow depth and content of phosphorus in the needles, and in Experiment XI snow depth and distance of plots from the spore source. Figure 4 shows the correlation between crown volume and incidence of snow bligh in Experiments VI and XI.

Table 5. The association between amount of snow blight on the seedlings and fertilizer treatment, volume of crown (volume between ground level and 80 cm), snow depth, and distance to spore source. Analysis of covariance results for data from Experiments I, VI, and XI.

Taulukko 5. Männyn tainten lumikaristeisuuden riippuvuus lannoituskäsittelystä, latvuston tilavuudesta (tilavuus maan pinnasta 80 cm korkeuteen), lumen syvyydestä ja itiölähteen etäisyydestä. Kovarianssianalyysien tulokset kokeista I, VI ja XI.

	Expt. I		Expt. VI		Expt. XI	
	d.f.	F-values	d.f.	F-values	d.f.	F-values
Grown volume	1	0.872	1	1.931	1	+48.524***
Snow depth			1	2.718	1	0.447
Distance to spore source					1	—17.751***
N	3	0.940	2	1.014	3	1.446
P	3	0.980	2	1.549	3	— 7.791***
K	3	—40.072***	2	0.385	3	0.179
NP	9	2.109*				
NK	9	0.635				
PK	9	7.188***				
Ca			1	0.012		
Blocks	1	0.136				
Error	89		52		129	

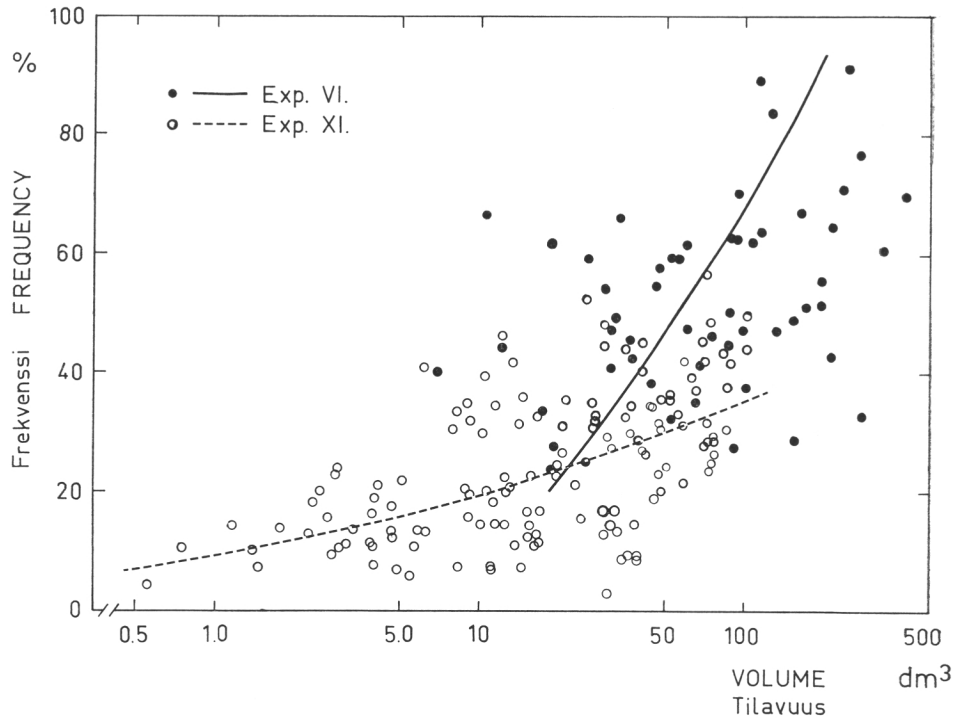

Figure 4. The effect of the crown volume portion which is exposed to snow blight (from ground level to 80 cm) on the amount of disease in Experiments VI and XI.

Kuva 4. Lumikaristeelle alttiina olevan latvuston osan (maasta 80 cm korkeuteen) tilavuuden vaikutus lumikaristeen esiintymiseen kokeissa VI ja XI.

Even if crown volume did not appear to have a significant effect on incidence of snow blight in Experiment I, the curves indicating effect of the fertilizers (Figure 6) were clearly different from curves drawn earlier and based on the same data (K u r k e l a 1965) but where the effect of crown volume had not been removed. In this analysis the logarithmic transformation of the volume was always used.

Effect of distance from spore source

The probable source of spores and its distance to the plots could be determined only in Experiment XI, where the incidence of snow blight was inversely related to that distance or its square (Figure 5). In the regression analysis the transformations of the distance, $1/x$ and $1/x^2$, were almost equal. The factors of these variables were statistically very significant (Table 5). The spore source was assumed to be the saplings infected by snow blight in Experiment I. When Experiment XI was established during the summer of 1964, an average of 6.8 % of the saplings in Experiment I were infected. Even if the disease did not seriously damage the saplings later on, the disease spread in the area so that in the summer of 1970, almost all needles that had been covered with snow had either been lost due to the disease or were infected and continued to sporulate. It was natural that in Experiment XI the most seriously infected plots were those closest to the

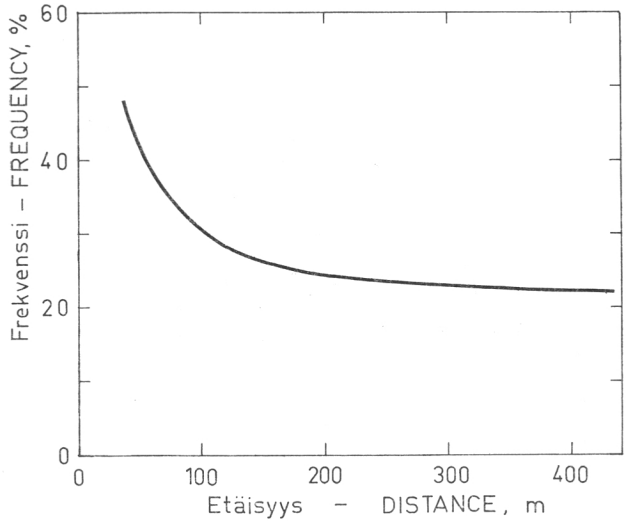

Figure 5. The effect of the distance to the spore source on the amount of snow blight in Experiment XI.

Kuva 5. Itiölähteen etäisyyden vaikutus männyn tainten lumikaristeisuuteen kokeessa XI.

area of Experiment I. The curve in Figure 5 shows a regression between incidence of snow blight and distance from the spore source. Other independent variables (crown volume and snow depth) have a fixed value equal to the mean for the total experiment. The curve shows that on an average up to 20 % the frequency of snow blight was caused by spore sources independent of Experiment I.

Effect of depth of snow cover

In spite of the fact that a thick and late-melting snow cover has been found to increase incidence of snow blight, the present study did not show any effects due to snow depth (Table 5). Of the statistical analyses, only the regression analysis of Experiment VI, where the other independent variables were crown volume and phosphorus content of the needles, indicated that snow depth significantly increased incidence of snow blight.

During the winters prior to 1971, there had been more snow; and the differences between the plots had been greater. Therefore, measurements made earlier might possibly have indicated the effect of snow depth more clearly. In the statistical analyses the effects of the fertilizer treatments and crown volume might have masked the effect of snow depth, which was indirectly or directly dependent on these variables (cf. p. 17).

Effect of fertilizers

The effect of the fertilizers on incidence of snow blight varied among the experiments. Those nutrients which were most lacking in the original substrate seemed, in general, to affect the incidence of snow blight the most.

In Experiment I, the results of which have already been published in a preliminary report (K u r k e l a 1965), both phosphorus and potassium increased the incidence when applied separately; but together they reduced the amount of disease. In the re-analysis of the data the effect of the fertilizers on crown volume was taken into consideration. Even if the size of the crown did not appear to have a significant effect on the amount of disease, the results of the statistical analysis did change somewhat when the crown volume was used as an independent variable. When crown volume was not taken into consideration, potassium fertilization appeared also to reduce the amount of disease when no phosphorus was applied. It is, of course, more correct to include crown volume in the analysis. Consequently, the analysis indicated that fertilization with potassium alone increased the amount of disease the same way as did fertilization with phosphorus alone

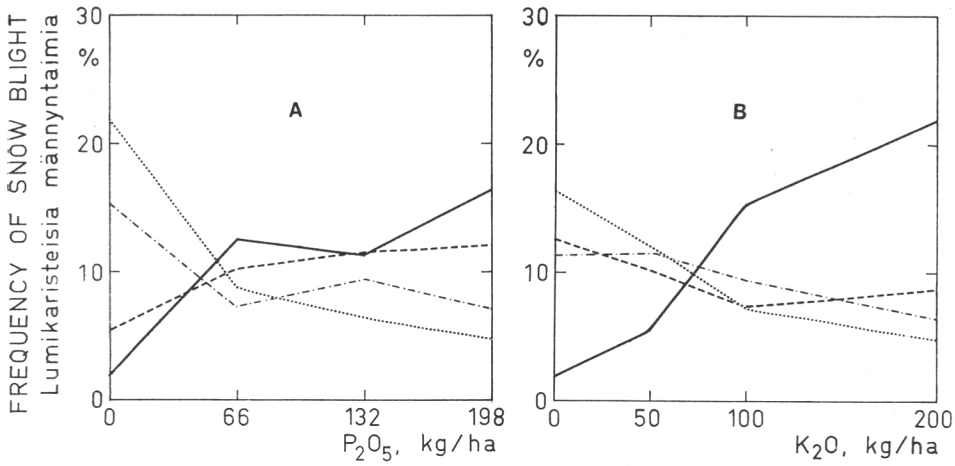

Figure 6. The effect of fertilization with phosphorus and potassium on the amount of snow blight in Experiment I. A) The effect of phosphorus on plots having received various levels of potassium, ——— = 0, — — — = 50, —·—·— = 100, and ····· = 200 kg/ha K_2O. B) The effect of potassium on plots having received various levels of phosphorus ——— = 0, — — — = 66, —·—·— = 132 and ... = 198 kg/ha P_2O_5.

Kuva 6. Fosfori- ja kalilannoituksen vaikutus lumikaristeen esiintymisrunsauteen kokeessa I. A) Fosforilannoituksen vaikutus eri kalitasoilla, ——— = 0, — — — = 50, —·—·— = 100 ja ····· = 200 kg/ha K_2O. B) Kalilannoituksen vaikutus eri fosforitasoilla, ——— = 0, — — — = 66, —·—·— = 132 ja ····· = 198 kg/ha P_2O_5.

(Figure 6). On plots fertilized with phosphorus the addition of potassium clearly reduced the amount of disease. The effect of potassium appeared to be independent of the amount of phosphorus applied. In other words, even the smallest amount of phosphorus (200 kg fertilizer/ha) was enough to balance the P/K-relation in the young trees. As more potassium was applied simultaneously with phosphorus, the more favorable was the effect of the phosphorus fertilization. Broadcast fertilization with nitrogen did not have any statistically significant effect on the amount of disease.

In Experiment V, where the fertilizers had been applied in patches around the planted seedlings, interactions between fertilizers could not be found, contrary to the situation described above. This may have been due to the fact that the zero-level of phosphorus was lacking in all except one plot. In the summer of 1964 an average of 6.5 % of the seedlings were infected with snow blight. At the zero-level of nitrogen the corresponding figure was about 2 %, compared to 7.5 % on plots that had received nitrogen. Fertilization with phosphorus and potassium reduced, in an almost linear manner, the amount of disease as increasing amounts of these elements were applied. The total reduction was, however, only 3—5 percent units. Analysis of variance was not carried out in this experiment due to its incompleteness.

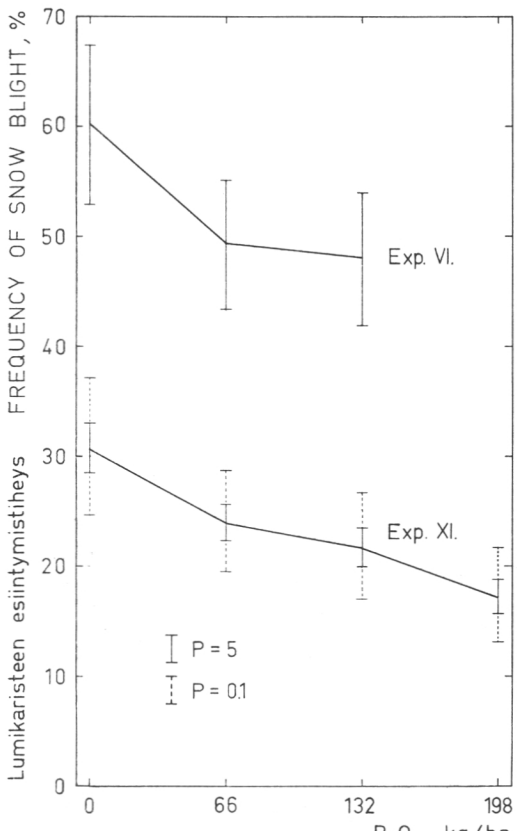

Figure 7. The effect of phosphorus fertilization on amount of snow blight in Experiments VI and XI. Experiment VI was 8 years old, and Experiment XI was 6 years old at the time of investigation.

Kuva 7. Fosforilannoituksen vaikutus lumikaristeen esiintymisrunsauten kokeissa VI ja XI; Kokeen VI ikä tarkastusaikaan oli 8 vuotta ja kokeen XI 6 vuotta.

In Experiments VI and XI the number of diseased young trees was counted during the summer of 1970. In Experiment VI the trees had grown for 8 years on the area; in Experiment XI they had grown 6 years. In Experiment VI about 53 % of the young trees were infected with snow blight; in Experiment XI about 23 % were infected. The following independent variables were used in the analysis of covariance: Fertilizer treatments, crown volume, snow depth, and (only in Experiment XI) distance to the source of spores (Table 5). Of the fertilizers, only phosphorus appeared to have any effect on the amount of snow blight (Figure 7). In Experiment VI only 48 % of the young trees which had received the highest amount of phosphorus were infected, compared to 60 % on plots with no phosphorus. Due to the large variation, this difference was not statistically significant. In Experiment XI phosphorus (600 kg fertilizer/ha) reduced snow blight about 11 percent units in comparison with the plots receiving no phosphorus. In this experiment the decrease of the amount of disease due to phosphorus

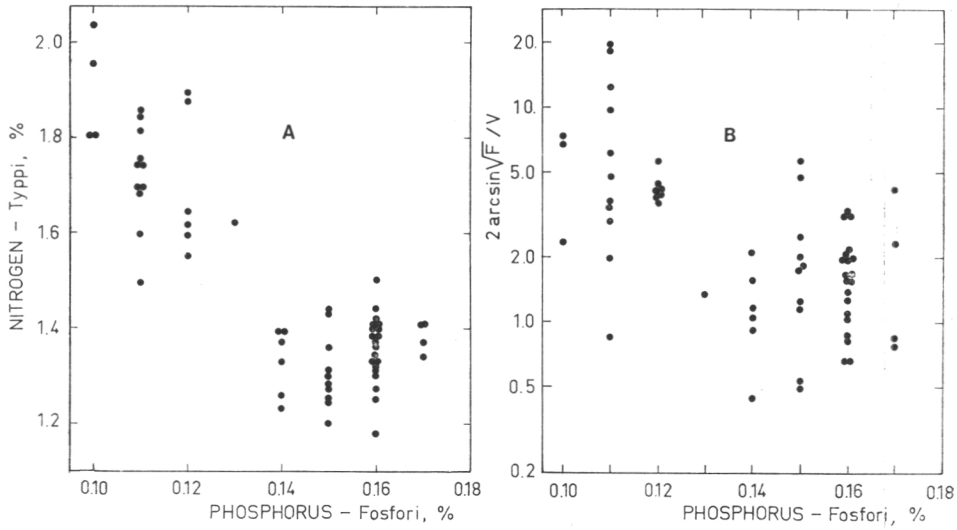

Figure 8. A) The ratio of phosphorus and nitrogen content in needles on the plots in Experiment VI. B) The ratio of phosphorus content of needles and incidence of snow blight on the plots in Experiment VI, F = frequency of snow blight and V = volume of crown exposed to snow blight.

Kuva 8. A) Neulasten fosfori- ja typpipitoisuuksien suhde koeruuduittain kokeessa VI. B) Neulasten fosforipitoisuuden ja tainten lumikaristeisuuden suhde koeruuduittain kokeessa VI, F = lumikaristefrekvenssi ja V = latvuston taudille alttiin osan tilavuus.

fertilization was very significant. Based on the effect of fertilizers on the growth of the trees, the needle analysis made in Experiment VI, and also on results presented by K a u n i s t o (1972), it may be concluded that phosphorus was the most important nutrient, of those applied, for the development of the young trees in these experiments.

The ratio of phosphorus to potassium in the applications was apparently very important for development of the resistance mechanism. In Experiment I the unfertilized and balanced PK-fertilized plots had a P/K ratio of about 0.4 in the substrate. Fertilizing only with phosphorus the ratio was 0.7 and with potassium only the ratio was 0.2 (cf. R e i n i k a i n e n 1967, K a u n i s t o 1972). On plots where the P/K ratio reached its maximum or minimum, the amount of disease reached a maximum. In Experiment XI the P/K ratio in the substrate was 0.1 on the non-fertilized plots (cf. K a u n i s t o 1972). When the amount of potassium was comparatively high, and that of phosphorus low, an addition of phosphorus reduced the amount of snow blight.

In Experiment VI there is no information about the nutrients in the substrate. The P/K ratio of the needles varied from 0.33—0.89 and averaged 0.48 on the whole area. Plots most severely infected with snow blight were found among those where the P/K ratio in the needles was low. On the

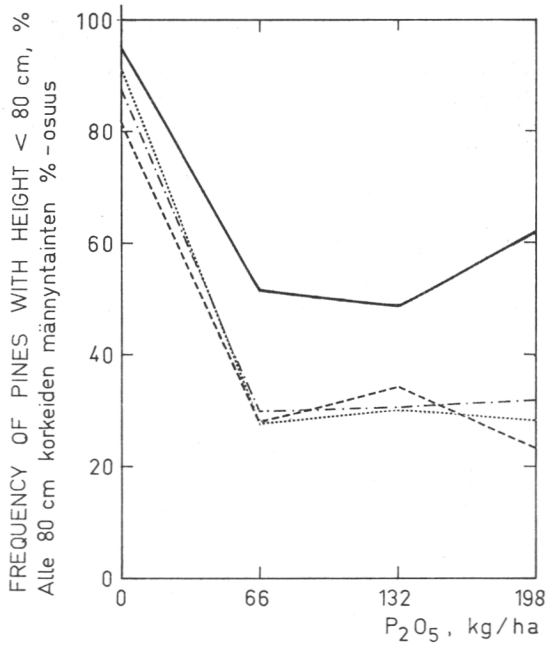

Figure 9. Percentage of saplings smaller than 80 cm on plots having received various amounts of phosphorus in Experiment I. ——— = 0, — — — = 50, —·—·— = 100, and ····· = 200 kg/ha K_2O.

Kuva 9. 80 cm matalampien tainten %-osuus erilaisia fosforimääriä saaneilla koeruuduilla kokeessa I. ——— *= 0,* — — — *= 50,* —·—·— *= 100 ja* ····· *= 200 kg/ha* K_2O.

other hand, on these plots there was a phosphorus deficiency, which had resulted in a very significant increase in nitrogen content (Figure 8). It is, therefore, possible that either a phosphorus deficiency or a high nitrogen content had increased the amount of snow blight. The dependence of snow blight frequency on mineral content of needles could not be determined in this experiment with the aid of multiple regression since too many independent variables were correlated with each other or with the same fertilizer treatment. When the analyzed nutrients (N, P, K, and Ca), crown volume and snow depth were included in the equation, the correlation coefficient was high (= 0.909); but the factors for the various variables were not statistically significant. No mineral variable was found to have a more pronounced effect than other variables.

The effects of fertilizers and mineral content of needles on amount of snow blight has been reported above. This may be regarded as the effects of soil nutrients on disease resistance. The importance of the damage caused by snow blight is, however, mostly dependent on the size of the young trees at

the time of infection. The infection is usually very devastating to small seedlings, but if the crown of saplings is already above the snow cover, they remain alive in spite of the needle loss caused by the disease. Consequently, a sapling stand which grows rapidly during its first growing seasons will be damaged less than one which grows slowly. Since fertilization causes the young trees to grow rapidly above the snow cover, the time during which they are exposed to damage by the snow blight is reduced; and as a consequence, the mortality caused by snow blight is reduced.

In all the current experiments at Kivisuo fertilization with phosphorus incerceased height growth the most (Tables 2 and 3). In this study the height of 80 cm was taken to be a threshold value above which the young trees were assumed to remain alive after attacks by snow blight. In Experiment I the average height of the young trees on plots fertilized with phosphorus exceeded this threshold during the fifth growing season when the average height in the fall of 1963 was about 90 cm. On plots with no phosphorus the height was about 50 cm. In the fall of 1963 the proportion of young trees likely to be killed by snow blight (height < 80 cm) was 30 % on plots fertilized with phosphorus and potassium, compared to 55 % on plots with no potassium and 88 % on plots with no phosphorus (Figure 9). On plots with no phosphorus the average height of the young trees usually reached 80 cm during their eighth growing season after being planted out. Correspondingly, in the other experiments the seedlings also reached above the threshold faster on plots fertilized with phosphorus.

Mortality due to snow blight in the various experiments was not determined in this study. To determine mortality, the seedlings should have been examined each year beginning at the time when the experiment was established. In Experiment XI most young trees being alive on plots containing the least phosphorus were still in 1974, after ten growing seasons, endangered by snow blight.

DISCUSSION

The primary purpose of fertilization is usually to obtain increased growth in a stand. A secondary purpose may be to improve its quality in such a manner that it would be more resistant to disease. When studying the effects of fertilization on disease resistance, there is always a great danger of making the wrong conclusions. Fertilization may increase disease resistance; but on the other hand, in the host population improved by fertilization, the spread of the pathogen and infection of the host may be facilitated.

In the cases currently studied, fertilization with phosphorus and potassium caused a manifold increase in growth compared to unfertilized plots. The increased growth caused the crowns of the host plants to become more dense. The number of needles in relation to the crown volume was greater in larger, more vigorous young trees compared to trees deficient in phosphorus or potassium, where the needles are cast off at an earlier age (Reinikainen 1967). In red pine (*Pinus resinosa* Ait.) potassium fertilization has also been found to increase longevity of needles (Madgwick et al. 1970). The volume of the crown (< 80 cm) was found in the present investigation to correlate positively with incidence of snow blight. It is clear that the probability of infection increases if the number of needles, which trap the spores of the causal agent, increases.

The data on snow depth used in this study can perhaps explain the amount of snow blight on the plots for only 2—3 years. Of course, the spread of the disease on the experimental area started already during the first winters after the experiments were established, when differences in height between the young trees of various fertilizer treatments did not exist and consequently, did not cause unequal drifting and accumulation of snow on the area. Only later, when the young trees were taller, did snow begin to accumulate more on plots with rapidly growing trees. According to Mattsson Mårn (1944) and Björkman (1948), accumulation of snow increases the damage caused by snow blight.

There was more snow blight close to a heavily infected, older sapling stand compared to areas farther away from that stand. Correspondingly,

in ordinary planting areas, the damage from snow blight may be much greater if planting is done close to an older sapling stand which is already infected or if beating up is done in a previously infected stand. Snow blight may thrive for several years on the lower branches of young trees which have tops reaching above the snow cover without causing damage to the trees. Small trees in the immediate vicinity may, however, acquire a very severe infection.

If it is assumed in the analysis that the variation caused by the most important enviromental factors responsible for increasing the amount of blight (number of needles, accumulation of snow, distance to source of spores) were eliminated, then it may be concluded that fertilization, which is conductive to growth, in these experiments increased the resistance of the pine needles to snow blight. The increased resistance in the pines due to fertilization, which balances the nutritional status of the host, supports what is known about the relationship between nutrition and diseases caused by facultative parasites. It has often been possible to reduce the damage caused by facultative leaf pathogens by means of applying fertilizers which increase host vigour and correct the proportions of available nutrients in the soil (Shidei et al. 1954, Mayer-Krapoll 1957, Curschmann 1960, Zöttl and Jung 1964, van der Meiden 1964, Donaubauer 1965, Lanier et al. 1965, Pagony 1969). The effects of fertilizers on the amount of disease are always dependent on the proportions of nutrients in the soil prior to fertilization. When there are enough nutrients in the soil or in the correct proportions, fertilization does not seem to have any beneficial effect on the amount of disease (cf. Rack 1965, Baule and Fricker 1967, Pagony 1969).

In this study the resistance mechanism affected by the fertilizers was not investigated. According to Keller (1970), the resistance against pathogens which are active during the winter is somehow associated with the respiration of the host plant. The results obtained in this study do not contradict Keller's assumption. The increased respiration activity may affect the host by reducing the energy sources and thus reduce the formation of protective substances important for resistance. Also, the nitrogen content of the plant and the amount and quality of various nitrogen compounds, amino acids and proteins, may affect the development of resistance. Durzan and Steward (1967) found that the lack of phosphorus especially, but also that of potassium, caused considerable change in the amount and proportions of amino acids in the needles of white spruce (*Picea glauca*) and Jack pine (*Pinus banksiana*). Even if the nitrogen fertilization at Kivisuo was not found to affect the amount of snow blight, it may have a significant effect on disease resistancse under different conditions (Björkman 1967).

SUMMARY

The effects of various NPK-fertilizer combinations and liming on the amount of snow blight on pine saplings were studied in experiments established on peatland deficient in phosphorus and potassium. In addition to the effects of fertilizers, the independent variables used in the analysis included the volume of the crown exposed to the disease, distance to the spore source, depth of the snow cover, and the needle content of N, P, K, and Ca. Not all these variables could, however, be used in analyzing all the data.

In all experiments the amount of phosphorus was extremely low in the unfertilized plots. In one experiment there was, in addition, a clear lack of potassium. No lack of nitrogen was apparent on the unfertilized plots, but nitrogen deficiency was sometimes evident on plots fertilized with an excess of P and K.

Phosphorus strongly increased the height growth of the saplings and sometimes nitrogen and potassium increased the growth to a lesser degree. The more vigorously the saplings were growing, the sooner they reached above the snow cover where the snow blight was not able to kill them. Concurrently with the increased growth, the volume of the crown exposed to the pathogen increased. The amount of snow blight increased along with an increase in the average size and volume of the crown exposed to the pathogen.

The great differences in size of saplings on different plots caused the snow to drift from plots with small saplings and to accumulate on those with large saplings. In spite of the fact that the depth of the snow cover generally has a crucial influence on the amount of snow blight, the effect of snow accumulation could not, in the present study, be shown or separated from the effect of increased crown volume.

In the vicinity of a heavily infected, older sapling stand the amount of disease was much greater compared to saplings located farther away. On areas infected with snow blight the spread of the disease may be slowed down by separating reforestation areas of different ages with strips of some other tree species. By slowing down the spread of the disease, the saplings will have more time to reach above the snow cover. Also, when beating up in a pine stand infected with snow blight, some other tree species should be used if possible.

Fertilizers which improved the nutrient balance of the soil reduced the amount of snow blight. On the substrate deficient in phosphorus the application of this nutrient increased resistance to snow blight. When there was very little of both phosphorus and potassium in the substrate, the addition of either one of these nutrients increased the amount of disease. When phosphorus and potassium were applied together the increase was controlled.

The smallest amount of disease was found on plots which had received neither phosphorus nor potassium. Fertilization with phosphorus and potassium was, however, necessary for the growth of the seedlings. Even if fertilization with nitrogen somewhat increased the saplings' growth, it had no effect on the amount of disease when applied by broadcasting. When nitrogen applied by spot fertilization, it appeared to increase the amount of disease somewhat. Potassium and phosphorus applied in the same manner seemed to reduce the amount of disease. Application of calcium did not affect the amount of snow blight.

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LANNOITUKSEN JA ERÄIDEN YMPÄRISTÖTEKIJÄIN VAIKUTUKSESTA MÄNNYN TAINTEN LUMIKARISTEISUUTEEN

Seloste

Erilaisten NPK- (typpi-, fosfori- ja kali-) lannoituksen sekä kalkituksen vaikutusta männyn tainten lumikaristeisuuteen tutkittiin vähäravinteiselle turvemaalle perustetuissa kokeissa. Lannoituksen vaikutusta analysoitaessa käytettiin lumikaristeisuutta selittävinä muuttujina myös taudille alttiin latvuston tilavuutta, itiölähteen etäisyyttä, lumipeitteen vahvuutta sekä neulasten N, P, K ja Ca -pitoisuuksia. Kaikkia lueteltuja muuttujia ei kuitenkaan voitu käyttää jokaisen aineiston analyysissä.

Kaikissa tutkituissa kokeissa lannoittamattomassa kasvualustassa oli erittäin vähän fosforia. Yhdessä kokeessa oli lisäksi selvä kalinpuute. Typenpuute ei ilmennyt lannoittamattomilla aloilla, mutta saattoi joskus tulla esiin PK-yliannostuksen saaneilla koeruuduilla.

Fosfori lisäsi voimakkaasti tainten pituuskasvua ja joskus vähäisemmässä määrin myös typpi ja kali. Mitä voimakkaammin taimet kasvoivat sitä nopeammin ne selviytyivät lumipeitteen yläpuolelle, jolloin lumikariste ei voinut enää tappaa taimia. Lisääntyneen kasvun myötä suureni tainten taudille alttiin latvuston tilavuus. Lumikaristefrekvenssi koeruuduilla oli sitä suurempi mitä suurempi oli taudille alttiin latvuston osan keskimääräinen tilavuus koeruuduilla.

Suuret erot tainten koossa eri koeruuduilla aiheuttivat sen, että tuulen heikkokasvuisilta ruuduilta irroittama lumi kasautui osaksi reheväkasvuisille ruuduille. Huolimatta siitä, että lumipeitteen vahvuudella on yleensä ratkaiseva merkitys lumikaristetuhojen muodostumiselle, ei tässä tapauksessa lumen kasautumisen vaikutusta pystytty osoittamaan tai erottamaan latvuston tilavuuden tautia lisäävästä vaikutuksesta.

Voimakkaasti saastuneen vanhemman taimiston läheisyydessä oli lumikaristeisuus huomattavasti runsaampaa kuin kauempana siitä. Lumikaristeen pahoin vaivaamilla alueilla voitaisiinkin taudin leviämistä ehkä hidastaa erottamalla eri-ikäiset männynviljelmät toisistaan muuta puulajia olevilla kaistoilla. Hidastamalla taudin leviämistä annetaan taimille lisää aikaa lumenpinnan saavuttamiseen. Samoin lumikaristeen saastuttaman männyn taimiston täydennyksessä ei pitäisi käyttää männyn taimia, jos jonkin muun puulajin istuttaminen on mahdollista.

Ravinnesuhteita tasapainottava lannoitus vähensi tautisuutta. Fosfori- ja kaliköyhällä turvemaalla yksipuolinen P- tai K-lannoitus lisäsi tautisuutta. Ilman kalia ja fosforia jääneisiin ruutuihin nähden ei PK-lannoitus vähentänyt tautisuutta, mutta yksipuolisen lannoituksen haitta, lisääntyvä tautisuus, voitiin välttää. Kun otettiin huomioitiin myös tainten koon vaikutus, tautisuus oli vähäisintä fosfori- ja kaliköyhällä alueella PK-lannoituksen O-ruuduilla ja ruuduilla, jotka olivat saaneet vähintään 200 kg/ha sekä fosforilannoitetta (33 % P_2O_5) että kalisuolaa (50 % K_2O.

Fosforin puutteesta kärsivällä alueella, jolla toisaalta oli kalia riittävästi, esiintyi lumikaristetta runsaimmin fosforilla lannoittamattomilla ruuduilla. Yksipuolinen kalilannoitus ei tässä tapauksessa lisännyt tautisuutta, mutta fosforilannoitus vähensi sitä aina.

Typen määrän muuttuminen muihin ravinteisiin nähden ei aiheuttanut muutoksia tautisuudessa. Lumikaristeen rusaus tutkituissa kokeissa näytti siis olevan varsin kiinteästi riippuvainen nimenomaan fosforin ja kalin keskinäisistä suhteista silloin, kun näitä molempia tai toista niistä oli niukasti käytettävissä. Tehtyihin havantoihin perustuen voidaan päätellä, että tasapainoisella PK-lannoituksella ei aiheuteta lumikaristeen merkittävää lisääntymistä. Yksipuolista fosfori- tai kalilanoitusta olisi ilman lumikaristeen lisääntymisriskiä mahdollista käyttää vain, jos sekä fosforin että kalin määrä maassa tunnetaan, jolloin lannoituksen tulisi olla ko. ravinteiden suhteita tasapainoittavaa.

THE EFFECT OF FERTILIZATION ON THE BASIC DENSITY OF SCOTS PINE
(Pinus silvestris L.)

A densitometric study on the X-ray chart curves of wood

OLAVI SAIKKU

LYHENNELMÄ

Lannoituksen vaikutuksesta männyn *(Pinus silvestris L.)* puuaineen tiheyteen
Densitometritutkimus puuaineen röntgenkuvista

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FOREWORD

Measurement of wood density by X-rays has been under development at the Department of Forest Technology, the Finnish Forest Research Institute, since 1970. On the basis of orientating studies the method was considered to give such accurate results that it was possible to use it for the acquisition of practical information. Fertilized wood was chosen as the target as it was possible to follow minutely its annual variations in density.

Hubert Polge's densitometric method has been adopted to use at the Forest Research Institute by Mr. Kari Sauvala. He participated in the different phases of the work by taking the roentgenograms of the wood samples, by drawing up the density measurement scales and advising in the interpretation of the roentgenograms.

Mrs. Arja Winter, M.Sc., did most of the statistical analysis of the material. Mrs. Kaarina Koskinen and Mr. Tauno Savolainen participated in the calcultation work. Mrs. Aune Rytkönen typed the manuscript; the drawings were made by Mrs. Leena Muronranta.

The manuscript was checked by Professors Pentti Hakkila and Veijo Heiskanen. I also received valuable advice from Professor Bror-Anton Granvik.

Assistance was given by Mr. Pertti Laakso and Messrs. Kymi Oy with the material collected from sample plots established by the Department of Soil Research of the Finnish Forest Research Institute.

I express my best thanks to all these persons mentioned.

Helsinki, January 1975

Olavi Saikku

1. INTRODUCTION

A problem besetting the wood-utilising industry is and will be insufficiency of raw material. Wood yield can be increased by silviculture, tree breeding and soil preparation. For instance, growthc an be improved appreciably by forest fertilization; this gives an increase in volume growth of approx. 30 per cent (Operation Forest Fertilization 1969). Growth increments of this magnitude are assumed often to cause changes also in the qualitative properties of wood, especially in wood density which is the mass of wood per volume unit.

The changes in density are reflected in the pulp industry in which the quantity of chemical and mechanical pulp obtained from the volume unit depends almost rectilinearly on the basic density. The quality of the products of the sawmill and particle board industry is also greatly dependent on basic density.

Although the primary aim of fertilization is to increase growth, it is well to consider also such fertilization effects as do not improve volume growth essentially but cause changes in wood density. When optimal wood yield is the aim it is necessary to consider simultaneously the growth in tree volume and the density of the wood that is formed.

The present study is based on the use of the densitometric method. It permits study of wood density from individual annual rings with sufficient accuracy compared with conventional density determination methods. Densitometry has proved to be a serviceable method especially for fertilization studies in which the duration of the fertilization effect is often less than 10 years.

The purpose of the study was to examine the possible single effects and interactions of different nutrients, in this case nitrogen, phosphorus, potassium and calcium, on the basic density of pine. Ring width was adopted as the independent variable of density, as the changes that occur in it are associated directly with the growth change caused by fertilization. Percentage summerwood, the strong independent variable of density in many studies, was also examined.

2. WOOD DENSITY

21. Concepts of density

Basic density depends for the most part on the ratio between the volume of cell walls and the volume of the intra- and inter-cellular spaces (E l l i o t t 1970). It is thus influenced by the structure of the cell wall, the average cell size, the quantity of resins and extractives and the volume of different ducts and pores. Density shows the wood mass per unit of volume and is usually expressed in grams per cubic centimetre or kilograms per cubic metre. Owing to the hygroscopic (moistureabsorbing) property of wood its mass per volume unit varies with the amount of water it contains. Wood mass is therefore generally determined as absolutely dry, whereas volume is determined as 1) green with moisture exceeding the fibre saturation point, 2) air-dry, i. e. with a moisture content of 12 or 15 per cent, or 3) as absolutely dry. In the present work, the first method was applied indirectly to the densitometer, determining the mass as absolutely dry and the volume as green (b a s i c d e n s i t y).

When determining density it is necessary to consider also the extractives which increase it. The question is ordinarily one of the density of unextracted wood which, because of the variation the quantity of extractives, is more inaccurate than the density of extracted wood as an independent variable of the mass of actual wood.

22. Density and quality of wood

The quality of wood is a concept linked with its mode of utilisation and there is no univocal unit of measure to express it. Density is an indicator of wood quality that describes the suitability of wood for a certain use.

Basic density in the s a w m i l l i n d u s t r y gives an idea of the mechanical properties of wood. There is a strong positive correlation between basic density and the strength characteristics of wood (tensile, crushing, tearing and bending strength) (S i i m e s and L i i r i 1953). The

great differences in Finnish pine have been taken into consideration in the strength grading instructions for structural timber. Shrinkage and swelling occur in sawn goods owing to the hygroscopic structure of wood. Wood of light weight absorbs more water on account of its greater space volume, whereas swelling and shrinkage are greater in dense wood.

Wood consumption and the quality of board in the particle board industry depend largely on wood density. Particle board is generally manufactured in a certain weight (g/sq. cm) and the consumption of wood is therefore greater the lighter the wood.

In the pulp industry pulpwood density is of essential importance for the yield of pulp and the quality of paper. The proportion of thick-walled summerwood cells, though they are smaller in diameter, is higher in heavy wood and the pulp yield (kg/cu. m.) is correspondingly greater.

High density improves opacity and tearing strength, affecting the quality of paper. Wood of low density containing abundant springwood is best for printing paper grades which require an even paper surface and a high bursting and tensile strength.

The role of density for paper quality has become topical also in very fast-growing, short-rotation cultivations, e.g. in the tropics where the proportion of juvenile wood is considerable when rotation is under 20 years (Zobel et al. 1972).

23. Factors that affect density variation

231. Variation within stems

Variation within stems is affected strongly by the springwood and summerwood ratio. The density of summerwood is double and even three times that of springwood (e.g. Trendelenburg 1955). The difference in densities is due to the differences in the thickness of the secondary walls and cell size. Larson (1957) was able to explain 60 per cent of the density variation of Pinus Elliottii and Hakkila (1966) 53 per cent of the pine density variation as being caused solely by the variation in percentage summerwood.

However, total basic density cannot be explained by the variation in springwood and summerwood as the density within spring- and summerwood also varies. Springwood density declines progressively 10-15 years outwards from the pith in the juvenile wood zone, affecting the variation within the annual ring in this zone. Summerwood density increases with age especially after the juvenile wood zone and exerts a strong effect on the density of mature wood (Elliott 1970).

Contradictory results have been reported concerning the effect of the width of the annual ring on density. The effect of age on the width and density of the annual ring has often been disregarded in these studies. If only the effect of the annual ring width on density is examined, density decreases when the ring width increases. The density of quite thin annual rings of conifers is lower than it is in slightly thicker rings (Siimes 1938).

In examining the effect of position on density it can be assumed that wood in different parts of the stem is produced by cambium tissue of a certain age. Wood density in the radial direction of the stem is lowest near the pith and grows with age towards the surface (Elliott 1970). However, overmaturity changes the trend to a falling one and Hakkila (1966), for instance, obtained the maximum density of pine in annual rings originating at the age of 80 years. Density decreases in the longitudinal direction of the tree in the same annual ring until crown height, and then increases slightly again (Elliott 1970). Density has been observed to be roughly equally high from the pith in a juvenile wood zone in certain years and to decrease somewhat with age.

Wood density decreases on average from butt to top (Spurr and Hsiung 1954, Hakkila 1966, Usvaara 1974). The reasons for this are the high proportion of juvenile wood in the top parts, young age and the width of the annual rings.

232. Variation between stems

The variation in density between stems for a certain tree species is dependent for the greatest part on the same factors as the within-stem density variation. The strongest affecting factors are the age and rate of growth of the tree. The degree of explanation of age is high for pine, according to e.g. Hakkila (1966) 32 per cent of variation. Density generally grows with age until over-maturity reverses the trend. Faster growth, on the other hand, usually means decreasing density for pine.

In addition to the above-mentioned characteristics that illustrate within-stem density variation as well, habitat and geographical location are also important. There is a positive correlation between the fertility of the habitat and rate of growth, and the effects of habitat are consequently reflected in the growth rate. A tree growing on a good habitat tends to form wood of lower density than one on a poor habitat in otherwise the same conditions. An exception to this is the tree growing on a very barren site; it has a low density because of the limiting habitat or climatic factors. This phenomenon is explained at least in part by the inadequate formation of summerwood (Elliott 1970).

Geographical location plays a role in density variation. The reasons for geographical variation in density have been sought in soil, humidity relations and temperature factors. However, opinions vary as to their degree of explanation, and what appears to be in question here is a combination of many of the factors which affect density that have already been mentioned (Elliott 1970). Hakkila (1968) has shown that the density of Finnish pine pulpwood declines distinctly from south to north. No difference was seen in the east-west direction.

Several studies have established that wood characteristics are transmitted from parents to offspring. In addition, investigations of young growing stock have provided indications of the heritability of density also to an older age (Elliott 1970). High heritability values were obtained by Velling (1974) for pine, and they speak in favour of the common opinion that basic density is a property subject to genetic control.

3. FOREST FERTILIZATION

Tree growth is a phenomenon in which organic compounds are formed of water and carbon dioxide as well as of inorganic nutrient salts by solar radiation. The factors that affect growth are partly internal, partly external. The internal growth factors are genes that direct the growth and development of trees. External growth factors comprise e.g. climatic factors and factors associated with soil and habitat.

The most important of the nutrients consumed by trees are nitrogen (N), phosphorus (P), potassium (K) and calcium (C). N i t r o g e n is an important constituent of the proteins of cellular tissues and of enzymes that regulate the metabolism of trees. The nitrogen requirement is greatest in the phase of wood mass production when cell-building substances are needed. There is great shortage of utilisable nitrogen in mineral soils because, despite its abundance, it is bound in a form unfit for use by plants. P h o s p h o r u s is a structural component of many enzymes and proteins. The absence of phosphorus is manifested in pines as thin shoots, frost injury to the top and shedding of needles. P o t a s s i u m promotes the formation of carbohydrates and, indirectly, also proteins in the photosynthesis of trees. C a l c i u m promotes the decomposition of humus firm forest lands, increasing the amount of nutrients available to the trees.

The most commonly used fertilizers in Finland in a forest approaching the timber stage are Oulu saltpetre (26 per cent N) and urea (46 per cent N). In addition, the nitrogen-rich NKP fertilizer is recommended for more fertile lands (V i r o 1972). A suitable quantity of fertilizer for a single fertilization is 120-150 kg of pure nitrogen per hectare. In fertilizing for the second time or several times the best have been achieved with approx. 120 kg of nitrogen.

In the last few years, about 200,000 hectares have been fertilized yearly in Finland. This is half of the targets fixed for the forest improvement plans. An indication of the increase in wood yield produced by fertilization in Finland is the fact that the average growth increment is calculated to be about 1. 3 solid cu. m. per hectare (Operation Forest Fertilization 1969). The growth achieved in the whole country in 1974 would thus have been over 1. 25 million solid cu. m. if the effects of fertilization from 1969 are included.

4. METHOD OF INVESTIGATION

41. Densitometric method

This study is based on H u b e r t P o l g e's method as modified for the Forest Research Institute by K a r i S a u v a l a. Density is determined in this method from the piece of wood by means of X-rays. A densitometer is used for interpretation of the X-ray negatives taken of the sample. Using a light passing through the negative, the densitometer plots on graph paper the changes in the density of the sample. The density of the curve traced on the graph paper is obtained from a scale prepared from control pieces of known density (cf. P o l g e 1966).

The samples are prepared by sawing from wood discs 5 mm thick cores in which the wood fibres are at right angles to the surface of the core. The samples are dried to a moisture content of 8 per cent by keeping them after the seasoning of the wood for 24 hours in an exsiccator containing sodium dichromate.

The samples to be X-rayed are placed on the film in an envelope, together with the density scale prepared of celluloid sheets. The distance of the film from the source of radiation is 2.5 m. To ensure that the X-rays penetrate the wood exactly parallel to the fibres, the ends of the samples are glued in position with pieces of paper. An exposure time of 5 min. at 23 kV gives a good contrast between black and white on the film.

The density scale, the »step wedge», is prepared on the basis of a piece of wood with 22 different densities ranging from 260 to 936 kg/cu. m. The step wedge is made stepwise of ten 0.5 mm thick celluloid sheets.

A Joyce & Loebl microdensitometer which registers with double beam was used in the study. It plots density curve on graph paper on a non-linear scale. Planimetry was employed for the determination of density on the graph paper curve. The surface area was calculated separately for each annual ring and the average density of the annual rings was obtained by dividing the surface area by ring width (Fig. 1). The spring- and summerwood boundaries of the annual ring were calculated according to the definition expounded by G r e e n e & W o r r a l (1964): summerwood cells are those in which the

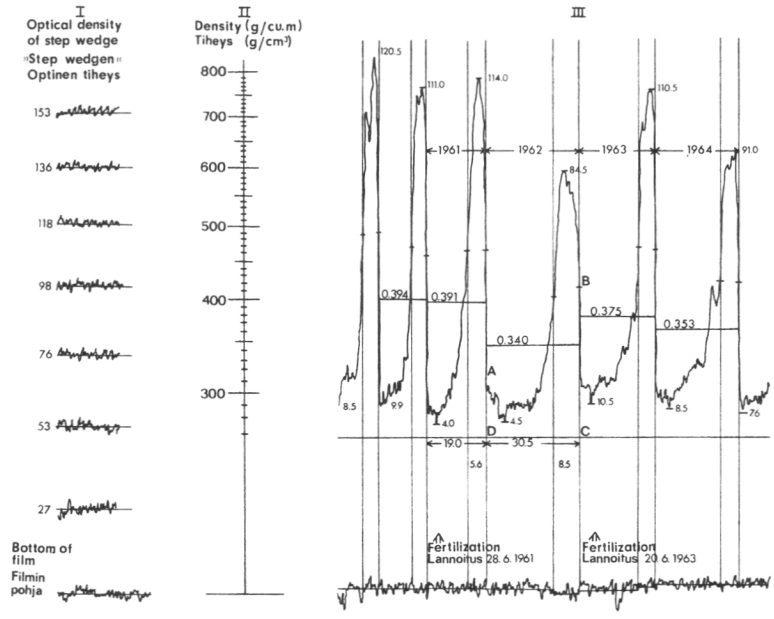

Figure 1. Optic density of step wedge (I), the density scale of wood (II) and density curve on graph paper (III).

Kuva 1. Step wedgen optiset tiheydet (I), puuaineen tiheysasteikko (II) ja densitometrikäyrä (III).

thickness between the cell spaces along the direction of the ray is greater than the mean of the distances between the cell spaces of the first springwood cells and last summerwood cells.

42. Accuracy of the method

A method comprising many different work phases always involves a high potential error. In the densitometric method the following factors affect accuracy:

1) thickness variation in the sample to be X-rayed;
2) deviation of the sample fibres from the perpendicular to the plane in which the sample is placed, and/or deviation of X-rays from the wood fibres;
3) inaccuracies in the development of the film;
4) appearance of the light streak from the densitometer on the film (see Item 1);
5) inaccuracy of the step-wedge.

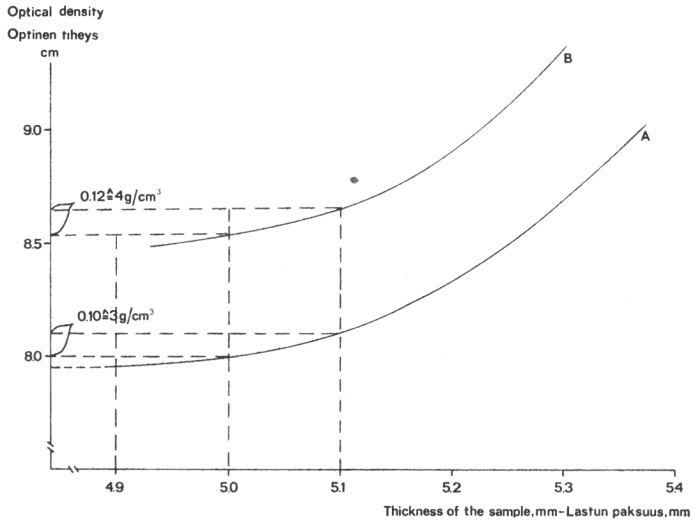

Figure 2. The correlation of optical density and core thickness. Samples taken from pieces of wood, A and B.

Kuva 2. Optisen tiheyden riippuvuus lastun (näytteen) paksuudesta. Lastunäytteet otettu puukappaleista A ja B.

To establish the significance of the thickness variation of the sample, an experimental series was organised in which cores of different thicknesses were sawn from two pieces of wood (A and B); from a thickness of 4.9 to 5.3 mm. The thickness of each core was measured in several places to an accuracy of 1/100 mm and the mean of these measurements was taken as the thickness of the core.

The results of the experiment for the correlation of optical density and core thickness are presented in Fig. 2. A 0.1 mm deviation upwards from the target thickness (5.0 mm) caused a 3 g/cu. m. increase in density in test piece A and a 4 g/cu. cm. increase in test piece B. Corresponding downward changes from the target thickness had an effect that was less than a half of that in a thicker sample.

To find out the deviation of core thickness, 179 core samples were collected from the investigation material by random sampling. The results obtained were as follows:

$\bar{x} = 5.005$ mm $\quad \triangle \bar{x} = 0.022$ mm $\quad t = 1.81$

$s = 0.037$ mm $\quad n = 179$

in which

$\bar{x}$ = average core thickness
$\triangle \bar{x}$ = average deviation from the mean of core thickness
s = standard deviation
n = number of core samples
t = t-value obtained in the testing

The results of the material with normal distribution are perhaps too good; the deviation was only 0.04 mm. The density variation caused by core thickness would then be only $\pm$ 1.2 g/cu. cm at a statistically significant level. Taking $\pm$ 2 per cent as the permissible error in the thickness of the annual core used in the material, the maximum possible error according to Fig. 2 is 5 g/cu. cm.

It was difficult to dry the negative evenly after developing the film. The water that ran to the lower part of the film on negatives dried by hanging caused a slight difference in darkness compared with the rest of the film. To correct this, a blower was used for faster drying. The error of the darkness differences was reduced to insignificance by placing the samples and the step wedge to the upper part of the film.

Experiments were made to establish the appearance of the densitometer light streak on the film: exposure were made at several points along the length of the sample. The appearance of the light streak was not observed to be of importance; the deviation was statistically insignificant.

The reliability of the step wedge is affected most by the accuracy with which the density of the samples was measured by mercury immersion method.

5. MATERIAL

The material was collected in autumn 1971 and 1972 from fertilization sample plots No. 114 (1) and 156 (2) (Fig. 3) established in Heinola by the Department of Soils of the Finnish Forest Research Institute. The composi-

Table 1. Sample plot data before fertilization.
Taulukko 1. Koealatiedot ennen lannoitusta.

No. of sample plot *Koealanumero*	Year of establishment *Perustamisvuosi*	Site type *Metsätyyppi*	Age, years *Ikä, v*	Average height, m *Keskimääräinen pituus, m*	Number of stems, /ha *Runkoluku kpl/ha*	Volume, cu.m./ha *Tilavuus, m³/ha*	Annual increment without bark, cu. m./ha *Vuotuinen kasvu k:tta, m³/ha*
1	1961	VT	60	20.7	531	202	6.2
2	1962	VT	55	19.7	560	178	6.0



Figure 3. Sample plot in a 60-year old Scotch pine stand.
Kuva 3. Tutkimuskoeala 60-vuotiaassa männikössä.

tion of the growing stock of the sample plots was nearly the same as that of the more mature growing stock approaching the timber stage that is recommended in the fertilization instructions. Sample plots were selected for the investigation material because of their serviceability for a densitometric study.

Both sample plot series formed an independent factorial experiment in which four nutrients were examined: calcium (Ca), nitrogen (N), phosphorus (P) and potassium (K). Each sample plot had 17 compartments, of which two were 0 or control compartments (Fig. 4). According to the principle of the

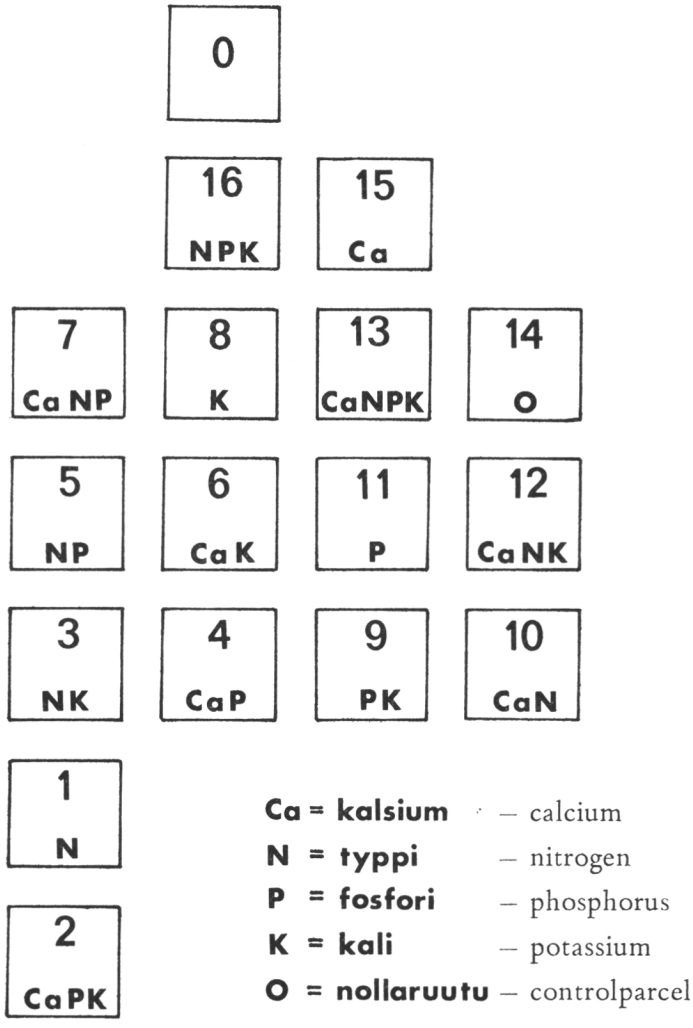

Figure 4. Fertilized compartments on sample plot 2.
Kuva 4. Lannoitusruutujen sijainti koealalla 2.

factorial experiment with a system of 16 (in this case 17) compartments, an eight-fold repetition was obtained for the single effects of each nutrient and for their combined effects.

The fertilization per sample plot was as follows:

No. of fertilization	Time of fertilization	Fertilization
		Sample plot 1
I (F)	June 1961	Factorial experiment (Ca 2 000, N 400, P 400 and K 200 kg/ha)
II (N_1)	June 1963	Nitrogen fertilization of compartments given only nitrogen, 400 kg/ha of ammonium sulphate
III (N_2)	May 1969	Nitrogen fertilization of compartments given only nitrogen, 200 kg/ha of urea
		Sample plot 2
I (f)	July 1962	Factorial experiment (Ca 2 000, N 400, P 400 and K 200 kg/ha)
II (n_1)	June 1964	Nitrogen fertilization of compartments given only nitrogen, 400 kg/ha, ammonium sulphate
III (n_2)	May 1969	Nitrogen fertilization of compartments given only nitrogen, 200 kg/ha, urea

The size of the compartments in sample plot 1 was 40 × 40 and in sample plot 2 30 × 30 m. A 5 m border around each compartment was fertilized in the same way the compartment.

The trees in the sample plot compartments were classified into ten diameter classes from each of which one tree was chosen by systematic sampling. The number of sample trees from each sample plot was thus 170, making 340 in all. The height of the tree and the height of the green crown were determined from individual trees and the number of stems per hectare was determined from one compartment.

An approx. 5 cm thick disc from each tree taken at distances of 2, 6 and 10 m from the butt was examined in the laboratory. In addition, 31 trees from sample plot 1 were studied in greater detail; discs were sawn from the butt, at heights of 0.65, 1.3 and 2.0 m, and then at intervals of 2 m up to the top. To keep them moist, the discs were placed in plastic bags which were stored cold.

51. Selection of samples

To select sample heights that best represented the average wood density, the variation in density in the longitudinal direction of the stem was determined first from the above-mentioned material of 31 trees. The sample trees for this purpose were selected by systematic sampling on the basis of tree size (tree height and breast height diameter). The observations were as follows:

sample trees	31
sample heights (0, 0.65, 1.3, 2, 4, 6, 8, 10, 12, 14 and 16)	11
observation years (20 years)	1951—1970
observations (annual rings), total	3 780

As appears from Fig. 5, the density rises over a short distance on moving from top to butt. The peak comes at a height of 60 cm from the butt, after which a steep drop occurs. To draw the graph, the situation was divided into two parts, I and II; when the total situation was treated regression analysis did not give a sufficiently accurate picture of the sudden increase and decrease in density which occurs especially in the butt, despite the variations in height employed (x^2, x^3, $\frac{1}{x}$, $\frac{1}{x^2}$, $\frac{1}{x^3}$, ln x).

For the means (11 in number) of the observations at different heights, the degree of explanation was 99.1 per cent, which illustrates first and foremost only the good positioning of the mean on the regression line. Comparison with part I of the regression line with the results that H a k k i l a (1966) reported for pine showed the differences to be very small if allowance is made for the absence of juvenile wood in the latter study.

The table below gives the sums of the densities in different years calculated 1) for all heights, 2) for heights 2, 6 and 10 m and 3) for heights 2 and 6 m.

	Year									
	51	52	53	54	55	56	57	58	59	60
	Density, kg/cu.m.									
All heights together	409	397	415	405	408	425	436	424	441	430
Heights 2, 6, 10 together	397	388	406	398	399	417	430	419	434	421
Heights 2, 6 together	402	392	414	406	406	429	444	427	445	430

	Year									
	61	62	63	64	65	66	67	68	69	70
	Density, kg/cu.m.									
All heights together	399	381	441	412	404	423	435	413	422	424
Heights 2, 6, 10 together	394	374	431	405	398	415	425	406	415	418
Heights 2, 6 together	400	378	442	415	403	425	435	417	422	428

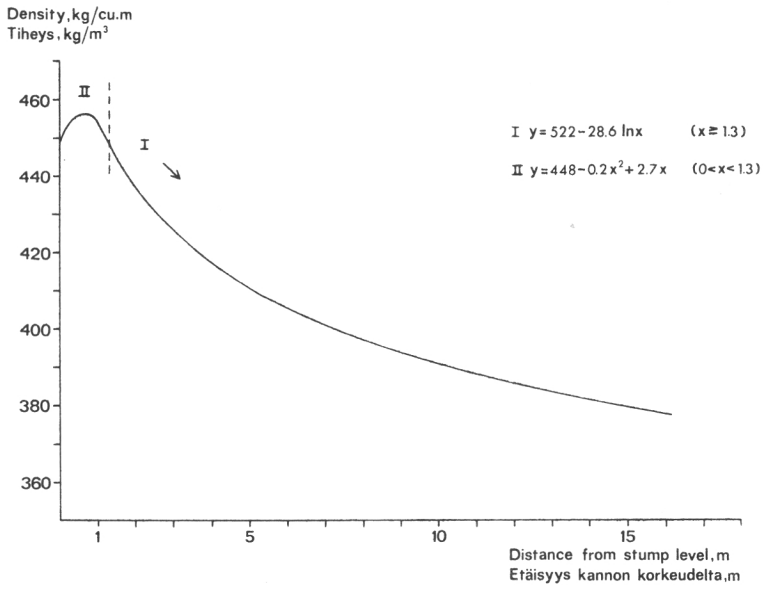

Figure 5. Correlation between density and distance from stump level in 20 outer year rings of the stem.

Kuva 5. Tiheyden riippuvuus etäisyydestä kannon korkeudelta rungon 20 uloimmassa vuosilustossa.

The sum of the heights of 2, 6 and 10 m was approx. 10 kg/cu. m. lower than that of all heights. The sum of heights 2 and 6 represented best the sum of all heights. The differences were of the order of a couple of kg/cu. m. However, as the share of the denser butt is weighted more heavily in the sum of all heights, the sum of the less dense 2, 6 and 10 m was considered to be most representative of the overall wood density for 20 surface annual rings.

The main material of the study was thus confined to sample heights 2, 6 and 10 m. The material for both sample plots was as follows:

	Sample plot 1	Sample plot 2
Stems	33	167
Discs from sample heights 2, 6 and 10	102	493
Annual rings	980	4 819

52. Statistical analysis of the material

A statistico-mathematical method in which the single effects and interactions of all nutrients were tested individually was used to discover the effects of the different nutrients. The method, which is of the nature of a factorial experiment, is based on the t-test. Variance analysis was employed

to study the influence of various factors that affect density, such as sample heights.

The covariance analysis generally used in fertilization experiments was abandoned as the density changes proved to be slight and the significance of the regression coefficients (e.g. age, climate) to be eliminated was complex because of the short age range (10 years) of the material. Another limiting factor is that covariance analysis requires a larger material.

Selective regression analysis was used for the study of different correlalations.

The statistico-mathematical HYLPS programme worked out by the University of Helsinki was used in the computer runs.

6. RESULTS

61. Significance of temperature

The role of temperature in explaining the annual variation in density became apparent during the analysis of the results. As it is necessary in a later phase to explain different results by means of variables that affect the variations in density, the results relating to the role of temperature are also presented.

Few observations have been made about the effect of temperature factors on density. P o l g e (1965) reported that maximum density, i.e. the density of summerwood, in the density variation within the annual ring was strongly dependent on climatic factors. N i c h o l l s (1971) also attributed the greatest density deviations to temperature. G i s l e r u d (1973) took the effect of temperature into consideration in his density study.

The annual average temperatures for June-August are presented in Fig. 6 together with the annual densities in sample plot 1. The effect of temperature

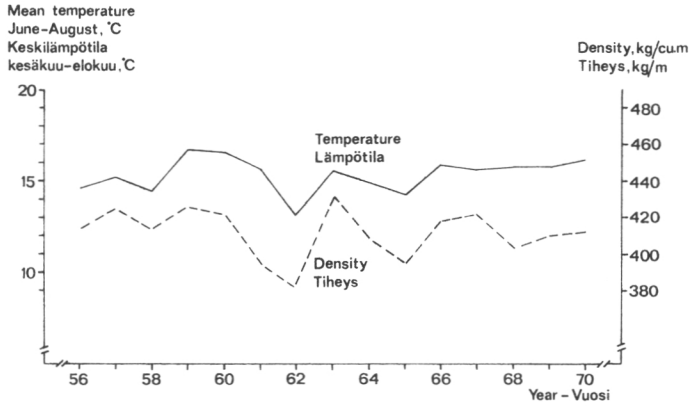

Figure 6. Annual average temperatures for June-August (upper curve) and annual densities (lower curve) in sample plot 1.

Kuva 6. Keskilämpötila kesä-elokuun aikana (ylempi käyrä) sekä tiheys (alempi käyrä) koealalla 1 eri vuosina.

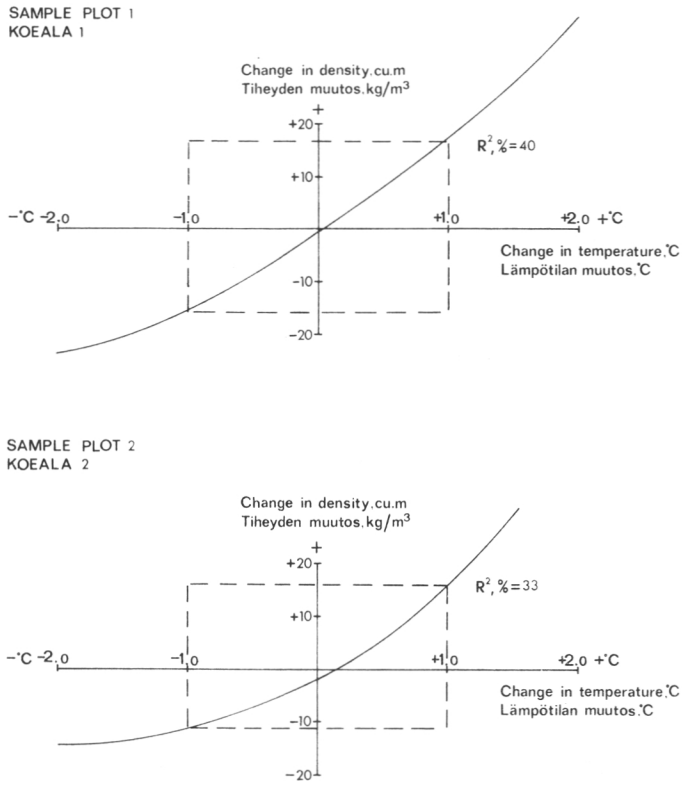

Figure 7. The effect of the change in temperature on the change in density. The observation values are changes in successive years from 1961 to 1971.

Kuva 7. Lämpötilan muutoksen vaikutus tiheyden muutokseen. Muutokset perättäisten vuosien eroluksia vuodesta 1961 vuoteen 1971.

on density seems to be obvious; annual temperature differences cause variations in density.

Regression analysis was applied to obtain a statistical picture of the effect of temperature, using as observation values the changes in successive years in both temperature and density. Fig. 7 shows the effect of temperature on density in both sample plots; it was about 15 kg/cu. m. when the temperature changed 1 degree on either side of »normal». The curves rise gently. The lowest density value coincided with a certain temperature level and then ceased to fall. The density rose evenly with the temperature, but it is clear that there could be no rise to a vere high level with the increase in temperature.

In the following analysis are seen the models given by regression analysis for each sample plot:

	Observations	Explained variance
Sample plot 1y $= -3.33 + 1.66\ x_1 + 0.03\ x_1^2$	n = 988	R^2, % = 40
Sample plot 2y $= -2.60 + 0.91\ \frac{x_1+x_2}{2} + 0.05\ x_1^2$	n = 4 335	R^2, % = 33

in which x_1 = yearly change in the average temperature for June-August;
x_2 = yearly change in the average temperature for July;
y = yearly change in density.

The explained variances, 40 and 33 per cent, are quite high in view of the fact that only 10 successive years were used, including temperature values differing little from one another.

62. Effect of fertilization on the variation in basic density

The effect of fertilization on density cannot be examined solely on the basis of the observed density changes. The changes possibly caused by fertilization in the factors (item 231) which influence density variation must also be taken into account. Of these factors, the thickness of annual ring is associated essentially with fertilization-induced growth increase. The changes in the proportion of summerwood are also important.

The primary aim in the following is in fact to throw light on the effects that fertilization has had on growth and the proportion of summerwood, and the influence of these changes on density. Only then are the changes in density caused by fertilization examined.

621. Annual ring width

The effect of different factors on annual ring width was examined. Every individual variable in Table 2 was of very great statistical significance for the width of the annual ring.

The material was distributed between nitrogen and non-nitrogen compartments in the variation source fertilized < > unfertilized (Table 2), because earlier studies by the Department of Soils, Finnish Forest Research Institute, have shown that only nitrogen has a role in growth increase. The significance of the time elapsing from fertilization was clear, for the effect of fertilization naturally changes with time. The annual ring width at different sampling heights differed owing to the growth physiology of wood, even in

Table 2. Variance analyses of the factors affecting on annual ring width.
Taulukko 2. Varianssianalyysi luston paksuuteen vaikuttavista tekijöistä.

Source of variation *Vaihtelulähde*	Sample plot *Koeala*	d.f. *Vapaus-asteet*	SS *Neliö-summa*	F
I Fertilized — *Lannoitetut*	1	1	85 955	31.54***
< >				
Unfertilized — *Lannoittamaottmat*...	2	15	1 489 435	41.84***
II Time — *Aika*	1	1	41 992	15.23***
	2	9	2 826 822	132.36***
III Sampling height — *Näytekorkeus*	1	2	69 423	12.59***
	2	2	881 304	185.69***
IV Tree height classes — *Pituusluokat* ..	1	1	27 186	9.86***
	2	1	868 184	365.86***
V Interactions — *Yhdysvaikutukset*	1	18	322 951	6.51***
	2	902	2 921 409	1.37***
V Interactions — *Yhdysvaikutukset*				
I × II	1	1	93 680	33.98***
	2	135	938 918	2.93***
I × III	1	2	4 948	0.90
	2	18	48 136	1.13
I × IV	1	1	64 944	23.56***
	2	9	102 020	4.77***
II × III	1	2	69	0.01
	2	30	309 704	5.49***
II × IV	1	1	24 115	8.75**
	2	15	801 306	24.12***
III × IV	1	2	38 521	6.99**
	2	2	3 607	0.76

No statistical significance of interactions of three variables was found.
Kolmen muuttujan yhdysvaikutuksilla ei tilastollisia merkitsevyyksiä.

annual rings originating in the same year. Tree height also had a distinct influence.

The variables mentioned in the foregoing also had distinct interactions. There was a definite correlation between fertilization and time and between fertilization and tree height. Other important interactions were observed between time and sampling heights and between time and tree height classes. On the other hand, the interactions of three variables were not statistically significant.

Table 3 shows the effect of different nutrients on the annual ring width in sample plot 2. Of the single effects, only nitrogen had a definite role in increasing growth. The yearly incerease in the growth of the annual ring during the first 5-year period was 0.27 mm and during the second 5-year period 0.14 mm.

Table 3. The effect of different nutrients on ring width in sample plot 2.
Taulukko 3. Eri ravinteiden vaikutus luston paksuuteen koealalla. 2.

Nutrients *Ravinteet*	Ring widht, mm *Luston paksuus, mm*		Difference *Ero, mm*	t (3888)	Ring widht, mm *Luston paksuus, mm*		Difference *Ero, mm*	t (3888)
	Nutrient *Ravinne*	Others *Muut*			Nutrient *Ravinne*	Others *Muut*		
	1962 — 1966				1967 — 1971			
Single effects — *Yksittäisvaikutukset*								
Ca — Others — *Muut*	1.39	1.36	+0.03	1.40	1.55	1.57	—0.02	1.10
N — Others — *Muut*	1.52	1.25	+0.27	13.83***	1.64	1.50	+0.14	6.94***
P — Others — *Muut*	1.37	1.37	—	0.10	1.55	1.58	—0.03	1.85
K — Others — *Muut*	1.40	1.36	+0.04	2.01*	1.56	1.57	—0.01	0.51
Interactions — *Yhdysvaikutukset*								
CaN	1.30	1.47	—0.17	8.60***	1.55	1.58	—0.03	1.60
CaP	1.32	1.44	—0.12	6.03***	1.54	1.62	—0.08	3.77***
CaK	1.33	1.43	—0.10	4.77***	1.55	1.59	—0.04	2.16*
NP	1.38	1.37	+0.01	0.55	1.60	1.53	+0.07	3.72***
NK	1.36	1.39	—0.03	1.55	1.59	1.54	+0.05	2.51**
PK	1.36	1.40	—0.04	1.96*	1.54	1.59	—0.05	2.56**

The interactions of two factors showed a growth increase only in the NP and NK combinations at the end of the phase of the fertilization period. In contrast, the combinations CaN, CaP and CaK showed a decrease. However, these results must be treated with reserve, for the differences are relatively small although highly significant statistically. The starting points of the annual ring width of the growing stock of compartments treated with different fertilizers were also different.

As nitrogen was the only nutrient affecting growth, the classification fertilized and unfertilized is used in the following analysis of the results. The former comprises all non-nitrogen and 0 compartments, and the latter compartments treated with nitrogen fertilization.

The effect of fertilization on the thickness of the annual ring in different years is presented in Fig. 8. There was no distinct growth increase until the post-fertilization year. The duration of growth effect of fertilization was 5-6 years from the time of institution of the experiments, although repeat fertilization was performed in both sample plots two years after the first treatment. The annual ring was always wider in large-sized than in small trees in both sample plots. The effects of fertilization were also similar in different years in these sample plots. The ring width of the short trees of sample plot 1 was considerably greater in the unfertilized than in the fertilized trees after 1967. However, the material in this group was fairly small. The narrow annual

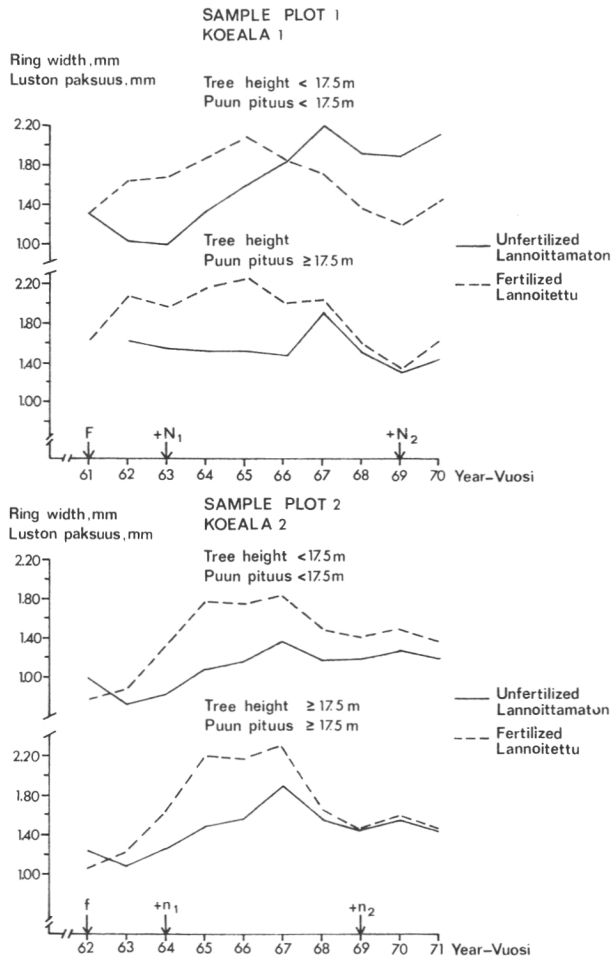

Figure 8. The average annual ring width at 2, 6 and 10 m heights from stump level in fertilized and unfertilized trees from 1961 to 1971.

Kuva 8. Luston paksuus korkeuksien 2, 6 ja 10 keskiarvona lannoitetuissa ja lannoittamattomissa rungoissa vuosina 1961-1917

ring width in 1963, even under 1 mm in the short trees of sample plot 2, is worthy of note.

The statistical significance of the fertilization-induced increase in the annual ring thickness by 5-year periods is given in Table 4. Additional growth was statistically highly significant during the first 5-year period in both sample plots. The growth increase in ring width was about 0.4 mm in sample plot 1 and about 0.3 mm in sample plot 2. The additional growth decreased considerably in the second 5-year period, but was still statistically significant.

Table 4. The effect of fertilization on ring width at different periods.
Taulukko 4. Lannoituksen vaikutus luston paksuuteen eri ajanjaksoina.

Sample plot *Koeala*	Time *Aika*	Tree length, m *Puun pituus, m*	Ring width, mm, mean *Luston paksuus, mm, keskiarvo*		Difference, *Ero, mm*	t	Observations/ mean *Havaintoja/ keskiarvo*
			Fertilized *Lannoitettu*	Unfertilized *Lannoittamaton*			
1	1961—65	<17.5	1.75	1.29	+0.46	4.89**(*)	
		≥ 17.5	2.03	1.60	+0.43	7.40***	$n_{<17.5}=100$
1	1966—70	<17.5	1.52	2.03	—0.51	5.28**	
		≥ 17.5	1.73	1.55	+0.18	3.08**	$n_{\geq 17.5}=160$
2	1962—66	<17.5	1.33	1.01	+0.32	8.00***	
		≥ 17.5	1.59	1.35	+0.24	9.89***	$n_{<17.5}=300$
2	1967—71	<17.5	1.55	1.28	+0.27	6.01***	
		≥ 17.5	1.67	1.59	+0.08	3.27**	$n_{\geq 17.5}=900$

Numerous results concerning the effect of annual ring width on density in which sufficient allowance has not been made for other fectors affecting density have been reported (Chapter 231). Fig. 9 shows the effect of annual ring width on density in the present material. The influence of age was not eliminated in this case as its effect was considered to be fairly small during a period of 10 years. However, the degree of determination of annual ring width in relation to density was examined separately at each sample height, and thus the role of age has been taken into account for the most part.

There was a negative correlation between ring width and density. When thickness increased, the decrease in density was similar in both sample plots. It averaged 17 kg/cu. m. when the annual ring width increased from 1 to 2 mm.

Observations on annual rings of under 1 mm in width are included in curve 2 (Fig. 9). A distinct decrease in density was seen when the ring width was narrower than 0.8 mm. Visual observation of the densitometry curves showed in thin annual rings disturbances that differed from the »normal structure» of density and caused a lowering of density.

In the following are given regression equations for the curves of sample plot 2 and, for comparison, the equation obtained by H a k k i l a (1966) for pine from increment cores without juvenile wood:

Fertilized $y = 437—26x—13\frac{1}{x}$ $n = 2\,290$ R^2, % = 6

Unfertilized $y = 411—5x^2$ $n = 2\,529$ R^2, % = 7

y = width of annual ring, mm
x = average density of annual ring, kg/cu. m.

H a k k i l a (1966): $y = 432—23x$ R^2, % = 11

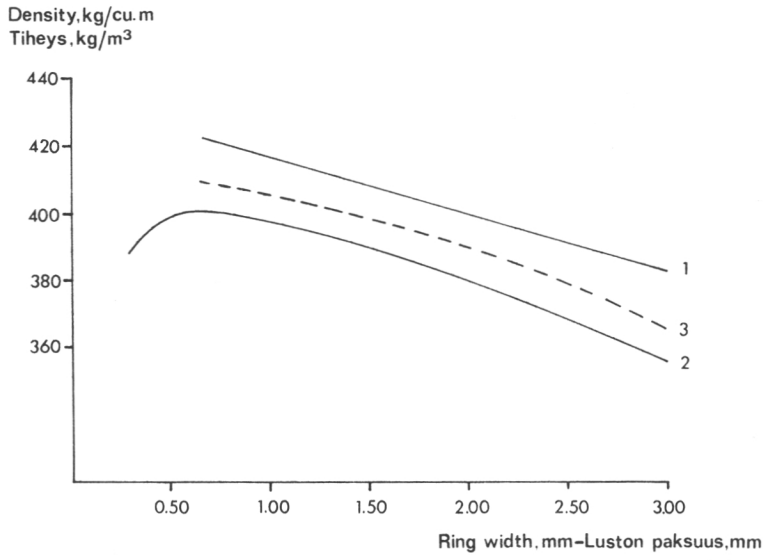

Figure 9. The correlation between ring width and density. All trees (1) in sample plot 1, unfertilized (2) and fertilized (3) trees in sample plot 2.
Kuva 9. Vuosiluston paksuuden vaikutus puuaineen tiheyteen koealalla 1 kaikissa rungoissa (1), sekä koealalla 2 lannoittamattomissa (2) ja lannoitetuissa (3) rungoissa.

The explained variance of 6-7 per cent in annual ring width, which was of the same magnitude at all sampling heights, was surprisingly low. This low degree of explanation cannot be attributable solely to the effect of age, but was probably caused largely by the influence of temperature and heredity. Worthy of note also is the low explanation of variance, 11 per cent, of the earlier study mentioned by way of comparison. The coefficient of regression in equations of the first degree are almost equally great in both studies (23 in Hakkila's and 20 in the present work, which indicates that the effect of annual ring width on density was similar in both studies.

622. Proportion of summerwood

The proportion of summerwood is a very important independent variable for density variation, as mentioned in Chapter 231.

Table 5. Means of ring widths, annual ring densities and summerwood per centages in sample plot 1 in fertilized and unfertilized trees at different years. Fertilization was started in 1961.

Taulukko 5. Keskiarvoja luston paksuuksista, luston tiheyksistä ja kesäpuuprosenteista koealalla 1 lannoitetuissa ja lannoittamattomissa rungoissa eri vuosina. Lannoitus aloitettu vuonna 1961.

Year *Vuosi*	Temperature, July *Lämpötila, heinäkuu*	Fertilized *Lannoitettu*			Unfertilized *Lannoittamaton*		
		Ring width *Luston paksuus, mm*	Density *Tiheys, kg/m³*	Percentage summerwood *Kesäpuuprosentti*	Ring width *Luston paksuus, mm*	Density *Tiheys, kg/m³*	Percentage summerwood *Kesäpuuprosentti*
51	14.7	1.66	421	30	1.48	406	34
52	15.6	2.07	401	28	2.04	395	32
53	16.5	2.21	430	34	2.22	418	35
54	16.9	2.17	416	31	2.00	408	33
55	17.7	1.74	427	34	1.63	389	28
56	15.3	1.30	441	38	1.10	429	42
57	18.1	1.58	455	36	1.63	433	36
58	15.3	1.23	436	33	1.46	419	37
59	18.1	1.19	459	36	1.57	424	36
60	18.0	1.12	446	36	1.36	435	38
61	16.0	1.52	396	27	1.70	403	32
62	14.5	2.10	385	26	1.71	378	27
63	16.7	1.97	461	39	1.52	450	35
64	16.5	2.34	419	35	1.85	398	31
65	14.2	2.37	412	31	1.95	387	30
66	17.0	1.91	440	37	1.85	412	35
67	16.7	1.84	454	37	2.20	411	32
68	14.9	1.40	426	32	1.82	388	29
69	16.4	1.11	432	36	1.62	410	34
70	16.5	1.53	437	36	1.87	420	38

Table 5 shows that density depends to a considerable extent on percentage summerwood. It was low in e.g. 1961 and 1962, and density, too, was consequently lower in both unfertilized and fertilized trees.

In the compartments that were fertilized later, percentage summerwood before fertilization seems to have been lower throughout. However, percentage summerwood seems to have risen a few years after fertilization in the fertilized compartments above the level in the untreated compartments. It is thus possible that the tree evens out the early fertilization-induced decrease in density by an increase in density in a later phase (E l l i o t t 1970). In drawing conclusions from the table, the distinctly higher initial density of fertilized stems must be borne in mind.

As percentage summerwood varies considerably from year to year, the effect of annual ring thickness on percentage summerwood was examined separately for each 20 years in order to elicit the possible effect of fertilization.

The explained variance in different years (1951-1970) between the percentages summerwood and annual ring thickness and percentages summerwood and annual ring densities were as follows when the number of observations per year was 40.

	Explained variance of the proportion of summerwood, R_3, %	Range of variation of the variance explained in 1951—1970
Annual ring width	14	0—28
Annual ring density	51	35—66

The fairly weak negative correlation between annual ring width and percentage summerwood is worthy of note (Fig. 10). In contrast, there was a definite positive correlation between annual ring density and percentage summerwood; the explained variance was an average of 51 per cent, which is high for the small number (approx. 40) of observations. In addition, percentage summerwood explaining density was as high as 82 per cent in a larger material (number of observations 187).

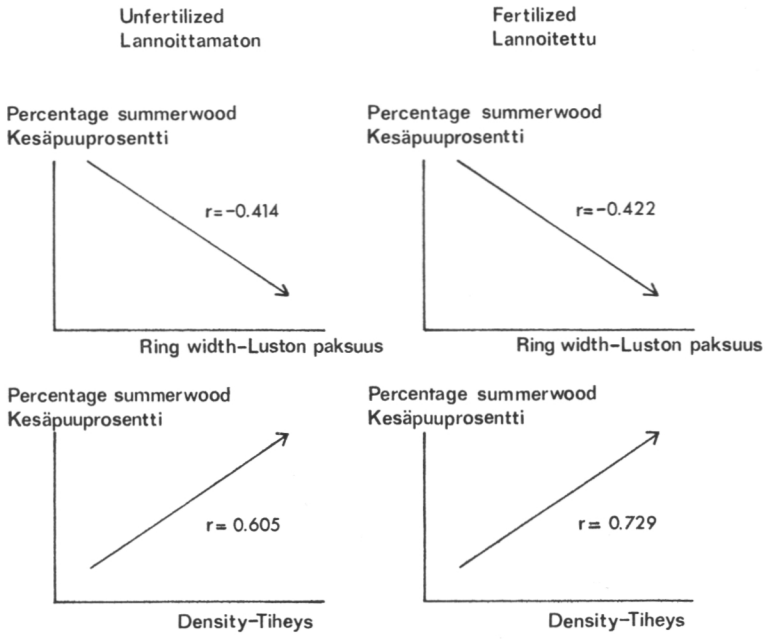

Figure 10. The correlation between summerwood and other characters of year ring in sample plot 1.

Kuva 10. Korrelaatiokertoimia kesäpuuprosentin ja luston muitten tunnusten välillä koealalla 1.

623. Yearly variation of density

Numerous studies have been published on the effect of fertilization on basic density. To generalise, if fertilization achieves a distinct increase in growth, the basic density of pine decreases (Elliott 1970, Ostrom 1972). Data on the quantitative decrease in density are highly conflicting on account of the differences in the material and measuring methods employed.

An important factor to be considered in density comparisons between two groups of material is the density difference associated with the origin, the genetic properties of the tree which may exist in these groups. The density curves for sample plots 1 and 2 before and after fertilization are presented in Fig. 11. The pre-fertilization density in sample plot 1 was the same in both groups. Density changes occurred after the first fertilization. Hence, for inter-group comparisons in sample plot 1 it may be assumed that the initial densities were similar.

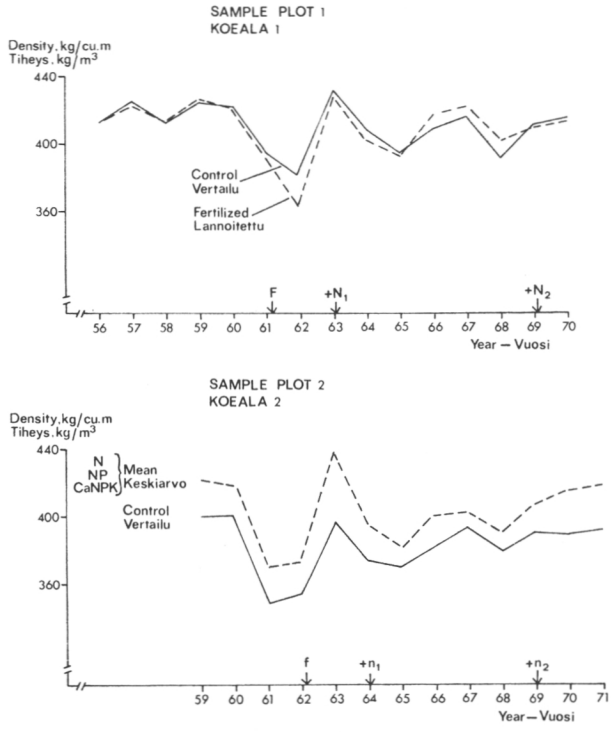

Figure 11. The yearly changes in density before and after fertilization. The dotted curve in sample plot 2 represents the average density of compartments given N, NP and CaNPK nutrients.

Kuva 11. Tiheyden vaihtelut ennen ja jälkeen lannoituksen. Koealan 2 murtoviivakäyrä on N, NP ja CaNPK ravinteita saaneitten ruutujen tiheyksien keskiarvojen mukaan piirretty.

The initial density in the group given N, NP and CaNPK fertilizers in sample plot 2 (Fig. 11) was about 20 kg/cu. m. higher than that of the control group, and this must consequently be taken into account. It may also be assumed that the pre-fertilization year, too, gives a sufficiently good idea of the traditional density differences and those due to other reasons in the different groups. M e g r a w and N e a r n (1972) observed that a stem with a high density preserved it in spite of fertilization.

The yearly uniformity of the variation in pre-fertilization density between the groups is worthy of note. The inter-group variation was within the range of approx. 2 kg/cu. m. in both sample plots. The same phenomenon, that is, the way in which a group with a certain density retained that density level in different years compared with other groups, has also been observed in smaller material (cf. M e g r a w and N e a r n 1972).

The role of fertilization, time and sampling heights was highly significant statistically (Table 6). Height classes were of some importance as independent

Table 6. Variance analyses of the factors effecting on density.
Taulukko 6. Varianssianalyysi tiheyteen vaikuttavista tekijöistä.

Source of variation *Vaihtelulähde*	Sample plot *Koeala*	d.f. *Vapaus-asteet*	SS *Neliösumma*	F
I Fertilized — *Lannoitetut*	1	1	52	0.04
< >				
Unfertilized — *Lannoittamattomat*...	2	15	328 005	20.79***
II Time — *Aika*	1	1	59 343	44.02***
	2	9	1 175 561	124.16***
III Sampling height — *Näytekorkeus*	1	2	224 436	83.25***
	2	2	2 486 590	1 181.84***
IV Tree height classes — *Pituusluokat* ..	1	1	2 354	1.75
	2	1	14 630	13.91**
V Interactions — *Yhdysvaikutukset*	1	18	66 384	2.73**
	2	902	936 054	0.99
V Interactions — *Yhdysvaikutukset*				
I × II	1	1	14 297	10.61**
I × III	1	2	5 704	2.12
I × IV	1	1	622	4.46
II × III	1	2	1 724	0.64
II × IV	1	1	3 600	2.67
III × IV	1	2	11 648	4.32*

No statistical significance of interactions of three variables was found.
Kolmen muuttujan yhdysvaikutuksilla ei tilastollisia merkitsevyyksiä.

Table 7. The effect of different nutrients on density in sample plot 2 when the differences in initial densities before fertilization have not been noticed.

Taulukko 7. Eri ravinteitten vaikutus tiheyteen koealalla 2, kun lähtökohtatiheyksien eroja ei ole huomioitu.

Nutrients *Ravinteet*	Density, kg/cu.m, mean *Tiheys, kg/m³, keskiarvo*			t (3888)
	Nutrient *Ravinne*	Others *Muut*	Difference *Ero*	
Single effects — *Yksittäisvaikutukset*				
Ca — Others — *Muut*	395	391	+4	4.17***
N — Others — *Muut*	396	390	+6	6.84***
P — Others — *Muut*	395	391	+4	4.80***
K — Others — *Muut*	392	394	—2	1.92
Interactions — *Yhdysvaikutukset*				
CaN	392	394	—2	2.24*
CaP	395	391	+4	3.63***
CaK	394	392	+2	1.71
NP	390	395	—5	5.24***
NK	390	396	—6	6.51***
PK	391	396	—5	5.34***

variables for density variation. Sample plot 1 revealed interactions between fertilisation and time, but there were none in sample plot 2. The role of time as an independent variable for density variation is clear from the very great yearly variation in density due to some extent to temperature (Fig. 7). The role of sampling heights, on the other hand, is associated essentially with density variation due to age.

Before examining the effect on density of nitrogen which is of essential importance for fertilization, a study was made of the effect of all the nutrients used on basic density even if they had not contributed at all to the growth increase. According to Table 7, calcium and phosphorus in addition to nitrogen had an effect indicative of density increase. However, as the initial density of the trees treated with calcium and phosphorus was about 4 kg/cu. m. higher than that of the trees in the control compartments, no actual increase in density resulted from the use of these nutrients. The nitrogen-induced 6 kg/cu. m. increase in density becomes a density decreace of about 4 kg/cu. m when the apporox. 10 kg/cu. m. higher pre-fertilization density of the stems given nitrogen compared with the non-nitrogen stems is taken into consideration (Fig. 12, sample plot 2, year 1962). The effect of interactions is questionable because of various density differences possibly associated with heredity and the difficult-to-interpret small though statistically significant differences possibly caused by interactions.

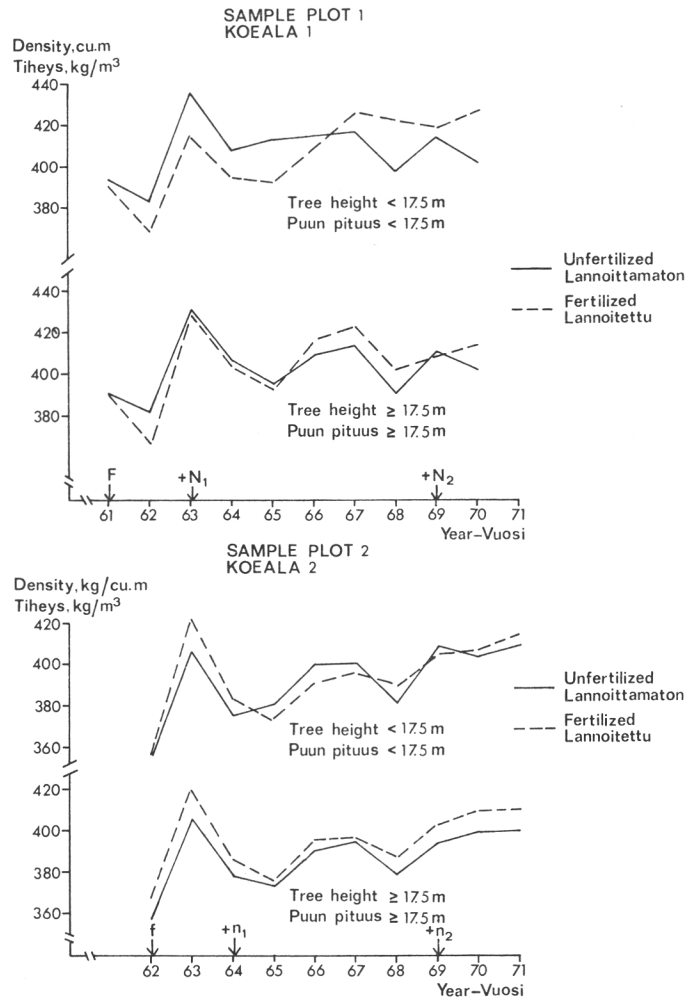

Figure 12. The average density of 2, 6 and 10 m heights in fertilized and unfertilized trees at different years.

Kuva 12. Tiheys, korkeuksien 2, 6 ja 10 m keskiarvo, lannoitetuissa ja lannoittamattomissa rungoissa eriajankohtina.

The density differences in fertilized and unfertilized trees can be seen in Fig. 12. The initial density was the same in both the short ($<$ 17.5 m) and the tall trees ($\geq$ 17.5 m) of sample plot 1 in the year of fertilization. In the post-fertilization year when there was a strong increase in growth the density declined about 12 kg/cu. m. in the fertilized plots. From then on the effect of fertilization in density was distinctly lowering in young trees until the year 1966, after which the density rose to a level higher than that of the unfertilized trees. The decrease in density was not equally definite after 1963 in

the tall trees of sample plot 1. Both height groups displayed an increase in density towards the end of the fertilization period although the growth increase had ended by then (Fig. 12).

In sample plot 2, the initial density was higher in fertilized than in unfertilized small trees in 1962. Fertilization increased the density in the post-fertilization years 1963 and 1964 in sample plot 2; this can be accounted for by the exceptionally low annual ring width in 1963 and 1964 (Fig. 8). By then, when fertilization had increased the annual ring width, fertilized rings had reached the peak of the density curve in Fig. 5 and density increased. The annual ring width was exceptionally low (under 1 mm) in unfertilised annual rings, and hence the density also was lower than in the fertilized annual rings. Density declined from 1965 until 1967 when the growth increase also ceased. The decrease was more distinct, about 5 kg/cu. m. per year, in the larger trees. It was slightly more pronounced, about 8 kg/cu. m., in young trees. As in sample plot 1, there was a slight increase in density in plot 2 after the year 1967. The increase in 1970 was about 4 kg/cu. m. compared with the initial density.

A common feature of the density curves of Fig. 12 is the decreasing of density in the first 4-5 post-fertilization years, that is when the growth increase was most pronounced. After this the density rose to slightly over the level of the unfertilized trees although there was still some fertilization-induced growth increase. Corresponding results were arrived at by P o s e y

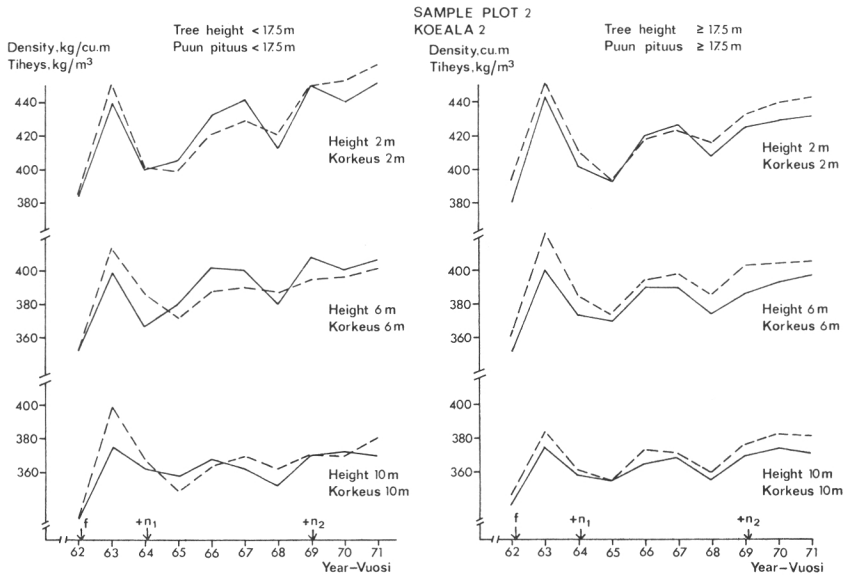

Figure 13. The effect of fertilization on density at different heights.
Kuva 13. Lannoituksen vaikutus tiheyden vaihteluun eri korkeuksilla.

Table 8. Change in density and ring width in pencentages in fertilized trees compared to unfertilized at different years.

Taulukko 8. Tiheyden ja luston paksuuden muutos prosentteina lannoitetuissa rungoissa lannoittamattomiin verrattuna eri vuosina.

Sample plot *Koeala*	Tree height *Puun pituus, m*		Year — Vuosi										
			61	62	63	64	65	66	67	68	69	70	71
			Change in density and ring width in percentages *Tiheyden ja luston paksuuden muutos prosentteina (%)*										
1	< 17.5	Density — *Tiheys*	−0.7	− 3.9	− 4.6	− 3.2	− 5.1	− 1.5	+ 2.4	+ 6.3	+ 1.0	+ 6.2	
		Ring width — *Luston paksuus* ...	+ 2.3	+65.0	+70.0	+40.7	+31.3	+ 2.8	−20.5	−28.2	−36.8	−28.6	
	≥ 17.5	Density — *Tiheys*	−0.2	− 4.2	− 0.7	− 0.7	− 0.5	+ 2.0	+ 2.2	+ 2.8	− 0.5	+ 3.0	
		Ring width — *Luston paksuus* ...	−2.9	+27.3	+25.8	+41.2	+49.0	+33.3	+ 5.1	+ 5.3	+ 3.8	+13.9	
2	< 17.5	Density — *Tiheys*		0.0	+ 3.2	+ 1.3	− 2.6	− 3.0	− 2.0	+ 1.6	− 1.7	0.0	+ 0.7
		Ring width — *Luston paksuus* ...		−20.0	+26.7	+65.5	+65.4	+50.8	+30.7	+25.0	+18.3	+15.4	+16.6
	≥ 17.5	Density — *Tiheys*		0.0	+ 1.0	− 0.5	− 2.1	− 1.3	− 2.0	− 0.5	0.0	0.0	0.0
		Ring width — *Luston paksuus* ...		−16.0	+11.8	+32.0	+46.7	+37.5	+21.1	+ 6.5	+ 3.4	+ 3.2	+ 2.1

(1966) according to whom wood density and percentage summerwood exceeded the values for normal wood 7-8 years after fertilization.

The effect of fertilization on density at different heights differed (Fig. 13). G o o d i n g and S m i t h (1972) also noted that the effects were different at different heights. The decrease in density was most pronounced in the lower part of the tree at a height of 2 m where the relative growth of the annual ring width was greatest. Density changes were smallest at a height of 10 m. Fig. 3 shows the clear increase in density in fertilized trees at every height in 1963 and partly also in 1964. The annual ring thickness was low at that time especially in small-sized stems (Fig. 8).

A picture of the real changes after fertilization is given in Table 8. The pre-fertilization density difference probably associated with heredity in the fertilized stems compared with unfertilized stems was corrected by converting

the density level of the fertilised to that of the unfertilized stems. The figure used in the table to denote the per cent density change was calculated in the following manner:

$$\frac{\left(\begin{matrix}\text{density of}\\ \text{fertilized wood}\end{matrix} - \begin{matrix}\text{density difference}\\ \text{before fertilization}\end{matrix}\right) - \begin{matrix}\text{density of un-}\\ \text{fertilized wood}\end{matrix}}{\text{density of unfertilized wood}} \cdot 100$$

The density decrease in the smaller trees of sample plot 1 was at its highest, 5.1 per cent, in 1965. More pronounced density decreases occurred in larger trees of the same sample plot only in 1962, when the drop was 4.2 per cent. A distinct increase in density was observed after 1967 when the annual ring width of smaller trees was also smaller on average in fertilized than in unfertilized trees. The annual ring continued to be thicker in fertilized than in unfertilized large trees although the density increased.

In sample plot 2, density declined most (3.0 per cent) in small trees in 1966 and in large trees (2.1 per cent) in 1965. The abnormally narrow ring widths in 1963 and 1964 are reflected clearly in the increases in the densities of fertilized stems.

To summarise (Table 9), the density of small trees in sample plot 1 was lowered 3.7 per cent by fertilization during the period of vigorous growth (five years) while the increase in width growth was 42 per cent. The density decreased by only 0.8 per cent in trees of over 17.5 m while the growth increase was 35 per cent. Correspondingly, the density decrease in sample plot

Table 9. The average change in density and growth in percentages per year during a period when the effect of fertilization on growth has been strong and during a period, when the effect on growth has been slight.

Taulukko 9. Keskimääräinen tiheyden ja kasvun muutos prosentteina/v ajanjaksona, jolloin lannoituksen vaikutus kasvua lisäävästi on ollut voimakas ja ajanjaksona, jolloin vaikutus on ollut vähäinen.

	Tree height, m *Puun pituus, m,*	Change in percentage/year *Muutos prosentteina/vuosi*			
		Density *Tiheys*	Ring width *Luston paksuus*	Density *Tiheys*	Ring width *Luston paksuus*
		62 — 66		67 — 70	
Sample plot 1 — *Koeala 1*	<17.5	—3.7	+42.0	+3.9	—28.5
	≥17.5	—0.8	+35.3	+1.9	+ 7.0
		63 — 67		68 — 71	
Sample plot 2 — *Koeala 2*	<17.5	—0.6	+47.8	+0.2	+18.8
	≥17.5	—1.0	+29.8	—0.1	+ 3.8

2 was 0.6 per cent in small and 1.0 per cent in large trees when the growth increase was 30 per cent. The only notable increase in density, 3.9 per cent, occurred in the under 17.5 m trees of sample plot 1 in the second post-fertilization 5-year period when growth was some 30 per cent smaller in fertilized than in unfertilized stems.

7. DISCUSSION

Numerous studies have reported on the strong effect of nitrogen on growth in mineral soil (e.g. Brantseg and Viro). Recent studies have shown that phosphorus also promotes growth in longer-term fertilizations in which the growth-stimulating action of nitrogen during the first years has reduced the amount of phosphorus that would normally suffice (Viro 1972).

The present work revealed distinctly the effect of nitrogen during the first five years. The effect of phosphorus was also manifested as an NP interaction, with phosphorus appearing to increase growth in the latter part of the fertilization period. However, an attitude of reserve must be adopted to this effect of phosphorus, as the interactions of different nutrients appear to be conflicting because of the internal growth variation of the sample plot. The growth increase achieved during the first five years was about 30 per cent in sample plot 1. This is very close to the 29 per cent for the increase in volume growth calculated during Operation Forest Fertilization (1969) in Finland. The approx. 20 per cent growth increase in sample plot 2 is lower than the average level.

Negative correlation between the annual ring width of pine and density was observed by e.g. Moltesen (1957), Echols (1958), Nylinder (1961), Ericson et al. (1966) and Uusvaara (1974). Ericson (1966) reported a density decrease of about 20 kg/cu. m. when the annual ring width grew by 1 mm. Density decreased in thin annual rings of under 1 mm, according to Siimes (1938). Choong et al. (1970) found that annual ring width had no effect on density.

Taking the temperature factor into consideration sheds additional light on the density-reducing effect of low determination degree that the growth of annual ring width was observed to cause in the study. Indeed, temperature differences explained 40 per cent of the density variation, and thus the low explanatory value of annual ring width for density can be attributed in part to the temperature factors. Another factor that causes unexplained variation is genetic origin. Age, on the other hand, was not found to be of decisive importance because of the short observation period, 10 years.

Changes in the lowering of density when the annual ring width increases may be caused by the lowering of the internal density of the annual ring in springwood or summerwood or in both at the same time. In addition, a change in the springwood/summerwood ratio influences the annual ring density strongly. It has been found in several studies that the proportion of summerwood decreases on account of the growth increase produced by fertilization (Ericson and Lambert 1958, Williams and Hamilton 1961, Ericson 1962, Klem 1964, Posey 1966, Choong 1970, Siddiqui et al. 1972, and Manwiller 1972). In the opinion of Nicholls (1971), the lowering effect of fertilization on percentage summerwood corresponds to the similar reaction caused by thinning. Fertilization had no effect on percentage summerwood in slow-growing pine (Pechman and Wutz 1960).

It is difficult to draw conclusions from Table 5 about the variation of percentage summerwood. Although percentage summerwood showed in all the cases a negative correlation with annual ring width, the degree of determination was low (14 per cent). According to Fig. 10, percentage summerwood decreased in both fertilized and unfertilized stems when the annual ring width increased. Since the observation groups (29 observations and a group of 12 units) were fairly small, the results can be regarded as indicative only.

One of the objects of the study was to discover the effects of various nutrients on density even when they did not influence growth. It is clear that in addition to volume growth the achievement of high density leads to an increase in the dry matter yield. The results of this study warrant the conclusion that the nutrients that did not influence growth did not affect density either.

Minor density decreases (1-3 per cent) through fertilization in the Pinus genus were reported by e.g. Posey (1966), Hagner (1967), Klem (1969), Nicholls (1971), and Smith and Wahlgren (1971). Greater density decreases have been observed especially when the growing stock has responded with very strong growth to the liberal use of fertilizers (Ericson et al. 1971). When 180 kg of nitrogen per hectare was given, they reported a 5 per cent decrease in density and when quantity was 600 kg of nitrogen per hectare the decrease was 13 per cent. The density decrease was more pronounced also in young, vigorously reacting growing stock (Siddiqui et al. 1972). Some studies (Lönnberg and Palenius 1970, Elliot 1970, Gooding and Smith 1972, Echols 1972) suggest that density remains unchanged or even increases slightly under the influence of fertilization. Results of this kind may be due partly to different initial density values at the time of investigation associated with heredity to which reference was made earlier, and to the effect of age.

The results of the present study indicate a definite but slight decrease in density whenever the growth increase was considerable. In sample plot 2, in which the material was also of considerable magnitude, the growth response of small growing stock seemed to be more pronounced than the response of larger growing stock. The density decrease was correspondingly greater. The vigorous response of small growing stock was probably due to the free access of the crown of the trees to sunlight and growing space; few small trees in the sample plot were overshadowed.

An interesting point is the density increase in sample plot 2 during 1963 and 1964 (Fig. 12) when the annual rings were narrow in the unfertilized stems (Fig. 8). It was not until 1965—1967 when the growing stock was »normal» in annual ring width that the density was able to decrease. The fertilization-induced density decrease was then 1.5—3.0 per cent.

The quantitative changes in density (kg/cu. m.) were most pronounced at a stem height of 2 m (Fig. 13). The relative growth increase was also greatest at this height. Density is about 40 kg/cu. m. lower at 10 m than in the butt part of the tree, and the density changes in the top are of relatively the same magnitude as in the butt part. Upper-part wood is also considerably younger than lower-part wood which has its own effect on the sensitiveness of the reaction of wood at the sampling height.

The results showed clearly the variation in the initial density values before fertilization in the different fertilization compartments. The variation between compartments appeared to be of the same size in different years while the factors affecting growth remained similar, which is suggestive of a hereditary effect (Ericson 1960, Elliott 1970, Velling 1974).

Several references have been made to the density decrease that accompanies an increase in growth. If the quantitative density decrease values resulting from growth increases during fertilization (Fig. 12) are compared with the values for density changes caused solely by the annual ring width (Fig. 9), the figures are surprisingly similar. An increase from 1 to 2 mm in annual ring thickness caused a 17 kg/cu. m. decrease in density (Fig. 9). A fertilization-induced 30 per cent width increase resulted in an average density decrease of 5 kg/cu. m. If 30 per cent growth is added to a 1 mm thick annual ring, the result concurs well with the values of Fig. 9. According to this, the change in annual ring width itself shows the density decrease associated with additional growth.

It seems evident that the density decrease produced by fertilization can be explained with the help of the annual ring width provided that the temperature factor and, in the longer term, age are taken into consideration as variables affecting density.

8. SUMMARY

The aim of fertilization is to increase the yield of the tree. Attention must then be paid not only to the additional growth produced but also to the density of the wood that is formed. Together they indicate the dry matter yield of wood which is important for the pulp industry in particular. In this work the yearly effect of fertilization on the basic density of the pine (Pinus silvestris L.) at different stem heights was studied. In addition to fertilizers which increase tree growth distinctly, the importance for basic density of nutrients that have not been found to influence growth was also examined.

The study is based on the use of H. P o l g e's densitometric method which has been adopted and developed at the Department of Forest Technology, Finnish Forest Research Institute. Density was determined by means of X-rays from 5 mm thick wood samples dried to a moisture content of 8 per cent. The material was collected from two sample plot series in which the growing stock was 60 years old. Each sample plot series formed an independent factorial experiment in which the nutrients were calcium (Ca), nitrogen (N), phosphorus (P) and potassium (K). After the actual initial fertilization, nitrogen fertilization was performer twice for the compartments in the sample plots that had been treated with nitrogen. Three sampling heights, 2, 6 and 10 m, were selected ftom samples taken at different heights. These heights represented best the within-stem density variation in the longitudinal direction of the tree. The material from the two sample plots consisted of 595 core samples from 200 sample trees. The total of annual rings studied was 5,799.

The main results of the study were:

1) Temperature proved to be a very important factor explaining the annual density variation. When the temperature was 1 degree (C°) warmer than »normal» density increased by about 15 kg/cu. m. Correspondingly, when temperature fell by 1 degree, density decreased by 15 kg/cu. m. The density decrease ceased at a low temperature level. The degree of determination of temperature for density was apporox. 40 per cent (Fig. 7).

2) Nitrogen (N) was the only nutrient with a pronounced augmenting effect, increasing the growth of annual ring width by about 30 per cent. The nutrient combinations NP and NK appered to be of little importance in

increasing growth, at least in the latter part of the 10-year fertilization period (Table 3).

3) When the annual ring width increased from 1 to 2 mm, density decreased by about 17 kg/cu. m. When the ring width narrowed to under 0.8 mm, density was lowered sharply (Fig. 9). The low degree of explained variance (7 per cent) of annual ring width for density can be attributed in part to temperature factors.

4) Density is greatly dependent on percentage summerwood (or vice versa). The explained variance was 82 per cent. There was a negative correlation between annual ring width and percentage summerwood (Fig. 10).

5) Comparison of compartments treated with different nutrients disclosed a sharp density variation that is possibly associated with heredity. For instance, the initial density of stems given N, NP and CaNPK nutrients was approx. 20 kg/cu. m. higher than that of the control stems (Fig. 11).

6) As far as fertilization is concerned, only the growth-inducing nitrogen affected density. The nutrients which had no effect on growth did not affect density either.

7) Density was clearly diminished when the effect of fertilization was at its most pronounced. The average yearly density decreases were 1.0—4.0 per cent during the five post-fertilization years (Fig. 11).

8) About 7—8 years after fertilization an increase in density compared with the control growing stock was observable, although fertilization still had some growth-increasing effect.

9) Density was raised by fertilization in growing stock in which the annual ring thicknesses were under 0.8 mm.

10) Relative density changes in stems of different sizes and at different stem heights were of the same magnitude and dependent on the intensity of the additional growth caused by fertilization.

11) Taken as a whole, density decreased by about 1 per cent during the strong growth increase in the first 5-year period after fertilization. In the 10-year fertilization period as a whole, the effect of fertilization on the decrease of density became smaller and density tended to rise towards the end of the period.

12) It appeared in the study that the density decrease caused by fertilization-induced additional growth can be explained fairly well by means of the annual ring width provided that temperature and age are taken into consideration as variables that affect density. For stem-to-stem density variation the effect of heredity must be taken into account.

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LANNOITUKSEN VAIKUTUKSESTA MÄNNYN *(Pinus silvestris L.)* PUUAINEEN TIHEYTEEN MINERAALIMAALLA

Densitometritutkimus puuaineen röntgenkuvista

Lyhennelmä

Puun tuotoksen lisäämiseen voidaan vaikuttaa metsänhoidon, metsänjalostuksen ja maanparannuksen keinoin. Esimerkiksi metsänlannoituksella voidaan kasvua parantaa voimakkaasti kuutiokasvun lisäyksen ollessa noin 30 prosentin luokkaa. Näin suurten kasvunlisäysten oletetaan usein aiheuttavan muutoksia myös puun laadullisiin ominaisuuksiin, etenkin puun tiheyteen, joka osoittaa puuaineen massan tilavuusyksikköä kohden. Muutokset tiheydessä heijastuvat massateollisuuteen, jossa tilavuusyksiköstä saatavan sellun ja hiokkeen määrä riippuu melkein suoraviivaisesti puuaineen tiheydestä. Myös saha- ja lastulevyteollisuudessa tuotteiden laatu on suuresti riippuvainen puuaineen tiheydestä.

Käsillä oleva tutkimus perustuu H u b e r t P o l g e n densitometrimenetelmään, jonka Metsäntutkimuslaitokseen on soveltanut K a r i S a u v a l a. Tässä menetelmässä tiheys määritettiin 5 millimetrin paksuisista 8 %:n kosteuspitoisuuteen kuivatetuista puunäytteistä röntgensäteiden avulla. Menetelmä mahdollistaa puun tiheyden tutkimisen yksittäisistä vuosilustoista.

Tutkimusaineisto kerättiin Metsäntutkimuslaitoksen maantutkimusosaston perustamilta kahdelta koealasarjalta Heinolasta, joissa puuston rakenne vastasi järeydeltään lannoitusohjeissa suositeltavaa varttuneempaa, tukkipuuastetta lähentelevää puustoa (kuva 3). Molemmat koealasarjat eli systeemit muodostivat itsenäisen faktorikokeen, jossa tutkittavana on ollut neljä ravinnetta: kalkki (Ca), typpi (N), fosfori (P) ja kali (K). Lannoitusruutuja oli kullakin koealasarjalla 17, jolloin faktorikokeen periaatteen mukaan saadaan kahdeksankertainen toisto (kuva 4).

Kaikkiaan kaadettiin 200 koepuuta, joista valittiin tutkimusaineistoksi 2, 6 ja 10 metrin etäisyydeltä tyvileikkauksesta otetut kiekkonäytteet. Kiekkoja ja niistä sahattuja lastunäytteitä oli yhteensä 595 ja analysoitavia vuosilustoja yhteensä 5799. Puitten keski-ikä oli n. 60 v., keskipituus 20.2 m, runkoluku 545 kpl/ha ja kuutiomäärä 190 m^3/ha (taulukko 1). Tutkimuksen tärkeimmät tulokset ovat seuraavat.

1) Lämpötila osoittautui erittäin merkitykselliseksi tiheyden vuotuista vaihtelua selittäväksi tekijäksi. Lämpötilan muuttuessa »normaalilämpötilasta» 1 asteen lämpimämmäksi nousi tiheys noin 15 kg/m^3. Vastaavasti lämpötilan laskiessa 1 asteen verran laski tiheys myös 15 kg/m^3. Tiheyden lasku pysähtyi alhaisella lämpötilatasolla. Lämpötilan tiheyttä selittävä selittävyysaste oli noin 40 % (kuva 7).

2) Typpi (N) oli ainoa ravinne, joka vaikutti voimakkaasti lisäten luston paksuuden kasvua noin 30 %. Pienoista merkitystä kasvun lisäykseen varsinkin 10 vuotisen lannoitusajanjakson loppupuolella näytti olevan NP ja NK ravinneyhdistelmillä (taulukko 3).

3) Luston paksuuden suuretessa 1 millimetristä 2 millimetriin aleni tiheys noin 17 kg/m³. Luston paksuuden pienetessä alle 0.8 millimetrin tapahtui jyrkkä lasku tiheydessä (kuva 9). Luston paksuuden tiheyttä selittävä alhainen selittävyysaste 7 % voidaan osittain selittää lämpötilatekijöistä johtuvaksi.

4) Tiheys riippuu suuresti kesäpuuprosentista. Selitysasteeksi saatiin 82 %. Luston paksuus korreloitui kesäpuuprosentin kanssa negatiivisesti (kuva 10).

5) Tutkimuksessa ilmeni selvästi mahdollisesti perinnöllisyyteen liittyvä voimakas tiheyden vaihtelu verrattaessa eri ravinteita saaneitten ruutujen runkoja toisiinsa. Esimerkiksi N, NP ja CaNPK ravinteita saaneitten runkojen alkutiheys oli noin 20 kg/m³ suurempi kuin vertailuruutujen (kuva 11).

6) Lannoituksen kannalta ainoastaan kasvua lisänneellä typellä oli vaikutusta tiheyteen. Niillä ravinteilla, joilla ei ollut vaikutusta kasvuun, ei myöskään ollut vaikutusta tiheyteen.

7) Tiheys on selvästi laskenut lannoituksen vaikutuksen ollessa voimakkaimmillaan. Keskimäärin ovat vuotuiset laskut tiheyksissä olleet 1.0-4.0 % lannoituksen jälkeisenä 5 vuotena (kuva11).

8) Noin 7—8 vuoden jälkeen lannoituksesta on havaittavissa tiheyden nousua normaalipuustoon verrattuna, vaikka lannoituksella on ollut vielä jonkinlaista vaikutusta kasvun lisäykseen.

9) Lannoituksen vaikutuksesta on tiheys noussut puustossa, jossa vuosilustojen paksuudet ovat olleet alle 0.8 millimetriä.

10) Eri kokoisissa rungoissa sekä rungon eri korkeuksilla ovat tiheyden suhteelliset muutokset olleet saman suuruisia ja riippuvaisia lannoituksen aikaansaaman lisäkasvun voimakkuudesta.

11) Kokonaisuutena on tiheys alentunut voimakkaan kasvun lisäyksen, lannoituksen jälkeisen ensimmäisen 5 vuoden jakson aikana noin 1 %. Jos tarkastellaan 10 vuoden lannoitusjaksoa kokonaisuutena, pieneni lannoituksen tiheyttä alentava vaikutus, koska loppuaikoina tiheys pyrki nousemaan lannoitetuissa puissa.

12) Tutkimuksessa ilmeni, että lannoituksella saadun lisäkasvun aiheuttama tiheyden aleneminen voidaan selittää melko hyvin luston paksuuden avulla, mikä edellyttää lämpötilatekijän sekä iän huomioimista tiheyteen vaikuttavina muuttujina. Mikäli tarkastelun kohteena on runkojen välinen tiheyden vaihtelu, on perinnöllisyyden vaikutus huomioitava.

JYRSINTÄMUOKKAUS JA LANNOITTEIDEN SIJOITUS MÄNNYN KYLVÖN YHTEYDESSÄ TURVEMAALLA

KASVIHUONEKOKEITA

SEPPO KAUNISTO

Summary

ROTAVATION AND FERTILIZER PLACEMENT IN CONNECTION WITH DIRECT SEEDING OF SCOTS PINE ON PEAT

Greenhouse experiments

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ALKUSANAT

Tutkimus kuuluu osana laajempaan kokonaisuuteen, jonka tarkoituksena on selvittää turpeen jyrsinnän ja lannoituksen vaikutusta kylvötaimien kehitykseen ojitetulla suolla.

Tutkimus on suoritettu metsäntutkimuslaitoksen Parkanon tutkimusaseman kasvihuoneessa Karvian Alkkiassa. Kokeiden käytännöllisessä toteuttamisessa on avustanut työnjohtaja Esko Mansikkaviita ja Tauno Suomilammi. Aineiston laskennan on suorittanut pääasiassa merkonomi Pirkko Marjamäki. Käsikirjoituksen ovat tarkastaneet tehden siihen monia varteenotettuja korjausehdotuksia ja antaen arvokkaita ohjeita professorit Leo Heikurainen ja Olavi Huikari, vt. professorit Matti Leikola ja Kustaa Seppälä sekä dosentti Eero Paavilainen.

Kaikille edellä mainituille, samoin kuin muille tutkimuksen toteuttamisessa avustaneille, esitän parhaat kiitokseni.

Parkanossa tammikuussa 1975

Seppo Kaunisto

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1. JOHDANTO

11. Muokkaus ja lannoitteiden sijoittaminen turvemaiden metsänviljelyssä

Pintaturpeen kääntäminen metsänviljelyalustaksi lienee yksi vanhimmista metsänviljelyä varten tehdyistä muokkaustoimenpiteistä suolla. Vanhimmat tiedot käännettyyn turpeeseen istuttamisesta ovat Zehetmayrin (1954) mukaan 1700-luvun lopun Irlannista. Jo tuolloin menetelmän tarkoituksena oli sekä viljelyalustan valmistus että kuivatus. Menetelmä näyttää jääneen unohduksiin useiksi vuosikymmeniksi, kunnes belgialaiset 1830-luvulla kehittivät oman menetelmänsä, joka maan muokkauksen ja kuivatuksen osalta oli edellisen kaltainen. Brittein saarilla belgialaista menetelmää alettiin kokeilla 1900-luvun alussa (Stirling — Maxwell 1906, 1909, 1925), mutta käännettyyn turpeeseen istutuksesta tuli normaali toimenpide viljelyaloilla vasta 1920-luvun lopulla (Zehetmayr 1954).

Suomessa suon pinnan muokkausta metsänviljelyn yhteydessä alettiin tutkia 1930-luvulla (Lukkala 1934). Tällöin pyrittiin selvittämään lähinnä vain turpeen kääntämisen (joko paikallaan tai koskemattomalle suon pinnalle) ja maan möyhentämisen vaikutusta. Belgiassa ja Brittein saarilla kokeiltuun »turf planting» - menetelmään liittynyt kuivatustarkoitus jäi näin tutkimuksen ulkopuolelle. Myöhemmin Heikurainen ym. (1966) ja Seppälä (1968) ovat tutkineet turpeen kääntämisen vaikutusta metsänviljelyn onnistumiseen Suomessa. Yleensä taimien kehitys on osoittautunut nopeammaksi käännetyssä turpeessa kuin käsittelemättömällä suon pinnalla, vaikka muokkaus, koneellisten menetelmien puuttuessa, jäikin aluksi varsin vaatimattomaksi.

Tutkimusten tulokset loivat lujan perustan koneellisen maanmuokkauksen menetelmille sen käytyä teknisesti mahdolliseksi 1940-luvulla. Varhaisen maanmuokkaustutkimuksen varsin yksipuolinen suuntautuminen käännetyn turpeen tekniikan hyväksikäyttöön lienee osaltaan vaikuttanut siihen, että koneellisen maanmuokkauksen menetelmistä nimenomaan auraus on nykyään vallitseva. Tähänhän aikaisempien tutkimusten tuloksia on voitu verrattain suoraan ja helposti soveltaa. Erilaisten palleaurojen kehittäminen onkin esim. Brittein saarilla ollut tärkeä tutkimuskohde (Taylor 1970 ja Everard 1972).

Lukuisissa tutkimuksissa ja artikkeleissa on todettu aurauksen ja auran palteeseen viljelyn yleensä takaavan koskemattomaan suon pintaan istutusta paremman metsitystuloksen (Zehetmayr 1954, Wright 1959, Meshechok 1968, Althen 1970, Paavilainen 1970 b, Erik 1971, Kaunisto 1972, Valk 1972). Yhtenä tärkeimmistä syistä aurauksen edulliseen vaikutukseen on yleensä pidetty pintakasvillisuuden kilpailun vähenemistä. Tätä tukevat pintakasvillisuuden myrkyttämistä selvittelevät kokeet (Althen 1970, Dickson ja Savill 1974, Mac Kenzie 1974). Samaan suuntaan viittaavat myös Sarast on (1964) tutkimukset rämevarvuston kasvusta, Weatherellin (1953), Leytonin (1954), Parkinin (1957), Dicksonin (1962) ja Handleyn (1963) maininnat kanervan merkityksestä kilpailijana sekä Goodmanin ja Perkinsin (1959), Päivänen (1970) ja Tammin (1954) tulokset pintakasvillisuuden sitomista ravinteista. Muina positiivisesti viljelyyn vaikuttavina tekijöinä on esitetty vesi- ja lämpöolojen paraneminen (Meshechok 1969 a ja b, Braekke 1972), mitkä puolestaan edistävät ravinteiden mobilisaatiota. Istutettaessa auran palteeseen voidaan myös lisätä turpeen luontaista fosfori- ja kalipitoisuutta taimien välittömässä läheisyydessä, koska näiden alkuaineiden määrä lisääntyy suon pintaa kohden (esim. Binns 1962 ja Holmen 1964).

Suon muokkauksen intensiivisemmistä muodoista, täyskynnöstä ja jyrsinnästä, on vähemmän tutkimustuloksia. Zehetmayr (1954) mainitsee taimien kasvaneen huonommin täyskynnetyllä kuin vaotetulla alueella. Samaa seikkaa korostaa O'Carroll (1962 ja 1964) ja toteaa myös täydellisen jyrsintämuokkauksen johtaneen huonoon taimien kasvuun. Yleisenä syynä ovat em. tutkijat esittäneet maan liiallisen vettymisen. Samantapaisia kokemuksia on saatu myös Suomessa, joskaan julkaistua numeroaineistoa ei ole käytettävissä. Tosin Paavilainen (1965) mainitsee männyn taimien alkukehityksen olleen nopeampaa ojasta nousseella jyrsinturpeella kuin koskemattomalla suon pinnalla.

Juuselan ym. (1969) tutkimustulokset osoittavat jyrsintämuokkauksen vähentävän voimakkaasti turpeesta tapahtuvaa haihduntaa. Turpeen vesiolojen huonontuminen taimien kannalta lieneekin ollut yksi syy metsänviljelyjen epäonnistumiseen jyrsityllä ja kynnetyllä turpeella. Aurattaessa ja viljeltäessä auran paltteeseen taimi kohoaa suon pinnan keskimääräisen tason yläpuolelle. Lisäksi vako toimii veden keräysaltaana ja poistumisreittinä alueelta. Myös Meshechok (1969 a ja b) Päivänen ja Seppälä (1971) ja Päivänen (1974) pitävät vaotusta tärkeänä kuivatuksen kannalta. Eräissä aikaisemmissa tutkimuksissani olen korostanut vaon merkitystä taimikohtaisen kuivatuksen varmistajana (Kaunisto 1972 ja 1974 b).

Jos kuivatus voidaan järjestää tyydyttävästi, näyttää jyrsintämuokkaus

lisäävän taimien kasvua, kuten kasvihuoneolosuhteissa saamani tulokset osoittavat (K a u n i s t o 1971). Samaan suuntaan viittaavat lisäksi kaistoittain tehdyn turpeen jyrsintämuokkauksen vaikutusta selvittelevien kenttäkokeiden tulokset (K a u n i s t o 1972, 1973 ja 1974 a). Myös V a l k (1970 ja 1972) toteaa, että erityisesti täysmuokkaus edistää taimien kasvua, joskin toisaalta P o l l i n (1970) aineistossa täysmuokkaus on ollut kaistamuokkausta jonkin verran huonompi.

Lannoitteiden sijoittamisen merkitystä on tutkittu maassamme runsaasti viljalajeilla (L a r p e s 1966, E l o n e n ym. 1967 a ja b, N i e m i n e n ym. 1967, K ä h ä r i ja E l o n e n 1969, P e s s i ym. 1970). Tulokset ovat olleet poikkeuksetta erittäin positiivisia. Sijoituslannoitus kuuluukin nykyään välttämättömänä toimenpiteenä tehokkaaseen viljanviljelyyn.

Vaikka puun taimien ravinteiden tarve on paljon vähäisempi kuin viljakasvien, voidaan kuitenkin olettaa, että ravinteiden sijoittamisella juurikerrokseen saavutettaisiin etua ainakin taimien kehityksen alkuvaiheessa, joskaan sijoituslannoitus, termin maatalouskäytön mukaisessa merkityksessä, tuskin tulee kysymykseen metsänviljelyn yhteydessä. Soiden metsänviljelyssä on tutkittu lähinnä vain hidasliukoisten fosforilannoitteiden sijoittamista, koska monissa tutkimuksissa on havaittu nimenomaan fosforin olevan turvemailla tärkein puuttuva ravinne metsityshetkellä (Z e h e t m a y r 1954, M e s h e c h o k 1968, M a n n e r k o s k i ja S e p p ä l ä 1971, H a u g e 1972). Lisäksi on todettu muiden pääravinteiden sekä myös liukoisen fosforin lisäyksen aiheuttavan helposti taimikuolleisuutta (H e i k u r a i n e n ym. 1966, S e p p ä l ä 1968 ja 1971, K a u n i s t o 1968 ja 1971, M a n n e r k o s k i 1971, P a a v i l a i n e n 1970 a ja b, H a u g e 1972). Samansuuntaisia tuloksia ovat L e i k o l a ja R i k a l a (1974) saaneet myös kivennäismailla.

Raakafosfaatin ja tuomaskuonan käytöstä on verrattain runsaasti ja pitkäaikaisia kokemuksia. Alunperin belgialaisessa käännettyyn turpeeseen istutuksessa lannoite sekoitettiin maahan, joka lisättiin istutuskuoppaan. S t i r l i n g-M a x w e l l (1906) havaitsi, että tämä lisäsi taimien kasvua enemmän kuin lannoitteen lisääminen suoraan istutuskuoppaan. H a u g e (1972) on myöhemmin Norjassa todennut, että pintalannoitukseen verrattuna hienofosfaatin lisäys suoraan istutuskuoppaan lisää kuusen taimien kasvua vain parin ensimmäisen vuoden aikana ja että tilanne myöhemmin muuttuu päinvastaiseksi. Hänen mukaansa raakafosfaatin lisääminen istutuskuoppaan aiheuttaa huonon, suppean juuriston ja tästä syystä kasvun taantumisen myöhemmin. Edelleen H a u g e n (1971) tutkimukset osoittavat juuriston muodon paranevan lannoitelaikun koon suuretessa. Nähtävästi samasta syystä on useissa tutkimuksissa havaittu, että fosforin sijoittaminen laajem-

malle alueelle, nauhana palteen alle tai hajalevityksenä ennen aurausta, on lisännyt taimien kasvua enemmän kuin sijoitus istutuskuoppaan (Zehetmayr 1954, Edwards 1962, McConaghy 1962, McConaghy ym. 1962, Parkin 1957, Jack 1970). Dickson (1971) toteaa, että nauhalannoitus palteen päälle on antanut yhtä hyvän tai paremman tuloksen kuin sijoituslannoitus palteen alle. Toisaalta omassa (Kaunisto 1972) aineistossani lannoitteen sijoittaminen palteen alle on ollut taimien kasvulle suotuisampi kuin pintalannoitus.

Edellä esitetyt tutkimukset ovat käsitelleet lähinnä fosforilannoitteiden sijoittamista vaotuksen ja istutuksen yhteydessä. Kaikkien pääravinteiden sijoittamisesta turvemaalla samoin kuin jyrsintämuokkauksesta ja kylvöstä tässä yhteydessä on kirjallisuudessa vain joitakin mainintoja. Kenttäkokeissa olen tutkinut kaikkien pääravinteiden (NPK) sijoituksen vaikutusta kylvötaimien kasvuun sekä auratulla että jyrsityllä turpeella (Kaunisto 1972 ja 1974 a). Tutkimuksissa männyn kylvötaimet ovat kasvaneet paremmin levitettäessä lannoite nauhana viljelykohtaan ennen muokkaustoimenpidettä kuin sen jälkeen. Kasvu on ollut paras, kun ravinteet on jyrsinnän yhteydessä sekoitettu muokattuun turvekerrokseen. Myös taimitarhassa tehdyissä kokeissa, joissa on käytetty syväkyntöä ja ravinteiden sijoittamista 10—15 cm:n syvyyteen, ravinteiden sijoituksesta NPK-lannoituksen ja kylvön yhteydessä on saatu hyviä kokemuksia (Giulimondi 1967 ja 1968).

12. Tutkimuksen tarkoitus

Nyt esitettävä työ on kolmas peräkkäinen kasvihuoneessa toteutettu tutkimus, jonka tarkoituksena on selvittää jyrsintämuokkauksen vaikutusta kylvämällä tapahtuvaan metsänviljelyyn (aikaisemmat: Juusela ym. 1969 ja Kaunisto 1971). Koska jyrsintä mahdollistaa lannoitteiden samanaikaisen sekoittamisen kasvualustaan ja koska voidaan olettaa taimien hyötyvän siitä, se on liitetty kiinteästi jyrsintätutkimuksen piiriin.

Aikaisemmassa tutkimuksessani totesin, että männyn ja kuusen kylvötaimet kasvoivat paremmin jyrsityllä kuin jyrsimättömällä turpeella (Kaunisto 1971). Eron oletettiin johtuvan osittain jyrsintämuokkauksesta, osittain siitä, että kylvön yhteydessä annetut lannoitteet sekoitettiin tasaisesti koko muokattuun turvekerrokseen, jolloin todennäköisesti valtaosa niistä sijoittui taimien ravinteiden saannin kannalta edullisiin olosuhteisiin.

Em. tutkimuksessa ei ollut lainkaan pintalannoitettuja, jyrsittyjä käsittelyjä. Näin ollen ei ollut mahdollista selvittää jyrsintämuokkauksen ja lannoitteiden sekoittamisen erillistä vaikutusta. Nyt esitettävän tutkimuksen päätarkoituksena on tämän vertailun suorittaminen.

Em. tutkimuksessa seurattiin erilaisten käsittelyjen vaikutusta taimien

lukumäärään kokeen loppuun saakka. Lukumäärä kokeen lopussa vaihteli nollasta useihin kymmeniin näyteastiassa. Tämän vuoksi ei tutkimuksessa voitu luotettavasti tarkastella käsittelyjen vaikutusta pintakasvillisuuteen eikä myöskään taimien verson ja juuriston kuiva-ainetuotokseen tai näiden suhteeseen. Nyt esitettävässä tutkimuksessa näiden selvittäminen onkin asetettu yhdeksi tavoitteeksi.

13. Käsitteiden määrittelyä

Nyt esitettävässä tutkimuksessa käsitellään eräitä toimenpiteitä, joille ei vielä ole vakiintunut selvää terminologiaa soiden metsänviljelyssä. Tästä syystä lienee paikallaan selvittää, mitä eräillä tekstissä käytetyillä sanoilla tässä yhteydessä tarkoitetaan.

Sanoilla jyrsintä ja jyrsintämuokkaus tarkoitetaan toimenpidettä, jossa turpeen pintakerros muokataan jyrsimällä. Käytännössä jyrsintäsyvyys on yleensä n. 10—20 cm. Jyrsittäessä pintaturve ja pintakasvillisuus murskaantuvat ja sekoittuvat verrattain tasa-aineiseksi, kasvuturvetta muistuttavaksi rouheeksi.

Sanaa muokkauslannoitus käytetään kuvaamaan menettelyä, jossa turve jyrsitään edellä esitetyllä tavalla ja samalla sekoitetaan viljelyn yhteydessä annettava lannoite jyrsittyyn turvekerrokseen. Käytännössä tämä tapahtuu siten, että lannoite levitetään jyrsinkoneen eteen koskemattomalle suon pinnalle ja jyrsin sekoittaa lannoitteen turpeeseen muokkauksen aikana (vrt. K a u n i s t o 1974 b). Muokkauslannoitus sisältää siis sekä jyrsinnän että lannoitteiden sekoittamisen.

Ilmaisuja lannoitteiden tai ravinteiden sijoittaminen tai sijoitus käytetään ilmaisun lannoitteiden sekoittaminen asemesta, koska lannoitteiden turpeeseen sekoittamisen tarkoituksena on nimenomaan sijoittaa osa ravinteista taimien juurikerrokseen. Käyttämällä sanoja sijoittaminen tai sijoitus saadaan toimenpiteen tarkoitus paremmin esille.

2. TUTKIMUSAINEISTO

21. Koejärjestely

Tutkimus perustuu kolmeen samanaikaisesti vuosina 1971—1973 metsäntutkimuslaitoksen Parkanon tutkimusaseman kasvihuoneessa toteutettuun kokeeseen. Tutkitut muuttujat on esitetty taulukossa 1. Kussakin kokeessa tutkitut muuttujat muodostivat täysin vaihdellun, kokonaan arvotun fakto-

Taulukko 1. Tutkitut muuttujat.
Table 1. Variables studied.

Muuttuja — *Variable*	Kokeessa n:o ... — *In exp. No ...* 1	2	3
A. Jyrsintä ja lannoitteiden sijoittaminen — *Peat rotavation and fertilizer placement*	X	X	X
1 — Muokkaamaton, pintalannoitus — *Unprepared, topdress fertilization*	X	X	—
2 — Jyrsitty, pintalannoitus — *Rotavated, topdress fertilization*	X	X	—
3 — Jyrsitty, lannoite sijoitettu — *Rotavated, fertilizer worked into peat*	X	X	X
4 — Muokkaamaton, lannoite ruiskutettu — *Unprepared, fertilizer injected*	—	—	X
B. Ravinneyhdistelmä — *Nutrient combination*	X	—	—
1 — NPK	X	X	X
2 — PK	X	—	—
C. Ravinnemäärä — Amount of nutrients	X	X	X
0 — 0	X	—	—
1 — 75 kg/ha (N:nä, P_2O_5:na ja K_2O:na — *As N, P_2O_5 and K_2O*) [1]	X	X	X
2 — 150 kg/ha (N:nä, P_2O_5:na ja K_2O:na — *As N, P_2O_5 and K_2O*) [2]	X	X	X
D. Turvelaji — *Peat type*	X	X	X
1 — *Sphagnum fuscum* turve (S-t) — *Sphagnum fuscum peat (S-t)*	X	X	X
2 — Sararahkaturve (CS-t) — *Carex-Sphagnum peat (CS-t)*	X	X	X
3 — Metsärahkasaraturve (LSC-t) — *Woody Sphagnum-Carex peat (LSC-t)*	X	X	X
Faktorikokeen muoto — *Form of the factorial exp.*	2×3^3	2×3^2	3×2^2

1) Kokeessa 3: 54—75—65 kg/ha vastaavasti — In Experiment 3: 54—75—65 kg/ha respectively
2) » 108—150—130 kg/ha vastaavasti — In Experiment 3: 108—150—130 kg/ha respectively

rikokeen. Erilaisia käsittelyjä oli yhteensä 84 ja toistoja 3. Arvonta tehtiin täydellisenä myös kokeiden kesken, mikä mahdollisti myös kokeiden välisen tulosten vertailun.

Muokkauslannoituksen ja sen kahden osatekijän, jyrsinnän ja jannoitteiden sijoittamisen vaikutusta on tutkittu lähinnä kokeissa 1 ja 2. Jyrsinnän vaikutusta on em. kokeissa tutkittu vain pintalannoitusta käytettäessä. Kokeessa 3 on jyrsinnän vaikutusta tutkittu silloin, kun ravinteet on sijoitettu sekä muokkaamattomissa että muokatuissa näytteissä. Näin pyrittiin selvittämään voitaisiko pelkällä ravinteiden sijoittamisella ilman jyrsintää lisätä taimien kasvua. Muokkaussyvyys oli 20 cm. Käytetyt lannoitteet olivat kokeessa 1 oulunsalpietari (26-0-0), hienofosfaatti (0-33-0) ja kalisuola (0-0-60). Kokeessa 2 lannoitteet olivat muutoin samat kuin edellä, mutta hienofosfaatin asemesta käytettiin superfosfaattia (0-19-0). Arveltiin, että fosforilannoitteen liukoisuuden lisääminen saattaisi muuttaa muokkauslannoituksen vaikutusta, koska tällöin pintalannoitetussakin turpeessa ravinteet ehkä helpommin kulkeutuisivat taimien juurikerrokseen. Kokeessa 3 lannoitteena oli nestemäinen super Y-lannos (5-7-6), joka sisältää myös hivenaineita.

Ravinteiden määrän vaikutusta tutkittiin kolmella tasolla (taul. 1). Kokeessa 3, jossa käytettiin valmista lannoiteliuosta, pääravinteiden määrät olivat seuraavat:

Ravinne	Taso 1	Taso 2
N	54	108 kg/ha
P_2O_5	75	150 »
K_2O	65	130 »

Jäljempänä kuvissa ja taulukoissa ravinnetasoja on merkitty luvuilla 0, 75 ja 150, vaikka ne eivät kokeen 3 kohdalla tarkoin pidäkään paikkaansa.

Jokaisessa kokeessa oli taimien kasvualustana kolme eri turvelajia: rahka-, sararahka- ja metsärahkasaraturve. Rahkaturve (S-t) oli lyhytkortisen nevan laaja-alaisesta mättäästä. Tärkein rahkasammallaji oli *Sphagnum fuscum*. Kenttäkerroksen valtalaji oli *Empetrum nigrum*. Sararahkaturve (CS-t) oli lyhytkortisen nevan tasapinnasta, jossa pohjakerroksessa olivat vallitsevina *Sphagnum recurvum* -ryhmän lajit ja kenttäkerroksessa *Eriophorum vaginatum* ja *Andromeda polifolia*. Metsänrahkasaraturve (LSC-t) oli varsinaisen sararämeen laajasta nevapinnasta, jossa vallitseva kenttäkerroksen kasvilaji oli *Carex lasiocarpa*. Lisäksi esiintyi *Eriophorum vaginatumia* ja *Andromeda polifoliaa*. Pohjakerroksessa oli *Sphagnum recurvum* -ryhmän ja *Polytrichum* -suvun lajeja.

Eri turvelajien ominaisuuksia on esitelty taulukoissa 2 ja 3. Kaikki turvelajit ovat olleet vähän maatuneita. S-turve on ollut vähiten ja LSC-turve eniten maatunut. Turvelajit ovat olleet verrattain happamia ja vähäravinteisia.

Taulukko 2. Eri turvelajien maatumisaste v. Postin mukaan ja tilavuuspaino kokeessa 2. Muokkaamaton turve.

Table 2. The degree of humification (according to v. Post) and volume weight in different peat types in Experiment 2. Unprepared peat.

Turvekerros, cm *Peat layer, cm*	Maatumisaste *Degree of humification*			Tilavuuspaino g/l *Volume weight grm./l*		
	S-t	CS-t	LSC-t	S-t	CS-t	LSC-t
0—5	H_1	H_1	H_1	34	50	52
5—10	H_1	H_2	H_2	31	54	70
10—15	H_1	H_2	H_3	35	58	72
15—20	H_2	H_2	H_3	36	55	71

Taulukko 3. Ennen kokeiden perustamista määritetyt N-, P- ja K-pitoisuudet (totaali) sekä pH (H_2O:ssa) eri turvelajeilla.

Table 3. The total macronutrient contents and pH (in H_2O) in the different peat types, before the experiments were established.

Mitattu tunnus *Measured quantity*	Turvekerros — *Peat layer, cm*					
	0 — 10			10 — 20		
	Turvelaji — *Peat type*					
	S-t	CS-t	LSC-t	S-t	CS-t	LSC-t
N, %	0.81	0.99	1.29	0.80	1.20	1.46
P, mg/g —mg./grm.	0.32	0.39	0.59	0.28	0.45	0.52
K, mg/g —mg./grm.	0.85	0.93	0.71	0.86	0.50	0.34
pH	3.6	4.0	4.2	3.8	3.9	4.3

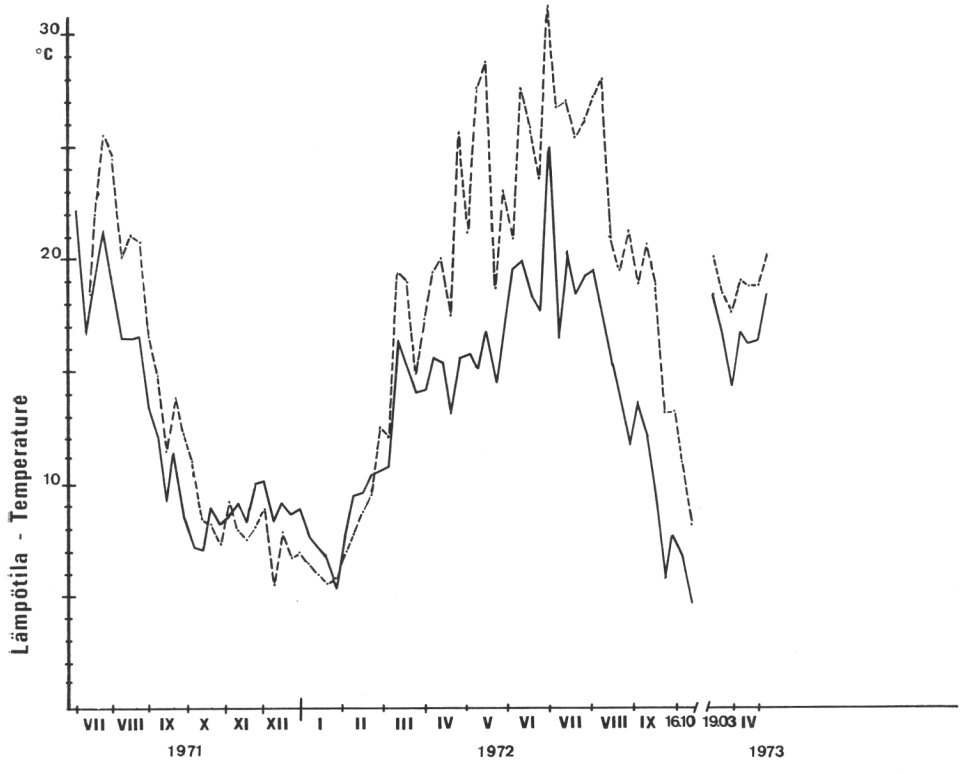
Typpeä ja fosforia on ollut eniten LSC-turpeessa ja vähiten S-turpeessa. Kalia on ollut eniten S-turpeessa.

Turvenäytteet otettiin kesäkuussa 1971 J u u s e l a ym. (1969) kehittämällä menetelmällä ns. »häiriintymättöminä turvenäytteinä» ja kuljetettiin kasvihuoneeseen, jossa ne asetettiin kasvatusalustalle siten, että turpeen pinta oli n. 120 cm:n korkeudella maan pinnasta. Muokattavista näytteistä poistettiin 20 cm:n paksuinen pintakerros. Syntynyt tila täytettiin muokatulla turpeella, joka oli hienonnettu koneellisesti Fiskarsin metsänviljelyjyrsimellä maastossa näytteenottopaikoilla. Ravinteiden sijoittaminen suoritettiin siten, että kiinteät lannoitteet sekoitettiin muokattuun turpeeseen täyttövaiheessa ja nestemäinen lannoite ruiskutettiin täytön jälkeen mahdollisimman tasaisesti 0—20 cm:n turvekerrokseen. Muokkaamattomissa koejäsenissä ruiskutus tehtiin erittäin varovaisesti, jotta turpeen rakenne muuttuisi mahdollisimman vähän. Muokkaamattomista koejäsenistä poistettiin kaikki maanpäällinen kuollut kasviaines, joka sisälsi lähinnä edellisenä talvena kuolleen ruohovartisen kasvillisuuden. Pohjaveden pinta säädettiin

J u u s e l a n ym. (1969) kehittämällä menetelmällä 30 cm:n vakiosyvyyteen. Lannoituksen jälkeen turvetta sadetettiin voimakkaasti (35 mm:n sadetta vastaava määrä), jotta annetut lannoitteet liukenisivat jonkin verran ennen kylvöä. Tämä oli mahdollista muuttamatta pohjaveden tasoa, sillä jokaisessa koeastiassa oli vedenpoistoaukko 1 cm säännöstellyn pohjavesipinnan yläpuolella.

Jokaiseen koeastiaan kylvettiin 30. 6. 1971 20 männyn siementä (alkuperä Ähtäri). Turpeen sadetusta jatkettiin päivittäin n. 5 viikon ajan kylvön jälkeen, jotta turpeen pinta pysyisi koko ajan kosteana. Tämä oli välttämätöntä riittävän taimimisen varmistamiseksi. Turvetta sadetettiin 15. 3. 1972 jälkeen aina taimien kasvujaksojen aikana 2 kertaa viikossa koesarjan lopettamiseen saakka. Tällä tavoin haluttiin estää samanlainen pitkäaikainen jatkuva ylöspäin suuntautuva veden liikkuminen turpeessa kuin aikaisemmassa tutkimuksessa (K a u n i s t o 1971).

Kasvihuoneen lämpötilaa säädeltiin kesällä tuuletuksen avulla. Talvella



Kuva 1. Turpeen ja ilman lämpötila viikottaisina keskiarvoina kokeiden aikana. Turpeen lämpötila (---) on mitattu 5 cm syvyydessä ja ilman lämpötila (—) taimien tasolla.

Figure 1. The weekly average peat and air temperature (---, —, respectively) during the study. Peat temperature is measured at the depth of 5 cm and air temperature at the level of seedlings.

1971—1972 kasvihuonetta lämmitettiin. V. 1973 lämmitys aloitettiin maaliskuun alussa. Ilman keskilämpötila seitsemän vuorokauden jaksoina on esitetty kuvassa 1. Iltapäivälämpötilat kesäkausina olivat yleensä n. 20—30°C. Turpeen lämpötilat mitattiin viitenä arkipäivänä viikossa samaan aikaan, klo 14.30. Turpeen lämpötila on vaihdellut verrattain paljon (kuva 1). Huippulämpötila 5 cm:n syvyydessä on ollut 33.0°C. Viiden päivän perusteella lasketut viikottaiset keskilämpötilat ovat touko-elokuussa yleensä olleet yli 20°C.

Huhtikuussa 1972 kylvötaimet harvennettiin leikkaamalla sammalkerroksen pintaa myöten. Jokaiseen koeastiaan jätettiin tällöin viisi valtatainta. Samanaikaisesti poistettiin edellisenä kesänä ja samana keväänä kasvanut maitohorsma, jouhisara ja tupasvilla turpeen pintaa myöten kaikista koejäsenistä ja punnittiin uunikuivana (1 vrk 70—80°C:ssa+2 vrk 105°C:ssa). Kokeiden myöhemmässä vaiheessa ei maitohorsmaa eikä muitakaan siemenlevinnäisiä kasveja päästetty kasvamaan kasvualustalla, koska haluttiin seurata nimenomaan turpeessa tutkimuksen aloittamishetkellä olleen pintakasvillisuuden kenttäkerroksen maanpäällisten osien kasvua. Kevätkesällä 1972 poistettu maitohorsma ei liene sanottavasti häirinnyt kokeen kulkua, koska sen määrä oli vain n. 1.5 % koko tutkimuksen aikana talteen otetusta pintakasvillisuuden kenttäkerroksen kuiva-aineen määrästä. Jäljempänä käytetään sanoja pintakasvillisuus ja kenttäkerros viittaamaan pintakasvillisuuden kenttäkerroksen maanpäällisiin osiin.

22. Aineiston keräys ja laskenta

Koesarja lopetettiin toukokuussa 1973. Tällöin mitattiin taimien verson pituus ja juurenniskan läpimitta. Kaikissa kokeissa taimien verso-osa leikattiin irti ja punnittiin uunikuivana.

Kokeissa 1 ja 3 määritettiin myös juuriston kuivapaino. Tätä varten turve jaettiin 5 cm:n paksuisiin kerroksiin 20 cm:n syvyyteen saakka ja juuret erotettiin turpeesta vesihuuhtelulla (vrt. Grosskopf 1950, Heikurainen 1955 a ja b, Paavilainen 1966). Kokeessa 1 mitattiin lannoitetuista koejäsenistä kahdesta toistosta juurten pituus kerroksittain. Juurten pituus mitattiin kunkin turvelajin osalta vain 2 muokkaamattomasta ja 2 muokatusta lannoittamattomasta näytteestä. Juurten pituus mitattiin näin yhteensä 78 näytteestä. Mitattujen juurten yhteenlaskettu pituus oli 1264 m. Lisäksi laskettiin juurten pituudella painotettu juuriston keskisyvyys. Juuret tutkittiin turvenäytteiden koko poikkileikkauspinta-alalta, koska haluttiin erityisesti saada selville juuriston paino verso/juuri -painosuhteen laskemiseksi. Juuriston syvyyden tarkasteluun olisi sopinut paremmin näytelieriön keskeltä otettu osanäyte, jolloin ns. reunavaikutus, juuris-

ton hakeutuminen näytelieriön reunaosia pitkin pohjaveden läheisyyteen, olisi ainakin osittain eliminoitunut.

Koesarjan lopussa poistettiin koko pintakasvillisuuden kenttäkerros sammalkerroksen pintaa myöten ja punnittiin uunikuivana. Tällöin kerättiin talteen tuoreiden kasvinosien lisäksi myös kesän 1972 aikana syntynyt kasviaines.

Pintakasvillisuuden ja taimien neulasten N-, P- ja K-pitoisuudet kokeissa 1 ja 2 määritettiin Viljavuuspalvelu Oy:ssä. Pintakasvillisuuden sisältämät ravinteet määritettiin vain muokkaamattomista ja taimien vain muokatuista näytteistä, koska kuiva-aineen määrä ei muissa tapauksissa olisi yleensä riittänyt analyysien tekoon. Ravinneanalyysejä varten toistot yhdistettiin.

Aineiston testauksessa on käytetty pääasiassa varianssianalyysiä. Keskiarvojen erojen merkitsevyyttä on tutkittu T u k e y n HSD-menetelmällä (Honestly Significant Difference). Varianssianalyysien vaikeutena ovat olleet monet yhdysvaikutukset, jotka ainakin osin ovat johtuneet turvelajien erilaisuudesta. Tämän vuoksi laajimmassa kokeessa (n:o 1), jossa on ollut 4 muuttujaa, varianssianalyysit on laskettu turvelajeittain. Tämän jälkeen ei kokeessa 1 yleensä ole esiintynyt yhdysvaikutuksia, ja tuloksia on lähes poikkeuksetta voitu tarkastella vain päävaikutusten osalta. Kokeissa 2 ja 3 turvelajeja ei ole yleensä eroteltu, koska aineisto olisi näin menetellen supistunut kovin pieneksi ja tulosten luotettavuus vastaavasti heikentynyt. Näissä kokeissa yhdysvaikutuksia on pyritty selvittämään kuvin ja taulukoin. Erojen merkitsevyyden testauksessa on käytetty seuraavia yleisesti hyväksyttyjä riskirajoja:

F	Ero on	
$F_{5}\%$	= Melkein merkitsevä	*
$F_{1}\%$	= Merkitsevä	**
$F_{0,1}\%$	= Erittäin merkitsevä	***

Tuloksia esitettäessä käytetään tekstissä sanaa merkitsevä kaikille riskitasoille, mikäli ne on numeroarvoina esitetty taulukoissa tai liitetaulukoissa. Testien F-arvot on yleensä esitetty liitetaulukoissa. Luettavuuden helpottamiseksi on ravinneyhdistelmän osalta esitetty päävaikutusten F-arvot myös taulukoissa.

Laskennassa pääpaino on asetettu lannoitetuista koejäsenistä tehtyihin analyyseihin, jotta ravinteiden sijoituksen ja muokkauksen vaikutus saataisiin mahdollisimman selväpiirteisenä esille. Kaikki taulukoissa esitetyt jyrsinnän, lannoitteiden sijoittamisen tai ravinneyhdistelmän vaikutusta kuvaavat luvut onkin laskettu pelkästään lannoitettujen näytteiden perusteella. Lisäksi liitetaulukoissa 1—4 esitetyt F-arvot koskevat vain lannoitettujen näytteiden välisiä vertailuja. Lannoittamattomista näytteistä on laskettu joitakin suppeita erillisanalyysejä muokkauksen vaikutuksen valaisemiseksi

luontaisissa ravinteisuusoloissa. Muutoin lannoittamattomat näytteet ovat olleet mukana vain lannoituksen voimakkuuden vaikutusta koskevissa yhteisanalyyseissä. Tällaisia analyysejä on tehty vain kokeesta 1. Näistä ei ole esitetty varianssianalyysin F-arvoja, vaan pelkästään päävaikutusten keskiarvojen testauksessa käytetyt $^{W}_{5\,\%}$ -arvot, jotka osoittavat eron 95 %:n luotettavuustasolla.

Pintakasvillisuuden kilpailun vaikutusta taimien kasvuun ei ole sisällytetty koesuunnitelmaan luokittelutekijänä. Tätä on kuitenkin voitu tarkastella laskemalla kovarianssianalyysejä aineistosta siten, että taimista mitattujen tunnusten vaihtelun selvittämiseen on luokittelumuuttujien lisäksi käytetty regressiomuuttujana pintakasvillisuuden kuivapainoa koeastiassa.

3. TULOKSET

31. Taimet

311. *Verson kasvu*

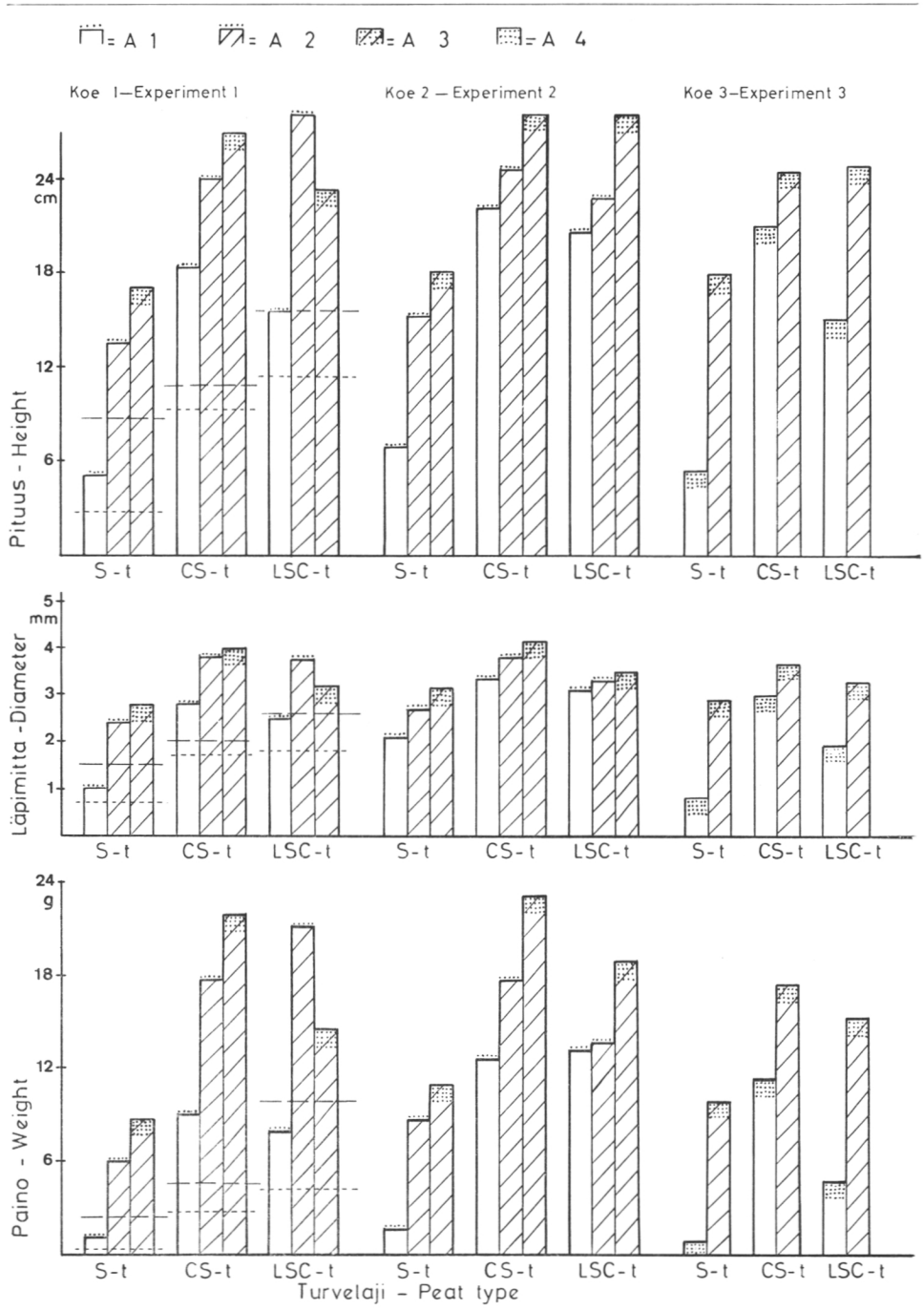
3111. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus

Jyrsinnän ja lannoitteiden sijoittamisen vaikutusta taimien verson kasvuun koskevat tulokset on esitetty taulukossa 4 ja kuvassa 2. Vastaavat lannoitettujen näytteiden perusteella laskettujen varianssianalyysien testiarvot löytyvät liitetaulukosta 1.

Kuvasta 2 ja taulukosta 4 (sarakkeet A 1 ja A 2) havaitaan, että jyrsintä on parantanut taimien verson kasvua kaikissa tapauksissa merkitsevästi. Jyrsinnän aiheuttama taimien kasvun lisäys on ollut suhteellisesti suurempi S-turpeella kuin muilla turvelajeilla (kuva 2). Tähän viittaa myös kokeissa 2 ja 3 havaittu turvelajin sekä jyrsinnän ja lannoitteiden sijoittamisen välinen merkitsevä yhdysvaikutus (liitetaul. 1).

Myös lannoittamattomat taimet ovat kasvaneet merkitsevästi paremmin jyrsityllä kuin muokkaamattomalla turvepinnalla (kuva 2 katkoviivat). Tällöinkin näyttää taimien kasvureaktio olleen S-turpeella voimakkaampi kuin muilla turvelajeilla.

Taulukon 4 sarakkeiden A 2 ja A 3 vertailu osoittaa, että lannoitteiden sijoittaminen jyrsittyyn turpeeseen on edistänyt taimien verson kasvua S- ja CS-turpeella, joskaan muutos pintalannoitetulla jyrsityllä turpeella kasvaneiden taimien kasvuun verrattuna ei jälkimmäisellä ole merkitsevä (vrt. myös kuva 2). LSC-turpeella lannoitteiden sijoittaminen on lisännyt verson kasvua kokeessa 2, mutta sitä vastoin vähentänyt sitä kokeessa 1. Kokeiden 1 ja 2 tuloksen erilaisuuden testaamiseksi on NPK-lannoitettujen taimien pituuskasvusta laskettu erikseen jokaisella turvelajilla varianssianalyysi, jossa koe on ollut yhtenä luokittelumuuttujana. LSC-turpeella kokeen ja lannoitusmenetelmän välinen yhdysvaikutus oli merkitsevä, mikä varmistaa tulosten erilaisuutta tältä osin em. kokeissa.



Kuva 2. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus taimien verson pituuteen, läpimittaan (juurenniskasta) ja painoon eri turvelajeilla.

Selitykset: A 1 = muokkaamaton, pintalannoitus; A 2 = jyrsitty, pintalannoitus; A 3 = jyrsitty, lannoitteet sekoitettu tai ruiskutettu (koe 3) turpeeseen; A 4 = lannoitteet ruiskutettu muokkaamattomaan turpeeseen; ---- = muokkaamaton, lannoittamaton; — — — = muokattu, lannoittamaton.

Figure 2. The shoot height, base diameter, and weight, as affected by rotavation and fertilizer placement. Key: A 1 = unprepared, topdress fertilization; A 2 = rotavated, topdress fertilization; A 3 = rotavated, fertilizers mixed or injected (Exp. 3) into peat; A 4 = unprepared, fertilizers injected into peat; ---- = unprepared, unfertilized; — — — = rotavated, unfertilized.

Taulukko 4. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus taimien verson kasvuun.
Table 4. Shoot growth of seedlings, as affected by peat rotavation and fertilizer placement.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Jyrsintä ja lannoitt. sijoitt.(1 *Rotavation and fert. placement*(1				
		A 1	A 2	A 3	A 4	w_s %
		Pituus, cm — *Height, cm.*				
1	S-t	5.2	13.4	17.1	—	3.3
1	CS-t	18.2	24.6	27.0	—	3.7
1	LSC-t	17.3	27.7	23.4	—	4.5
2	—	16.6	20.9	24.9	—	3.5
3	—	—	—	22.4	13.8	—
		Juurenniskan läpimitta, mm — *Base diameter, mm.*				
1	S-t	1.0	2.4	2.8	—	0.4
1	CS-t	2.8	3.8	4.0	—	0.6
1	LSC-t	2.5	3.8	3.2	—	0.2
2	—	2.5	3.2	3.6	—	0.5
3	—	—	—	3.3	2.0	—
		Kuivapaino, g — *Dry weight, grm.*				
1	S-t	1.1	6.0	8.7	—	2.6
1	CS-t	9.1	17.7	21.7	—	6.3
1	LSC-t	7.9	21.1	13.9	—	5.8
2	—	9.7	12.7	17.7	—	5.0
3	—	—	—	14.2	5.6	—

1) Kuten taulukossa 1 — As in Table 1.

Kokeiden 1 ja 2 käsittelyt ovat NPK-lannoitetuissa koejäsenissä olleet fosforilannoitetta lukuunottamatta samanlaiset. Taimien fosforin saannin mahdollista erilaisuutta em. kokeissa toisaalta pintalannoituksen ja toisaalta lannoitteiden sijoittamisen yhteydessä on tutkittu neulasista tehdyin ravinneanalyysein. Taulukosta 5 havaitaan, että LSC-turpeella neulasten fosforipitoisuus on ollut hieman suurempi sekä N/P - ja K/P -suhde pienempi kokeessa 2 kuin kokeessa 1. Vaikka ero onkin vähäinen, viittaa se kuitenkin taimien parempaan fosforin saantiin kokeessa 2 kuin kokeessa 1. Samansuuntaisia ovat neulasanalyysin tulokset myös CS-turpeella. Toisaalta N/P -suhde on ollut kaikissa tapauksissa pienempi kuin kirjallisuudessa yleensä esitetyt fosforin puutoksen raja-arvot (G a s t 1939, van G o o r 1953, W e h r m a n n 1959 ja P u u s t j ä r v i 1962). Sen sijaan lannoitteiden sijoittamisen aiheuttamat muutokset taimien fosforipitoisuudessa sekä N/P - ja K/P -suhteessa ovat LSC-turpeella kummassakin kokeessa olleet samansuuntaisia. Molemmissa sijoittaminen on pienentänyt suhteita ja lisännyt fosforipitoisuutta. Analyysitulokset eivät siis osoita lannoitteiden sijoittamisen vaikuttaneen taimien fosforin käyttöön eri tavoin kokeen 1 kuin kokeen 2 LSC-turpeella.

Edellä mainitussa kokeita 1 ja 2 vertailevassa varianssianalyysissä ei yllä esitetyn lisäksi havaittu muita merkitseviä eroja tuloksissa kokeiden välillä, joten hieno- ja superfosfaatti ovat nähtävästi muilta osin olleet saman veroi-

Taulukko 5. Taimien neulasten N-, P- ja K-pitoisuus ja niiden keskinäiset suhteet NPK-lannoitetuissa, muokatuissa näytteissä kokeissa 1 ja 2.

Table 5. The N, P, and K contents in needles and N/P, and K/P ratios on NPK-fertilized, rotavated peat in Experiments 1 and 2.

Ravinne *Nutrient*	Lannoitusmenetelmä *Fertilization method*	Turvelaji — *Peat type*					
		S-t		CS-t		LSC-t	
		Koe n:o — *Experiment No*					
		1	2	1	2	1	2
N %	A 2	1.2	1.2	1.3	1.3	1.5	1.2
	A 3	1.1	1.0	1.4	1.1	1.3	1.2
P ‰	A 2	1.8	1.6	1.7	1.8	1.5	1.7
	A 3	1.6	1.4	1.5	1.7	1.6	1.8
K ‰	A 2	8.0	7.1	7.5	6.4	6.7	6.4
	A 3	7.5	6.6	6.7	5.4	6.9	5.6
N/P	A 2	6.5	7.6	7.9	7.5	9.8	7.4
	A 3	7.2	7.4	9.1	6.5	8.9	7.0
K/P	A 2	4.4	4.6	3.7	3.7	4.4	3.9
	A 3	4.7	4.9	4.5	3.2	4.3	3.3

sia taimien kannalta. Sen sijaan kokeessa 3 taimet ovat kasvaneet yleensä huonommin kuin muissa kokeissa, vaikka ravinteet on sijoitettu sekä muokattuun että muokkaamattomaan turpeeseen. Vaikka kokeen 3 tulosten vertailukelpoisuutta muiden kokeiden kanssa häiritseekin erilainen lannoite, näyttää kuitenkin siltä, että lannoitteiden sijoittamisen edullisuus taimien kasvulle näyttää kiinteästi kytkeytyvän jyrsintään.

Taulukon 4 luvuista on vielä syytä todeta, että taimet ovat jokaisessa tapauksessa kasvaneet huomattavasti paremmin muokkauslannoitetulla kuin pintalannoitetulla jyrsimättömällä turpeella (sar. A 1 ja A 3 ja liitetaul. 1).

3112. Ravinneyhdistelmän ja -määrän vaikutus

Taulukosta 6 havaitaan, että taimet ovat kehittyneet ripeämmin NPK- kuin PK-lannoitetulla turpeella. Typen lisäyksen aiheuttama taimien verson kasvun parantuminen on ollut yleensä merkitsevä, mikä viittaa siihen, että kaikissa turvelajeissa on ollut puutetta kasveille käyttökelpoisesta typestä.

Taulukon 6 luvut osoittavat edelleen, että taimet ovat kasvaneet sitä paremmin, mitä enemmän ravinteita on annettu. On kuitenkin huomattava, että taimien kasvun lisäys siirryttäessä lannoitemäärästä 75 kg/ha lannoitemäärään 150 kg/ha kutakin vaikuttavaa ainetta on merkitsevä vain S-turpeella (vrt. myös liitetaul. 1). Tulos tukee aikaisemman tutkimukseni (K a u -

Taulukko 6. Ravinneyhdistelmän ja -määrän vaikutus taimien verson kasvuun.
Table 6. Shoot growth of seedlings, as affected by combination and amount of applied nutrients.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Ravinneyhdistelmä *Nutrient combination*			Ravinteiden määrä *Amount of nutrients*			w_s %
		NPK	PK	F-suhde — *F ratio*	0	75	100	
		Pituus, cm — *Height, cm.*						
1	S-t	13.2	10.5	6.57*	6.7	10.6	13.2	2.2
1	CS-t	25.7	20.7	17.15***	9.4	22.7	23.7	2.6
1	LSC-t	24.3	21.2	4.50	15.2	21.9	23.6	3.5
2	—	—	—	—	—	20.0	21.7	—
3	—	—	—	—	—	16.9	19.2	—
		Juurenniskan läpimitta, mm — *Base diameter, mm.*						
1	S-t	2.3	1.9	8.73**	1.3	1.9	2.2	0.3
1	CS-t	3.7	3.3	5.33*	1.7	3.4	3.6	0.4
1	LSC-t	3.4	2.8	9.44**	2.3	3.1	3.2	0.5
2	—	—	—	—	—	2.9	3.3	—
3	—	—	—	—	—	2.5	2.8	—
		Kuivapaino, g — *Dry weight, grm.*						
1	S-t	6.0	4.6	2.76	1.7	4.4	6.2	1.7
1	CS-t	18.9	13.3	7.31*	3.3	15.2	17.1	4.2
1	LSC-t	17.1	11.5	8.91*	7.9	13.9	14.7	4.4
2	—	—	—	—	—	12.2	14.5	—
3	—	—	—	—	—	9.0	10.7	—

Taulukko 7. Taimien verson kasvu lannoittamattomissa ja lannoitetuissa näytteissä eri turvelajeilla.
Table 7. The shoot growth of seedlings on different unfertilized and fertilized peats.

Lannoitus *Fertilization*	Mitattu tunnus *Measured quantity*	Koe n:o *Exp. No*	Turvelaji — *Peat type*			w_s %
			S-t	CS-t	LSC-t	
Lannoittamaton — *Unfertilized*	Pituus, cm — *Height, cm.*	1	5.9	10.3	14.1	2.5
	Läpim., mm — *Diam., mm.*	1	1.1	1.8	2.0	0.4
	Paino, g — *Weight, grm.*	1	1.4	4.4	5.8	1.0
Lannoitettu — *Fertilized*	Pituus, cm — *Height, cm.*	1	11.9	23.3	22.8	7.4
		2	13.4	25.1	23.9	3.5
		3	11.5	22.7	20.0	4.2
	Juurenniskan läpimitta, mm —	1	2.1	3.5	3.2	0.9
		2	2.3	3.8	3.2	0.5
	Base diameter, mm.	3	2.0	3.3	2.6	0.6
	Paino, g — *Weight, grm.*	1	5.3	16.2	14.3	9.3
		2	7.1	17.8	15.5	5.0
		3	5.2	14.4	10.0	5.4

nisto 1971) perusteella esitettyä käsitystä, että tietyn peruslannoituksen ylittävä lannoitteiden lisäys ei sanottavasti enää paranna taimien verson kasvua.

Taimien verson kasvua eri turvelajeilla vertaillaan taulukossa 7. Nähdään, että ilman lannoitusta taimet ovat kasvaneet huonoimmin S-turpeella. Kasvu on ollut merkitsevästi parempi CS-turpeella kuin S-turpeella ja LSC-turpeella edelleen merkitsevästi parempi kuin CS-turpeella. Tulos tukee ravinneanalyysien osoittamia turvelajien välisiä luontaisen ravinteisuuden eroja.

Myös lannoitetuissa näytteissä taimet ovat olleet keskimäärin pienimpiä S-turpeella. Taulukon 7 luvut osoittavat kuitenkin, että, päinvastoin kuin edellä todettiin, taimet ovat kasvaneet keskimäärin jonkin verran paremmin CS- kuin LSC-turpeella. Lannoituksella on siis voitu parantaa enemmän CS- kuin LSC-turpeen ominaisuuksia taimien kasvualustana.

312. *Juuriston kasvu*

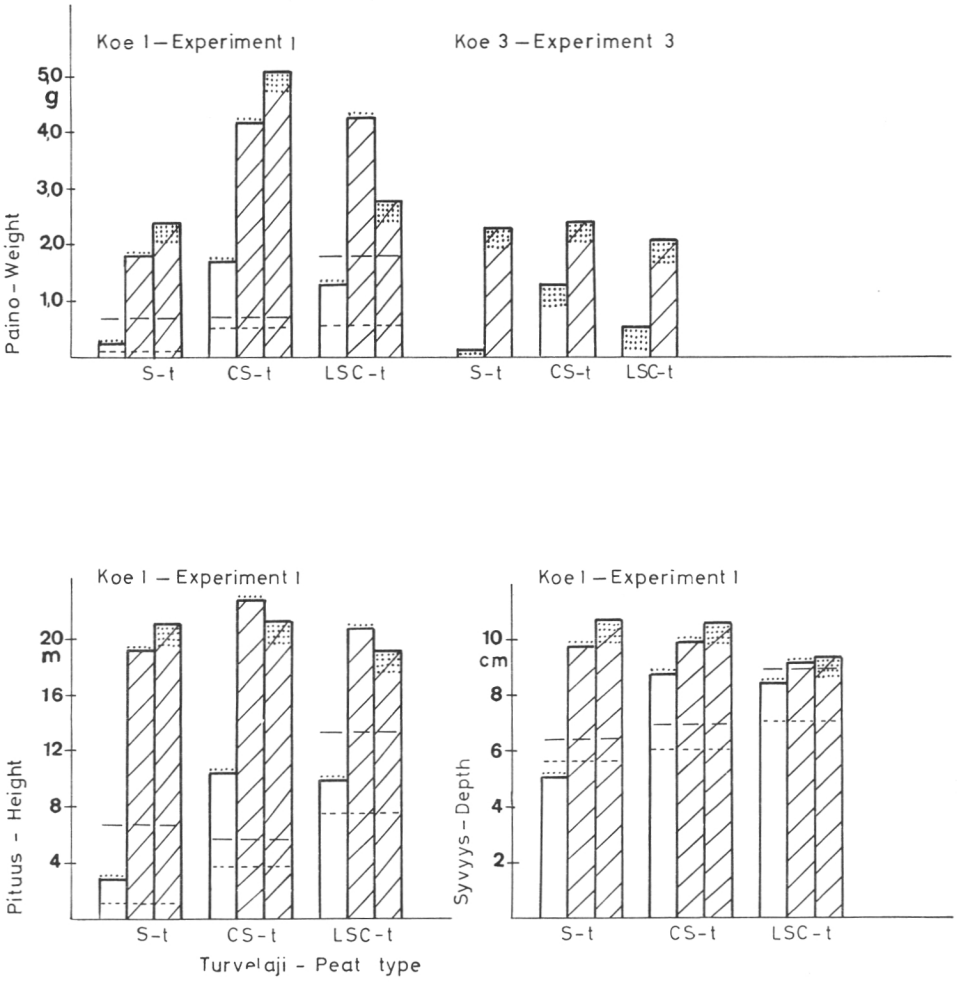
3121. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus

Jyrsinnän ja lannoitteiden sijoittamisen vaikutusta taimien juuriston kasvuun selvitellään kuvassa 3 ja taulukossa 8. Lannoitetuista näytteistä lasketttujen varianssianalyysien F-arvot ovat liitetaulukossa 2. Yleisesti voidaan sanoa, että juuriston kasvusta saadut tulokset varsin paljon myötäilevät edellä verson kasvusta esitettyjä.

Kuvasta 3 ja taulukosta 8 (sar. A 1 ja A 2) havaitaan, että lannoitettujen taimien juuriston paino ja pituus on ollut jyrsityssä turpeessa moninkertainen muokkaamattomaan verrattuna. Jyrsinnän aiheuttama juuriston kasvun paraneminen on merkitsevä kaikilla turvelajeilla (vrt. myös liitetaul. 2). On kuitenkin todettava, että juuristonkin kasvua näyttää jyrsintä edistäneen suhteellisesti enemmän S-turpeella kuin muilla turvelajeilla. Tulos on siis samansuuntainen kuin edellä verson kasvua tarkasteltaessa todettu, joskaan juuriston kasvun yhteydessä tulosta ei ole voitu tilastollisesti vahvistaa. Kuva 3 (katkoviivat) osoittaa edelleen, että jyrsintä on edistänyt juuriston kasvua myös lannoittamattomassa turpeessa.

Taimien juurten pituudella painotettu juuriston keskisyvyys on ollut suurempi jyrsityssä kuin rakenteeltaan rikkomattomassa turpeessa (kuva 3 ja taul. 8). Jyrsinnän aiheuttama juuriston syveneminen on merkitsevä kuitenkin vain S-turpeella. Jyrsintä on lisännyt juuriston syvyyttä myös lannoittamattomassa turpeessa.

Taulukon 8 sarakkeiden A 2 ja A 3 vertailu osoittaa, että lannoitteiden sijoittaminen jyrsittyyn turpeeseen on lisännyt juuriston kuivapainoa S- ja CS-turpeella, joskaan ero ei pintalannoitettuihin, muokattuihin näytteisiin



Kuva 3. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus juuriston painoon ja pituuteen näyteastiassa sekä juurten pituudella painotettuun keskisyvyyteen. Selitykset kuten kuvassa 2.

Figure 3. The root weight and length/pot, and average rooting depth weighted by root length of seedlings, as affected by rotavation and fertilizer placement. Key as in Figure 2.

verrattuna ole kummallakaan turvelajilla ollut merkitsevä (myös kuva 3). LSC-turpeella sijoittaminen on merkitsevästi pienentänyt juuriston painoa. Tulokset vastaavat tältä osin varsin tarkoin aiemmin taimien kasvusta esitettyjä.

Lannoitteiden sijoittaminen ei ole vaikuttanut juuriston pituuteen. Juuriston syvyys on ollut jonkin verran, mutta ei merkitsevästi, suurempi lannoitteiden sijoituksen kuin pintalannoituksen yhteydessä.

Vertailtaessa taulukon 8 sarakkeita A 1 ja A 3 nähdään, että muokkaus-

Taulukko 8. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus taimien juuriston kasvuun.

Table 8. Root growth of seedlings, as affected by peat rotavation and fertilizer placement.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Jyrsintä ja lannoitt. sijoitt.(1 *Rotavation and fert. placement*(1				
		A 1	A 2	A 3	A 4	W_s %
		Kuivapaino, g — *Dry weight, grm.*				
1	S-t	0.23	1.78	2.41	—	0.68
1	CS-t	1.70	4.15	5.08	—	1.54
1	LSC-t	1.29	4.27	2.79	—	1.29
3	—	—	—	2.25	0.63	—
		Pituus, cm — *Height, cm.*				
1	S-t	278	1 909	2 102	—	1 050
1	CS-t	1 030	2 283	2 131	—	680
1	LSC-t	985	2 069	1 914	—	910
		Syvyys, cm — *Depth, cm.*				
1	S-t	5.0	9.7	10.7	—	1.7
1	CS-t	8.7	9.9	10.6	—	1.7
1	LSC-t	8.4	9.1	9.3	—	2.0

1) Kuten taulukossa 1 — As in Table 1.

lannoitetussa turpeessa taimet ovat kasvattaneet sekä painavamman, pitemmän että syvemmälle turpeeseen tunkeutuvan juuriston kuin pintalannoitetussa muokkaamattomassa turpeessa (myös kuva 3). Erona verson kasvusta esitettyihin tuloksiin todettakoon, että muokkauslannoituksen suotuisuus taimien juuriston kehitykselle on johtunut pääasiassa jyrsinnästä, ja että lannoitteiden sijoittamisen osuus on ollut vähäisempi juuriston kuin verson kasvun paranemisessa.

3122. Ravinneyhdistelmän ja -määrän vaikutus

Taulukon 9 luvuista nähdään, että NPK-lannoitetut taimet ovat kasvattaneet painavamman ja pitemmän juuriston kuin PK-lannoitetut. Painon lisäys on merkitsevä S- ja LSC-turpeella, mutta pituuden lisäys vain S-turpeella. Juuristo on ollut keskimäärin jonkinverran syvemmällä NPK- kuin PK-lannoitetussa turpeessa, mutta ero ei ole merkitsevä.

Taulukon 9 luvut osoittavat edelleen, että lannoitus on, lannoittamattomaan verrattuna, voimakkaasti lisännyt taimien juuriston painoa ja pituutta (vrt. myös Paavilainen 1967 ja 1968). Valtaosa lannoituksen aiheuttamasta kasvun lisäyksestä on kuitenkin saatu jo pienintä tutkimuksessa esiintynyttä määrää (75 kg/ha kutakin vaikuttavaa ainetta) käytettäessä. Tällöin muutos on ollut kaikissa tapauksissa merkitsevä. Sen sijaan em. ravinnemäärän kaksinkertaistaminen ei sanottavasti ole enää lisännyt juuriston kasvua.

Taulukko 9. Ravinneyhdistelmän ja -määrän vaikutus taimien juuriston kasvuun.
Table 9. Root growth of seedlings, as affected by combination and amount of applied nutrients.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Ravinneyhdistelmä *Nutrient combination*			Ravinteiden määrä *Amount of nutrients*			
		NPK	PK	F-suhde — *F ratio*	0	75	100	w_s %
		Kuivapaino, g — *Dry weight, grm.*						
1	S-t	1.80	1.14	8.80**	0.48	1.31	1.64	0.48
1	CS-t	4.05	3.23	2.63	0.53	3.35	3.93	1.01
1	LSC-t	3.31	2.26	6.05*	1.39	2.58	2.99	0.89
3	—	—	—		—	1.43	1.46	—
		Pituus, cm — *Height, cm.*						
1	S-t	1 777	1 082	4.67	494	1 298	1 561	430
1	CS-t	1 922	1 708	1.06	517	1 679	1 950	590
1	LSC-t	1 682	1 630	0.03	1 137	1 599	1 713	670
		Syvyys, cm — *Depth, cm.*						
1	S-t	8.7	8.2	1.14	6.2	8.5	8.5	1.5
1	CS-t	9.9	9.5	0.57	6.6	9.9	9.6	1.8
1	LSC-t	9.5	8.4	3.87	8.7	8.9	9.0	2.0

Lannoitus näyttää vaikuttaneen myös juuriston keskisyvyyteen lisäten sitä lannoittamattomaan verrattuna. Lannoituksen aiheuttama juuriston syveneminen on kuitenkin merkitsevä vain S- ja CS-turpeella. Annettujen ravinteiden määrällä ei tutkimuksen puitteissa ole ollut merkitystä.

Lannoituksen ja juuriston syvyyden välinen vuorosuhde poikkeaa P a a v i l a i s e n (1967) esittämien kenttäkokeiden tuloksista. Myöhemmässä tutkimuksessaan P a a v i l a i n e n (1968) kuitenkin mainitsee lannoituksen lisänneen juuriston kasvua aina 19—21 cm:n syvyydelle saakka. PK- ja NPK-lannoitus lisäsivät jonkin verran myös männyn juuriston keskisyvyyttä, joskaan Paavilainen ei pidä tätä merkittävänä. Syyksi erilaisiin tuloksiin Paavilainen esittää mm., että jälkimmäisessä tapauksessa ravinteilla on ollut enem-

Taulukko 10. Taimien juurten paino, pituus ja syvyys lannoittamattomissa ja lannoitetuissa näytteissä eri turvelajeilla kokeessa 1.
Table 10. The weight, length, and depth of tree roots in different unfertilized and fertilized peats in Experiment 1.

Lannoitus *Fertilization*	Mitattu tunnus *Quantity measured*	Turvelaji — *Peat type*			w_s %
		S-t	CS-t	LSC-t	
Lannoittamaton — *Unfertilized*	Paino, g — *Weight, grm.*	0.4	0.6	1.0	0.4
	Pituus, cm — *Length, cm.*	497	517	1 497	800
Lannoitettu — *Fertilized*	Paino, g — *Weight, grm.*	1.5	3.6	2.8	0.5
	Pituus, cm — *Length, cm.*	1 430	1 815	1 656	768
	Syvyys, cm — *Depth, cm.*	8.4	9.7	8.9	1.5

män aikaa kulkeutua turveprofiilissa alaspäin. Nyt esitetyissä tuloksissa on verrattain voimakas sadetus saattanut vaikuttaa saman suuntaisesti.

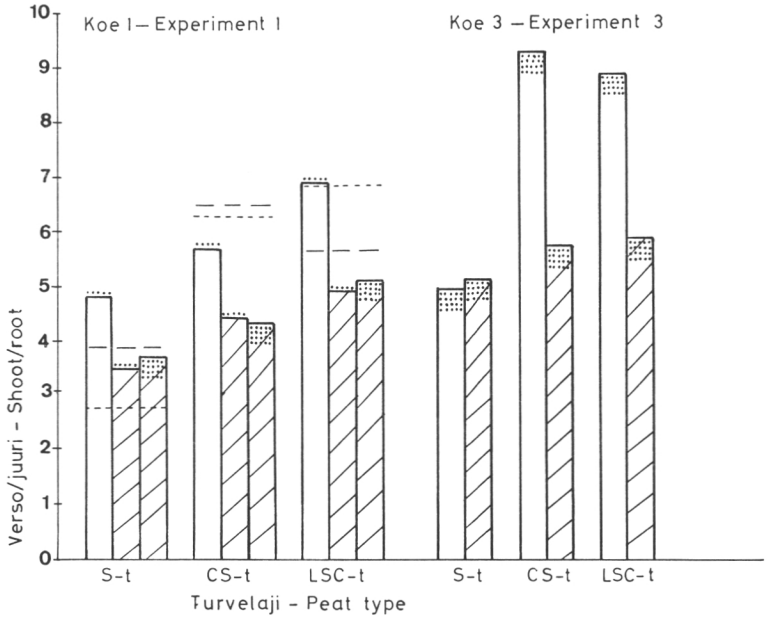
Taimien juuriston keskimääräistä kasvua eri turvelajeilla tarkastellaan taulukossa 10 kokeen 1 perusteella. Nähdään, että ilman lannoitusta juuristo on kasvanut parhaiten LSC-turpeessa ja huonoiten S-turpeessa. LSC-turpeessa kasvu on ollut merkitsevästi suurempi kuin muissa turpeissa.

Myös lannoitettaessa juuriston kasvu on ollut huonoin S-turpeessa. LSC-turpeessa juuriston paino on ollut merkitsevästi suurempi kuin S-turpeessa ja CS-turpeessa edelleen merkitsevästi suurempi kuin LSC-turpeessa. Juuriston pituuden ja keskisyvyyden osalta tulokset ovat samansuuntaiset, mutta erot eivät ole tilastollisesti merkitseviä. Tulos tukee aiemmin verson kasvusta esitettyä.

313. *Verso/juuri -painosuhde*

3131. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus

Jyrsinnän ja lannoitteiden sijoittamisen vaikutusta taimien verso/juuri -painosuhteeseen tarkastellaan taulukossa 11 ja kuvassa 4. Lannoitettujen



Kuva 4. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus verso/juuri -suhteeseen kokeissa 1 ja 3. Selitykset kuten kuvassa 2.

Figure 4. Shoot/root ratio as affected by rotavation and fertilizer placement in experiments 1 and 3. Key as in Figure 2.

Taulukko 11. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus taimien verso/juuri -painosuhteeseen.

Table 11. Effect of peat rotavation and fertilizer placement on root/shoot ratio of seedlings.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Jyrsintä ja lannoitt. sijoitt.(1 *Rotavation and fert. placement*(1				
		A 1	A 2	A 3	A 4	w_5 %
1	S-t	4.8	3.5	3.7	—	1.3
1	CS-t	5.7	4.4	4.3	—	1.3
1	LSC-t	6.9	4.9	5.1	—	1.8
3	—	—	—	5.6	7.7	—

1) Kuten taulukossa 1 — As in Table 1.

näytteiden perusteella laskettujen varianssianalyysien F-arvot on esitetty liitetaulukossa 3.

Kuvasta 4 ja taulukosta 11 (sar. A 1 ja A 2) nähdään, että kokeessa 1 suhde on kaikilla turvelajeilla ollut pienempi jyrsityllä kuin rikkomattomalla turpeella. Jyrsinnän aiheuttama muutos on merkitsevä jokaisella turvelajilla. Kokeessa 3 jyrsintä on pienentänyt suhdetta muilla paitsi S-turpeella. Näyttää siis siltä, että jyrsintä on lisännyt yleensä enemmän juuriston kuin verson kasvua.

Lannoitteiden sijoittaminen ei näytä vaikuttaneen taimien verso/juuri -painosuhteeseen millään turvelajilla.

3132. Ravinneyhdistelmän ja -määrän vaikutus

Taulukosta 12 havaitaan, että taimien verso/juuri -painosuhde on CS- ja LSC-turpeella ollut ravinneyhdistelmästä riippumaton. Sen sijaan S-turpeella typen lisäys on merkitsevästi pienentänyt suhdetta (vrt. myös liitetaul. 3). Yleensä typpilannoitus lisää enemmän verson kuin juuriston kasvua

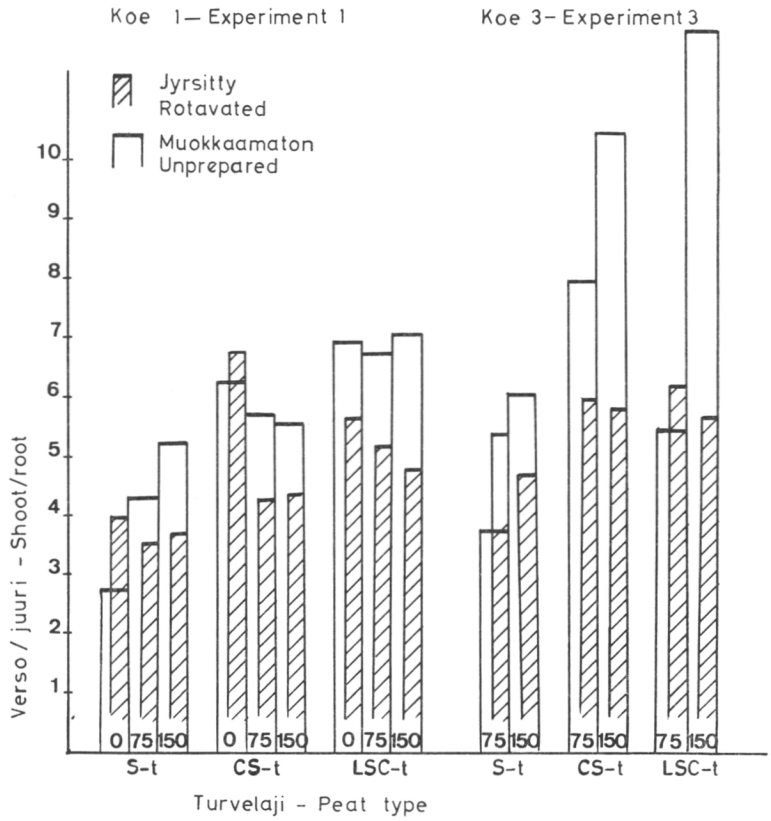
Taulukko 12. Ravinneyhdistelmän ja -määrän vaikutus taimien verso/juuri -painosuhteeseen.

Table 12. Effect of combination and amount of applied nutrients on shoot/root ratio of seedlings.

Koe n:o *Exp. No*	Turvelaji *Peat type*	Ravinneyhdistelmä *Nutrient combination*			Ravinteiden määrä *Amount of nutrients*			
		NPK	PK	F-suhde — *F ratio*	0	75	100	w_5 %
1	S-t	3.5	4.5	5.37	3.6	3.8	4.2	1.2
1	CS-t	4.9	4.6	0.39	6.6	4.8	4.8	1.3
1	LSC-t	5.5	5.8	0.19	6.1	5.7	5.5	1.5
3	—	—	—	—	—	5.8	7.4	—

(esim. Mitchell 1939, Schmidt 1961 ja McGee 1963). On kuitenkin todettava, että S-turpeessa oli luontaista typpeä varsin vähän, joten lisäämällä typpeä fosforin ja kalin ohella ylläpidettiin vain normaaleita ravinnesuhteita turpeessa.

Taulukosta 12 nähdään edelleen, että lannoitus on S-turpeella keskimäärin suurentanut, mutta muilla turvelajeilla pienentänyt verso/juuri -suhdetta. Lannoituksen aiheuttama muutos suhteessa on merkitsevä kuitenkin vain CS-turpeella. Mielenkiintoisen lisän verso/juuri -suhteen tarkasteluun antaa kuva 5, josta nähdään, että lannoituksen vaikutus suhteeseen riippuu turpeen muokkauksesta. Muokkaamattomissa näytteissä lannoitus on selvästi suurentanut suhdetta S-turpeella. Muilla turvelajeilla lannoituksella ei ole ollut sanottavaa merkitystä. Sen sijaan jyrsityissä näytteissä lannoitus on pienentänyt verso/juuri -painosuhdetta kaikilla turvelajeilla. Lannoituksen vaikutuksen erilaisuutta jyrsityllä ja muokkaamattomalla turpeella osoittaa myös



Kuva 5. Jyrsinnän ja lannoituksen voimakkuuden vaikutus verso/juuri -suhteeseen kokeissa 1 ja 3.

Figure 5. Shoot/root ratio as affected by rotavation at different fertilizer rates in Experiments 1 and 3.

se, että kummassakin kokeessa lannoituksen voimakkuuden ja jyrsinnän välinen yhdysvaikutus oli merkitsevä (kokeen 3 osalta vrt. liitetaul. 3). Tulos korostaa jyrsinnän edullisuutta pyrittäessä kasvattamaan voimakkaita, kestäviä taimia samoin kuin sitä, että pelkällä lannoituksella, pitämättä muutoin huolta juuriston kasvuympäristön parantamisesta, saatetaan tuottaa pienijuuristoisia, heikkoja taimia.

32. Pintakasvillisuuden kenttäkerros

321. Kenttäkerroksen biomassa

Kenttäkerroksen valtalajit ja niiden osuudet (painon mukaan) muokkaamattomissa koejäsenissä kokeiden päättyessä olivat seuraavat:
S-turpeella *Empetrum nigrum* (n. 95 %); CS-turpeella *Eriophorum vaginatum* (n. 80 %) ja *Andromeda polifolia* (n. 20 %); LSC-turpeella *Carex lasiocarpa* (n. 55 %), *Eriophorum vaginatum* (n. 40 %) ja *Andromeda polifolia* (n. 5 %).

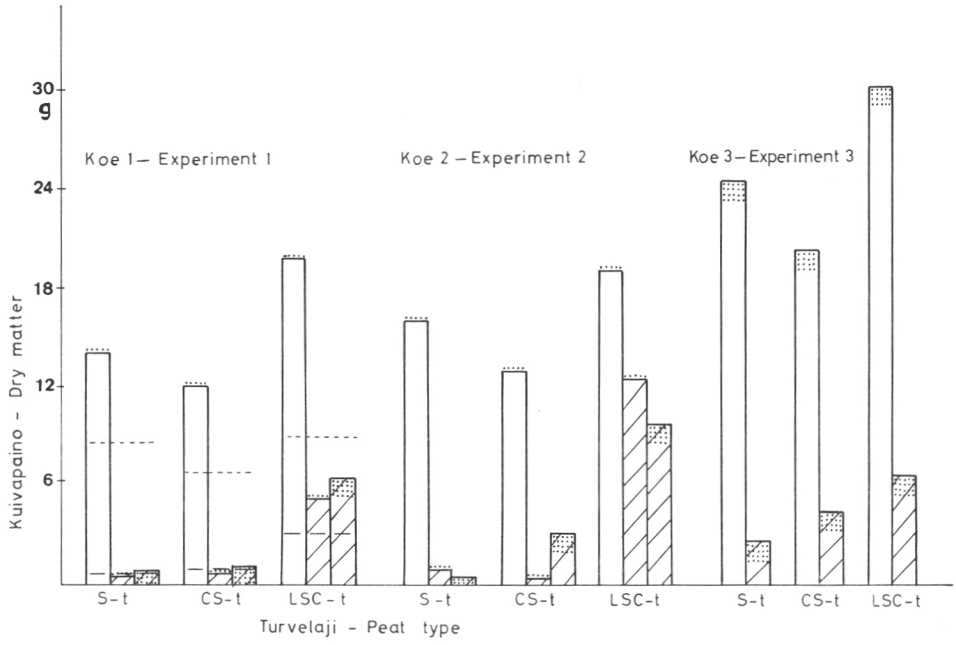
Kahden ensimmäisen kasvujakson aikana ruohovartisten kasvilajien kasvu oli niukkaa ja riippui vain vähän lannoituksesta. Tästä syystä tulosten esittely seuraavassa perustuu tutkimuksen aikana kerätyn kokonaisbiomassan tarkasteluun. Tällöin lukuihin on sisällytetty myös varpukasvit. Varpujen ja ruohovartisten kasvien erottamista toisistaan tuloksissa ei ole pidetty tarpeellisena, koska jokaisella turvelajilla toinen ryhmistä on ollut selvästi vallitseva.

3211. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus

Jyrsinnän ja lannoitteiden sijoittamisen vaikutusta kenttäkerroksen biomassaan selvitellään kuvassa 6 ja taulukossa 13. Lannoitettujen näytteiden varianssianalyysien F-arvot on esitetty liitetaulukossa 4.

Kuvasta 6 ja taulukosta 13 (sar. A 1 ja A 2) havaitaan, että kenttäkerroksen biomassa on ollut yleensä useita kertoja suurempi muokkaamattomalla kuin jyrsityllä turpeella. Yleisesti voidaankin sanoa, että muokkaamattomalla turpeella suon luontaiset kasvilajit ja jyrsityllä turpeella männyn taimet ovat olleet vallitsevina. Tämä näkyy havainnollisesti kuvassa 7, jossa on esitetty taimien kuivapainon osuus taimien ja kenttäkerroksen yhteenlasketusta kuivapainosta.

LSC-turpeella kenttäkerroksen valtalaji, *Carex lasiocarpa* on alkanut jo elpyä jyrsinnän aiheuttamasta tuhoutumisesta. Tälläkin turvelajilla kenttäkerroksen biomassa kokeen lopussa on ollut kuitnkin vain n. ¼—½ muok-



Kuva 6. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus pintakasvillisuuden kuiva-ainetuotokseen eri turvelajeilla. Selitykset kuten kuvassa 2.

Figure 6. The above-ground dry matter procuction of the ground vegetation on different peat types, as affected by rotavation and fertilizer placement. Key as in Figure 2.

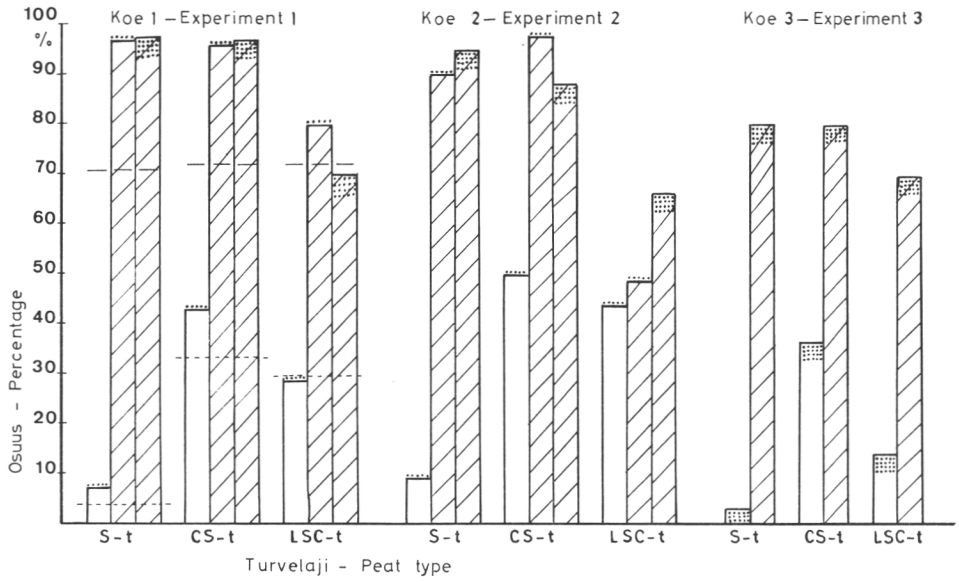
Taulukko 13. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus pintakasvillisuuden biomassaan (g/näyte uunikuivana).

Table 13. Effect of peat rotavation and fertilizer placement on the biomass of ground vegetation (grm./pot as oven dry weight).

Koe n:o *Exp. No*	Turvelaji *Peat type*	Jyrsintä ja lannoitt. sijoitt.(1 *Rotavation and fert. placement*(1				
		A 1	A 2	A 3	A 4	W_5 %
1	S-t	14.1	0.2	0.4	—	2.9
1	CS-t	12.1	0.6	1.0	—	4.0
1	LSC-t	19.7	5.4	6.4	—	5.6
2	—	16.4	4.6	4.5	—	4.4
3	—	—	—	4.7	25.0	—

1) Kuten taulukossa 1 — As in Table 1.

kaamattoman turpeen kenttäkerroksen biomassasta. CS-turpeella elpyminen on ollut vähäisempi. S-turpeen valtalaji, *Empetrum nigrum*, ei ole kasvattanut jyrsityllä turpeella lainkaan maanpäällisiä versoja. Sekin pintakasvillisuus, mikä taulukossa 13 ja kuvissa 6 ja 7 näyttää S-turpeella olevan, on ollut tupasvillaa. Yli-Vakkuri (1959) mainitsee *Empetrum*-lajien hyvin hitaasti



Kuva 7. Jyrsinnän ja lannoitteiden sijoittamisen vaikutus taimien verson kuivapainon osuuteen taimien ja pintakasvillisuuden kenttäkerroksen koko maanpäällisen osan biomassan tuotoksesta. Selitykset kuten kuvassa 2.

Figure 7. The dry weight ratio (%) of tree shoots/tree shoots + the total biomass production of the above-ground field layer of the ground vegetation, as affected by rotavation and fertilizer placement. Key as in Figure 2.

palanneen kulotetulle suolle, kun sitä vastoin *Eriophorum vaginatum* ja *Carex lasiocarpa* tavattiin alueelta jo kulotusta seuraavana kasvukautena.

Lannoitteiden sijoittaminen ei ole vaikuttanut biomassan määrään kokeissa 1 ja 2 (kuva 6 ja taul. 13 sar. A 2 ja A 3). Kaikkien kokeiden välinen vertailu kuitenkin paljastaa, että kokeessa 3, jossa lannoitteet on muokkaamattomissakin näytteissä sijoitettu turpeeseen (ruiskuttamalla), pintakasvillisuuden kehitys on ollut voimakkaampaa kuin muissa kokeissa, kuten kuvasta 6 ja taulukosta 13 (sar. A 1 ja A 4) sekä seuraavan asetelman NPK-lannoitetuista muokkaamattomista näytteistä lasketuista luvuista nähdään:

	Koe 1	Koe 2	Koe 3
S-t	17.9 g/koeastia	15.9 g/koeastia	24.5 g/koeastia
CS-t	18.4 »	14.1 »	20.1 »
LSC-t	21.2 »	19.1 »	30.4 »

Kuiva-aineen määrä on kokeen 1 CS-turvetta lukuunottamatta ollut kokeessa 3 merkitsevästi suurempi kuin muissa kokeissa. Vaikuttaa siltä, että lannoitteiden sijoittaminen muokkaamattomaan turpeeseen rehevöittää pintakasvillisuutta enemmän kuin pintalevitys, joskin se, että kokeissa käytettiin erilaisia lannoitteita, häiritsee luotettavan vertailun suorittamista.

3212. Ravinnyhdistelmän ja -määrän vaikutus

Taulukon 14 luvut osoittavat, että NPK-lannoitus on edistänyt pintakasvillisuuden biomassan tuotosta enemmän kuin PK-lannoitus. Erityisen selvänä tämä on ilmennyt CS-turpeella, jolla valtalajina on ollut *Eriophorum vaginatum* (kuva 8). Tätä osoittaa myös ravinneyhdistelmän ja -määrän väli-

Taulukko 14. Ravinneyhdistelmän ja -määrän vaikutus pintakasvillisuuden biomassaan (g/näyte uunikuivana).

Table 14. Effect of combination and amount of applied nutrients on the biomass of ground vegetation (grm./pot as oven dry weight).

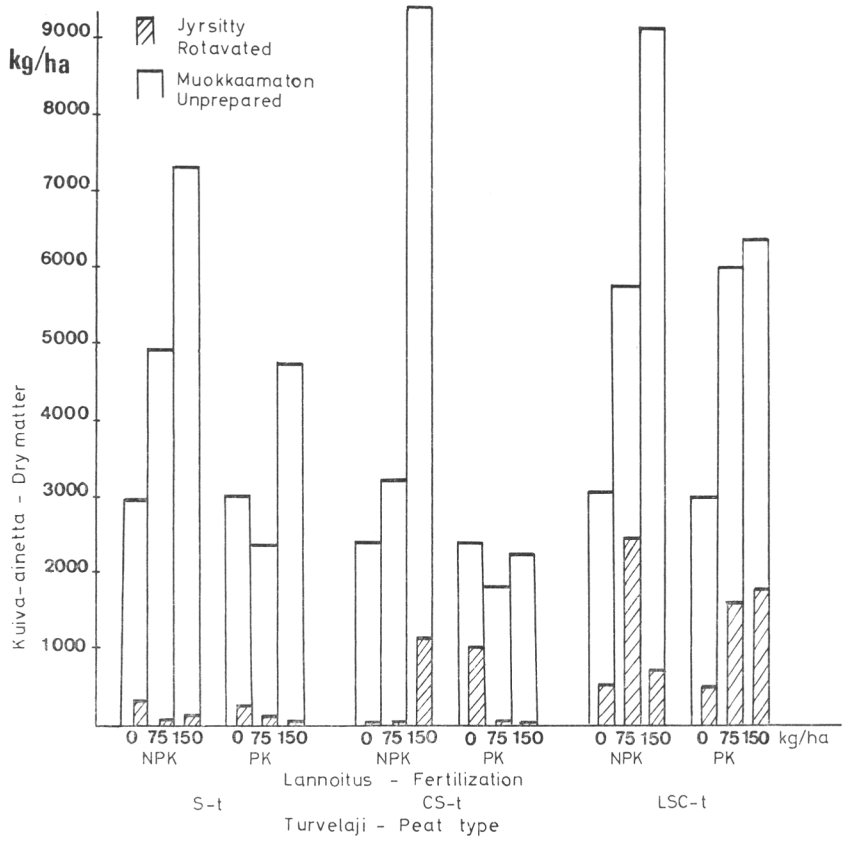
Koe n:o *Exp. No*	Turvelaji *Peat type*	Ravinneyhdistelmä *Nutrient combination*			Ravinteiden määrä *Amount of nutrients*			
		NPK	PK	F-suhde — *F ratio*	0	75	100	w_5 %
1	S-t	6.4	3.7	7.91**	3.5	3.8	6.3	2.2
1	CS-t	6.7	2.5	10.25**	3.0	3.1	6.1	2.7
1	LSC-t	11.3	9.6	0.92	5.2	9.3	11.7	3.8
2	—	—	—	—	—	8.3	8.7	—
3	—	—	—	—	—	12.7	17.0	—

nen merkitsevä yhdysvaikutus tällä turvelajilla (liitetaul. 4). LSC-turpeella ero on ollut vähäisempi kuin muilla turvelajeilla, mikä viittaa muita turvelajeja suurempaan kasveille käyttökelpoisen luontaisen typen määrään.

Päivänen ja Seppälä (1968) mainitsevat PK-lannoituksen lisänneen kenttäkerroksen (lähinnä *Eriophorum*) peittävyyttä NPK-lannoitusta enemmän. Samasta alueesta esittää Päivänen (1970) myöhemmin kuitenkin kuiva-aineanalyysin perusteella päinvastaisia tuloksia. Tamm (1954) ja Raitio (1974) ovat todenneet NPK-lannoituksen lisänneen tupasvillan kasvua PK-lannoitusta enemmän, joskin Raition tutkimuksessa vaikutus ei ole kaikissa tapauksissa selvä. Mannerkoski (1970) on havainnut eräiden *Carex* -lajien elpyneen voimakkaasti NPK-lannoitetuilla alueilla. Tutkimustulokset ovat siis varsin yhdenmukaisia.

Lannoitus on tässä tutkimuksessa rehevöittänyt myös rahkaturpeen valtalajia variksenmarjaa (*Empetrum nigrum*). Suurin lannoituksen tällä lajilla aiheuttama kasvun lisäys on ollut kokeen 3 NPK-lannoitetulla S-turpeella. Lisäys oli n. 2 100 kg/ha yhden kasvujakson aikana. Sen pohjoinen alalaji *Empetrum nigrum hermaphroditum* on ilman lannoitusta luonnonoloissa kasvanut vain 150—160 kg/ha yhden kasvukauden aikana (Flower-Ellis 1972).

Myös Rantala (1974) on havainnut lannoituksen lisäävän variksenmarjan kasvua. Sarasto (1963) on todennut tuhkalannoituksen rehevöit-



Kuva 8. Jyrsinnän ja lannoituksen vaikutus pintakasvillisuuden verso-osan kuiva-ainetuotokseen kokeessa 1.

Figure 8. The above-ground dry matter production of the ground vegetation in Experiment 1, as affected by rotavation and fertilization.

tävän tätä lajia. Toisaalta R e i n i k a i n e n (1965) on maininnut lannoituksen jopa vähentävän lajin esiintymistä. Syyksi hän esittää muun kasvillisuuden kilpailun. Nyt esitettävässä tutkimuksessa ei tällä ole ollut merkitystä.

Taulukosta 14 nähdään edelleen, että lannoitus on lisännyt kenttäkerroksen kuivapainoa sitä enemmän, mitä enemmän ravinteita on annettu (vrt. myös H e i k u r a i n e n ja V e i j o l a 1971). Kuva 8 osoittaa kuitenkin, että lannoitus on rehevöittänyt pintakasvillisuutta lähinnä vain muokkaamattomalla turpeella. Havainnon merkitystä lisäävät muokkauksen ja lannoituksen väliset yhdysvaikutukset (liitetaul. 4). Jyrsittäessä lannoitus on selvästi edistänyt kenttäkerroksen kasvua vain LSC-turpeella. Saman suuntaisia ovat M a n n e r k o s k e n (1970) esittämät tulokset lannoituksen vaikutuksesta lyhytkortisen ja varsinaisen saranevan pintakasvillisuuden elpymiseen laikutuksen jälkeen.

LSC-turpeella kenttäkerroksen biomassa on ollut kaikissa kokeissa keskimäärin suurempi kuin muilla turvelajeilla, kuten taulukon 14 ja kuvan 8 lisäksi myös seuraavan asetelman koko aineistosta lasketut keskiarvoluvut (g/näyteastia) osoittavat:

	S-t	CS-t	LSC-t	W_s%
Koe 1	4.5	4.0	8.4	1.6
Koe 2	5.8	5.9	13.7	4.4
Koe 3	13.7	12.3	18.5	7.5

322. *Kenttäkerroksen sitomat ravinteet muokkaamattomalla turpeella*

Kasviaineksen ravinnepitoisuuksia (taul. 15) tarkastellaan seuraavassa vain muokkaamattomien näytteiden osalta, koska suurimmassa osassa muuta aineistoa pintakasvillisuuden määrä oli liian vähäinen kemiallisten analyysien tekemiseen.

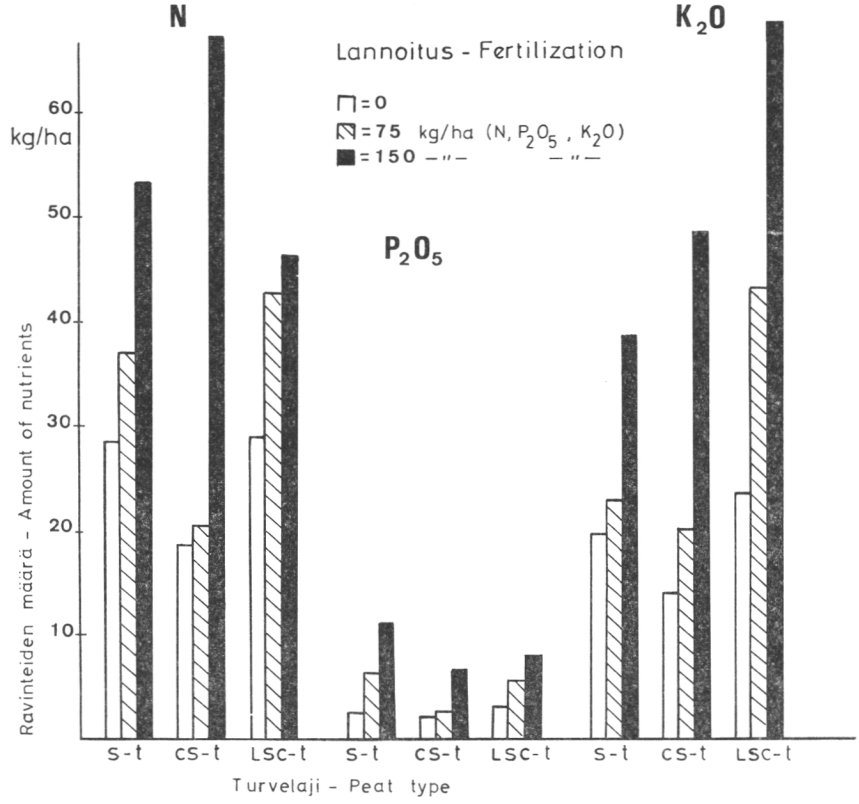
Kasviaineksen typpipitoisuus on ollut matala verrattuna eräisiin kirjallisuudessa esim. tupasvillalle (*Eriophorum vaginatum*) esitettyihin (K i v i n e n 1933, M a t t s o n ja K a r l s s o n 1944, H a v e r a a e n 1967 ja P ä i v ä n e n 1970), ja se näyttää vähentyneen lannoituksen johdosta. Erityisen matala on typpipitoisuus ollut LSC-turpeen kasvillisuudessa, jos sitä verrataan M a l m e r i n ja S j ö r s i n (1955) *Carex lasiocarpalle* saamiin lukuihin. Samoin on kasviaineksen fosfori- ja kalipitoisuus ollut yleensä kirjallisuu-

Taulukko 15. Lannoituksen vaikutus pintakasvillisuuden kenttäkerroksen N-, P- ja K-pitoisuuksiin muokkaamattomalla turpeella.

Table 15. The N, P, and K contents of the ground vegetation on unprepared peats, as affected by fertilization.

Koe *Exp.*	Turvelaji *Peat type*	Ravinneyhdistelmä *Nutrient Combination*	N, %			P, ‰			K, ‰		
			Lannoitus — *Fertilization*, kg/ha N, P_2O_5, K_2O								
			0	75	150	0	75	150	0	75	150
1	S-t	NPK	0.81	0.73	0.71	0.83	1.59	1.40	6.5	5.8	6.2
		PK	0.79	0.85	0.74	0.80	1.81	2.31	6.2	6.5	6.4
		Keskim. — *Avg.*	0.80	0.79	0.73	0.82	1.70	1.86	6.4	6.2	6.3
	CS-t	NPK	1.12	0.61	0.72	0.86	0.67	0.93	7.5	6.2	8.0
		PK	1.03	0.75	0.89	0.75	1.34	1.61	6.2	9.9	8.7
		Keskim. — *Avg.*	1.08	0.68	0.81	0.81	1.01	1.27	6.9	8.1	8.4
	LSC-t	NPK	0.94	0.73	0.51	0.91	0.83	0.86	7.0	6.7	7.9
		PK	0.86	0.68	0.61	0.80	0.91	1.22	7.3	7.6	10.1
		Keskim. — *Avg.*	0.90	0.71	0.56	0.86	0.87	1.04	7.2	7.2	9.0
2	S-t	NPK	0.80	0.58	0.64	0.82	1.70	2.20	6.4	5.2	5.7
	CS-t	NPK	1.08	0.57	0.77	0.81	0.84	1.60	6.9	6.8	7.1
	LSC-t	NPK	0.90	0.63	0.61	0.86	0.96	1.40	7.2	6.1	5.5

dessa esitettyjä arvoja pienempi (M a t t s o n ja K a r l s s o n 1944, M a l m e r ja S j ö r s 1955, G o r e 1961). Syynä CS- ja LSC-turpeella on ilmeisesti ollut kuolleen aineksen osuus kasvimateriaalissa (vrt. myös N ö m m i k ja P o p o v i c 1971). Tulokset viittaavat siihen, että ravinteista huomattava osa siirtyy tupasvillan ja jouhisaran maanalaisiin osiin maanpäällisten osien kuollessa. Saman ovat fosforin ja kalin osalta todenneet aikaisemmin myös T a m m (1954), G o o d m a n ja P e r k i n s (1959), G o r e (1961) sekä G o r e ja O l s o n (1967). Keskinäisiä vertailuja tässä tutkimuksessa voitaneen kuitenkin pitää luotettavina, koska kasvimateriaalin käsittely on kaikissa tapauksissa ollut sama. Tosin S-turpeen kenttäkerrokseen sitoutunut ravinteiden määrä ei ole täysin vertailukelpoinen muiden kanssa, koska sen valtalaji,



Kuva 9. Pintakasvillisuuteen sitoutuneiden pääravinteiden määrä N:nä, P_2O_5:na ja K_2O:na kokeen 1 muokkaamattomissa näytteissä erilaisten lannoitusten yhteydessä. Typen määrä on laskettu vain NPK-lannoitetuista näytteistä. Fosforin ja kaliumin määrä on NPK- ja PK-lannoitettujen näytteiden keskiarvo.

Figure 9. The amount of main nutrients, as N, P_2O_5, and K_2O, fixed in the above-ground field layer of ground vegetation in unprepared pots of Experiment 1, as affected by the rate of fertilizer application. The amount of nitrogen is based on only NPK-fertilized test members. The amount of phosphorus and potassium is the mean of the NPK and PK fertilized test members.

variksenmarja, on sisältänyt myös ennen tutkimuksen alkua kasvanutta kasviainesta ja sen lisäksi koostunut lähes yksinomaan elävistä kasvin osista, joten ravinnepipitoisuudet kuvaavat todellisia arvoja.

Kasviaineksen fosforipitoisuus on yleensä kohonnut PK-lannoituksen johdosta sitä enemmän, mitä enemmän ravinteita on annettu (vrt. myös G o r e 1961), joskin LSC-turpeella nousu on ollut muita turvelajeja vähäisempi. NPK-lannoitus on lisännyt selvästi fosforipitoisuutta kaikilla turvelajeilla kokeessa 2, mutta kokeessa 1 vain S-turpeella. Tämä vahvistaa aikaisemmin esitettyä käsitystä suuremmasta käyttökelpoisen fosforin määrästä kokeessa 2 kuin kokeessa 1.

Lannoitus on lisännyt pintakasvillisuuden kalipitoisuutta, mutta muutos on ollut vähäinen. Rahkaturpeella kasviaineksen kalipitoisuus on ollut matalin. Erot turvelajien välillä ovat kuitenkin olleet pieniä.

Esimerkkinä pintakasvillisuuteen sitoutuneiden ravinteiden määrästä on kokeen 1 muokkamattomien näytteiden perusteella laadittu kuva 9. Kuvasta voidaan laskea, että muokkaamattomalla turpeella on lannoituksen ja turvelajin mukaan kenttäkerroksen maanpäällisiin osiin sitoutunut typpeä 16—68, fosforia 2—5 ja kaliumia 11—56 kg/ha. Edelleen havaitaan, että pääravinteista erityisesti typpeä ja kalia on sitoutunut runsaasti pintakasvillisuuteen, ja yleensä sitä enemmän, mitä enemmän ravinteita on annettu. P ä i v ä n e n (1970) toteaa lannoittamattomalla alueella pintakasvillisuuteen (lähinnä *Eriophorum vaginatum*) sitoutuneen n. 11 kg typpeä, 1.2 kg fosforia ja 4.3 kg kaliumia hehtaarilla sekä NPK-lannoitetulla alueella (100 kg hehtaarilla kutakin vaikuttavaa ainetta) 46.5, 11.3 ja 20.4 kg/ha vastaavasti. Päiväsen esittämät luvut sopivat siis varsin hyvin tässä tutkimuksessa saatuihin vaihteluväleihin, joskin kalin määrä näyttää Päiväsen aineistossa olleen suhteellisesti pienempi.

Lannoitetypestä, -fosforista ja -kalista on sitoutunut pintakasvillisuuteen seuraavat osuudet:

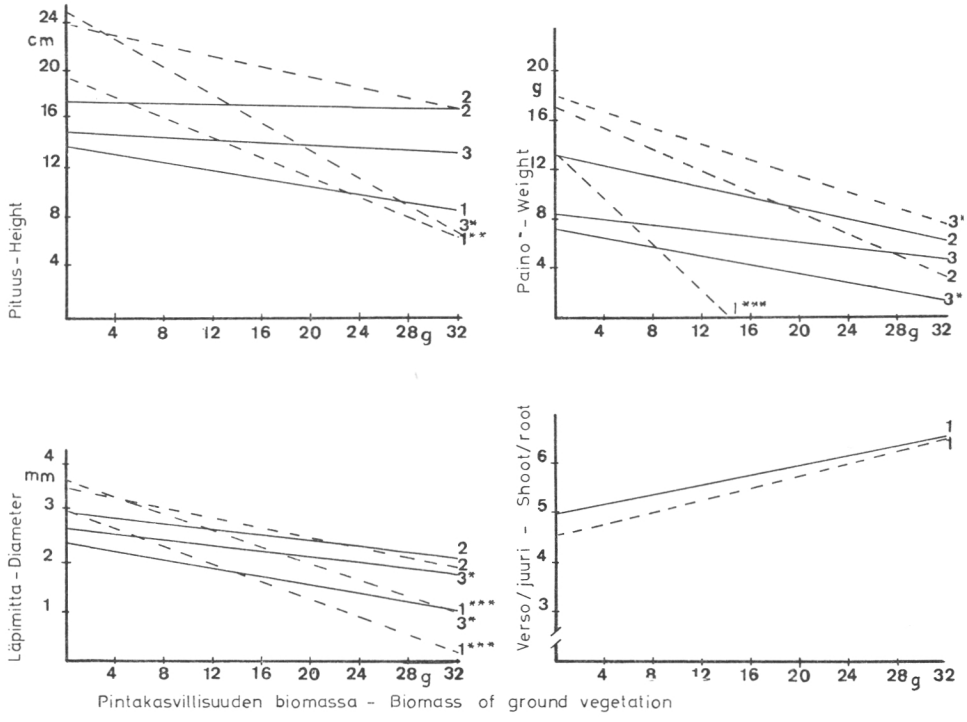
N	P	K
14.6 %	7.8 %	20.6 %

Laskelma on tehty olettaen, että lannoituksen aiheuttamaan pintakasvillisuuden kasvun lisäykseen on käytetty pelkästään lannoitteista saatuja ravinteita. Vaikka tämä ei todennäköisesti täysin pidäkään paikkaansa, laskelma kuitenkin valottanee pintakasvillisuuden merkitystä ravinteiden käyttäjänä. B j ö r k m a n ym. (1967) mainitsevat lannoitetypestä sitoutuneen pintakasvillisuuteen (juuristo mukaan luettuna) ensimmäisen kasvukauden aikana n. 7—24 % sekä N ö m m i k ja P o p o v i c (1971) n. 11—12 %. P a a v i l a i s e n (1974) tutkimuksessa on todettu pintakasvillisuuden sitoneen 19.4 % lannoitetypestä. Ø d e l i e n ja J e r v e n (1968) mainitsevat pintakasvilli-

suuden verso-osaan olleen sitoutuneena n. 30, 10 ja 20 % lannoitetypestä, -fosforista ja -kalista vastaavasti kolmen vuoden jälkeen. Samat tutkijat Ø d e l i e n ja J e r v e n (1971) mainitsevat pintakasvillisuuden kasvun lisäyksen lannoittamattomaan verrattuna sitoneen kuuden vuoden kuluessa 90 % lannoitetypestä vastaavan määrän. Pintakasvillisuuteen sitoutuneen typen määrä on tässä tutkimuksessa ollut edellä esitettyä pienempi. Syynä saattaa olla se, että osa analysoidusta kasvimateriaalista oli kuollutta jo keräyshetkellä, kuten aikaisemmin on todettu.

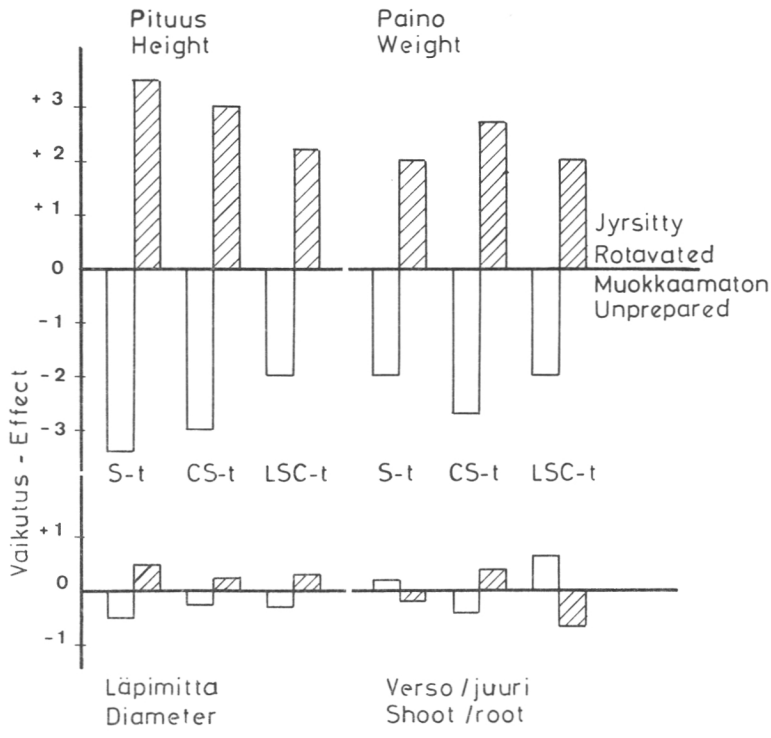
33. Pintakasvillisuuden vaikutus taimien kasvuun

Pintakasvillisuuden kuiva-ainetuotoksen ja eräitten taimista mitattujen tunnusten välistä riippuvuutta on testattu kovarianssianalyysillä, joka mahdollistaa luokittelumuuttujien vaikutuksen poistamisen ja mainitun riippu-



Kuva 10. Taimien pituuden, kuivapainon, juurenniskan läpimitan ja verso/juuri-suhteen riippuvuus pintakasvillisuuden määrästä kokeessa 1. Selitykset: 1, 2, 3 = koenumeroita; — = muokkaamaton; --- = muokattu.

Figure 10. The height, dry weight, base diameter, and shoot/root ratio of seedlings, as affected by the biomass (grm./pot) of ground vegetation. Key: 1, 2, 3 = Experiments; — = unprepared; --- = prepared.



Kuva 11. Pintakasvillisuuden suhteen kovarianssikorjatut jyrsinnän vaikutukset eräisiin taimista mitattuihin tunnuksiin.

Figure 11. The effect of rotavation, corrected for regression (ground vegetation), on some measured quantities of seedlings.

vuuden häiriöttömän tarkastelun. Kokeessa 1 on tutkittu sekä suora- että käyräviivaista (hyperbeli) mallia. Analyyseissä hyperbelin 1/x -tekijä ei ollut merkitsevä. Tämän vuoksi tarkastellaan seuraavassa kaikissa kokeissa vain suoraviivaista riippuvuutta. Aineisto on jaettu ensin kahtia, muokattuihin ja muokkaamattomiin näytteisiin, joista on laskettu kovarianssianalyysit edellä selostetulla tavalla.

Analyysitulosten mukaan taimien verson kasvu on ollut sitä vähäisempi, mitä runsaampaa pintakasvillisuus on ollut (kuva 10, liitetaul. 5). Pintakasvillisuus on vaikuttanut voimakkaimmin taimien verson painoon ja juurenniskan läpimittaan ja vähiten pituuskasvuun. Pintakasvillisuuden kilpailun johdosta näyttää täten syntyvän hentoja, suhteellisen pitkiä taimia. Verso/juuri -painosuhde on kasvanut pintakasvillisuuden lisääntyessä, mikä osoittaa, että kilpailu on vaikuttanut erityisen epäedullisesti juuriston painon kehitykseen.

Muokatulla turpeella pintakasvillisuus on vähentänyt taimien kasvua enemmän kuin muokkaamattomalla. Syynä nähtävästi on, että muokatuissa

Taulukko 16. Kovarianssianalyysien F-arvot ja merkitsevyydet eri turvelajeilla muokkauksen vaikutuksen osalta. Pintakasvillisuuden vaikutus poistettu.

Table 16. The F ratios and significances in the analyses of covariance concerning the effect of site preparation. Corrected for regression (ground vegetation).

Mitattu tunnus *Measured quantity*	Turvelaji — *Peat type*		
	S-t	CS-t	LSC-t
Pituus — *Height*	11.45**	6.80*	2.61
Kuivapaino — *Dry weight*	13.57**	4.40*	2.26
Läpimitta — *Base Diameter*	14.82**	4.60*	3.40
Verso/juuri — *Shoot/root*	0.08	0.26	1.24

näytteissä suurin pintakasvillisuuden kuivapaino on ollut vain 18 g/koeastia, kun se muokkaamattomissa näytteissä on ollut yli 45 g. Sovellettaessa suoraviivaista mallia hyperbelin muotoinen käyräviivaisuus suurentaa kulmakertoimen itseisarvoa sitä enemmän, mitä lähempänä y-akselia havaintojen painopiste on. Vaikka 1/x -tekijä ei edellä olekaan ollut merkitsevä, on se saattanut vaikuttaa edellä esitetyllä tavalla.

Edellä on osoitettu, että pintakasvillisuuden lisääntyessä taimien kasvu pienenee. Aikaisemmin havaittu jyrsinnän suotuisuus taimien kasvulle on näin ollen johtunut ainakin osaksi sen aiheuttamasta pintakasvillisuuden tuhoutumisesta. Pintakasvillisuuden tuhoutumisen ja muokkauksen muiden mahdollisten vaikutusten erottamiseksi toisistaan on pintalannoitetuista näytteistä laskettu kovarianssianalyysejä turvelajeittain siten, että pintakasvillisuuden vaikutus on poistettu. Kuvasta 11 ja taulukosta 16 nähdään, että jyrsintä on tällöinkin lisännyt merkitsevästi taimien kasvua S- ja CS-turpeella. Myös LSC-turpeella vaikutus on ollut positiivinen, joskaan ei tilastollisesti osoitettavissa. Tulos osoittaa, että pintakasvillisuuden tuhoamisen ja siitä aiheutuvan kilpailun vähenemisen lisäksi jyrsintä parantaa muullakin tavoin taimien kasvuedellytyksiä.

4. TULOSTEN TARKASTELUA

Viljelylannoituksen tarkoituksena on antaa taimille ravinneannos, joka varmistaa niiden ravinteiden saannin muutaman viljelyä seuraavan vuoden ajaksi. Sijoittamalla lannoitteet kasvualustaan voidaan varmistaa, että ainakin osa ravinteista joutuu taimien juurikerrokseen taimien ravinteiden oton kannalta sopiviin olosuhteisiin. Voidaan olettaa, että lannoitteiden sijoittaminen näin ollen lisäisi taimien kasvua.

Esitetyt tulokset osoittavat, että yleensä lannoitteiden sijoittaminen kasvualustaan onkin parantanut taimien kasvua. Tuloksen merkitystä lisää vielä se, että tutkimuksessa turvetta sadetettiin verrattain runsaasti, jolloin ravinteita todennäköisesti kulkeutui alaspäin myös pintalannoitetussa turpeessa. Onkin mahdollista, että lannoitteiden sijoittamisen vaikutus taimien kasvuun on tutkimuksessa ollut todellista pienempi.

On kuitenkin syytä kiinnittää huomiota eräisiin tutkimuksessa esiintyneisiin poikkeavuuksiin yleisestä säännöstä. Lannoitteiden sijoittaminen ilman jyrsintää näyttää huonontaneen taimien kasvua pintalannoitukseen verrattuna. Toisaalta pintakasvillisuus muokkaamattomalla turpeella rehevöityi enemmän silloin, kun lannoitteet sijoitettiin. Tulokset eivät tältä osin ole täysin vertailukelpoisia, koska sijoitettaessa lannoitteet muokkaamattomaan turpeeseen käytettiin erilaista lannoitetta kuin pintalannoituksessa. Taimien ja pintakasvillisuuden erilainen reagointi lannoitteiden sijoittamiseen antaa kuitenkin aiheen olettaa, että sijoitetut ravinteet ovat muokkaamattomassa turpeessa koituneet lähinnä pintakasvillisuuden hyväksi. Tämä onkin varsin ymmärrettävää, koska pintakasvillisuudella on juuristo valmiina ottamaan annetut ravinteet vastaan. Erityisesti kylvötaimille saattaa tilanne tällöin muodostua varsin tukalaksi, koska ne eivät sanottavasti kykene parina ensimmäisenä vuotena kilpailemaan sen paremmin ravinteista kuin kasvutilastakaan. Näyttää siis siltä, että kylvön yhteydessä lannoitetta ei kannata sijoittaa, ellei samanaikaisesti turvetta muokata tai hävitetä pintakasvillisuutta muulla tavoin.

Toinen poikkeus lannoitteiden sijoittamisen yleensä edullisesta vaikutuksesta taimien kasvulle havaittiin kokeessa 1, jossa taimet jyrsityllä LSC-turpeella kasvoivat paremmin levitettäessä lannoitteet pintaan kuin sijoitetta-

essa ne turpeeseen. Toisaalta kokeen 2 vastaavissa olosuhteissa lannoitteiden sijoittaminen lisäsi taimien kasvua myös LSC-turpeella. Koska ainoa ero kokeiden 1 ja 2 NPK-lannoitettujen näytteiden välillä oli fosforilannoite, täytynee olettaa, että tämä on ollut syynä tulosten erilaisuuteen, vaikka sitä ei olekaan ravinneanalyysein voitu kiistatta osoittaa.

On ilmeistä, että turpeen mikrobitoiminta on ollut varsin vilkasta lämpimässä kasvihuoneessa. Runsainta se on todennäköisesti ollut LSC-turpeessa, koska sekä sen pH että typpipitoisuus ovat olleet korkeammat kuin muiden turvelajien. Jyrsittäessä koko pintaturvekerrokseen sekoittuu tuoretta, vielä hajaantumatonta kasviainesta, mistä osa on aina helposti hajaantuvaa. Näissä olosuhteissa on todennäköistä, että ensisijaisesti ravinteiden saanti rajoittaa mikrobien toimintaa. Muokkauslannoituksessa lannoitteet sekoitetaan tasaisesti turpeeseen. Näin syntyy mikrobitoiminnalle erittäin suotuisat olosuhteet. Tällaisessa tilanteessa on ilmeistä, että jos joku lisätyistä ravinteista on vaikealiukoisessa muodossa, ensisijaisesti juuri tämä ravinne rajoittaa mikrobien lisääntymistä. Koska muut olosuhteet ovat mikrobitoiminnalle suotuisat muodostuu kilpailu tästä niukasti saatavissa olevasta ravinteesta erittäin tiukaksi. Kilpailussa mikrobisto on taimia voimakkaampi. Tässä tapauksessa on mahdollista, että näin on käynyt hienofosfaattia käytettäessä. Pintalannoituksen yhteydessä ravinteet jäävät ohuempaan turvekerrokseen, jossa konsentraatio on verrattain korkea. Tällöin esim. sopivan hajoitettavan kasviaineksen vähäisyys saatavilla olevien ravinteiden määrään verrattuna on saattanut rajoittaa mikrobien toimintaa. Mikäli näin todella on käynyt, tarvinnee vastaavaa tuskin pelätä kenttäolosuhteissa, koska silloin esim. turpeen lämpötila on huomattavasti matalampi kuin kasvihuoneessa ja mikrobitoiminta jo tästä syystä jää vähäisemmäksi.

Alunperin kokeen 2 tarkoituksena oli selvittää, voitaisiinko lannoitteiden sijoittaminen korvata käyttämällä pintalannoituksessa helppoliukoisia lannoitteita. Soiden metsänviljelyssä kysymykseen tulee tällöin lähinnä superfosfaatin käyttäminen hieno- tai raakafosfaatin sijasta. Tätä taustaa vasten onkin varsin yllättävää, että liukoisuusasteen lisääminen hienofosfaatin trikalsiumfosfaatista superfosfaatin monokalsiumfosfaattiin ei vähentänyt lannoitteiden sijoittamisen merkitystä, vaan pikemminkin päinvastoin.

Jyrsintä tuhoaa turpeen pintakasvillisuuden. Sekä jyrsintä että pintakasvillisuus tai sen puuttuminen vaikuttavat ilmeisesti turpeen fysikaalisiin, kemiallisiin ja biologisiin ominaisuuksiin. Kaikki mainitut puolestaan ovat osatekijöinä taimien kasvuedellytyksiä luotaessa. On näin ollen selvää, että tarkasteltaessa jyrsinnän merkitystä taimien kasvulle ollaan tekemisissä monien tekijöiden vaikeasti toisistaan erotettavien yhteis- ja/tai yhdysvaikutusten kanssa. Tutkimuksessa ei ole pyritty näiden yksityiskohtaiseen erittelyyn, vaan on tyydytty verrattain karkeapiirteiseen syysuhteiden selvittelyyn.

Tutkimuksessa on taimien kasvun ja pintakasvillisuuden biomassan välillä vallinnut selvä negatiivinen vuorosuhde niin jyrsityllä kuin jyrsimättömälläkin turpeella. Kun otetaan huomioon, että pintakasvillisuuden biomassa on ollut muokkaakattomalla turpeella keskimäärin useita kertoja suurempi kuin jyrsityllä, on ilmeistä, että jyrsinnän positiivinen vaikutus taimien kasvuun on ainakin osittain seuraus pintakasvillisuuden kilpailun vähenemisestä.

Jyrsinnän merkitystä pintakasvillisuuden kilpailun vähentäjänä lisää vielä se, että metsänviljelyn yhteydessä on yleensä suoritettava lannoitus, joka saattaa rehevöittää voimakkaasti pintakasvillisuutta, kuten tämän tutkimuksen lisäksi useissa aikaisemmissakin on esitetty (vrt. luku 3212). Toisaalta näyttää siltä, että sopivalla lannoituksella, välttämällä runsaita ravinnemääriä ja erityisesti typpeä, lannoituksen aiheuttamaa pintakasvillisuuden rehevöitymistä voidaan vähentää pienentämättä sanottavasti taimien kasvua. Ø d e l i e n ja J e r v e n (1968 ja 1971) pitivät pintakasvillisuuden rehevöitymistä lannoituksen jälkeen positiivisena ilmiönä, koska tällöin ravinteiden huuhtoutuminen vähenee. Kehityksensä alkuvaiheessa oleville puun taimille on kuitenkin tärkeämpää kilpailun kuin huuhtoutumisen väheneminen. Myöskään vesistöjen kannalta huuhtoutumisella ei liene merkitystä, koska viljelylannoituksessa käytetyt ravinnemäärät ovat verrattain pieniä.

Eräs pintakasvillisuuden kilpailun muoto on kilpailu ravinteista. Tässä työssä on osoitettu, että muokkaamattomalla turpeella sitoutuu varsin huomattavia määriä eri ravinteita pintakasvillisuuden kenttäkerroksen maanpäällisiin osiin. Tutkimuksessa ei ole selvitetty pintakasvillisuuden kenttäkerroksen maanalaisten osien eikä sammalkerroksen sitomia ravinteita, mutta esim. T a m m (1954), G o o d m a n ja P e r k i n s (1959) sekä G o r e ja O l s o n (1967) mainitsevat tupasvillan (*Eriophorum vaginatum*) varastoivan runsaasti kalia ja fosforia elävinä säilyviin maanalaisiin osiinsa. S a r a s t o (1964) ilmoittaa rämevarvuston juuriston määrän olevan n. 12 m³/ha. Näin ollen pintakasvillisuuteen sitoutunut ravinteiden määrä tässä tutkimuksessa on ilmeisesti ollut huomattavasti tuloksissa esitettyä suurempi. Kun otetaan huomioon tutkimuksessa havaitut suuret erot pintakasvillisuuden määrässä muokatulla ja muokkaamattomalla turpeella, on ilmeistä, että muokkaamattomalla turpeella ravinteita on sitoutunut pintakasvillisuuteen enemmän kuin jyrsityllä. On otettava huomioon, että tutkimuksessa tarkasteltiin vain tutkimuksen aloittamishetkellä suolla olleen pintakasvillisuuden reagointia erilaisiin toimenpiteisiin. Suolla lannoituksen jälkeen esiintyvästä pintakasvillisuudesta kuitenkin huomattavan osan muodostaa siemenlevinnäinen kasvillisuus. Useat siemenlevinnäiset kasvit viihtyvät varsin hyvin jyrsityllä turvepinnalla. Tutkimuksen tuloksia käytäntöön sovellettaessa onkin muistettava, että edellä esitetystä syystä jyrsinnän vaikutus pintakasvillisuuteen tässä tutkimuksessa on todennäköisesti ollut suurempi kuin luonnonoloissa.

Jyrsinnän suotuisuus taimien kasvulle tutkimuksessa ei ole johtunut pelkästään pintakasvillisuuden kilpailun vähenemisestä. Tätä osoittaa se, että senkin jälkeen, kun pintakasvillisuuden vaikutus on laskennallisesti poistettu, on muokkauksen vaikutus useissa tapauksissa ollut merkitsevä ja jokaisessa tutkitussa tapauksessa positiivinen. Syynä voi olla ravinteiden mobilisaation nopeutuminen ja/tai turpeen fysikaalisten ominaisuuksien muuttuminen taimille edullisemmiksi.

Jyrsinnän vaikutuksesta yksittäisiin mitattuihin tunnuksiin ansaitsee lähemmän tarkastelun taimien verso/juuri -suhde, mikä yleensä oli selvästi pienempi jyrsityllä kuin jyrsimättömällä turpeella kasvaneissa taimissa. Taimien kasvatuksessa istutusta varten pidetään yleensä verrattain pientä verso/juuri -suhdetta hyvänä, koska tällöin taimet ovat kestävämpiä viljelyn jälkeisessä vedensaannin kriisivaiheessa (Mitchell 1939, Schmidt 1961, Ingestad 1963 ja Hermann 1964). Vaikka viljelypaikalla syntyneillä kylvötaimilla ei samanlaista juuriston vahingoittumisen aiheuttamaa shokkivaaraa veden saannin suhteen olekaan, on selvää, että erityisesti taimien kehityksen alkuvaiheessa, lähinnä kylvökesänä, juuriston nopea kasvu on tärkeätä. Tällöin pintaturpeen kuivuminen ei pääse vaikuttamaan taimien elossa pysymiseen. Myös tutkimuksessa havaittu jyrsinnän aiheuttama juuriston keskisyvyyden lisääntyminen vaikuttaa samansuuntaisesti. Juuriston nopea kehitys vähentänee myös roustevaurioiden mahdollisuutta viljelyä seuraavana syksynä ja keväänä.

Tutkimuksessa on todettu muokkauslannoituksen molempien osatekijöiden, jyrsinnän ja lannoitteiden sijoittamisen parantavan männyn kylvötaimien kasvua turpeella. Mielenkiintoisen lisän tarkasteluun tuo turvelajien välinen vertailu. Luontaiselta ravinteisuudeltaan LSC-turve oli paras ja S-turve huonoin. Sama järjestys näkyy myös taimien kasvussa lannoittamattomalla, muokkaamattomalla turpeella. Myös muokkauslannoitusta käytettäessä ovat taimet kasvaneet huonommin S-turpeella kuin muilla turvelajeilla. On kuitenkin ilmeistä, että suhteellisesti taimien kasvu on lisääntynyt muokkauslannoituksen johdosta selvästi eniten tällä turvelajilla. Varsin yllättävä on havainto, että CS- ja LSC-turpeen luontainen edullisuusjärjestys taimien kasvualustana on muokkauslannoituksen johdosta vaihtunut päinvastaiseksi. Näyttää siis siltä, että muokkauslannoituksella voidaan ainakin aluksi pienentää turpeen luontaisten ominaisuuksien vaikutusta kylvötaimien kasvuun.

Koska tutkimus on toteutettu kasvihuoneessa, on selvää, että tuloksia ei sellaisenaan voida soveltaa luonnonoloihin, kuten edelläkin on ilmennyt. Tutkimus kuitenkin selventänee osaltaan muokkauslannoituksen merkitystä soiden metsänviljelyssä, varsinkin kun aikaisemmin eräissä suppeissa kenttäkokeissa saadut tulokset (vrt. Kaunisto 1972 ja 1974 a) varsin hyvin myötäilevät edellä esitettyjä.

5. TIIVISTELMÄ

Tässä työssä on tutkittu muokkauslannoituksen vaikutusta erilaisiin taimista ja pintakasvillisuuden kenttäkerroksen maanpäällisistä osista mitattuihin tunnuksiin käytettäessä erilaisia määriä typpeä, fosforia ja kalia NPK- ja PK-ravinneyhdistelminä. Ravinteet annettiin kokeessa 1 oulunsalpietarina, kalisuolana ja hienofosfaattina. Kokeessa 2 käytettiin viimemainitun asemesta superfosfaattia. Kokeessa 3 käytettiin nestemäistä super Y-lannoitetta. Tutkimus on suoritettu kolmella erilaisella turpeella: rahka-, sararahka- ja metsärahkasaraturpeella (S-t, CS-t ja LSC-t vastaavasti). Erityisesti on haluttu tarkastella muokkauslannoituksen osatekijöiden, jyrsinnän ja lannoitteiden sijoittamisen erillistä vaikutusta mitattuihin tunnuksiin.

Tutkimus on suoritettu metsäntutkimuslaitoksen Parkanon tutkimusasemalla vuosina 1971—1974. Se koostuu kolmesta samanaikaisesti kasvihuoneessa tehdystä kokeesta, jotka sisälsivät yhteensä 84 erilaista käsittelyä.

Taimista on mitattu verson pituus ja paino, juurenniskan läpimitta, juurten pituus ja paino sekä määritetty juuriston keskisyvyys, verso/juuri -painosuhde ja neulasten ravinnepitoisuus. Pintakasvillisuuden kenttäkerroksesta on punnittu kokeen aikana kerätty kuiva-aineen määrä sekä analysoitu sen sisältämät pääravinteet.

Muokkauslannoitus lisäsi taimien kasvua erittäin selvästi muokkaamattomiin, pintalannoitettuihin käsittelyihin verrattuna. Yleensä sekä jyrsintä että lannoitteiden sijoittaminen vaikuttivat taimien kehitykseen.

Jyrsintä lisäsi taimien verson ja juuriston kasvua kaikilla turvelajeilla. Taimien verso/juuri -painosuhde oli muokatulla turpeella pienempi kuin muokkamattomalla, joten jyrsintä siis paransi enemmän juuriston kuin verson kasvua. Juuriston pituudella painotettu keskisyvyys oli suurempi jyrsityssä kuin rikkomattomassa turpeessa. Edellä esitetyn perusteella taimien oletetaan selvityvän kesän kuivakausista paremmin jyrsityllä kuin jyrsimättömällä turpeella.

Pintakasvillisuus tuhoutui jyrsittäessä täysin. S-turpeen valtalaji, *Empetrum nigrum*, ei neljän kasvujakson aikana kasvattanut lainkaan maanpäällisiä versoja. CS-turpeen valtalaji, *Eriophorum vaginatum*, sitävastoin elpyi jonkin verran. Parhaiten elpyi LSC-turpeen valtalaji, *Carex lasiocarpa*,

mutta senkin biomassan tuotos koko tutkimuskaudella oli vain ¼—½ muokkaamattomissa näytteissä kasvaneesta biomassasta.

Laskennallisesti osoitettiin, että jyrsinnän suotuisuus taimien kasvulle johtui osittain pintakasvillisuuden kilpailun vähentymisestä osittain muista jyrsinnän vaikutuksista, joita tutkimuksessa ei kuitenkaan tarkemmin pyritty erittelemään.

Lannoitteiden sijoittaminen muokkauslannoituksessa lisäsi taimien kasvua vähäravinteisilla turvelajeilla (S-t ja CS-t). LSC-turpeella se lisäsi taimien kasvua kokeessa 2, mutta vähensi sitä kokeessa 1. Syyksi kasvun heikkenemiseen on oletettu vähäisempi liukoisen fosforin määrä viimemainitussa kokeessa, jossa fosforilannoitteena oli hienofosfaatti (kokeessa 2 superfosfaatti). Muutoin superfosfaatti ei näyttänyt tarjoavan mitään etua hienofosfaattiin verrattuna. Esim. superfosfaatin käytöllä pintalannoituksessa ei voitu korvata lannoitteiden sijoittamisen vaikutusta.

Lannoitteiden sijoittaminen muokkauslannoituksessa ei vaikuttanut pintakasvillisuuden kuiva-ainetuotokseen. Sen sijaan muokkaamattomalla turpeella, kokeessa 3, pintakasvillisuus rehevöityi paljon enemmän kuin muissa kokeissa. Tämän on oletettu johtuvan lannoitteen sijoittamisesta muokkaamattomaan turpeeseen tässä kokeessa, joskin lannoitteen erilaisuus muihin kokeisiin verrattuna vähentää tuloksen luotettavuutta.

Lannoitus lisäsi kaikissa tapauksissa taimien kasvua. Korkein koesarjassa käytetty lannoitemäärä (150 kg/ha vaik. ainetta) lisäsi alimpaan (75 kg/ha) verrattuna taimien kasvua merkitsevästi kuitenkin vain S-turpeella. Taimet kasvoivat kaikilla turvelajeilla paremmin NPK- kuin PK-ravinneyhdistelmää käytettäessä.

Lannoitus rehevöitti pintakasvillisuutta sitä enemmän, mitä runsaammin ravinteita annettiin, joskin vaikutus jyrsityissä näytteissä oli verrattain vähäinen S- ja CS-turpeella. Yksittäisistä ravinteista erityisesti typpi lisäsi kenttäkerroksen lajien kasvua. Muokkaamattomissa näytteissä kenttäkerroksen maanpäällisiin osiin sitoutui, turvelajin ja lannoitemäärien mukaan seuraavia määriä pääravinteita: typpeä 20—68, fosforia 2—5 ja kalia 11—56 kg/ha (luvut alkuaineina).

Tiivistetysti voidaan sanoa, että muokkauslannoituksessa jyrsintä lisäsi taimien kasvua vähentämällä pintakasvillisuuden kilpailua ja parantamalla turpeen ominaisuuksia taimien kasvualustana ja että lannoitteiden sijoittamisella voitiin jyrsinnän suotuisaa vaikutusta vielä lisätä saattamalla taimille välttämättömät ravinteet taimien juurikerrokseen.

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SUMMARY

Material and methods

This study aims at clarifying the effect of site preparation by means of a rotavator and fertilization on the growth of pine *(Pinus silvestris)* and on the above-ground herb-shrub layer of ground vegetation on some peat soils (later in the text mere ground vegetation is used). Special attention was given to fertilizer placement in connection with site preparation. The study is based on three complete factorial experiments performed in a greenhouse at Parkano Research Station of the Finnish Forest Research Istitute. The experiments involved 84 different treatments with three replicates totalling 252 experimental units. Table 1 lists the variables for the different experiments.

The peat for the experiments was extracted directly into plastic tubes as 40 cm deep »undisturbed profiles» with the method introduced by J u u s e l a et al. (1969). The diameter of the profile was 19 cm. In the soil preparation treatment, 20 cm surface peat layer was cut off from each profile and the space was filled with shredded peat from the sampling area. Shredding was performed in the field with a rotavator which thoroughly broke and mixed the top 15—20 cm layer.

The Finnish abbreviations of peat types have been used in the Tables and Figures in order to avoid the repetition of almost similar abbreviations in English. *Sphagnum fuscum* peat (S-t) was from a *Sphagnum fuscum* hummock, *Carex Sphagnum* peat (CS-t) was from an even surface of a small-sedge bog and woody *Sphagnum-Carex* peat (LSC-t) was from a treeless, level surface of a sedge pine swamp. The properties of the different peat types are shown in Tables 2 and 3.

The fertilizers used in these experiments were as follows.

Experiment 1: Oulu saltpetre (26-0-0, percentages of N, P_2O_5, and K_2O respectively), ground mineral phosphate (0-33-0), and muriate of potash (0-0-60).

Experiment 2: as above, except superphosphate (0-19-0) replaced ground mineral phosphate.

Experiment 3: liquid NPK-fertilizer (5-7-6), which, in addition, contains the following micronutrients: B, Mo, Fe, Mn, Ca, Mg, Cu, Zn, and Co. The application rates differed from those in Experiment 1 and 2 being in Experiment 3 as follows: Level 1: 54, 75, and 65 kg/ha; level 2: 108, 150, and 130 kg/ha as N, P_2O_5, and K_2O respectively (Table 1). To simplify the illustrations, the levels are listed in Tables and Figures as 75 and 150 kg/ha, as in Experiments 1 and 2, for all nutrients.

In Experiments 1 and 2 fertilizer placement was performed by mixing fertilizers evenly in the shredded 20 cm peat layer. In Experiment 3 fertilizer was injected by means of a hypodermic needle evenly in the 20 cm surface peat layer.

The ground water was kept at a constant 30 cm level from the peat surface by means of the lysimeter system used by J u u s e l a et al. (1969) and K a u n i s t o (1971). In additon, the peat surface was watered during the study period. Seedlings grew for four growing periods. The average weekly peat and air temperature during the study is shown in Figure 1.

During the study the herb-shrub layer of ground vegetation was collected, dried in 105°C and weighed. At the end of the study, the last cut of vegetation, which also included the vegetation of the previous summer, was analysed for N, P, and K. Height, dry weight and base diameter of the pine seedlings, as well as the root dry weight and length were measured. The needles were analysed for N, P, and K.

Results

Rotavation greatly improved the shoot growth (Table 4, Figure 2, App. 1) as well as the root growth (Table 8, Figure 3, App. 2) of seedlings. The shoot/root ratio was lower on rotavated than undisturbed peat (Table 11, Figures 4 and 5, App. 3). Thus rotavation favoured more root than shoot growth of seedlings. On the average, roots penetrated deeper in rotavated than undisturbed peat.

The favourable effect of rotavation on seedling growth appeared to be partly a result of reducing the ground vegetation and consequently the competition for nutrients, space, and light (Figure 10, App. 5). In conditions with similar ground vegetation, rotavation still improved seedling growth (Figure 11, Table 16).

Fertilizer placement improved both shoot (Table 4, Figure 2, App. 1) and root (Table 8, Figure 3, App. 2) growth of seedlings on S-peat and CS-peat. On the other hand fertilizer placement improved seedling growth on LSC-peat in Experiment 2 but lowered it in Experiment 1. This seems to indicate that seedlings suffered from the shortage of soluble phosphorus in experiment 1. Also the chemical analyses showed that seedlings and ground vegetation used less phosphorus in Experiment 1 than 2 (Tables 5 and 15). The favourable effect of fertilizer placement on seedling growth was usually more distinct the poorer the peat.

Seedlings grew better on NPK than PK fertilized peat, although the difference was small. Seedlings responded best to the heaviest fertilizer application (150 kg/ha as N, P_2O_5 and K_2O), although at this application level growth was only slightly better than at the lower level (75 kg/ha) (Tables 6 and 9, App. 1 and 2). In the unfertilized treatments seedlings grew best on woody *Sphagnum-Carex* peat, whereas in fertilized treatments *Carex-Sphagnum* peat (CS-t) was the best substratum in most cases (Tables 7 and 10).

Rotavation destroyed the ground vegetation completely. During four growing periods very little vegetation appeared on shredded *Sphagnum fuscum* (S-t) peat (Tables 13, App. 4, Figure 6). The main species of herb-shrub layer before soil preparation, *Empetrum nigrum*, disappeared completely. On *Carex-Sphagnum* (CS-t) peat the main species, *Eriophorum vaginatum*, revived. *Carex lasiocarpa*, the main species on woody *Sphagnum-Carex* (LSC-t) peat revived quite vigorously. Even so, the biomass production during four growing periods was on shredded woody *Sphagnum-Carex* peat only $\frac{1}{4}$—$\frac{1}{2}$ from that on undisturbed peat. On shredded peat, tree seedlings and on undisturbed peat ground vegetation produced the bulk of the dry matter (Figure 7). Fertilizer placement had no special effect on ground vegetation on shredded peat (Table 13, Figure 6, App. 4).

The fertilizer application accelerated the growth of ground vegetation (Table 14, Figure 8). This was especially true on undisturbed peat using NPK combination. Ground vegetation on undisturbed peat responded more pronouncedly to fertilization in Experiment 3 than in the other experiments. This may be due to the fact that nutrients were worked into (by injection) the undisturbed peat in Experiment 3, whereas in the other experiments they were spread on the peat surface.

In undisturbed peat vast amounts of nutrients were fixed in the ground vegetation (Figure 9).

LIITETAULUKOT

Liitetaulukko 1. Taimien pituudesta, juurenniskan läpimitasta ja kuivapainosta laskettujen varianssianalyysien F-arvot ja merkitsevyydet. Lannoitetut koejäsenet.

Appendix 1. F ratios and significances in the analyses of variance concerning the height, base diameter and dry weight of the seedlings. Fertilized testmembers.

Muuttuja — *Variable*	Koe 1 — *Experiment 1* Turvelaji — *Peat type*			Koe 2 *Exper. 2*	Koe 3 *Exper. 3*
	S-t	CS-t	LSC-t		
	Pituus, cm — *Height, cm.*				
A. Lannoitusmen. ja muokkaus — *Site prep. and fert. meth.*	42.85***	18.83***	16.63***	16.88***	39.81***
B. Ravinneyhdistelmä — *Nutrient combination*	6.57*	17.15***	4.50	—	—
C. Ravinnemäärä — *Amount of nutrients*	5.75*	0.60	1.41	4.06	2.68
D. Turvelaji — *Peat type*	—	—	—	40.95***	24.28***
A × B	0.42	0.68	0.72	—	—
A × C	2.26	3.17	0.18	0.98	0.35
A × D	—	—	—	1.11	3.52*
B × C	3.46	0.41	2.16	—	—
B × D	—	—	—	—	—
C × D	—	—	—	0.46	0.04
	Juurenniskan läpimitta, mm — *Base diameter, mm.*				
A	74.11***	13.42***	13.72***	13.65***	50.69***
B	8.73**	5.33*	9.44**	—	—
C	4.08	1.31	0.02	3.59	2.68
D	—	—	—	28.65***	18.15***
A × B	0.41	1.24	0.09	—	—
A × C	1.00	0.50	0.08	0.46	3.09
A × D	—	—	—	3.70*	4.37*
B × C	2.10	0.03	0.05	—	—
B × D	—	—	—	—	—
C × D	—	—	—	1.89	1.09
	Kuivapaino, g — *Dry weight, grm.*				
A	27.60***	13.01***	15.94***	7.97**	23.80***
B	2.76	7.31*	8.91**	—	—
C	4.33*	0.86	0.17	1.86	0.98
D	—	—	—	14.94***	9.03**
A × B	0.14	2.26	2.75	—	—
A × C	1.74	1.99	1.06	0.12	1.37
A × D	—	—	—	1.19	0.66
B × C	0.06	0.31	0.84	—	—
B × D	—	—	—	—	—
C × D	—	—	—	0.17	0.20

Liitetaulukko 2. Taimien juurten kuivapainosta, pituudesta ja pituudella painotetusta keskisyvyydestä laskettujen varianssianalyysien F-arvot ja merkitsevyydet. Lannoitetut koejäsenet.

Appendix 2. The F ratios and significances in the analyses of variance concerning the dry weight, length, and average depth of roots weighted by length. Fertilized testmembers.

Muuttuja — *Variable*	Koe 1 — *Experiment 1* Turvelaji — *Peat type*			Koe 3 *Exper. 3*
	S-t	CS-t	LSC-t	
	Kuivapaino, g — *Dry weight, grm.*			
A. Lannoitusmen. ja muokkaus — *Site prep. and fert. meth.*	33.58***	15.84***	16.54***	44.60***
B. Ravinneyhdistelmä — *Nutrient combination*	8.80**	2.63	6.05*	—
C. Ravinnemäärä — *Amount of nutrients*	2.22	1.32	0.90	0.01
D. Turvelaji — *Peat type*	—	—	—	2.38
A × B	0.67	0.75	0.94	—
A × C	0.68	0.94	2.23	4.32
A × D	—	—	—	1.59
B × C	0.96	1.26	0.24	—
B × D	—	—	—	—
C × D	—	—	—	2.82
	Pituus, cm — *Length, cm.*			
A	13.05***	14.35***	5.37*	—
B	4.67*	1.06	0.03	—
C	0.67	1.69	0.15	—
D	—	—	—	—
A × B	0.77	0.31	0.15	—
A × C	0.08	0.19	2.05	—
A × D	—	—	—	—
B × C	0.25	7.69	0.31	—
B × D	—	—	—	—
C × D	—	—	—	—
	Keskisyvyys, cm — *Average depth, cm.*			
A	47.14***	4.40*	0.71	—
B	1.14	0.57	3.87	—
C	0.01	0.43	0.06	—
D	—	—	—	—
A × B	0.43	0.51	0.85	—
A × C	1.98	0.11	0.51	—
A × D	—	—	—	—
B × C	5.84*	0.73	0.89	—
B × D	—	—	—	—
C × D	—	—	—	—

Liitetaulukko 3. Taimien verso/juuri -suhteesta laskettujen varianssianalyysien F-arvot ja merkitsevyydet. Lannoitetut koejäsenet.

Appendix 3. The F ratios and significances concerning the shoot/root ratio of seedlings. Fertilized testmembers.

Muuttuja — *Variable*	Koe 1 — *Experiment 1* Turvelaji — *Peat type*			Koe 3 *Exper. 3*
	S-t	CS-t	LSC-t	
A. Lannoitusmen. ja muokkaus — *Site prep. and fert. meth.*	3.97*	4.64*	4.15*	23.25***
B. Ravinneyhdistelmä — *Nutrient combination*	5.37*	0.39	0.18	—
C. Ravinnemäärä — *Amount of nutrients*	1.05	0.00	0.07	13.40**
D. Turvelaji — *Peat type*	—	—	—	13.25***
A × B	0.75	0.92	0.90	—
A × C	0.05	0.09	0.25	25.44***
A × D	—	—	—	6.62*
B × C	0.04	1.32	0.12	—
B × D	—	—	—	—
C × D	—	—	—	2.69

Liitetaulukko 4. Pintakasvillisuuden kenttäkerroksen kuiva-ainetuotoksesta lasketttujen varianssianalyysien F-arvot ja merkitsevyydet. Lannoitetut koejäsenet.

Appendix 4. The F ratios and significances in the analyses of variance concerning the above-ground dry matter production of the ground vegetation. Fertilized testmembers.

Muuttuja — *Variable*	Koe 1 — *Experiment 1* Turvelaji — *Peat type*			Koe 2 *Exper. 2*	Koe 3 *Exper. 3*
	S-t	CS-t	LSC-t		
A. Lannoitusmen. ja muokkaus — *Site prep. and fert. meth.*	94.75***	33.72***	25.00***	28.72***	68.56***
B. Ravinneyhdistelmä — *Nutrient combination*	7.91**	10.25**	0.92	—	—
C. Ravinnemäärä — *Amount of nutrients*	7.29*	5.58*	1.67	0.08	3.08
D. Turvelaji — *Peat type*	—	—	—	12.64***	2.39
A × B	6.90**	10.79***	0.15	—	—
A × C	5.48*	6.20**	2.33	0.11	0.96
A × D	—	—	—	1.26	0.97
B × C	0.01	8.49**	0.43	—	—
B × D	—	—	—	—	—
C × D	—	—	—	5.49**	1.31

Liitetaulukko 5. Taimien pituuden, painon, juurenniskan läpimitan ja verso/juuri -suhteen (y) suoraviivainen riippuvuus pintakasvillisuuden määrästä koeastiassa (x).

Appendix 5. The Linear regression between the dry weight of ground vegetation/pot (x) and the height, weight, base diameter, and shoot/root ratio (y).

Muokkaus *Preparation*	Koe n:o *Exp. No*	Yhtälö *Equation*	Regression F-suhde *F for regression*
		Pituus — *Height*	
Muokkaamaton — *Unprepared*	1	$y = -0.156 + 13.71$	2.71
» — »	2	$y = -0.022 + 17.71$	0.15
» — »	3	$y = -0.050 + 15.01$	0.24
Muokattu — *Prepared*	1	$y = -0.403 + 19.55$	10.66**
» — »	2	$y = -0.207 + 23.85$	0.85
» — »	3	$y = -0.567 + 25.03$	6.44*
		Kuivapaino — *Dry weight*	
Muokkaamaton — *Unprepared*	1	$y = -0.181x + 7.19$	5.86*
» — »	2	$y = -0.220x + 13.29$	0.89
» — »	3	$y = -0.113x + 8.40$	1.94
Muokattu — *Prepared*	1	$y = -0.943x + 13.67$	32.81***
» — »	2	$y = -0.431x + 17.13$	2.05
» — »	3	$y = -0.803x + 17.90$	6.75*
		Läpimitta — *Base diameter*	
Muokkaamaton — *Unprepared*	1	$y = -0.0426x + 2.39$	10.90**
» — »	2	$y = -0.0293x + 3.02$	1.14
» — »	3	$y = -0.0297x + 2.71$	6.87*
Muokattu — *Prepared*	1	$y = -0.0900x + 3.06$	35.07***
» — »	2	$y = -0.0350x + 3.52$	1.71
» — »	3	$y = -0.083x + 3.68$	8.43*
		Verso/juuri — *Shoot/root*	
Muokkaamaton — *Unprepared*	1	$y = 0.049x + 4.97$	0.68
Muokattu — *Prepared*	1	$y = 0.058x + 4.55$	1.24

TYPPILANNOITUKSEN VAIKUTUKSESTA MÄNNYN, KUUSEN JA KOIVUN PUUAINEEN TIHEYTEEN

OLAVI SAIKKU

THE EFFECT OF NITROGEN FERTILIZATION ON THE BASIC DENSITY OF SCOTS PINE (Pinus silvestris), NORWAY SPRUCE (Picea abies) AND COMMON BIRCH (Betula verrucosa)

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ALKUSANAT

Metsänlannoituksen tarkoituksena on lisätä puun kasvua sekä metsän tuottoa. Koska lannoittamalla saavutetaan suuriakin puun tuotoksen lisäyksiä, katsottiin tästä mahdollisesti aiheutuvan muutoksia puun rakenteeseen, etenkin puuaineen tiheyteen, joka osoittaa puuaineen määrän painona tilavuusyksikköä kohden.

Tutkimusta varten saatiin käyttöön Metsäntutkimuslaitoksen maantutkimusosaston keräämä ja mittaama laaja aineisto, josta metsäteknologian tutkimusosasto suoritti tarvittavat laskentatyöt. Aineiston laskentatyöt on suorittanut rouva Kaarina Koskinen. Ylioppilas Hannu Peltonen ja rouva Aune Rytkönen kirjoittivat puhtaaksi käsikirjoituksen. Kuvat piirsi rouva Leena Muronranta.

Käsikirjoituksen tarkastivat professorit Veijo Heiskanen ja Pentti Hakkila. Lisäksi olen saanut arvokkaita neuvoja professori Pentti Virolta sekä maat. metsät. lisensiaateilta Erkki Lippaalta ja Olli Usvaaralta. Kaikille edellämainituille, ja erityisesti maantutkimusosastolle, parhaimmat kiitokseni.

Helsingissä, huhtikuussa 1975

Olavi Saikku

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1. JOHDANTO

Puuraaka-aineen riittävyyden varmistamiseksi sekä puun tuoton kohottamiseksi on metsiämme ryhdytty voimallisesti lannoittamaan. Suomessa on viime vuosina lannoitettu noin 200 000 ha vuodessa. Lannoituksella saavutettu puuston kuutiokasvun lisäys on ollut keskimäärin noin 30 prosenttia (Operaatio metsänlannoitus 1969). Jos lannoituksen avulla saavutetuksi lisäkasvuksi lasketaan 1.3 k—m^3/ha ja lannoitusajan kestoksi viisi vuotta, on kasvun lisäys koko maassa ollut vuosittain yli 1.25 miljoonaa k—m^3. Kun kyseessä on näin huomattava kasvun nopeutuminen, voidaan siitä olettaa aiheutuvan myös muutoksia puun laadullisiin ominaisuuksiin, etenkin puuaineen tiheyteen, joka osoittaa puuaineen määrän painona tilavuusyksikköä kohden.

Puuaineen tiheys on virheettömän puuaineen laadun tunnus, jolla voidaan kuvata puun soveltuvuutta tiettyyn käyttötarkoitukseen. Sahateollisuudessa puuaineen tiheys antaa kuvan puun mekaanisista ominaisuuksista. Puuaineen tiheydellä ja puun lujuusominaisuuksilla on voimakas positiivinen korrelaatio (Siimes ja Liiri 1952). Suomalaisen mäntypuun suuret tiheyserot on huomioitu esimerkiksi rakennesahatavaran lujuusluokitteluohjeissa. Puutavaran hygroskooppisesta eli vettä imevästä rakenteesta johtuen paisuminen ja kutistuminen on suurempaa tiheässä puussa. Massateollisuudessa on kuitupuun tiheydellä oleellinen merkitys massan saantoon sekä paperin laatuun. Raskaassa puussa on paksuseinäisten mutta läpimitaltaan pienempien kesäpuusolujen osuus suurempi sekä vastaavasti puun kulutus massaa keitettäessä pienempi kuin kevyessä puussa. Paperin laatuun vaikuttaa korkea tiheys opasiteettia ja repäisylujuutta parantavasti. Painopaperilaaduissa, joissa tarvitaan tasaista paperin pintaa ja korkeata puhkaisu- ja vetolujuutta, on runsaasti kevätpuuta sisältävä alhaisen tiheyden omaava puu parasta.

Lannoituksen vaikutuksesta puuaineen tiheyteen on tehty lukuisia tutkimuksia, joista vuoden 1974 alkupuolella on ilmestynyt laaja kirjallisuuskatsaus (*Annoted bibliography* . . .). Pääasiassa havupuilla tehtyjen tutkimusten perusteella tiheyden on todettu laskevan, mikäli kasvun lisäys on ollut selvä. Pieniä lannoituksesta aiheutuvia tiheyden laskuja (1—3 %) ovat Pinus-suvussa havainneet mm. Posey (1966), Hagner (1967),

Klem (1969), Nicholls (1971) sekä Smith ja Wahlgren (1971). Tavallisen männyn (Pinus silvestris) hakkuukypsyyttä lähentelevässä puustossa on todettu 1—4 %:n puuaineen tiheyden laskua kasvun lisäyksen suuruudesta riippuen (Saikku 1974). Ruotsissa on männylle saatu noin 5 %:n lasku tiheydessä, mutta käytettäessä erittäin runsaasti lannoitteita (650 kg typpeä/ha) on tiheyden aleneminen ollut kymmenisen prosenttia (Ericson ym. 1971). Myös tiheyden ennallaan pysymiseen on viitattu (Lönnberg ja Palenius 1970). Lehtipuista on olemassa vain niukasti tutkimustuloksia, mutta yleisenä piirteenä on hajaputkiloisilla lehtipuilla, esimerkiksi koivulla, todettu lannoituksen aiheuttama puuaineen tiheyden lievä aleneminen. Kehäputkiloisilla lajeilla, esimerkiksi tammella, on puolestaan havaittu tiheyden nousua lannoituksen aiheuttaman kasvun lisäyksen seurauksena.

Käsillä olevan tutkimuksen tarkoituksena on selvittää lannoituksen vaikutusta männyn, kuusen sekä koivun puuaineen tiheyteen. Vertailuja on pyritty tekemään eri ikäluokkien, metsätyyppien ja maantieteellisten alueitten välillä. Lisäksi on laskettu erikseen lannoituksella aikaansaadun kuiva-ainetuotoksen määrä huomioimalla puuaineen tiheydessä tapahtuneet muutokset.

2. AINEISTO JA MENETELMÄ

21. Aineisto

Aineisto on kerätty ja mitattu Metsäntutkimuslaitoksen maantutkimusosaston toimesta kyseisen osaston pääasiassa vuosina 1960—1962 perustamilta koealoilta. Melkein kaikki koealat ovat faktorikokeita, joissa on käytetty kalsiumin, typen, fosforin ja kalin eri yhdistelmiä. Yleisin faktorikoe on ollut 2^3, jossa tutkittavana ovat olleet typpi, fosfori- ja kalkki. Tällöin on koealalla ollut yhteensä 8 lannoitusruutua vertailuruudut mukaanluettuina. Faktorikokeiden lisäksi on ollut muutamia koealoja, joissa on käytetty pelkästään typpilannoitteita eri suuruisina määrinä.

Lannoitteita on käytetty hehtaaria kohden seuraavasti: ammoniumsulfaattia 400 tai 200 kg, kotkafosfaattia 400 tai hienofosfaattia 200 kg, kalisuolaa 200 kg ja kalkkikivijauhetta 2 000 kg. Muutamilla koealoilla on ammoniumsulfaatin tilalla käytetty ureaa 200—400 kg. Lisälannoituksessa, mikäli sellainen on suoritettu, on aina käytetty ureaa.

Taulukosta 1 selviää koealasarjojen lukumäärä sekä puulajeittain että metsätyypeittäin. Mäntyvaltaisten koealasarjojen määrä oli suurin eli 31 kpl. Koivu ei muodostanut puhtaita koivuvaltaisia koealoja vaan se esiintyi sekapuulajina noin 40 % suhteessa. Sarjassa oli keskimäärin 8—10 ruutua. Niistä noin puolet sisälsivät ravinteita, joilla ei ollut vaikutusta kasvuun (typettömät ruudut) tai olivat kontrolliruutuja, joilla ei ollut suoritettu lannoitusta.

Taulukko 1. Koealasarjojen ja ruutujen lukumäärä pääpuulajeittain.
Table 1. The number of sample plot series and parcels

Pääpuulaji *Main tree species*	Metsätyyppi — *Site type* OMT	MT *)	VT *)	CT	Yhteensä *Total*	Ruutuja keskimäärin/sarja *Parcels/series* Ilman typpeä *Without nitrogen*	Typpeä saaneet *With nitrogen*
	Koealasarjoja, kpl *Sample plot series*						
Mänty — *Pine*	2	11	13	5	31	5	5
Kuusi — *Spruce*	5	6	3	—	14	4	4
Koivu **) — *Birch*	—	3	2	—	5	4	4
Yhteensä — *Total*	7	20	18	5	50		

*) Vastaavat Pohjois-Suomen metsätyypit mukaanluettuina. — *Corresponding site types of North-Finland included.*

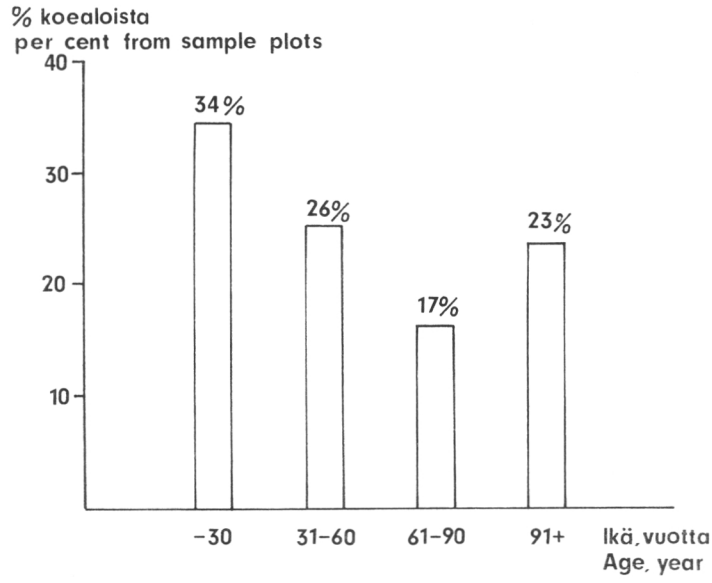
**) Koivu sekapuulajina, osuus noin 40 %. — *Birch as mixed tree species, proportion about 40 per cent.*

Koealaruutujen koot olivat joko 0.09 ha (30 × 30 metriä) tai 0.16 ha (40 × 40 metriä). Lannoitusruutujen välille oli jätetty vähintään 5 metrin vyöhyke, jolla oli suoritettu ruutuja vastaava lannoitus.

Aineiston mittaus on suoritettu keskimäärin 5 vuotta lannoitusajankohdan jälkeen. Mikäli mittaus on suoritettu kyseistä aikaväliä myöhemmin, on tämä huomioitu tuloksia analysoitaessa.

Koealojen sijainti selviää tutkimuksen tuloksia esittelevästä osasta (kuvat 2, 3 ja 4). Sen mukaan pääosa koealoista keskittyy Etelä- ja Länsi-Suomeen.

Koealojen ikäluokkajakautuma on melko tasainen (kuva 1). Nuorten, iältään alle 60-vuotiaitten koealojen osuus on 60 %. Lannoitussuosituksissa tärkeimmälle sijalle asetettujen hakkuukypsien metsien edullisin ikäluokka (61—90 vuotta) käsittää 17 % kaikista koealoista. Alueittaisesti ovat eri ikäluokat tasaisesti jakautuneet.



Kuva 1. Koealasarjojen ikäluokkajakautuma.
Figure 1. The age class deviation of the sample plots.

22. Menetelmä

Jokaisesta rungosta mitattiin puun pituus, rinnankorkeusläpimitta ja kapeneminen, joitten perusteella määritettiin rungon kuutiomäärä. Kultakin ruudulta määritettiin runkoluku ja kuutiomäärä hehtaaria kohti.

Koealojen jokaisesta ruudusta kerättiin keskimäärin 18:sta (relaskoopilla) valitusta rungosta kairanlastunäytteet rinnankorkeudelta. Lastut katkaistiin kahteen osaan puuaineen tiheysmäärityksiä varten siten että toinen pala edusti lannoitusta edeltänyttä ja toinen pala lannoituksen jälkeistä 5-vuotiskautta. Tiheyden määritys suoritettiin elohopeamittauksella, jossa kappaleen paino sekä tilavuus määritettiin absoluuttisen kuivana. Näin saatua tiheyttä kutsutaan kuivatiheydeksi.

Tiheyden lisäksi mitattiin luston paksuus sekä laskettiin kuutiokasvu, pintakasvu ja pituuskasvu ennen ja jälkeen lannoituksen. Kuutiokasvuprosentit saatiin kertomalla kuorettomat pintakasvuprosentit kertoimilla jotka määritettiin Ivessalon Pystypuiden kuutiomis- ja kasvunlaskentataulukoissa ilmoitettuja keskimääräisiä muotokorkeuden kasvuprosentteja apuna käyttäen.

Maantutkimusosaston suorittamien laskelmien mukaan näytti useimmilla koealoilla ainoastaan typellä olevan merkittävä vaikutus lisäkasvuun. Kun lisäksi tarkasteluajankohta oli 5 vuotta lannoituksen jälkeen, jona aikana viimeaikaisissa tutkimuksissa esille tullut fosforin merkitys ei vielä ole todennäköisesti päässyt vaikuttamaan (esim. Viro 1972), jaettiin koko aineisto ravinteena typpeä saaneitten ja muita ravinteita saaneitten kesken, edellisten edustaessa lannoitettuja ja jälkimmäisten lannoittamattomia runkoja.

Laskettaessa lannoituksen vaikutusta tiheyteen käytettiin tiheyden prosentuaalista muutosta ennen ja jälkeen lannoituksen, jolloin kyseisen aineiston kuivatiheydestä johtuva numeerinen ero normaalisti käytössä olevaan kuiva-tuoretiheyteen (paino absoluuttisen kuivana ja tilavuus tuoreena) eliminoitui.

Tulokset on esitetty kaikilta koealoilta puulajeittain, metsätyypeittäin sekä ikäluokittain. Koealakohtaisella tarkastelulla on pyritty antamaan kuva lannoituksella saavutetun kasvun lisäyksen aiheuttamasta puuaineen tiheyden muutoksesta. Muutosten merkitsevyys on testattu t-testillä käyttämällä havaintoarvoina jokaisen lannoitusruudun keskimääräistä tiheysarvoa. Testaus on suoritettu ainoastaan metsätyypeittäin havaintojen vähyyden vuoksi.

3. TULOKSET

31. Tiheyden vaihtelu ikäluokittain

Iän merkityksen selville saamiseksi jaettiin koko aineisto eri ikäluokkiin. Taulukon 2 mukaan on tiheyden lasku ollut lannoitettaessa männyllä kaikissa ikäluokissa saman suuruista. Pieniä eroja on kuitenkin havaittavissa lannoitetuista ja vertailuruuduista peräisin olevien aineistojen välillä. Tämä johtuu osittain lannoitettujen puustojen kasvun lisäyksen suuruudesta. Nuorissa puissa, joissa kuutiokasvu on normaalisti voimakasta on kasvun lisäys lannoittamattomiin verrattuna jäänyt alle 30 %:n. Tällöin on tiheys vastaavasti laskenut 2.3 %. Voimakkain, 3 %, on tiheyden lasku ollut tukkipuun kokoisessa metsikössä, jossa vastaavasti myös kasvun lisäys on ollut voimakasta. Keskimäärin on tiheyden lasku ollut männyllä 2.5 %.

Taulukko 2. Ikäluokittaiset tulokset männyllä ja kuusella.
Table 2. The results of pine and spruce by age class.

Ikäluokka *Age class*	Kuoreton kuutiomäärä lannoitushetkellä keskim. *Cubic volume without bark at the time of fertilization*, m³/ha	Lannoitettujen ja lannoittamattomien välinen kasvun ero *The difference in volume growth between unfertilized and fertilized parcels* m³/ha	Kasvun lisäys lannoittamattomaan verrattuna *The additional growth compared with unfertilized* %	Tiheyden muutos lannoittamattomaan verrattuna *The change in density compared with unfertilized* %
		Mänty — *Pine*		
10—30	74	1.3	26	—2.3
35—60	118	1.5	29	—2.3
65—90	136	1.0	35	—3.0
95+	131	0.8	33	—2.5
Keskim. — *Average*	115	1.2	31	—2.5***
		Kuusi — *Spruce*		
10—30	57	1.0	17	—2.1
35—60	65	0.3	15	—5.1
65—90	176	1.4	28	—3.9
95+	145	1.3	42	—5.1
Keskim. — *Average*	111	1.0	26	—4.1***

Taulukon 2 mukaan on kuusen tiheyden aleneminen ollut selvästi männyn tiheyden muutoksia voimakkaampaa. Koska koealoja on ollut vähän, esiintyy eri ikäluokkien välillä suuria vaihteluja tuloksissa. Nuorimmissa ikäluokissa (10—20 v) on tiheyen lasku, kuten kasvun lisäyskin, ollut vähäistä. Varttuneemmissa, jo tukkipuuastetta olevissa metsiköissä on tiheys laskenut 4—5 %, kun kasvun lisäys on ollut 35 %:n luokkaa.

32. Tiheyden vaihtelu metsätyypeittäin

321. Mänty

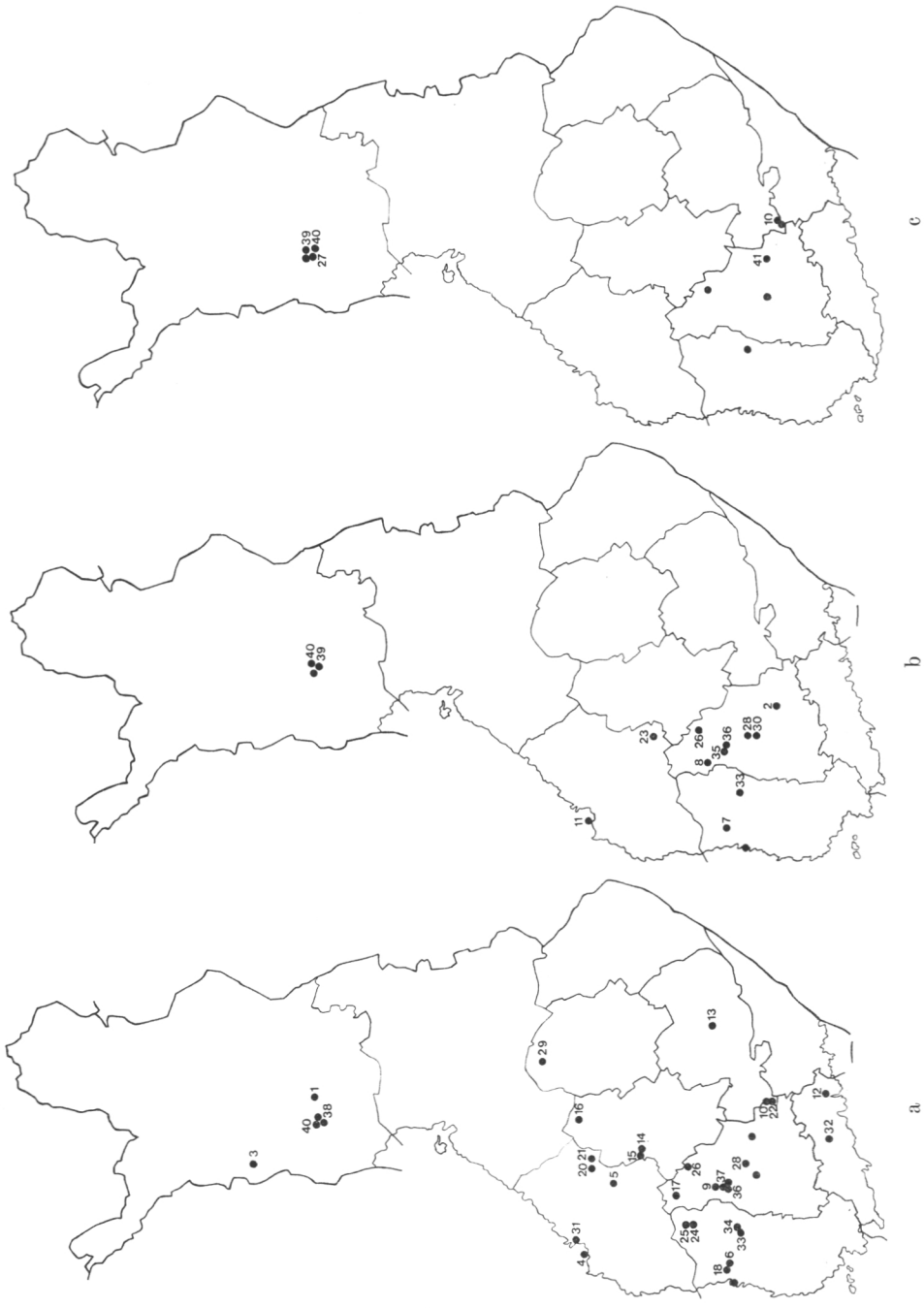
Mäntyä koskevat koealakohtaiset tulokset ilmenevät taulukosta 3. Koealasarjat on ryhmitelty taulukkoon metsätyypeittäin sekä iän mukaan. Koealojen sijainti selviää kuvasta 2 jossa koealojen numerot vastaavat taulukon koealojen numeroita. Seuraavassa tarkastellaan tuloksia metsätyypeittäin.

— OMT. Koealat ovat olleet puustoltaan nuoria ja vain Sahalahdessa on mitattu lannoituksen aiheuttama kasvun lisäys, 34 % lannoittamattomaan verrattuna, jolloin puuaineen tiheyden lasku on ollut 0.7 %. Maksamaan koealalla saatu 0.5 %:n tiheyden lasku on puuston nuoresta iästä johtuen hieman tulkinnan varainen. Tällöin näet on mahdollista että alhaisen tiheyden omaavalla nuorpuulla on vielä vaikutusta koealan tuloksiin.

— MT. Mustikkatyypillä on koealojen ikäjakautuma tasainen. Lannoituksella aikaansaatu todellinen ja suhteellinen kasvun lisäys on nuoressa puustossa suurempaa kuin vanhemmassa puustossa. Tiheyden aleneminen on ollut kauttaaltaan 1—3 %:n luokkaa. Alajärven koealalla saatuun suurehkoon tiheyden alenemiseen on puuston nuoresta iästä johtuen suhtauduttava varauksella. MT:llä on keskimääräinen tiheyden aleneminen ollut 2.3 % (ilman Alajärven koealaa 1.9 %) kasvun lisäyksen ollessa 22 %.

— VT. Kasvun lisäys on ollut tällä metsätyypillä voimakas. Tiheyden lasku vaihtelee 2—4 %:n välillä. Voimakas tiheyden aleneminen (6.2 %) on havaittavissa Parkanon koealalla n:o 25 ja vastaavasti vähäinen aleneminen (0.4 %) Juvan koealalla. Keskimäärin on tiheys alentunut 3.2 % kasvun prosentuaalisen lisäyksen ollessa 36.

— EVT. Tähän metsätyyppiin on sisällytetty myös koeala 3:n EMT. Tiheyden aleneminen on ollut 3—5 %, lukuunottamatta koealaa n:o 40, jossa tiheys on hieman lisääntynyt. Kyseisellä koealalla on luston paksuus ollut keskimäärin erittäin pieni (0.2 mm) ennen lannoitusta. Lannoituksen vaikutuksesta on luston paksuus suurentunut tällä koealalla



Kuva 2.

a) Koealasarjojen sijainti männyllä.
a) The location of the sample plots with pine.

b) Koealasarjojen sijainti kuusella.
b) The location of the sample plots with spruce.

c) Koealasarjojen sijainti koivulla.
c) The location of the sample plots with birch.

Taulukko 3. Keskimääräiset tulokset männyllä metsätyypeittäin eri koealasarjoilla.
Table 3. The average results for pine in site types at different sample plots.

Alue *Area*	N:o *No.*	Metsätyyppi *Site type*	Puuston ikä, v. *Age of stand, years*	Kuoreton kuutiomäärä lannoitushetkellä *Cubic volume without bark at the time of fertilization* m³/ha	Lannoitettujen ja lannoittamattomien ruutujen välinen kuutiokasvun ero *The difference in volume growth between fertilized and unfertilized parcels* m³/ha/v	Kasvun lisäys lannoittamattomaan verrattuna *The additional growth compared with unfertilized* %	Tiheyden muutos lannoittamattomaan verrattuna *The change in density compared with unfertilized* %
Sahalahti ...	28	OMT	28	109	2.2	34	—0.7
Maksamaa ..	4	OMT	10	40	—	—	—0.5
Keskimäärin — *Average*			—	—	—	—	—0.6
Kaltila	26	MT	100	236	0.6	14	—2.5
Mouhijärvi ..	33	MT	90	187	0.5	18	—3.5
Teisko	36	MT	70	164	0.7	28	—0.7
Järvenpää ..	32	MT	50	220	1.8	20	—3.2
Heinola	10	MT	45	150	1.8	26	—1.2
Vieremä	29	MT	30	107	1.9	26	—3.5
Pylkönmäki..	14	MT	25	87	1.4	27	—0.4
Pylkönmäki..	15	MT	25	98	1.5	28	—0.4
Alajärvi	5	MT	15	26	0.5	13	—4.9
Keskimäärin — *Average*			—	—	1.2	22	—2.3***
Perho	20	VT	130	143	1.0	39	—2.1
Parkano	24	VT	110	86	0.6	35	—3.5
Pihtipudas...	16	VT	90	134	1.4	50	—3.3
Noormarkku	6	VT	90	153	1.3	45	—3.8
Parkano	25	VT	70	117	0.7	24	—6.2
Heinola	22	VT	60	143	2.6	48	—3.0
Juva	13	VT	35	55	1.1	31	—0.4
Noormarkku	18	VT	30	65	1.5	39	—4.9
Virrat	17	VT	25	25	0.4	16	—3.3
Munsala	31	VT	10	—	—	—	—1.2
Keskimäärin — *Average*			—	—	1.2	36	—3.2***
Rovaniemi ..	1	EVT	125	80	0.7	39	—2.9
Rovaniemi ..	40	EVT	100	85	—	—	+0.1
Rovaniemi ..	3	EMT	50	71	1.6	32	—5.0
Rovaniemi ..	38	EVT	40	110	1.4	22	—4.6
Keskimäärin — *Average*			—	—	1.2	31	—3.1**
Teisko	9	CT	100	112	0.3	12	—1.1
Perho	21	CT	100	129	1.7	61	—3.2
Mouhijärvi ..	34	CT	65	60	1.2	46	—1.9
Liljendahl ...	12	CT	60	159	0.8	18	—2.9
Teisko	37	CT	50	84	0.9	32	+1.8
Keskimäärin — *Average*			—	—	1.0	34	—1.5*

*** = muutos tilastollisesti erittäin merkitsevä. — — *change statistically very significant*
** = muutos tilastollisesti merkitsevä. — *change statistically significant*
* = muutos tilastollisesti vähäinen. — *change statistically of minor significance*

huomattavasti (keskimäärin 0.6 mm). Tiheyden nousua voidaan osittain selittää siten, että aikaisemmin alhaisen tiheyden ja erittäin pienen luston paksuuden omaava ns. »nälkäpuu» on riittävän ravinteiden saannin johdosta muuttunut tiheydeltään »normaaliksi». Kaikki koealat huomioon ottaen on tiheys laskenut 3.1 % kasvun lisäyksen ollessa 31 %.

— CT. Kanervatyypillä on koealojen puuston keski-ikä suurehko. Suuria kasvun lisäyksiä on ollut koealoilla n:o 21 (61 %) ja n:o 34 (46 %). Näissä tapauksissa on tiheyden aleneminen vaihdellut 2—3 %:in. Koealalla n:o 37 on tiheys noussut lannoituksen jälkeen. Ilmiötä voidaan myös tällä koealalla osittain selittää siten, että »nälkäpuu» -vaiheen jälkeen on lannoituksen vaikutuksesta muodostunut tiheyden suhteen »normaalia» puuainetta. Keskimäärin on tiheys laskenut 1.5 % kasvun lisäyksen ollessa 34 %. Mikäli koeala 37 jätetään huomioimatta on tiheyden aleneminen ollut keskimäärin 2.3 %.

Tarkasteltaessa eri metsätyyppejä havaitaan, että lannoituksella saavutettu lisäkasvu on ollut saman suuruinen eri metsätyypeillä (vertaa Operaatio metsänlannoitus 1969). Keskimäärin on lannoitetuilla koealoilla saavutettu kasvun lisäys ollut lannoittamattomiin verrattuna 1.2 m^3/ha kaikilla metsätyypeillä. Kasvun prosentuaalinen lisäys on puolestaan voimistunut metsätyypin huonontuessa. Osittain tämän seurauksena on tiheyden prosentuaalinen pieneneminen huonoilla metsätyypeillä suurempi kuin paremmilla metsätyypeillä. Poikkeuksena tästä näyttää olevan kanervatyypin puusto, jossa tiheyden aleneminen (1.5 %) on ollut selvästi muita metsätyyppejä pienempää.

322. Kuusi

Taulukossa 4 esitetään kuusen keskimääräiset tulokset koealasarjoittain, joiden sijainti selviää kuvasta 3. Tulokset olivat metsätyypeittäin seuraavat:

— OMT. Useat kuusikoealat sijaitsivat käenkaali-mustikkatyypillä. Lannoituksen vaikutus kasvuun on ollut eri koealoilla hyvin vaihtelevaa. Selvää kasvun lisäystä (n. 30 % lannoittamattomiin verrattuna) on ollut havaittavissa koealoilla n:ot 7 ja 30, kun taas Evon ja Sahalahden koealoilla ei lannoitus ole vaikuttanut lainkaan. Keskimäärin on kasvun lisäys ollut OMT:llä 15 %, jolloin tiheys on laskenut 1.3 %.

— MT. Mustikkatyypillä ovat prosentuaaliset kasvunlisäykset huomattavasti OMT:tä suuremmat. Merkille pantavaa on myös tiheyden pienenemisen voimakkuus verrattuna vastaaviin mäntyä koskeviin tuloksiin. Keskimäärin on tiheys laskenut 4.8 % kasvun lisäyksen ollessa 29 %. Jos huomioidaan pelkästään yli 70 vuotias puusto on tiheyden lasku ollut yli 5 % ja kasvun lisäys keskimäärin 33 %.

Taulukko 4. Keskimääräiset tulokset kuusella metsätyypeittäin eri koealasarjoilla.
Table 4. The average results for spruce in site types at different sample plots.

Alue *Area*	N:o *No.*	Metsätyyppi *Site type*	Puuston ikä, v. *Age of stand, years*	Kuoreton kuutiomäärä lannoitushetkellä *Cubic volume without bark at the time of fertilization* m³/ha	Lannoitettujen ja lannoittamattomien ruutujen välinen kuutiokasvun ero *The difference in volume growth between fertilized and unfertilized parcels* m³/ha/v	Kasvun lisäys lannoittamattomaan verrattuna *The additional growth compared with unfertilized* %	Tiheyden muutos lannoittamattomaan verrattuna *The change in density compared with unfertilized* %
Noormarkku .	7	OMT	90	175	2.0	33	—3.0
Evo	2	OMT	35	121	—0.2	— 2	+1.3
Sahalahti ...	28	OMT	28	109	0.4	3	—0.2
Pälkäne	30	OMT	20	47	1.7	25	—1.9
Maksamaa ..	11	OMT	12	37	—	—	—2.7
Keskimäärin — *Average*					1.0	15	—1.3*
Kaltila	26	MT	100	236	0.8	22	—6.0
Kuru	8	MT	95	113	1.7	63	—8.9
Mouhijärvi ..	33	MT	90	187	1.1	22	—3.7
Teisko	35	MT	70	176	1.6	30	—7.4
Teisko	36	MT	70	164	0.8	26	—1.6
Yyteri	19	MT	20	61	0.6	9	—0.9
Keskimäärin — *Average*			—	—	1.1	29	—4.8***
Ähtäri	23	VT	25	32	1.1	31	—4.6
Rovaniemi ..	40	EVT	100	85	—	—	—0.3
Rovaniemi ..	39	EVT	60	28	0.7	27	—9.6

— VT. Puolukkatyypiltä on tiedot ainoastaan yhdeltä puustoltaan nuorelta koealalta. Tiheys aleni 4.6 % kasvun lisäyksen ollessa 31 %.
— EVT. Variksenmarja-puolukkatyypillä on kasvutietoja vain koealasarjalta n:o 39. Tiheyden lasku on ollut erittäin voimakas, 9.6 %, kasvun lisäyksen ollessa 27 %.

Kuten männyllä, näyttää lannoitus poistaneen metsätyyppien välisen kasvun määrällisessä lisäyksessä havaittavissa olevan eron. Kasvun lisäys on ollut lannoittamattomiin verrattuna keskimäärin 1.0 m³/ha kaikilla metsätyypeillä ja kasvun lisäys prosenteissa ilmaistuna on noussut metsätyypin huonontuessa. Koealojen lukumäärän perusteella antavat OMT ja MT paremman kuvan tiheyden muutoksesta kuin EVT ja VT. Mäntyyn verrattuna on tiheyden aleneminen kuusella suurempaa.

323. Koivu

Koivua koskeva tutkimusaineisto on suppea käsittäen vain viisi koealasarjaa. Lannoituksen vaikutusta koivupuun tiheyteen on tutkittu erittäin vähän, joten jokaista koealaa katsottiin tarpeelliseksi tarkastella erikseen. Koska kuutiokasvutietoja ei kyseisiltä koealoilta ole käytettävissä on tau-

lukkoon 5 merkitty kuutiokasvun tilalle lannoitettujen ja lannoittamattomien puiden välinen luston paksuuden ero. Sen eron perusteella voidaan tehdä johtopäätöksiä lannoituksen vaikutuksesta kasvuun.

— MT. Mustikkatyypillä, joka on kcivun luonnollista kasvumaata, on Heinolan koealasarjalla (10) mitattu 0.23 mm:n luston paksuuden lisäys lannoittamattomaan verrattuna, joka vastaa 26 %:n kasvun lisäystä. Tällöin on tiheys laskenut 2.4 %. Vesijaolla (n:o 41) ei lannoitus ole vaikuttanut kasvuun juuri lainkaan. Kyseisellä koealasarjalla vaikeuttaa vertailua kontrolliruutu, jolla lannoituksen jälkeinen kasvu on ollut lannoitettujen ruutujen kanssa saman suuruista. Koska minkäänlaista muutosta ei ollut tapahtunut kasvussa, oli myös tiheyden muutos merkityksetön.

— VMT. Rovaniemen koealasarjalla n:o 27 on nuorehkossa puustossa tapahtunut selvää kasvun lisäystä lannoittamattomaan verrattuna luston paksuutta tarkasteltaessa. Tällöin on myös tiheys laskenut 2.0 %.

— EVT. Variksenmarja-puolukkatyypillä, koealasarjalla n:o 40 laski tiheys melko vähän siitä huolimatta, että lannoitus vaikutti kasvuun voimakkaasti. Tällä koealalla on merkille pantavaa kuitenkin tiheyden muutosten suuri vaihtelu ruutujen välillä. Esimerkiksi suuren määrän Y-lannosta (1500 kg/ha) saanneella ruudulla oli voimakkaan kasvun lisäyksen tuloksena jopa 12.2 %:n lasku puuaineen tiheydessä. Toisaalta käytettäessä 1000 kg/ha Y-lannosta, tapahtui voimakkaalla kasvun lisäyksellä vain 3.5 %:n tiheyden aleneminen. Kyseisen koealan keskimääräisiin tuloksiin on täten syytä suhtautua varovaisesti. Taulukon 5 viimeisellä koealasarjalla n:o 39 kasvu lisääntyi vain vähän. Kyseisellä koealalla oli ainoastaan yksi vertailuruutu, jolloin vertailu lannoitettujen ja lannoittamattomien välillä ei ole tasapuolista, Kun lisäksi vertailuruuduissa on saatu melko suuri tiheyden nousu lannoitusajanjaksona lannoitettujen runkojen tiheyden laskuun verrattuna on keskimääräistä tulosta pidettävä tiheyden alenemista ajatellen liian suurena.

Taulukko 5. Keskimääräiset tulokset koivulla metsätyypeittäin eri koealasarjoilla.
Table 5. The average results for birch in site types at different sample plots.

Alue *Area*	N:o *No.*	Metsätyyppi *Site type*	Puuston ikä, v. *Age of stand, years*	Kuoreton kuutiomäärä lannoitushetkellä *Cubic volume without bark at the time of fertilization,* m³/ha	Luston paksuuden ero lannoittamattomiin verrattuna *The difference in ring width between fertilized and unfertilized parcels,* mm	Tiheyden muutos lannoittamattomaan verrattuna *The change in density compared with unfertilized* %
Heinola	10	MT	45	150	+0.23	—2.4
Vesijako	41	MT	30	100	—0.09	—0.4
Rovaniemi ..	27	VMT	35	74	+0.14	—2.0
Rovaniemi ..	40	EVT	100	85	+0.27	—0.8
Rovaniemi ..	39	EVT	60	46	+0.05	—3.5

Koealojen vähäisestä määrästä johtuen ei koivun osalta voi tehdä johtopäätöksiä metsätyypin ja iän vaikutuksesta puuaineen tiheyteen. Mikäli selvää kasvun lisäystä on havaittavissa lannoituksen seurauksena, näyttää tiheys laskevan 1—2 %. Järeätä puustoa käsittävien koealojen puuttuessa saadaan vain vaillinainen kuva siitä, miten lannoitus todella vaikuttaa puuaineen tiheyteen koivun ehkä yleisimmällä metsätyypillä MT:llä.

33. Lannoituksen vaikutus kuiva-ainetuotokseen

Lannoituksella pyritään puun tuotoksen lisäämiseen, jolloin erityisesti kuituteollisuuden kannalta on kuiva-ainetuotoksen lisäys tärkeä. Kuiva-ainetuotos muodostuu pääasiassa kahdesta tekijästä: 1) puun tilavuuden kasvusta ja 2) syntyvän puuaineen tiheydestä. Kun tehdään laskelmia lannoituksen kannattavuudesta, on aina huomioitava nämä kaksi tekijää.

Esimerkki kuiva-ainetuotoksen laskemisesta kun lannoituksesta johtuva puuaineen tiheyden pieneneminen on ollut 3.0 %:

	m^3/ha/v
Koealojen kasvu oli ennen lannoitusta	3.1
Kasvu parani metsikön iän karttuessa kokeen aikana lannoituksesta riippumatta	1.2
Lannoittamattomien ruutujen kasvu yhteensä	4.3
Lannoitus lisäsi kasvua 28 %	1.2
Lannoitettujen ruutujen kasvu yhteensä	5.5

Edellisen perusteella voidaan laskea kuiva-ainetuotos:

	Kasvu m^3/ha	Puuaineen tiheys kg/m^3	Kasvu tonnia/ha
Lannoittamattomat	4.3	400	17.2
Lannoitetut	5.5	388	21.3

Kuiva-ainetuotoksen lisäys prosentteina lannoittamattomaan verrattuna 24 %.

Yllä olevaan esimerkkiin perustuen on laskettu tutkimusaineistosta lannoituksella aikaansaatu kuiva-ainetuotoksen prosentuaalinen lisäys ottamalla huomioon sekä kuutiokasvun lisäys että vastaava muutos puuaineen tiheydessä.

Puulaji	Metsätyyppi			
	OMT	MT	VT	CT
	Kuiva-ainetuotoksen lisäys, %			
Mänty		19	32	32
Kuusi	14	24	25	

Asetelman mukaan kuiva-ainetuotoksen lisäys on männyllä paremmilla kasvupaikoilla (MT) 19 % ja niukkaravinteisemmilla kasvupaikoilla (VT ja CT) 32 %. Kuusella on kuiva-ainetuotoksen lisäys ollut keskimäärin vähäisempää kuin männyllä, noin 22 %.

Taulukko 6. Keskimääräinen kuutiokasvu lannoittamattomissa rungoissa sekä kasvun ja kuiva-ainetuotoksen lisäys lannoitettaessa.

Table 6. The average volume growth in unfertilized trees and the additional growth and dry substance when fertilized.

	Mänty *Pine*			Kuusi *Spruce*		
	MT	VT	CT	OMT	MT	VT
	m³/ha/v					
Kuutiokasvu ennen lannoitusta	5.4	3.3	2.9	6.7	3.8	3.7
Kasvun lisäys lannoitettaessa	1.2	1.2	1.0	1.0	1.1	1.1
Todellinen kuivan ainetuotoksen lisäys kuutiometreiksi muutettuna ...	1.0	1.1	0.9	0.9	0.9	0.9

Taulukossa 6 vertaillaan kuiva-ainetuotoksen määrällistä kasvua (m³/ha) eri metsätyyppien välillä. Lannoitus aiheuttaa näin laskien männyllä määrällisesti suurimman kuiva-ainetuotoksen lisäyksen puolukkatyypillä. Kuiva-ainetuotoksen lisäyksen erot eri metsätyypeillä ovat tosin hyvin pienet.

Kuusella ei metsätyyppien välillä ollut lainkaan eroja. Kuiva-ainetuotoksen lisäys oli 0.9 m³/ha/v kaikilla taulukon metsätyypeillä.

4. KÄYTÄNNÖN NÄKÖKOHTIA

Tulosten perusteella voidaan todeta lannoituksen alentavan puuaineen tiheyttä, mikäli selvää kasvun lisäystä tapahtuu. Lannoitettaessa esim. tukkipuuastetta lähenteleviä tai tukkipuuasteisia VT männiköitä on odotettavissa keskimäärin 2—4 %:n suuruinen puuaineen tiheyden aleneminen kasvun lisäyksen ollessa noin 40 %. Kuusella näyttää tiheyden pieneneminen olevan keskimäärin 4—6 % tukkipuuasteisessa tai tukkipuuastetta lähentelevässä metsikössä, kun kasvun lisäys on noin 30 %. Suppean aineiston perusteella näyttää myös koivupuun tiheys laskevan muutamia prosenttiyksikköjä.

Puuaineen tiheyden alenemisen merkitys selluteollisuudessa on melko vähäistä. Oy Keskuslaboratorio Ab suoritti keittokokeita käsillä olevan tutkimuksen koealalta n:o 22 Heinolasta kerätyllä suppeahkolla aineistolla. Kyseisellä koealalla oli tiheyden aleneminen 2—4 %, jolloin siis puun kulutus lannoitetun puuaineen osalta kasvaa kyseisellä prosenttiluvulla sitä selluteollisuudessa käytettäessä. Keskuslaboratorion tutkimusten mukaan ei saantoluvuissa (tuotteen kuivapaino % raaka-aineen kuivapainosta) ollut lainkaan eroa lannoitetun ja lannoittamattoman välillä. Lannoitettu puu kuituuntui sen sijaan paremmin kuin lannoittamaton.

Repäisylujuuden laskua (n. 10 %) lukuunottamatta lannoitettu puu ei paperiteknisiltä ominaisuuksiltaan näyttänyt eroavan lannoittamattomasta (L ö n n b e r g 1974).

Kuusta koskevia tutkimustuloksia on vain vähän, mutta yleisenä piirteenä on havaittavissa lannoituksen vaikutuksen samanlaisuus mäntyyn verrattuna. Koska kuusella puuaineen tiheys kuitenkin laskee lannoituksen johdosta hieman enemmän kuin männyllä, on puun kulutus myös vastaavasti suurempi. Kuusimassan paperiteknisistä ominaisuuksista esimerkiksi repäisylujuus ja opasiteetti saattavat myös jäädä mäntymassaa heikommiksi. Lannoituksella on todettu saatavan normaaliin puuaineeseen verrattuna tasalaatuisempaa raaka-ainetta (P r o c e e d i n g s . . . 1972).

Lannoituksen oletetaan aiheuttavan sahatavaran ominaisuuksiin seuraavia muutoksia: huonompi maalin pidättyvyys, puun työstettävyyden heikentyminen, höylätyn sahatavarapinnan ulkonäön huonontuminen ja lujuusominaisuuksien aleneminen. Eduista mainittakoon taivutettavuuden

parantuminen sahatavaraa höyrytettäessä (Proceedings... 1972). Aiheutuneet muutokset eivät niinkään johdu tiheyden alenemisesta vaan enemmänkin vuosiluston paksuuskasvusta. Edellä mainitut ominaisuuksien muutokset vaikuttavat sahatavaraan hyvin vähän, jos kysymyksessä on hakkuukypsälle puustolle suoritettu lannoitus. Tällöin lannoitettu puuaine käsittää 5—10 viimeistä vuosilustoa. Sahauksessa joutuu suurin osa tyviosan pintapuusta hakkeeksi, osa taas pintalaudoiksi, joille yllämainituilla sahatavaran ominaisuuksiin vaikuttavilla tekijöillä ei ole yhtä suurta merkitystä kuin sydäntavaraan.

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LYHENNELMÄ

Lannoituksella saavutettu kasvun lisäys Suomessa on ollut koko maassa vuosittain yli 1.25 miljoonaa k—m^3, jos lannoituksen avulla saavutetuksi lisäkasvuksi lasketaan 1.3 k—m^3/ha/v ja lannoitusajan kestoksi viisi vuotta. Kun kyseessä on näin huomattava kasvun nopeutuminen, voidaan siitä olettaa aiheutuvan myös muutoksia puun laadullisiin ominaisuuksiin, etenkin puuaineen tiheyteen, joka osoittaa puuaineen määrän painona tilavuusyksikköä kohden.

Käsillä olevan tutkimuksen tarkoituksena on selvitellä lannoituksen vaikutusta männyn, kuusen sekä koivun puuaineen tiheyteen. Vertailuja on pyritty tekemään ikäluokkien, metsätyyppien ja maantieteellisten alueitten välillä. Lisäksi on laskettu erikseen lannoituksella aikaansaadun kuiva-ainetuotoksen määrä ottamalla huomioon puuaineen tiheydessä tapahtuneet muutokset.

Tutkimusaineisto on kerätty ja mitattu Metsäntutkimuslaitoksen maantutkimusosaston toimesta. Lannoituskoealasarjoja oli puulajeittain seuraavasti: mäntyä 31, kuusta 14 ja koivua 5 kpl. Koivu esiintyi tosin sekapuulajina, osuuden ollessa noin 40 %. Koealojen sijainti selviää kuvista 2, 3 ja 4 sekä ikäluokkajakautuma kuvasta 1. Kukin koealasarja käsitti keskimäärin 8 lannoitusruutua. Jokaisesta ruudusta kerättiin 18:sta rungosta kairanlastunäytteet rinnankorkeudelta.

Koko aineisto jaettiin ravinteina typpeä saaneitten ja muita ravinteita saaneitten kesken, edellisten edustaessa lannoitettuja ja jälkimmäisten lannoittamattomia runkoja.

Tutkimuksen tulokset ovat seuraavat:

1) Sekä männyllä, kuusella että koivulla tiheys laski lannoituksen aiheuttaman kasvun lisäyksen seurauksena (taulukot 3, 4 ja 5).

2) Ikäluokittain tarkasteltuna on männyn tiheyden lasku ollut kaikissa ikäluokissa saman suuruista. Keskimäärin on tiheyden lasku ollut 2.5 % kasvun lisäyksen ollessa 31 %. Kuusella on tiheyden lasku ollut keskimäärin 4.1 % kun kasvun lisäys on ollut 26 % (taulukko 2).

3) Eri metsätyypeillä on *männyn* tiheyden lasku ollut suoraan verrannollinen lisäkasvuun. Keskimäärin tiheys laski MT:llä 2.3 %, VT:llä 3.2 % ja EVT:llä 3.1 %. Poikkeuksen tekee CT jossa tiheys laski vähän, 1.5 %

suurehkosta lisäkasvusta huolimatta. Lannoituksella saavutettu lisäkasvu on ollut saman suuruinen eri metsätyypeillä, noin 1.2 m^3 (taulukko 3). *Kuusella* on tiheyden lasku ollut voimakkainta mustikka-tyypillä, keskimäärin 4.8 %. Kasvun lisäys on ollut kaikilla metsätyypeillä melkein sama, noin 1.1 m^3 (taulukko 4). *Koivulla* näytti tiheys laskevan 1—2 % mikäli selvää kasvun lisäystä oli havaittavissa (taulukko 5).

4) Tiheyden laskusta johtuen vastasi lannoituksella aikaansaatu kuiva-ainetuotoksen lisäys männyllä noin 1.0 ja kuusella 0.9 m^3/ha/v.

5) Osalla aineistoa suoritetun Oy Keskuslaboratorio Ab:n tutkimuksen mukaan ei männyn saantoluvussa ollut lainkaan eroa lannoitetun ja lannoittamattoman välillä. Puuaineen tiheyden laskun johdosta puun kulutus kuitenkin kasvaa kyseisellä prosenttiluvulla sitä selluteollisuudessa käytettäessä.

SUMMARY

The additional growth achieved by fertilization yearly in all of Finland has been over 1.25 million solid cu.m. if the fertilization-induced additional growth is taken to be 1.3 solid cu.m./hectare and the duration of the fertilization period five years. Since this is such notable acceleration of growth, it may be assumed to have caused changes also in the qualitative properties of wood, especially basic density which denotes the amount of wood by weight per volume unit.

The purpose of this investigation was to study the effect of fertilization on the basic density of pine, spruce and birch. Comparisons were made between age classes, site types and geographic regions. In addition, dry substance production achieved through fertilization was calculated separately by taking the changes in basic density into consideration.

The Department of Soil Research, the Finnish Forest Research Institute commissioned the collection and measurement of the material. The number of sample plots by tree species were: pine 31, spruce 14 and birch 5. Birch occurred as a mixed tree species in a proportion of about 40 per cent. The location of the sample plots is given in Fig. 2 and the age class deviation in Fig. 1. Each sample plot series comprised an average of eight fertilization parcels. Increment cores were collected at breast height from 18 stems in each parcel.

The total material was distributed between stems receiving nitrogen and stems receiving other nutrients; the former represented fertilized and the latter unfertilized stems.

The investigation yielded the following results:

1) The density of pine, spruce and birch diminished in consequence of fertilization-induced additional growth (Tables 3, 4 and 5).

2) The decrease in pine density was of the same magnitude in all age classes. The average density decrease was 2.5 per cent when the additional growth was 31 per cent. The fall in spruce density was an average of 4.1 per cent when the additional growth was 26 per cent (Table 2).

3) The decrease in *pine* density was directly proportional to the additional growth in the different site types. The average density decrease was 2.3 per cent for MT, 3.2 per cent for VT and 3.1 per cent for EVT. The exception was CT where the density decrease was only 1.5 per cent despite the fairly great additional growth. The additional growth due to fertilization was of the same magnitude for different site types, approx. 1.2 cu.m. (Table 3). For *spruce* the decrease in density was most pronounced in MT, average 4.8 per cent. The additional growth was practically the same in all site types, approx. 1.1 cu.m. (Table 4). The density of *birch* seemed to decline by 1—2 per cent if distinct additional growth was perceivable (Talbe 5).

4) Because of the density decrease, the fertilization-induced increase in dry substance production was about 1.0 cu.m./hectare/annum for pine and about 0.9 for spruce.

5) According to the study carried out by the Finnish Pulp and Paper Research Institute on a part of the material, the yield figure for pulp showed no difference between fertilized and unfertilized stems (Lönnberg 1974). However, owing to the decrease in basic density, wood consumption increases by the percentage stated in the chemical pulp industry.

THE BIOLOGY OF PISSODES VALIDIROSTRIS GYLL. (COL., CURCULIONIDAE) AND ITS HARMFULNESS, ESPECIALLY IN SCOTS PINE SEED ORCHARDS

ERKKI ANNILA

KÄPYPIKIKÄRSÄKKÄÄN (PISSODES VALIDIROSTRIS GYLL.,) (COL., CURCULIONIDAE) BIOLOGIA JA VAHINGOLLISUUS ERITYISESTI MÄNNYN SIEMENVILJELMILLÄ

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1. INTRODUCTION

Pissodes species occur throughout the coniferous forest zone in the northern hemisphere (D o a n e et al. 1936, K u d e l a 1974). All members of the genus are bark feeders except the pine cone weevil (*Pissodes validirostris* Gyll.), which breeds in the cones of several *Pinus* species. Although the biology and economic importance of *Pissodes* species have been studied since the end of the last century, relatively few investigations have been published on the pine cone weevil, probably because the damage done by this insect has been considered to be of little importance to the seed crop of *Pinus silvestris* L. (E s c h e r i c h 1923, S a a l a s 1949).

The economic importance of the cone- and seed-destroying insects has had to be re-estimated as a result of the production of conifer seed in orchards (B r a m m a n i s 1964, B a k k e 1969, M e r k e l 1969, R o h m e d e r 1972, A n n i l a 1973, S a k s o n s 1973). About 6500 Scots pines had been selected for seed production and forest improvement in Finland by 1972 (O s k a r s s o n 1972). These trees, which were chosen because of their better-than-average characteristics, are called plus trees. Considerable sums have been invested in the selection of plus trees, grafting, and establishment and maintenance of seed orchards. Seed produced in the orchards is therefore more expensive than that collected in the forest, althouth harvesting costs are somewhat lower in the seed orchards than in the forests. Cone and seed insects cause economic losses not only by destroying seed but also by increasing the expenses of cone harvesting and seed extraction.

Conditions in seed orchards differ greatly from those in the forest. The trees are widely spaced and the cone-bearing branches are near the ground. These differences probably affect physical factors such as temperature, light, moisture, etc., which influence the abundance of many insects. Furthermore, the grafts are growing at long distances from the parent trees.

Preliminary studies on the damage done by insects in seed orchards indicated that the numbers of cones destroyed by the pine cone weevil were by no means negligible. Forest tree breeders also drew attention to the matter. *P. validirostris* also does great damage to the cones of the lodgepole pine, *Pinus contorta* Loud. (K a r v i n e n & R i k k o n e n 1956, K r o l &

Michalski 1961, Weissenberg 1972). Foresters in Finland are nowadays very interested in the cultivation of this pine species introduced from North America (Hakkila & Panhelainen 1970, Tigerstedt 1970).

Before resorting to the large-scale use of insecticides for the control of cone- and seed-destroying insects, we must examine whether the damage can be prevented by other means. Repeated spraying or dusting of the trees with chemicals foreign to the environment might gradually lead to accumulation of pesticide residues in the seed orchards. This might upset the balance between the pest insects and their enemies. There is also a risk that insects may become resistant to insecticides if chemical control is used in seed orchards year after year. Some insecticides may also have phytotoxic effects on the seeds, reducing the quality of the seed crop (Annila 1973).

If the biology and behaviour of pest insects are sufficiently well known, the damage can often be controlled by means other than insecticides; for instance, silvicultural, mechanical, biological and genetic measures can be used. Seed orchards provide excellent opportunities for investigating the insect resistance of different clones, because each plus tree is represented by several grafts, all of the same genetic constitution.

The large-scale investigations on other *Pissodes* species (*P. notatus* F., *P. piceae* Ill., *P. strobi* Peck) already published (Nüsslin 1897, Mac Dougall 1898 a, Taylor 1929, Hierholzer 1954) were not of much help in planning the control of *P. validirostris*, since the pine cone weevil differs greatly in its biology from other members of the genus.

The first aim of the present study was to ascertain the importance of the damage caused by the pine cone weevil in Scots pine seed orchards and in the stands of *Pinus contorta*, and to test how far this damage can be prevented without resort to direct chemical methods of control. Since knowledge of the habits of *P. validirostris* was very scanty, the first step was to investigate the biology of this insect to the degree that was needed for planning indirect control measures. These biological investigations were focused on the annual life-cycle, the modes of dispersal of the pine cone weevil and the factors controlling its abundance.

2. MATERIAL AND METHODS

The present study was carried out at the Finnish Forest Research Institute during the years 1969—1973. Since the Scots pine seed orchards have been established almost entirely in southern and central Finland most investigations were made in these regions. The biology of the pine cone weevil was studied mainly at Ruotsinkylä Experimental Forest, Tuusula (Fig. 1). Many observations on the life habits of the weevil were also made in seed orchards and natural stands in other localities (Pohja, Oitti, Punkaharju, Juupajoki, Hämeenkyrö, Jämsänkoski, Jurva, Rovaniemi).

The results are based largely on cone samples taken at regular intervals during the summer. The cones of *Pinus silvestris* were mostly collected in seed orchards. At Jurva, samples were taken from a pine plantation. The cone samples of *Pinus contorta* were collected from monocultures of this species.

Weevils and their parasites were bred in plywood boxes (length 60 cm, width and height 30 cm), fitted with covers of brass gauze. Emerging adults fell into a glass jar when making their exit through a hole bored at one end of the box. The traps were inspected at least twice a week. The insects that collected in the glass jars were preserved in 75 % alcohol for laboratory investigations. Each box contained only a thin layer of cones, and the insects could emerge without difficulty.

Temperature observations (2 m above the ground) were made at Ruotsinkylä climatological station, which belongs to the Finnish Meteorological Institute.

The injuries done by the pine cone weevil in seed orchards were studied at Tuusula (orchards 7 and 10), Punkaharju (orchard 1), Oitti, Pohja and Jämsänkoski, where the oldest Finnish seed orchards are situated. In connection with plus tree selection Finland has been divided into three zones: southern, central and northern, the symbols for which are E, K and P, respectively (Fig. 1). There are also grafts of some Russian plus trees in Finnish pine seed orchards, the symbol for which is SU. There are E, K, P and SU grafts at Tuusula and Punkaharju, E grafts at Pohja and Oitti, and P grafts at Jämsänkoski. In seed orchards a plus tree is usually represented

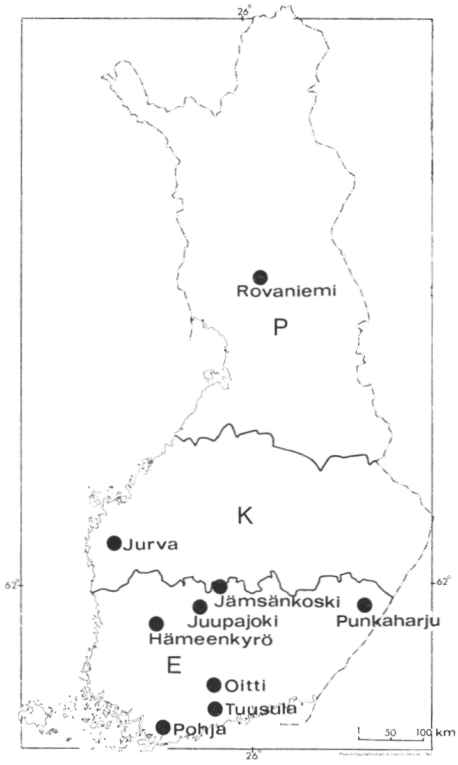

Fig. 1. Situation of the experimental sites and plus tree zones of Scots pine in Finland. E = south, K = central, P = north.

by 3 or 4 grafts planted in a row. The grafts of one plus tree make a clone. Only at Pohja has the seed orchard been divided into evensized blocks, in which the grafts have been planted at random. The average distance between grafts is 4 m. As some of the trees have died some clones are represented by only 1 or 2 grafts.

Damage caused by *P. validirostris* in lodgepole pine cones was investigated at Tuusula, Punkaharju and Juupajoki. Some *P. contorta* grafts growing in Scots pine seed orchards at Tuusula were also utilized in the study. All trees of lodgepole pine investigated in the present study belong to the broad-needle race of *P. contorta* (var. *latifolia* S. Wats.).

Information about pine seed orchards and lodgepole pine plantations is presented in Tables 1 and 2. At Tuusula and Oitti the seed orchards are situated in flat fields on clay soil, but at Punkaharju on undulating terrain with a morainic soil.

Further information about methods and material is given in each section.

Table 1. Notes on the Scots pine seed orchards used in the study.

Locality	Orchard no.	Year of establish-ment	Site	Area ha	No. of clones	No. of grafts
Tuusula	7	1953	field	0.6	86	332
Tuusula	10	1953	VT [1])	2.0	427	1 229
Punkaharju	1	1953	field	2.6	373	823
Pohja	—	1957	MT [2])	1.5	25	588
Oitti	17	1954	field	1.6	25	503
Jämsänkoski	22	1957	MT [2])	3.6	30	1 319

[1]) *Vaccinium* site type
[2]) *Myrtillus* site type

Table 2. Notes on the cultivated stands of *Pinus contorta* used in the study.

Locality	Provenance	Stand no.	Year of establish-ment	Site	Area ha	Dominant height m
Tuusula	Canada, Br. Columbia	6—8	1927	OMT [1])	2.5	22
Tuusula	Canada, Alberta	65	1930	VT	2.3	16
Tuusula	Canada, Br. Columbia	116—120	1931	VT	1.5	17
Punkaharju	Canada, Br. Columbia	99	1929	OMT [1])	0.9	19
Juupajoki	Unknown	—	1928	CT [2])	1.5	10

[1]) *Oxalis-Myrtillus* site type
[2]) *Cladonia* site type

3. LIFE HISTORY

31. Emergence from overwintering sites

Examination of the cones in late autumn showed that the adults of the pine cone weevil leave the cones before the winter. However, there is no information on record, as far as I know, about the overwintering sites of *P. validirostris* in the Northern or Central European countries. Nor have I found any statement about how the adult weevils reach the cones. In Spain, the pine cone weevil is known to overwinter in the forest litter or at the bases of the stems of *Pinus pinea* L. (Bachiller 1966, Cuevas & Bachiller 1969, 1970). In spring after a short search, weevils were found at Tuusula under the bark scales and in crevices at the bases of *P. contorta* and in the litter around the trunks.

According to Eckstein (1897), in Central Europe the pine cone weevil swarms in May and June. In Spain the weevils leave their overwintering sites at the end of April or beginning of May, when warm weather prevails (Romanyk & Bachiller 1965). In Finland the earliest observations of *P. validirostris* have been made at the end of May or in early June (Saalas 1923, Kangas 1938).

The time at which the pine cone weevils begin to emerge from the overwintering sites was studied in a lodgepole pine stand at Tuusula in the following way. Frames 1 sq.m. in size were constructed from 6″ hardbord and covered with tar board. A hole was bored in one side of each frame, and a glass jar was fixed over the hole. Under each of 7 trees a frame was placed as close to the base as possible, with the jar to the south. These traps were placed in the forest immediately after the snow had disappeared, and were inspected 3 times a week.

The first weevils were trapped in the beginning of May, when the daily temperature maxima exceeded 10 °C (Fig. 2). The weevils were caught during a relatively short period. The average catch was 50.3 weevils per frame, the maximum being 165 and the minimum 22 specimens per frame.

In spring 1970 an experiment was conducted to determine whether adult weevils can reach the cones on the crown of a tree by flying. 5 window flight traps (see Chapman & Kinghorn 1955) were placed between the

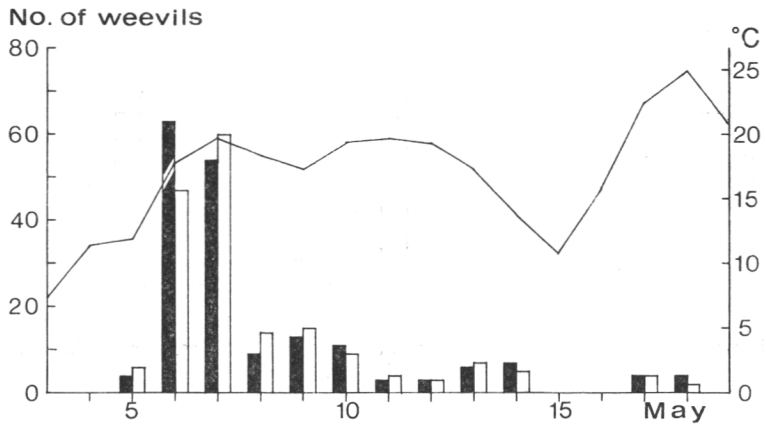

Fig. 2. The numbers of weevils that emerged from the ground. Black columns = females, white columns = males, solid line = maximum air temperature.

grafts of *P. contorta* at the level of the cone-bearing branches. Although the density of the pine cone weevil population was quite high (many adults had emerged from the cones of the previous year) the traps did not catch a single specimen. However, many weevils were observed feeding and ovipositing on the grafts from the middle of May onwards. The flying activity of adults collected from the overwintering places seemed to be very low even on relatively warm days (air temperature above 20 °C).

If, as appeared very likely, the adults do not reach the crown of a tree by flying, the only possibility is that they crawl up the trunks. This point was investigated as follows. Bands of tanglefoot were placed round the stems of lodgepole pines at a height of 1 ½ m. Before the bands were fixed in position the bark was smoothed with a knife. The bands, 2—5 cm wide, were applied in mid-April.

Weevils which had been caught by the tanglefoot or had gathered below the bands were collected daily with tweezers and placed in glass jars, those from each tree separately. Most weevils were found below the bands on a belt 20 cm wide, hiding partly in the bark crevices or under lichens growing on the stem, and only a few had attempted to cross the band. The weevils were stored at —18 °C and their sex and age were determined afterwards.

The average number of weevils per tree was 84.6 in 1971, 102.9 in 1972 and 78.8 in 1973 (range 19—208) (Fig. 3). Although the variation between trees was great, the difference between years was relatively small.

The great difference in numbers of weevils between the trees indicates that the distribution of weevils in a forest is very uneven. The reason for this was not examined in the present study, but may be connected with the variation in the numbers of cones produced the previous year.

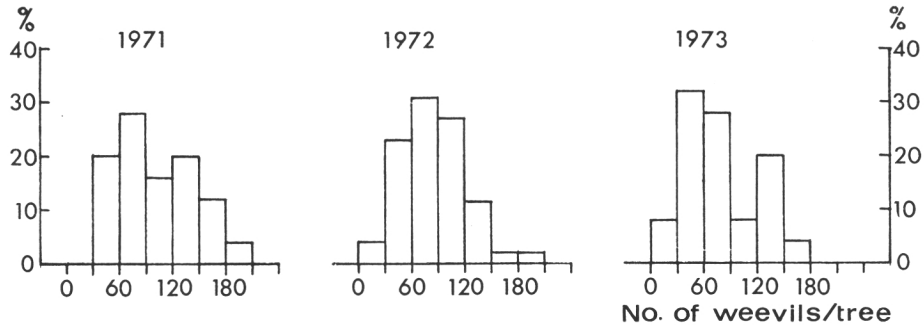

Fig. 3. Frequency distribution of infestation in *Pinus contorta* according to the numbers of weevils caught by the tanglefoot bands.

The first weevils were found creeping up the trunks when the temperature maximum exceeded 12 °C (Fig. 4). This occurred every year in early May. However, most weevils were collected after the temperature had reached 15 °C. On days when the air temperature was below 15 °C, only a few weevils were observed under the bands, and if it again fell below 10 °C they stopped climbing up the tree entirely. The vast majority of the weevils were collected in May.

Emergence of pine cone weevils in spring is obviously primarily dependent on temperature; 12 °C in the air can be considered the threshold for emergence, but mass occurrence does not begin until the temperature exceeds 15 °C. Emergence takes place during a relatively long period, as a consequence of the different reactions of individuals to temperature and the variation between overwintering places. At the base of a tree that is exposed to the sun all day the weevils start to climb several days earlier than in a shady forest.

In North America several investigators have tried to examine the role of temperature in the emergence of *Pissodes* weevils. According to S u l l i v a n (1959), *P. strobi* emerges only when the temperature in the overwintering sites (between the litter and the mineral soil) exceeds 6 °C. S i l v e r (1968) observed the adults of *P. sitchensis* Hopk. (another tip-infesting *Pissodes* species in North America) in spring only when the air temperature was above 60 °F (15.5 °C).

Although some specimens of other Finnish *Pissodes* species have been found as early as May, these weevils (*P. gyllenhali* Schönh., *P. pini* F., *P. piniphilus* Hbst., *P. harcyniae* Hbst.) have mostly not been seen until June (S a a l a s 1923, K a n g a s 1938). Some adults of *P. pini* also gathered under the bands of tanglefoot at Tuusula in the years 1971—1973. The earliest record was on May 7. In Central Europe the flight period of *Pissodes* species begins in April, but most weevils swarm in May or June

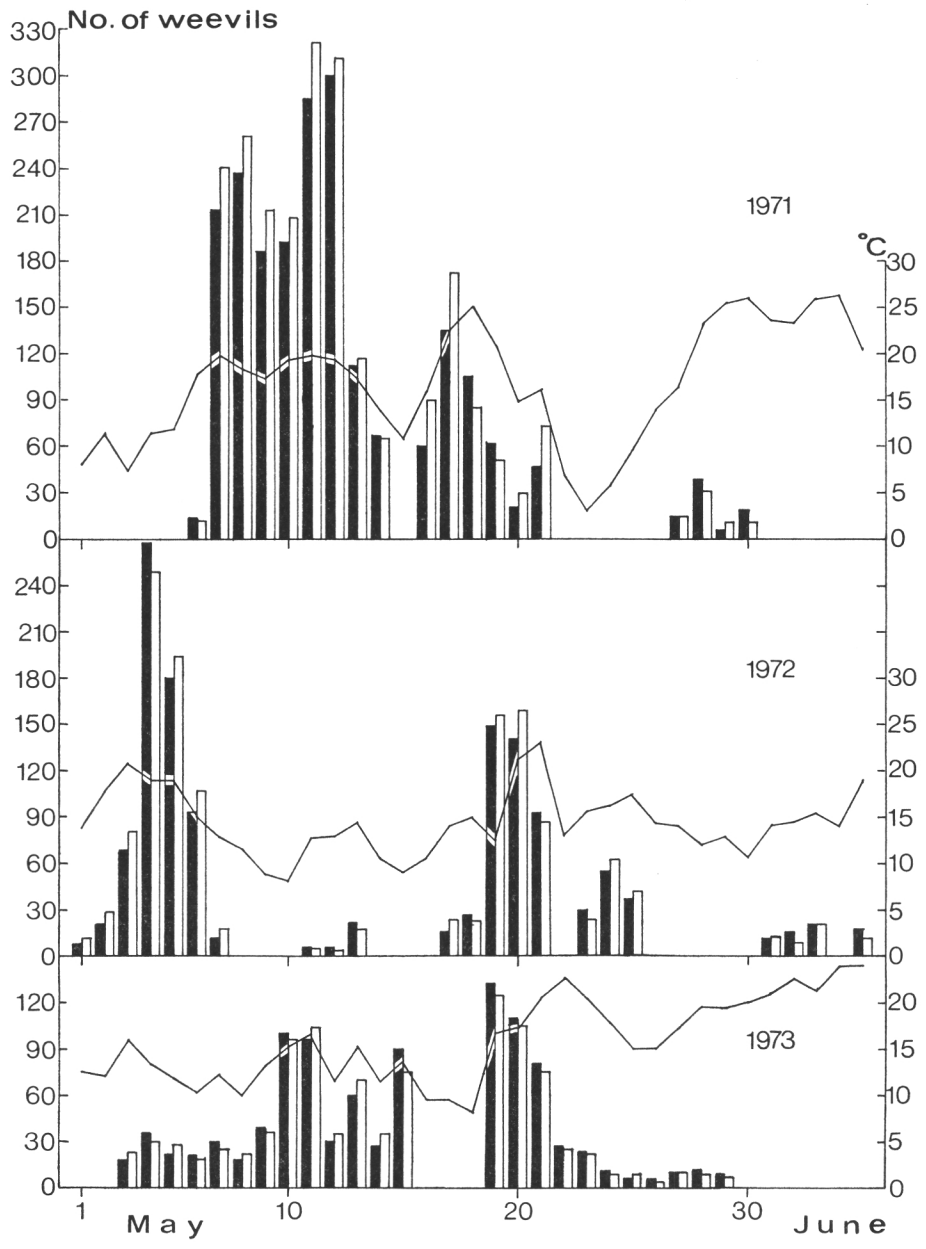

Fig. 4. The numbers of weevils caught with tanglefoot bands in successive springs. Black columns = females, white columns = males, solid line = maximum air temperature.

(Lorenz 1863, Georg 1865, Altum 1876, Eichhoff 1882, Hierholzer 1954). At the end of the last century Pauly (1892 b) and Nitsche (1895) noticed that in Germany specimens of *P. scabricollis* Redt. and *P. gyllenhali* gathered below tanglefoot bands which had been applied to catch caterpillars of *Lymantria monacha* L. The first weevils began to crawl up the trunks during the latter half of April.

As far as the results of the present study can be compared with those of previous investigations, emergence from the winter quarters and methods of reaching the food and breeding sites are the same in *P. validirostris* as in other *Pissodes* species. Although the adults of the pine cone weevil began to emerge much earlier in spring than is suggested by previous observations on the adults of other *Pissodes* weevils in Finland, I do not suppose that *P. validirostris* differs from other members of the genus in this respect. The difference is probably that adult weevils are easy to detect only when most specimens are feeding and ovipositing. Pine cone weevils and presumably also other *Pissodes* weevils start to emerge from their overwintering places quite early in spring, but during cold weather they hide in crevices under the bark scales or at the bases of the branches. Only when the temperature rises to 20 °C, which usually takes place in Finland in late May or early June, do the activities of the adults, such as feeding, mating, ovipositing, etc., become lively, so that the weevils are easy to detect.

32. Activities after emergence

Observations on the activities of *P. validirostris* after emergence were made in a seed orchard (no. 7) at Tuusula during the years 1971—1973. Since numerous adult weevils had emerged from the cones of the grafts during the previous summer the density of weevils in the area was expected to be high. After the beginning of emergence shoots and young cones of 3 grafts of *Pinus contorta* were inspected daily until feeding, copulation and oviposition had started. After that the grafts were inspected less regularly, but at least twice a week, up to mid-July.

321. Feeding

The appearance of small resin droplets on the shoots provided the first indication of a fresh attack. It is typical of *Pissodes* weevils that an adult cuts small punctures in the outer bark, through which it inserts its snout and chews out larger areas of the inner bark. Clear pitch later flows from these feeding punctures. Exuding pitch droplets are very easy to see, especially in clear weather, when they reflect the rays of the sun.

In 1971 the first pitch droplets were observed on 9 May, 4 days after the start of emergence. The following year the first feeding punctures were noticed on 4 May and in 1973 on 8 May, 5 and 8 days after the first weevils were gathered below the bands of tanglefoot. Adult weevils were very easy to detect on the shoots bearing pitch droplets. The weevils fed almost entirely on the shoots of the previous year. Those that had gathered below the tanglefoot bands made feeding punctures at the points where the bark had been cut thin, which indicates their strong urge to feed.

According to Vlasova (1966), *Pissodes notatus* loses water, fat and nitrogen during hibernation so that on emergence the weevils are feable. Evidently the physical condition of *P. validirostris* is also poor in spring, for specimens collected from below tanglefoot bands died in a few days unless fed on pine twigs.

322. Mating and oviposition

Very few observations have been published on the copulation or oviposition of the pine cone weevil. According to Kangas (1938), *P. validirostris* lays eggs in June. Altum (1886) stated that the pine cone weevil deposits eggs on the young pine cones in autumn, but this statement appears to be unfounded. In Central Europe copulation takes place in May (Eckstein 1906). In Spain the oviposition period lasts about a month but most females deposit their eggs within 10—14 days (Cuevas & Bachiller 1969, 1970). In his rearing experiments Bachiller (1966) observed the first feeding punctures at the end of April and the first eggs in the beginning of May. Oviposition was most frequent during late May but no new eggs or feeding punctures were found after mid-June.

In the present study the first copulating specimens on shoots were observed on the following dates: 11 May 1971; 20 May 1972; 11 May 1973. Weevils were usually seen pairing on shoots among the needles, sometimes on cones. Many copulating adults were also noted below the bands of tanglefoot (first records 11 May 1971; 4 May 1972 and 11 May 1973). Although no regular records were kept of the number of copulating pairs, most pairing weevils were found on relatively warm days (temperature maximum at least 20 °C).

The first eggs were observed in the second-year cones on 11, 21, and 19 May in 1971, 1972, 1973, respectively. Although no regular observations on oviposition were made in 1970, the first eggs were noted on 12 May. When ovipositing, a female excavates a small cavity near the tip of a cone scale. After laying an egg she covers the cavity with a small brown cap of frass so that the egg cannot be seen from outside. The adults also make feeding punctures in the cone but these cavities are not covered.

When oviposition begins the second-year cones are quite small and have just resumed growth. On the cones of *Pinus contorta* the female mostly deposits her eggs in the large scales situated near the middle of the cone. On the cones of *P. silvestris* the concentration of eggs is less evident, but the female lays most of her eggs in the middle zone of the cone. After ovipositing the female often retires between the cone and the shoot, where she is easy to find.

No records were made of the numbers of feeding, copulating or egg-laying adults. However, these activities continued vigorously until mid-June, after which weevils engaged in them were observed less and less frequently. The oviposition period was over by about mid-summer.

In 1973 experiments were made to ascertain the length of the oviposition period. In mid-April before the weevils emerged, young cones of *Pinus contorta* were isolated in cheesecloth bags on 3 grafts of the same clone (E 519). Many weevils had emerged from the cones on these grafts the preceding year, showing that the trees were very suitable for the breeding of pine cone weevils. The number of cones in a bag varied from 1 to 3. Weevils were collected from below the tanglefoot bands on 9 and 11 May, stored at 4 °C, and released into the bags on 30 May, 15 June, 2 and 13 July. Two pairs of weevils per bag were set free in 12 bags on each date. *Pissodes* weevils are easy to sex by differences in the last abdominal tergites (P u l l i a i n e n 1965, H a r m a n & K u l m a n 1966). The cones were collected on 10 September, and after transfer to the laboratory were divided into 3 groups: 1) cones with punctures cut by weevils, 2) cones inhabited by weevils, 3) healthy cones. Since the adults also made feeding punctures in the cones, it is just possible that the females had oviposited in the cones of the first group. However, as the punctures were shallow and without a cover of frass, it seemed unlikely that the females had laid eggs in these cones, and no remnants of eggs were found in the punctures. The weevils fed intensively on the shoots in all the bags. The results of the experiment were as follows:

Date	Number of cones			
	Group 1	Group 2	Group 3	Total
30. V	22	22	—	22
15. VI	23	17	—	23
2. VII	18	—	8	26
13. VII	—	—	23	23
Total				94

The cones in which the adults had only made feeding punctures were considered quite healthy, for the punctures did not seem to disturb the development of the cones in any way.

Oviposition is evidently possible as long as the cones are relatively soft. According to investigations carried out in Norrland, northern Sweden, the

water content of pine cones starts to decrease in the beginning of July, although their length increases until the end of July (Kardell 1973). *Pissodes terminalis* Hopping is able to lay eggs only on elongating leaders of *Pinus contorta*, where the bark is likewise very soft (Stark & Wood 1964).

Although no experiments were made on how temperature influences feeding, copulation and oviposition in *P. validirostris*, weevils engaged in these activities were mostly observed on days when the temperature was above 20 °C. The first weevils feeding, copulating or ovipositing in spring were observed when the temperature reached about 20 °C.

In the European literature dealing with *Pissodes* weevils there is little information about the physical factors (e.g. temperature) which govern feeding, copulation and oviposition. However, some investigations and observations have been published in North America. Sullivan (1960) studied the dependence of the activities of *P. strobi* on some weather conditions and found that this weevil did not start to feed until the temperature in the bark of a leader rose above 8 °C, and very little egg-laying occurred below 20 °C. Sullivan found that this weevil becomes less active as the relative humidity increases, most weevils being inactive in rainy weather. According to Silver (1968), oviposition activity in *P. sitchensis* increases rapidly when the temperature exceeds 60 °F (15.5 °C). However, Gara et al. (1971) stated that these weevils begin to lay eggs only when the temperature reaches 75 °F (24 °C) and that the optimal temperature for oviposition is 90 °F (32.2 °C).

Most observations on the copulation or oviposition of *Pissodes* weevils have been made in June and July (Lorenz 1863, Georg 1865, Eichhoff 1882, Nüsslin 1897, Gerlach 1898, MacDougall 1898 a, Elfving 1905, Furuhjelm 1905, Graham 1926, Hierholzer 1954, Nishiguchi 1961, Martin 1964). On the other hand, Gara et al. (1971) and Bliss & Kearby (1970) found copulating and egg-laying adults throughout the growing season.

Although *Pissodes* weevils were occasionally seen copulating and ovipositing in late summer or autumn, these activities are mainly restricted to May and June. So it seems that in this respect there is no great difference between *P. validirostris* and other *Pissodes* species.

33. Developmental stages

For a study of the various developmental stages of the pine cone weevil, cone samples of *Pinus silvestris* and *P. contorta* were collected in Ruotsinkylä Experimental Forest during the years 1970—1972. Cones of Scots pine were gathered from the grafts growing in seed orchard no. 10 and those of

lodgepole pine were taken from plantations nos. 116—120 (Table 2). Cones were collected once a week from mid-May to the end of September and then less regularly until late November. 10 cones at a time were taken from 5 different trees or clones, and one sample comprised 50 cones from each tree species. Since a high proportion of the cones of *P. contorta* were infested with *Pissodes validirostris*, cones of this tree species were taken at random, but only cones containing pine cone weevils were collected from Scots pine. The cones were stored in plastic bags at —18 °C. In the laboratory they were dissected and the specimens of *P. validirostris*, in various stages of development, were preserved in 75 % alcohol. The width of the head capsule of each larva was measured to the nearest 0.01 mm with a Wild M 20 microscope. Observations on the various developmental stages in other localities were based on several separate cone samples.

331. Egg

The egg of the pine cone weevil is ovoid, white and opalescent. The mean length of the 30 eggs measured was 0.78 mm ± 0.01 (range 0.62 mm to 0.86 mm) and the mean width 0.56 mm ± 0.01 (range 0.45 to 0.67 mm).

According to Eckstein (1897), the pine cone weevil usually deposits one egg, rarely two or three, in one puncture. Kangas (1938) stated that there is always one egg in a puncture, but a female may lay two or three eggs in the same cone, although this is uncommon. In *Pinus pinea* there may be 40 eggs in one cone and they hatch in 10—15 days (Romanyk & Bachiller 1965).

In the course of the present study not a single puncture was found which contained more than one egg, although the number of egg punctures inspected was 5220. A female may deposit several eggs in one cone, however, and the egg cavities may be situated very close to each other. There were great difference between *Pinus silvestris* and *P. contorta* concerning the number of eggs laid in a cone. In Scots pine there were 3.1 eggs per cone, with a maximum of 10, but in lodgepole pine 20.6 eggs per cone, with a maximum of 51 (Fig. 5). These values are based on samples collected in late June and early July. Samples taken earlier could not be used, since oviposition was still in progress. Cones collected after mid-July were so much destroyed by the larvae that the number of egg punctures could not be counted accurately. In cones collected in late June or early July many larvae had already hatched from the eggs, but this did not interfere with the counting of egg punctures, because the tunnels of the larvae originating from them were quite easy to trace.

Although oviposition of *P. validirostris* may be interrupted by cold weather for a relatively long period in May, the date when the first eggs

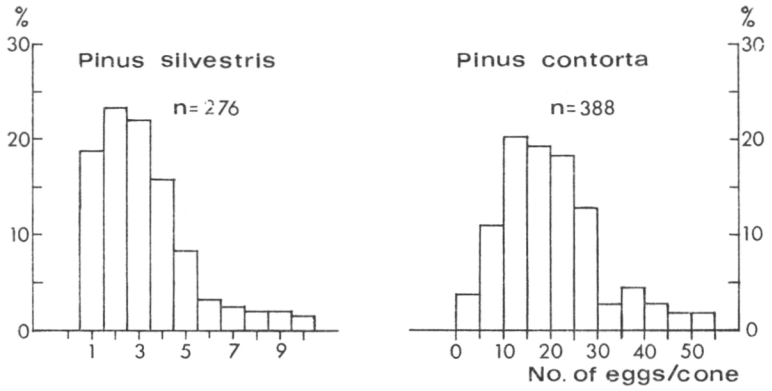

Fig. 5. Frequency distribution of the degree of infestation of the cones according to the numbers of eggs of *Pissodes validirostris*.

are found must be taken as the start of the egg period (Fig. 6). The end of the egg period is much more difficult to determine, because the eggs do not all hatch, yet they remain undamaged for a relatively long period. However, the egg period was assumed to be over when no more developing eggs were found.

The length of the egg stage was not investigated, but the time from the first egg to the first larva ranged from 22 to 29 days. The hatching time evidently depends on temperature, so that eggs deposited at the end of the oviposition period develop in a much shorter time than the first-laid eggs.

Observations on the egg stage of other *Pissodes* species have been made by many authors (e.g. Altum 1876, Pauly 1892 a, Gerlach 1898, Salman 1935, Drouin et al. 1963, Stark & Wood 1964, Johnson 1965, Carle 1967, Bliss & Kearby 1970). Eggs of *Pissodes* species breeding in stems can be found for a very long period. On the other hand, eggs of shoot-infesting species occur during quite a short time, — from May to early July.

In regard to the egg stage the pine cone weevil resembles those *Pissodes* species that attack leaders. This is obviously due to the similarities between cones and shoots.

332. Larva

Larvae of *P. validirostris* had formerly been found in Finland on 23 March, 2 and 18 April, 14 August and 10 October (Linnaniemi 1920, Kangas 1935, 1938). Probably these were full-grown larvae. It seems to me certain that some, at least, of these larvae were parasitized. In Germany mass feeding of larvae occurs in June and July, and mature larvae and pupae can be found in August (Altum 1886, Eckstein 1906).

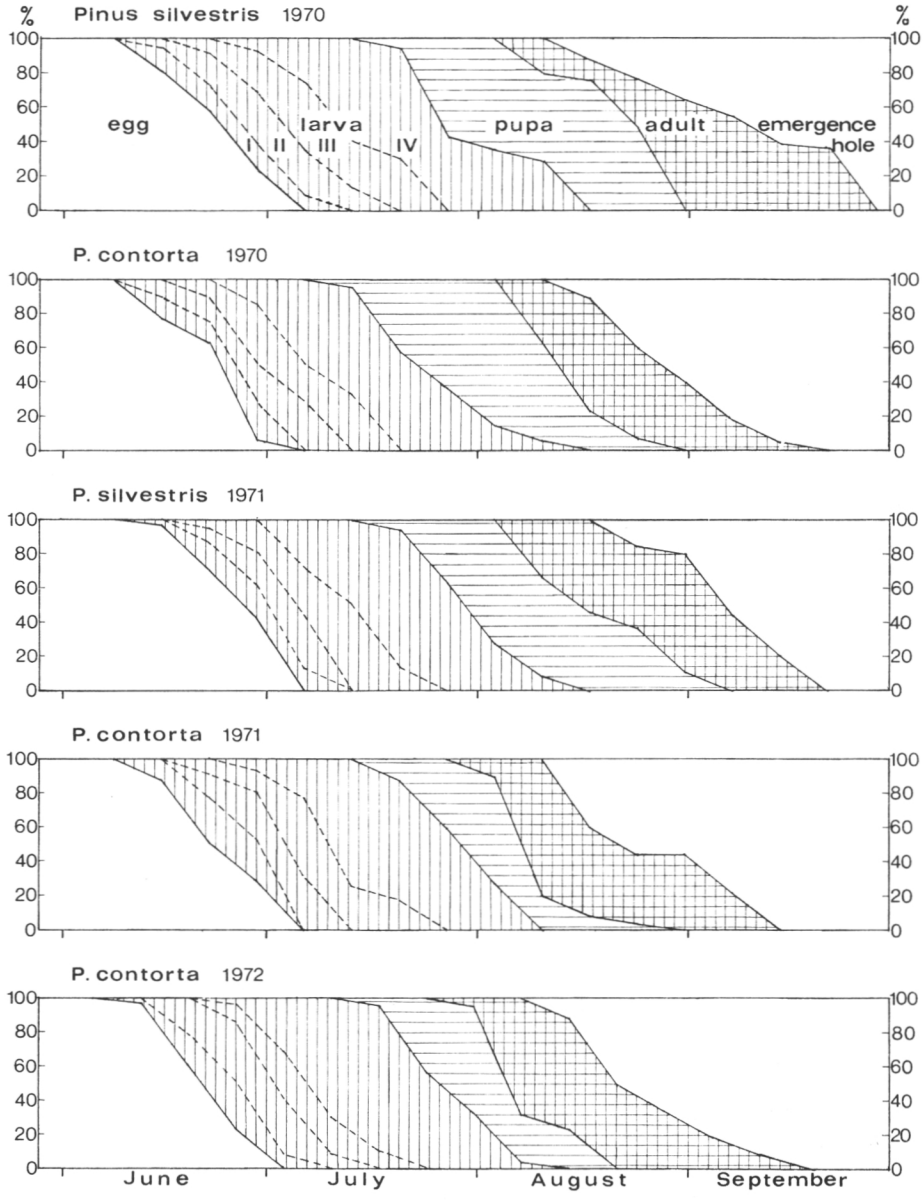

Fig. 6. Percentages of the various developmental stages of *Pissodes validirostris* in the cones of *Pinus silvestris* and *P. contorta*.

In this study the first newly hatched larvae of the pine cone weevil were found in the field in the first half of June (Fig. 6). In early July the new generation consisted exclusively of larvae, and these were common until the first week of August. Some larvae were also found in cones collected in

autumn, but most of them were parasitized. These parasitized specimens are not included in Fig. 6. At Tuusula healthy, overwintering larvae were found only a few times during the study.

Although the time of occurrence of the larvae of various stem-infesting *Pissodes* species has not been investigated in Finland, there are numerous records of larvae. Half-grown larvae of *P. notatus* and *P. pini* have mostly been found in summer, and mature larvae in autumn and early spring (Elfving 1905, Furuhjelm 1905, Saalas 1923, Kangas 1931, 1934 b, 1934 c, 1938). Immature larvae of *P. piniphilus* and *P. harcyniae* have been observed all the year round.

Several special investigations and many separate records of larvae of various *Pissodes* species have been published (e.g. Nüsslin 1897, Grujic & Milanovic 1963, Stevenson 1967). The larvae of *Pissodes* species breeding in shoots in North America occur from May to September. In *P. terminalis*, which breeds in the young leaders of various conifers, the larvae occur in June and July in Canada (Drouin et al. 1963).

Thus the pine cone weevil differs considerably from the other Finnish *Pissodes* species in the seasonal occurrence of the larvae. In this respect *P. validirostris* is very similar to *P. terminalis*.

The frequence distribution of larval head-capsule widths indicates 4 instars (Fig. 7). Since no difference was found between larvae from *Pinus silvestris* and *P. contorta*, the data were combined. The growth of the head-capsule shows a progressive geometric increase closely approximating to Dyar's rule, according to which the ratio of the width of one instar to that of the next tends to be constant throughout development (in this case the ratio is about 1.5). After measurement of the head-capsule width all larvae except the small ones (first and second instars) were dissected and searched for larvae of an endoparasite. The parasite in question is *Eubadizon atricornis* Ratz., which will be discussed in section 6. Parasitized larvae were separated from healthy ones and their head-capsule widths are presented in Fig. 7 with a hatched polygon. In the figure some parasitized larvae may have been included among the healthy third-instar larvae, because the larvae of the parasites are very small and difficult to detect until the host larva is full-grown. It is evident that most of the data of parasitized larvae in Fig. 7 refer to the last instar. In a parasitized larva the head-capsule is appreciably smaller than in an unparasitized larva of the same instar.

Hierholzer (1954) reported that *Pissodes piceae* has 5 larval instars, but Haeselbarth (1962) demonstrated that there are only 4. Many other *Pissodes* species also pass through 4 instars during larval development (*P. notatus*, *P. sitchensis*, *P. engelmanni* Hopk., *P. terminalis*, *P. approximatus* Hopk.). *P. strobi* sometimes has 5 larval stages, although the normal number is 4 (Harman 1970). According to Kishi (1971), it is very

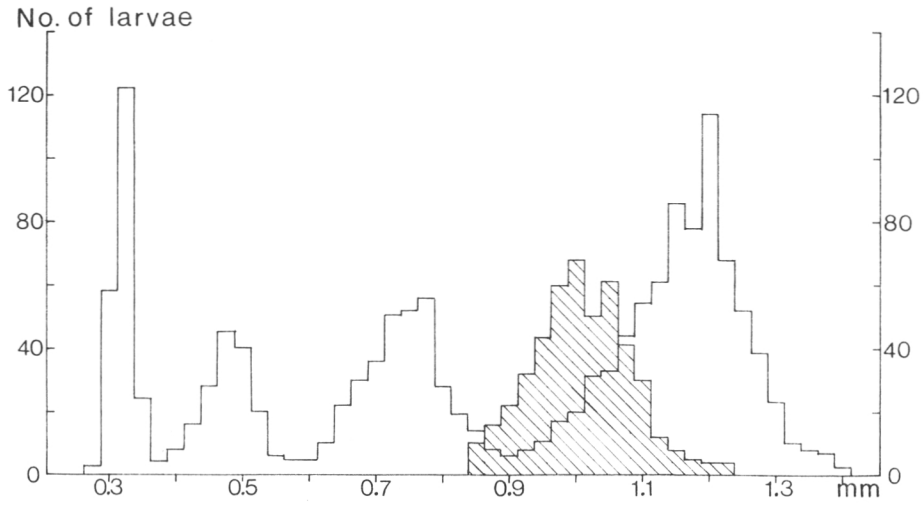

Fig. 7. Frequency distribution of the head capsule widths of the larvae of *Pissodes validirostris*. White polygon = healthy larvae, hatched polygon = parasitized larvae.

difficult to determine the number of larval instars of *P. nitidus* Roel. by measuring head-capsule widths, because the frequency distribution does not show any clear separation of the instars. However, in rearing experiments he found that *P. nitidus* has 4 larval instars.

Larvae of *P. piceae* parasitized by *Eubadizon* (*Brachistes*) *atricornis* are somewhat smaller than healthy ones (H a e s e l b a r t h 1962). Parasitic larvae influence the size of some Lepidopterous larvae, too (M c G u g a n 1955). The possible influence of parasites must be taken into account if the number of larval instars is determined from the frequency distribution of head-capsule widths.

The seasonal occurrence of the various larval instars proved difficult to determine, since larval mortality was very high during the first three instars. The dead larvae did not decay for a relatively long time, and as the cones were examined after storage at —18 °C it was very difficult to distinguish these dead ones from those that were alive at the moment of cone collection. The commencement of the seasonal occurrence of each larval instar can be determined quite easily. The development of larvae was at first so rapid that samples taken once a week did not afford a very exact picture of the beginning of the seasonal occurrence of the first two instars. Larvae were classified by head-capsule width as follows: first instar ≤ 0.39 mm, second instar 0.40—0.59, third instar 0.60—0.89 and fourth instar ≥ 0.90 mm. It is noteworthy that the fourth larval stage lasted as long as the other instars together.

If many larvae are present in one cone, a study of the life history of the individual larva is greatly hampered, since the cone is destroyed in a relatively short time. Therefore, observations on the biology of a larva were based on cones of *Pinus silvestris*, as these often contained only one larva. No differences in habits were noted between larvae feeding on Scots pine and on lodgepole pine.

After hatching, the larva burrows into the tissue of the cone scale through the side of the egg cavity. Initially it mines close to the surface of the cone scale, so that the tunnel is visible as a dark stripe under the epidermal tissue. When the larva makes its way from one scale to another, small holes are formed through which frass is extruded. The larva may start to tunnel in any direction, but typically it begins to circle the cone round the longitudinal axis. The first moult takes place at the time when the larva has bored from the egg cavity to the opposite side of the cone. The larva mines quite near the surface of the cone during the second-instar phase, too, often coming very close to its starting point. In *Pinus silvestris* resin is often pressed out from the tunnel, so that a telltale band of crystallized pitch is formed round the cone. Such a resin band is very seldom seen on the cones of *P. contorta*.

After incircling the cone and moulting a second time, the larva makes its way towards the inner part of the cone. In the beginning of the third instar the larva feeds on the scales at the tip of the cone, and at the end of this stage it starts to consume seeds. During the last instar the larva eats seeds and the basal parts of cone scales. The full-grown larva excavates a wide pupal cavity, which is often situated partly or wholly in the axis of the cone. The pupal chamber is not lined with wood fibres like those of other *Pissodes* species.

According to Romanyk & Bachiller (1965), the larvae of *P. validirostris* burrow into the cones of *Pinus pinea* to feed on the seeds, causing heavy exudates of resin, by which infested cones may be recognized in late June. In the pine cone weevil the habits of the larvae show several specific features, which are probably due to the great difference between the breeding sites of this and the other *Pissodes* species (e.g. construction of the chamber, regularity of the seasonal occurrence).

333. Pupa

According to Eckstein (1906), pupae of the pine cone weevil occur in Germany in August and an individual pupal stage lasts from 12 to 14 days. In Spain pupation starts in the cones of *Pinus pinea* in mid-August, but pupae are most frequent at the end of that month (Romanyk & Bachiller 1965). In Tyrkey, too, transformation from larva to pupa takes place in August (Canakcioglu 1959, 1969).

The first pupae of *P. validirostris* were observed in the field in mid-July (Fig. 6); the earliest date was 13 July. Either full-grown larvae or newly eclosed adults were found at the same time as pupae. The relative abundance of pupae was greatest (60—80 % of the total number of the specimens in the cones) in early August. The last healty pupae were found at the end of August, so the pupal period lasted a good month. The time from the first pupae to the first adults ranged from 14 to 28 days.

Although observations on the pupae of other *Pissodes* species (*P. notatus*, *P. pini*, *P. piniphilus*, *P. harcyniae*) have been made in Finland during the summer (31 May—21 August) (Elfving 1905, Furuhjelm 1905, Saalas 1923, Kangas 1931, 1934 c, 1938), the pupal period is considerably longer in these weevils than in *P. validirostris*. In North America larvae of the *Pissodes* species that breed in the leaders start to pupate in July, but pupae are most abundant in August and the pupal stage is over in September (Belyea & Sullivan 1956, Stark & Wood 1964, Stevenson 1967, Silver 1968). Pupal development generally lasts about 2 weeks.

In the seasonal occurrence of the pupae, the pine cone weevil differs from the other Finnish *Pissodes* species, instead resembling the North-American species which breed in the leaders. Pupal development in individuals of *P. validirostris* requires about 2 weeks.

334. Adult

There are very few records of the emergence of the pine cone weevil in Finland. Linnaniemi (1920) mentioned that an imago emerged from an old cone on 20 July. Kangas (1938) reared one adult from a cone of *Pinus contorta* on 27 October.

In Germany, according to Eckstein (1909), adults of *P. validirostris* leave the cones in October. In England Crooke (1948) found new imagos in early July, but no adults emerged from the cones until the end of the month. In Spain emergence begins in early September (Romanyk & Bachiller 1965).

In the present study the first new adults of *P. validirostris* were found in cones collected in the beginning of August; the earliest date was 31 July. After eclosion the adult remains in the pupal cavity for a few days until its cuticle has hardened, and then starts to bore a tunnel directly to the outer surface of the cone. Since the larva usually lies in the pupal chamber with its head directed outwards, the adult has the shortest possible way out from the cone. If the pupal cell is situated in the cone axis the emerging adult often cuts the stem of the cone, with the result that the cone drops to the ground.

The first emergence holes were observed in the field 1 or 2 weeks after the first new adults were found inside the cones. As the interval between cone collections was 1 week, it seems that hardening of the cuticle and emergence require about a week. Most specimens of the new generation had reached the adult stage by late August and most of the weevils had left the cones by mid-September.

For a study of the seasonal occurrence of emergence, cones of *Pinus silvestris* and *P. contorta* were collected at Tuusula in mid-July (15 July 1971). The cones were stored in plywood breeding boxes (cf. p. 7) in the forest and the boxes were inspected once a week. Cones of Scots pine gathered at Punkaharju on 29 July 1971 were brought to Tuusula for breeding experiments. Emergence began earlier from the cones of *P. silvestris* collected at Tuusula than from those gathered at Punkaharju (Fig. 8). Probably the development of the new generation had progressed a little further at Tuusula than at Punkaharju at the time of cone collection. Weevils emerged from the cones of lodgepole pine somewhat earlier than from those of Scots pine.

In the cones collected at Tuusula 32.7 % of the specimens did not emerge during the first summer, but passed the winter in the larval stage and emerged the following year. In the cones gathered at Punkaharju the corresponding propotion was only 2.4 %. The reason for the difference was evidently that the cones were collected at different times. The former percentage must be considered exceptionally high, since healthy overwintering larvae were seldom found in southern Finland during the present study. Conditions in the boxes probably differed considerably from those in the field, and this may have affected larval development. It was clear that these experiments did not give a true picture of emergence, and they were not repeated in later years.

The subsequent history of the weevils that hibernated in the larval stage was studied at Tuusula in 1972 and 1973. Cones of *P. silvestris* were collected for the breeding experiments in the following localities: Tuusula on 15 July 1971 and on 6 July 1972, Jämsänkoski on 5 September 1971, Jurva on 27 December 1971. These cones were transferred to the boxes, which were kept in the forest during the winter and the following summer. In addition to the above-mentioned experiments, the weevils were reared from cones of the previous year collected at Tuusula on 28 June 1971.

Because cones infested with *P. validirostris* usually fall to the ground during the autumn or winter, the development of the weevils in the boxes took place under more or less natural conditions. The results of the experiments appear in Fig. 9.

The cones of the previous year collected at Jurva on 15 July 1972 contained six freshly cut emergence holes, three just emerging weevils and one

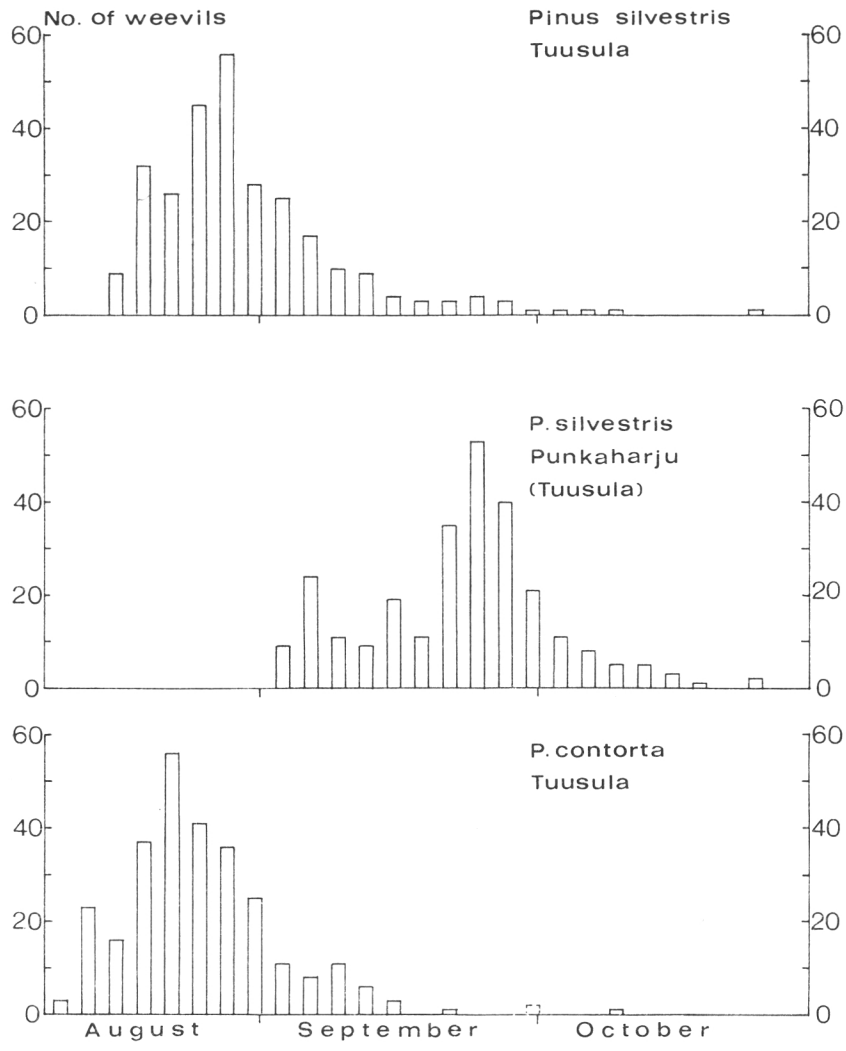

Fig. 8. Emergence of the new generation of *Pissodes valiairostris* from cones stored in breeding boxes. Tuusula 1971.

newly eclosed adult in the pupal cavity. In the same locality a light yellow adult was detected in an old cone lying on the ground on 10 August 1971. At the same time there were two pupae in a second-year cone.

Breeding experiments and observations in the field indicate that the specimens which spend the first winter in the larval stage emerge from the cones relatively late, — only about a month earlier than the specimens of the current year.

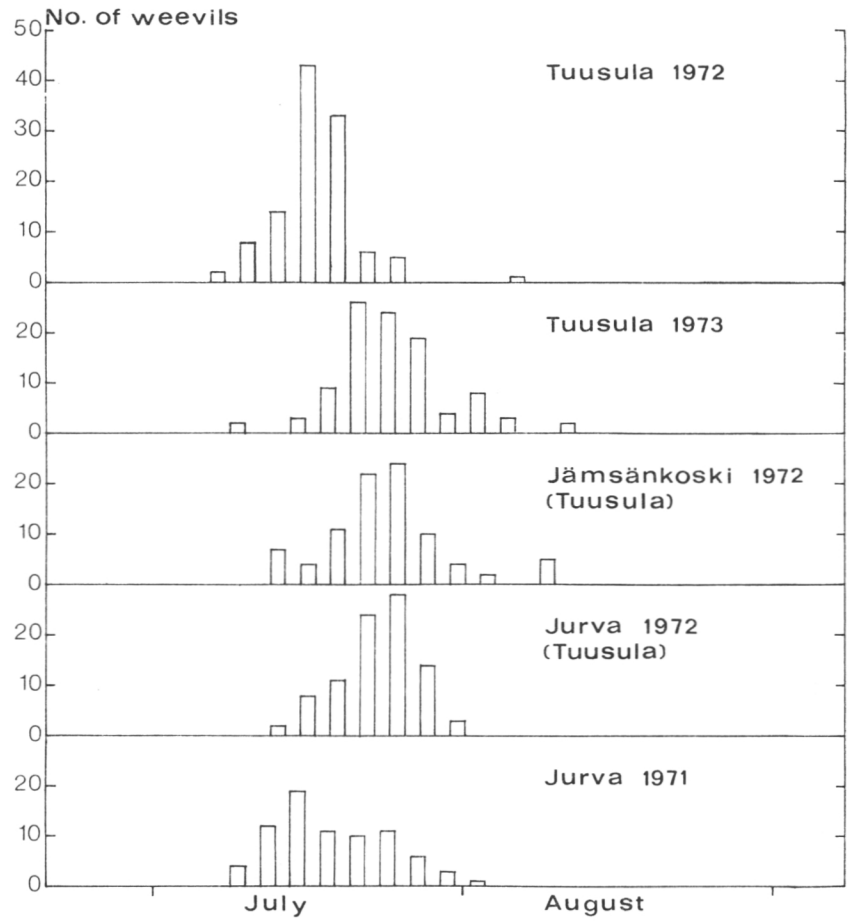

Fig. 9. Emergence from cones of *Pinus silvestris* of the adults that overwintered in the larval stage.

Not much information is available in the literature on the emergence of other *Pissodes* species in Finland. Most observations relate to July or August (Saalas 1923, Kangas 1931, 1934 c, 1938, 1957). Kangas found freshly abandoned pupal chambers of *P. notatus* on 2 June and adults of *P. pini* lying in the pupal cavity on 20 September.

In the present study only one adult of *P. validirostris* usually emerged from a cone of *Pinus silvestris* (Fig. 10 a). However, cones with 2 or 3 emergence holes were not rare (max. 8). The average number of weevils that emerged from one cone of *P. silvestris* was 1.24 (range for samples from different localities 1.08—1.40). Most weevils originated from cones which yielded only one adult (Fig. 10 b).

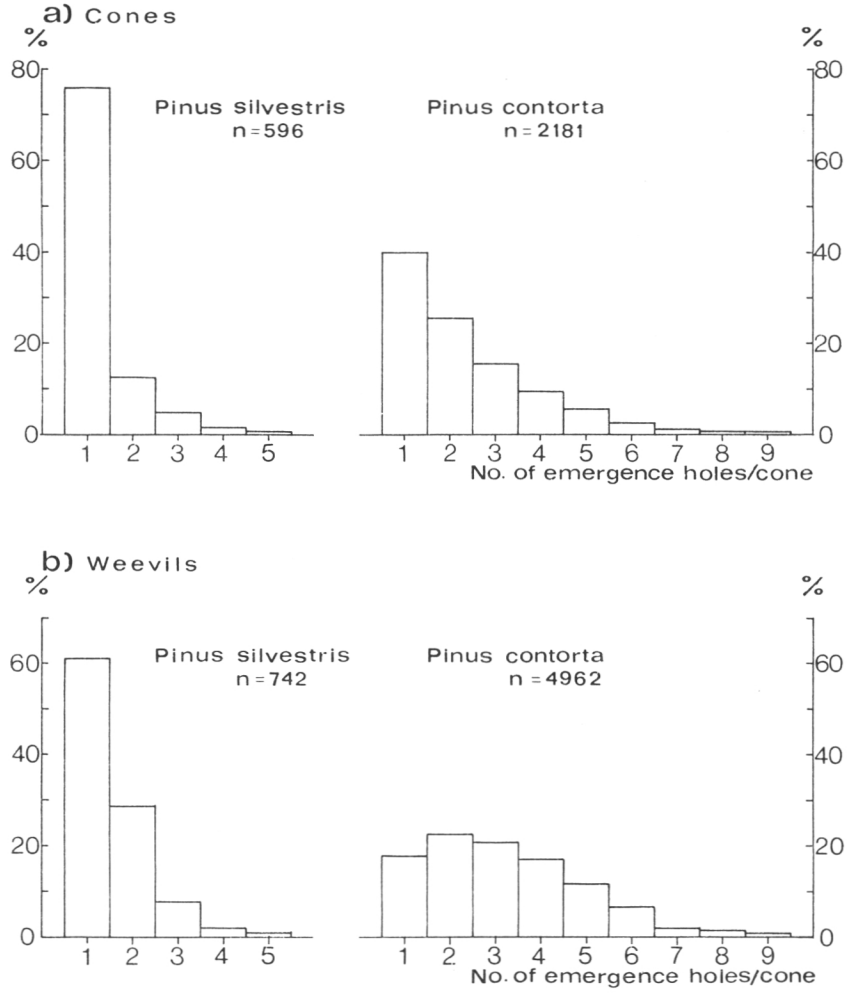

Fig. 10. — a) Frequency distribution of weevils in cones which actually yielded adults according to the average numbers of emergence holes. — b) Frequency distribution of adult weevils according to the numbers of emergence hole per cone.

In *Pinus contorta* 60 % of the cones contained more than one emergence hole (Fig. 10 a), and there were sometimes as many as 13 holes in one cone. Infested cones yielded an average of 2.28 adults; means ranged from 2.04 to 2.44 in the different years. About 80 % of the weevils came from cones that contained more than one emergence hole.

According to previous investigations, one cone of *Pinus silvestris* usually contains one larva of *P. validirostris*, and occasionally 2 or 3 (Kangas 1938, Kudela 1974). Eckstein (1906), on the other hand, found as many as 8 pupae in one cone. Bachiller (1966) reported that 1 to 4

adults usually emerge from one cone of *Pinus pinea*, and exceptionally as many as 7. In Poland according to Krol & Michalski (1961), one cone of *Pinus contorta* produces from 1 to 5 adults, with a mean value of 2.

On emerging from the cones, the young weevils of *P. validirostris* seek the shoots of the current year for feeding. The appearance of small clear resin droplets on these shoots in late August indicates the attack of adults of the new generation. Feeding continues throughout the late summer and early autumn, after which the weevils begin to seek overwintering places. The new adults of many *Pissodes* species were observed to start feeding on shoots and buds immediately after emergence (e.g. Nüsslin 1897, Silver 1968). Kangas (1931), however, stated that *P. notatus* does not feed in autumn.

The time from the commencement of oviposition to the observation of the first adults was 90 days in 1970 and 1971, and 71 days in 1972. The times from the start of oviposition to the beginning of emergence were 97, 104 and 78 days, respectively. Since the development of the first-deposited eggs takes place at a relatively low temperature (in May), the value obtained in 1972 (no eggs were observed until 21 May) indicates most accurately the individual time of development from egg to adult. If hibernation takes place in the larval stage, development requires at least a year.

The total developmental time of *Pissodes* weevils takes from 2 to 4.5 months in Central Europe, but if the individual overwinters in the larval stage development from egg to adult requires from 8 to 11 months (Pauly 1892 a, MacDougall 1898 b, Hierholzer 1954). The duration of development in *P. notatus* is 55 days at 25 °C (Carle 1967). The total length of development in North-American *Pissodes* species varies from 2 to 4 months (Graham 1926, Finnegan 1958, Stevenson 1967). The rate of development is naturally influenced by the prevailing weather conditions. According to Nüsslin (1897), the length of development of small *Pissodes* species is shorter (*P. piniphilus* 2 months) than that of larger species (*P. pini* about 3.5 months).

Compared with other *Pissodes* weevils, the pine cone weevil develops from egg to adult in a relatively short time. However, the rate of development is greatly influenced by environmental factors such as temperature and humidity, and these affect cones quite differently from stems lying on the ground.

34. Overwintering

Kangas (1938) supposed that pine cone weevils mostly pass the first winter in the larval stage, a few new adults emerging in late autumn. In Spain pine cone weevils move from the crown of the tree in autumn to the

base or into the surrounding litter when the weather grows cooler (Cuevas & Bachiller 1969, 1970).

In southern Finland, as mentioned earlier, most specimens of the new generation emerged from the cones before the winter and healthy overwintering larvae were found only exceptionally. Of 107 specimens found at Tuusula in autumn 1974, however, 25 % were in the larval stage on 19 September. The exceptionally high proportion of overwintering larvae was obviously due to the cold, rainy summer of 1974. The samples collected in late autumn included some pupae, too, but these were all dead. Thus it appeared that in southern Finland the pine cone weevil normally hibernates as the adult. In central and northern Finland, in contrast, the first winter is passed in the larval stage.

It would be possible for adult weevils to reach the overwintering sites (at the bases of trees or in litter on the ground) by flying, dropping or crawling down the trunk. The first alternative is hardly likely, since the flying activity of weevils is very low in late summer and autumn. The second alternative was studied by setting up plastic funnels 1 m in diameter under lodgepole pines in 1970 and 1971 (Fig. 11). For the purpose of catching crawling weevils, flanged plastic hoops coated with tanglefoot were fastened with nails on the trunks of lodgepole pines (Fig. 12). The traps were set up in early July and inspected once a week. Weevils caught in the traps were dissected in the laboratory for determination of sex and age. Since the reproduction organs of the new adults were incompletely developed in autumn, specimens that had emerged in the current year were easy to distinguish from those of earlier generations.

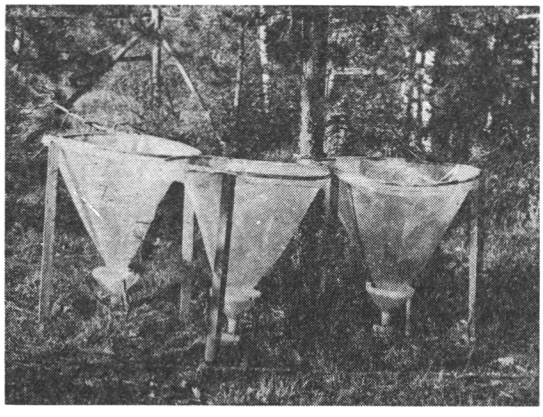

Fig. 11. Plastic funnels for collecting any weevils that dropped from the trees. — Photo E. Annila.

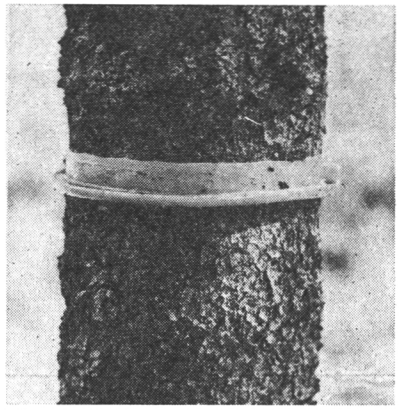

Fig. 12. Tanglefoot hoop trap for catching adult weevils creeping down the stem in autumn. — Photo E. Annila.

Some of the older weevils began to creep down the trunks quite soon after oviposition (Fig. 13). Weevils were to be found under the bark scales at the bases of the trees from mid-July. The adults of the new generation, however, only started to leave the shoots when the temperature sank close to 0. °C. Evidently, they continued to build up a reserve of nutrients for hibernation until cold weather force them to seek shelter. Weevils were

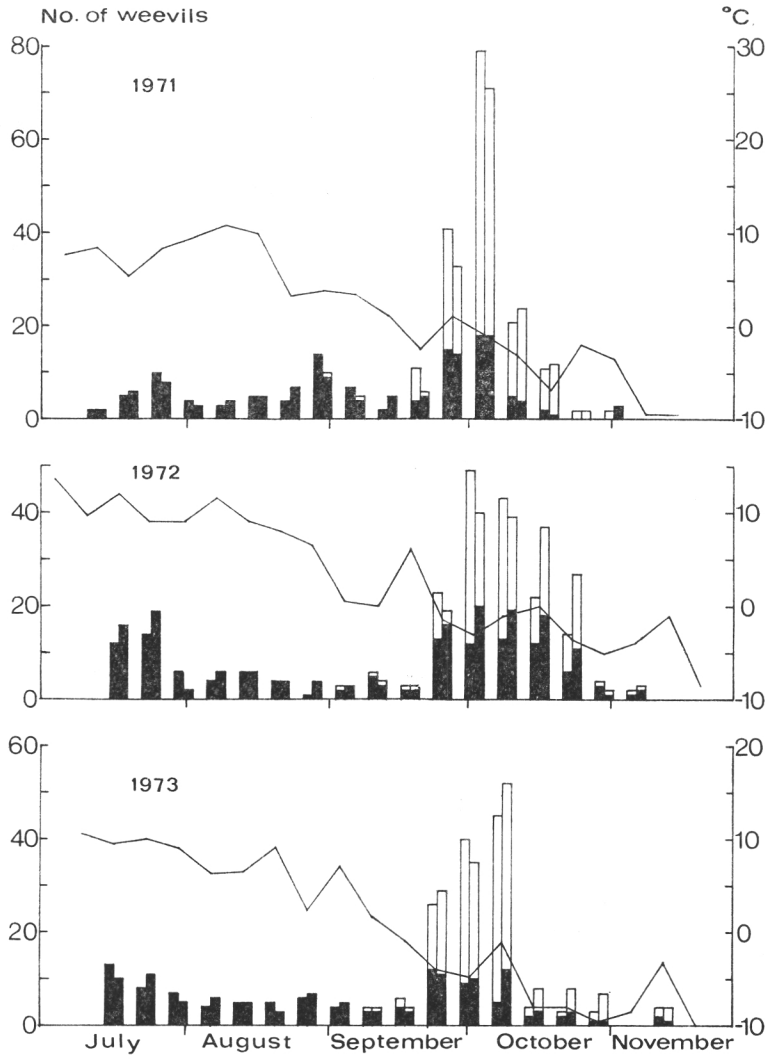

Fig. 13. The numbers of *Pissodes validirostris* trapped with tanglefoot hoops. — Black columns = old specimens, white columns = young specimens, left part of the column = females, right part of the column = males, solid line = minimum air temperature measured at 7-day intervals.

caught in the funnel traps only in late September and early October. The numbers of weevils in these traps were very small.

In 1971 weevils were collected from one lodgepole pine both with tanglefoot-coated hoops and with 3 funnel traps. The funnels covered an area of 2.4 m^2, and the crown of the tree projected over the ground for an area of 7.1 m^2. The funnels caught 26 weevils, and the corresponding number of specimens calculated for the area covered by the crown is 77; the tanglefoot hoops trapped 346 weevils. Accordingly, 82 % of the weevils crept down the trunk. Although investigations were carried out only on one tree, the results of the experiment show that most weevils move from the crown to their overwintering places by crawling down the stem. This view was supported by other observations, in which the numbers of weevils caught by tanglefoot hoops were much greater than the numbers trapped in funnels.

In November, when no further weevils were being caught, all the new cones were collected from the tree. From the number of emergence holes in the cones it was possible to calculate how many new adults had been produced by this tree. There were 435 emergence holes and 187 young weevils were caught with the tanglefoot hoops. Accordingly, 43 % of the young weevils were caught by this method.

Some of the weevils overwinter under the bark scales at the base of the tree just at the level of the litter layer. Usually, they aggregate as small groups of 3 to 6 specimens. Hibernating specimens are also to be found in the litter round the base of the tree, where they cling to pine needles, bits of twig, etc. Weevils were collected from the bases of two trees and from the litter within a 10 or 50 cm radius of the trunks, on 26 September 1971. They were gathered from the crevices in the trees with a knife and tweezers. Litter from round the trees was collected in boxes and brought to the laboratory, where the weevils emerged. Every specimen found was dissected for age determination. The results were as follows:

Hibernation place	Tree no. 1			Tree no. 2		
	number of weevils					
	old	new	total	old	new	total
trunk	15	3	18	17	5	22
litter						
0—10 cm radius	33	2	35	33	7	40
11—50 cm radius	17	14	31	12	14	26
total	65	19	84	62	26	88

Collection of weevils from the bases of the trees was both difficult and time-consuming, and unquestionably the weevils hiding there were not all observed by the collector. The proportion of young weevils was greatest in the belt farthest from the tree. Comparison of the catches of moving and

hibernating adults shows that some of the weevils that crawl down the stem do not remain on the trunk but enter the litter.

K a n g a s (1931, 1934 c, 1938) reported that *P. notatus*, *P. pini*, *P. piniphilus* and *P. harcyniae* overwinter in the larval or adult stage in Finland. He supposed that *P. notatus* may also hibernate in the pupal stage or as a new adult in the pupal chamber. The North-American *Pissodes* species principally overwinter in the adult stage, although sometimes as larvae (D r o u i n et al. 1963, M a r t i n 1964, B l i s s & K e a r b y 1970). S i l v e r (1968) reported that the larvae of *P. sitchensis* are very likely to perish during the winter. He did not suggest any cause for the death of the larvae, but possibly they were parasitized. Pupae of *P. terminalis* may also occur in late autumn and winter, but probably die during the winter (S t a r k & W o o d 1964).

The adults of many *Pissodes* species hibernate in the moss layer or litter, or in crevices in the bark at the bases of trees. On Vancouver Island in Canada the adults of *P. strobi* mostly pass the winter in the trees on the undersides of the lateral shoots (M c M u l l e n & C o n d r a s h o f f 1973).

Very little is known about the time when the adult weevils move to the hibernation places, the general view being that cold weather forces them to seek overwintering sites in autumn (F i n n e g a n 1958, D i r k s 1964). G r a h a m (1926) reported that *P. strobi* may start to enter winter quarters even before the weather has turned cold. There is also little information about the manner in which the adult weevils reach the overwintering sites. The adults of *P. sitchensis* drop down into the debris of the forest floor (W r i g h t 1960), but *P. engelmanni* crawls down the stem (S t e v e n s o n 1967).

The adults of *Pissodes* weevils may retreat to sheltered quarters quite early in summer (O l l i e u 1971). Imagos of *P. notatus* become inactive and start to seek shelter when the air temperature exceeds 34 °C (C a r l e 1967). H e l l e n (1928) observed an adult pine cone weevil at Terijoki, in the Karelian Isthmus, on 27 August under a bark scale of *Pinus silvestris*. It appears likely that after oviposition these weevils show restricted activity in mid- and late summer, staying in bark crevices at the bases of the trees.

4. LENGTH OF THE LIFE-CYCLE

K a n g a s (1938) believed that in Finland the life-cycle of *P. validirostris* is one year or somewhat longer. A l t u m (1886) and E c k s t e i n (1906) stated that the pine cone weevil has one generation a year in Germany. M j ö b e r g (1909) wrote that in Gotland *P. validirostris* lays eggs in summer, and overwinters as the half-grown larva, which feeds again the following spring; pupation takes place in early summer, and new adults emerge from the cones in mid-summer or a little later. M j ö b e r g's idea of the development and life-cycle of the pine cone weevil appears to have been based on specimens which hibernated in the larval stage. In Turkey and in Spain *P. validirostris* is univoltine (C a n a k c i o g l u 1959, C u e v a s & B a c h i l l e r 1969, 1970).

The length of the life-cycle depends not only on the total length of development but also on the time required by the new adults to reach sexual maturity. As pointed out in the previous section, adults of the new generation caught with tanglefoot hoops in autumn were not sexually mature. The developmental state of the reproductive organs of weevils collected with tanglefoot bands in spring was studied by dissection. The females were divided into two groups, old and new, according to whether they had *corpora lutea* in the ovarioles or not. Those which had fully developed ovarioles, mature oocytes, or sperm in the *receptaculum seminis* were also classed as old. Females which had poorly developed reproductive organs were regarded as young. It was relatively easy to sort the females according to the state of their reproductive organs, since intermediate forms were rare. The males could also be divided into two clearly separate groups on the basis of gonad size (Fig. 14). The scales on the elytra wear off during the life of the weevil; this fact was also utilized in age determination.

The proportion of young weevils was lower at the beginning than at the end of the spring emergence from winter quarters (Fig. 15). Every year a strikingly high proportion of the weevils were old specimens (in 1971 61.5 %; 1972 73.3 %; 1973 71.6 %). From the condition of the scales, it was inferred that the old specimens did not represent a uniform group; the scaly covering of some individuals had not worn off, but others had lost their scales almost

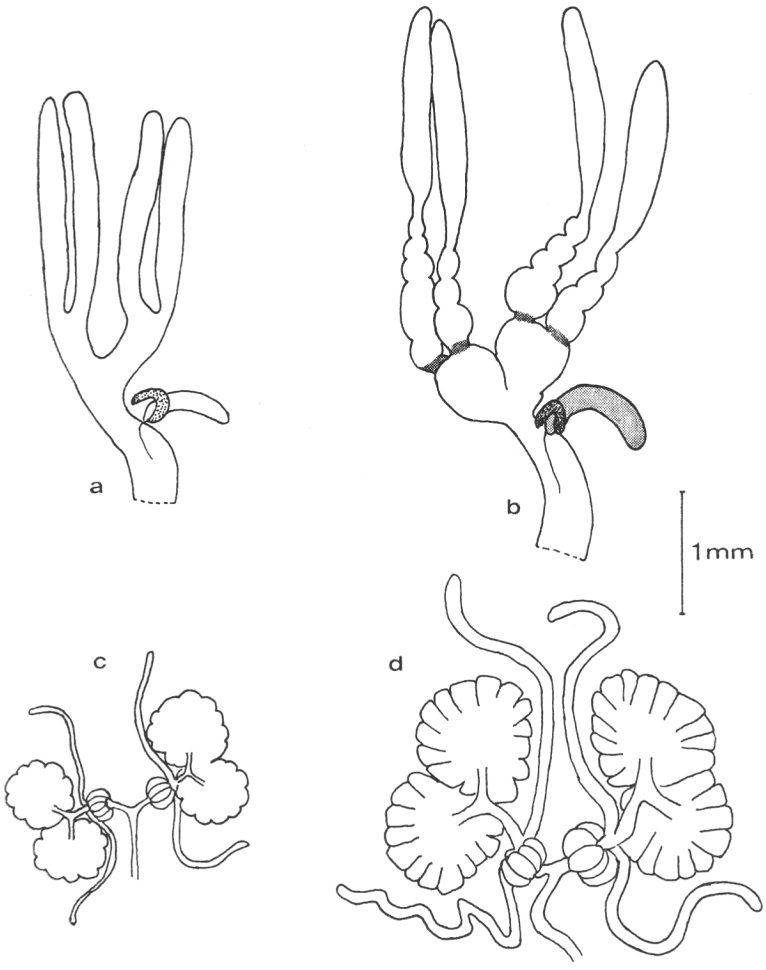

Fig. 14. Schemes of the reproductive organs of adult weevils collected with tanglefoot bands on 12 May 1971. — a) young callow female, b) old mature female, c) young callow male, d) old mature male. *Receptaculum seminis* stippled. — Orig.

entirely. Very probably, the old weevils consisted of specimens that had bred in 2 or even 3 successive years. Accordingly, the oldest specimens were nearly 4 years old. The weevils that had emerged the previous year were not sexually mature in spring.

The maturation of the gonads of newly eclosed adults was studied in the following experiments, carried out in 1971—1972. Young weevils were released into cheese-cloth bags on Scots pine twigs in August immediately after they emerged from the cones. The twigs were cut in the beginning of October and all the weevils were collected. A sample (50 specimens) was

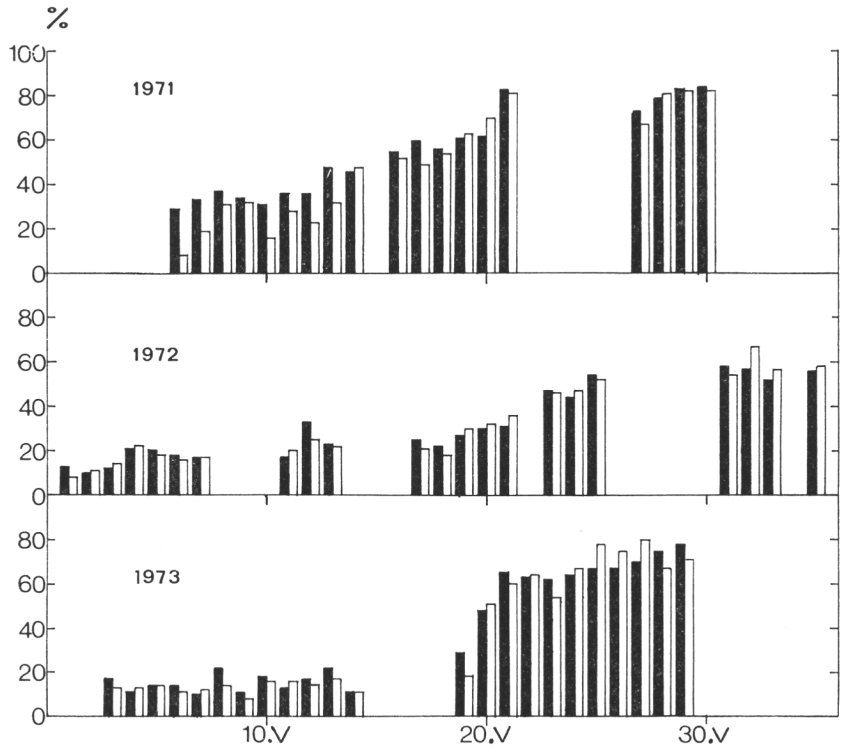

Fig. 15. Callow adults (emerged the previous year) as percentages of the total numbers of weevils trapped with tanglefoot bands in successive springs. Balck columns = females, white columns = males (cf. Fig. 3).

brought into the laboratory for determination of gonad development. The rest were left in the forest enclosed in small breeding boxes, which were buried in the litter. Dissection of the weevils brought into the laboratory revealed no development of gonads. The reproductive organs of these weevils did not differ in any way from those of newly emerged specimens.

The following spring (10 May) some of the weevils from the boxes were taken into the laboratory and fed on fresh pine twigs. 20 weevils were dissected every week. The first mature females were found after 4 weeks. Determination of maturation was based largely on the females, since development is much easier to observe in the ovarioles than in the testes. The rest of the weevils that had overwintered outdoors were caged on pine twigs again. These weevils were brought into the laboratory on 24 May, and 7 and 21 June. Immediate dissection of the first two groups revealed slight ovariole development. Only the last group included some sexually mature specimens. There was very great individual variation in maturation rate both in the laboratory and in the forest.

For a study of the seasonal maturation of the new adults after hibernation, weevils were caged on lodgepole and Scots pine twigs bearing new cones. Both pine species were represented by three trees, each furnished with five bags. 2 females and 2 males were released into each bag on 26 May 1972 (total 120 weevils). The cones in the bags were collected on 4 October. The weevils had excavated punctures in all the cones but there were no larvae, pupae or adults in the cones. In the bags there were 33 living females, but as their ovarioles did not contain *corpora lutea* none of them had laid eggs. However, the ovarioles were fully developed, showing that the females had become mature by autumn.

The arrangements of the experiments presented above may have influenced the behaviour of weevils. In the following test the possibility of such an effect was eliminated. Callow adults marked with yellow paint on the elytra were released on the bases of 4 lodgepole pines, 50 specimens on each, on 12 May 1972 and assumed to crawl up into the crowns. Tanglefoot hoops (Fig. 12) were fastened round the trunks on 4 July to catch the marked weevils that would soon crawl down the stem. 70 marked weevils, equal numbers of males and females, were entangled in the traps during the summer and autumn. Dissection revealed that the gonads of these weevils were fully developed, but only 4 females had signs of *corpora lutea* in the ovarioles, i.e. had deposited eggs.

Evidently, most weevils that emerged the previous year become mature so late the following summer that the oviposition period is already over. The cones have become so hard that the females are no longer able to lay eggs in them (cf. p. 16). Together, the above-mentioned observations strongly suggest that the females cannot effectively deposit eggs until the second year after they emerge from the cones. They are then nearly 2 years old. This hypothesis was confirmed by the observation that below the tanglefoot bands in spring there were many females with fully developed gonads but no *corpora lutea* (i.e. they had not deposited eggs).

Probably, the females that overwinter in the larval stage and emerge in July do not become mature the same autumn. Since development of the gonads seems to be very slight in late summer and autumn, some, at least, of these weevils are unlikely to be mature the following spring. Accordingly, they can lay eggs only when they are nearly 3 years old (age calculated from the egg stage).

Although cone samples were not regularly collected except at Tuusula, observations on the development and length of the life-cycle of the pine cone weevil were made at Pohja, Punkaharju, Juupajoki, Hämeenkyrö, Jämsänkoski and Jurva (Fig. 1, Tables 1 and 2). Cones collected in these localities were stored at +1 °C so that the various developmental stages would remain alive until the examination. However, the cones were dissected as soon as

Table 3. Percentages of the various developmental stages of *Pissodes validirostris* in the cone samples collected in various localities.

Locality	Date	Number of			Percentages of			
		trees	cones	*P. validirostris*	larvae	pupae	adults	emerg. holes
Pinus silvestris								
Pohja	28. VIII. 72	5	115	32	0	0	37.5	62.5
Punkaharju	27. VIII. 70	10	120	23	0	8.7	73.9	8.7
Hämeenkyrö	19. IX. 72	6	69	11	18.2	0	0	81.8
Jämsänkoski	5. IX. 71	2	11	12	91.7	0	8.3	0
Jurva	13. IV. 71	5	74	63	100	0	0	0
Jurva	27. XII. 71	8	94	34	82.4	0	0	17.6
Pinus contorta								
Punkaharju	27. VIII. 70	5	119	132	0	0	78.8	21.2
Punkaharju	3—15. III. 70	10	161	53	3.8	0	0	96.2
Juupajoki	19. IX. 72	15	225	415	0.5	0	0	99.5

possible after collection. Data obtained from these cone samples are presented in Table 3, and refer only to living specimens. Larvae parasitized by *Eubadizon* were not included in the table.

The development of the pine cone weevil at Pohja, Punkaharju, Juupajoki and Hämeenkyrö was about the same as at Tuusula in the respective years. In these localities most specimens of the new generation developed from egg to adult during one summer and emerged from the cones before the winter. At Jämsänkoski and Jurva, however, only a minor proportion of the specimens of the new generation emerged during the first summer; the majority overwintered as full-grown larvae.

Although the pine cone weevil develops from egg to adult in southern Finland during one summer, maturation of the new adults requires so much time that the length of the life-cycle is mostly 2 years. Roughly speaking, north of latitude 62 most weevils emerge from the cones in the second summer, development from egg to egg lasting 2 or 3 years.

New cones of lodgepole pine were collected at Kivalo Experimental Forest, Rovaniemi in 1971 and 1972, but none of them were infested with *P. validirostris*. However, emergence holes were observed in old cones lying on the ground. *P. validirostris* has been recorded as far north as Muonio (K a n g a s 1938). The occurrence of the pine cone weevil is evidently much more scattered in Lapland than in central and southern Finland. In most years the growing season is so short in northern Finland that the larvae of the new generation will not even be full-grown by the autumn. The half-grown larvae will die during the winter or will be unable to feed on the hard cones the following spring. This hypothesis was supported by the observations made at Tuusula in spring 1972. On 15 May 20 cones containing over-

wintering larvae were dissected. All living specimens (27 in number) were full-grown larvae lying in the pupal chamber, and none of them had fed during the current year. It is interesting to note that the average ripening limit for the seeds of Scots pine runs only slightly north of latitude 62, and in Lapland the seeds of *Pinus silvestris* ripen only in exceptionally warm summers (S a r v a s 1970).

As far as I know, no information is available in the literature about the duration of sexual maturation in the pine cone weevil. It is very interesting to note that in Central Europe and the Mediterranean countries, where the growing season is much longer and warmer than in Finland, the seasonal occurrence of the various developmental stages of *P. validirostris* is nonetheless the same as in the south of Finland. Evidently, the life-cycle of the pine cone weevil is considerably dependent on the seasonal life history of the host tree, and this is adapted to the local climate (cf. S a r v a s 1965).

It has been generally accepted that the length of the life-cycle of *Pissodes* species occurring in Finland is 1 year or somewhat longer (S a a l a s 1923, K a n g a s 1931, 1934 a, 1934 c, 1938, 1957). K a n g a s supposed that the whole life-cycle of *P. piniphilus* requires 1 ½—2 years in northern Finland. However, no exact data or records on the maturation of the new adults have been published in Finland.

According to experiments performed in Central Europe, young weevils require a relatively long period to mature after emergence from the breeding material. Even if development from egg to adult takes place during one summer, the young adults (*P. notatus*, *P. piceae*) do not become mature before the winter (N ü s s l i n 1897, M a c D o u g a l l 1898 a), but specimens which have overwintered in the larval stage have fully developed gonads immediately after emergence. According to B u k z e e v a (1965, 1968), in the Soviet Union (Voronezh region) young females of *P. notatus* that emerge in summer or autumn become mature in about 2 months, and most weevils emerging from the overwintering sites have completely developed reproductive organs. C a r l e (1967) reported that the maturation of the newly emerged adults of *P. notatus* requires 2 weeks at 22—23 °C.

Pissodes weevils are generally believed to be univoltine (K e l l n e r 1869, A l t u m 1887, N ü s s l i n 1897, G r a h a m 1918, W r i g h t 1960, N i s h i g u c h i 1961, K a r a m a n 1968). If conditions are unfavourable, however, the life-cycle may take 1 ½—2 years, while in favourable weather conditions there may be 3 generations in 2 years. In the laboratory C a r l e (1967) has managed to breed 2 generations of *P. notatus* in 1 year. In the mountain regions of British Columbia, the development of *P. alascensis* Hopk. (a stem-infesting species) from egg to ovipositing adult requires 2 years (D o i d g e 1967). Owing to the long oviposition period, the length of the life-cycle of *P. approximatus* (a stem-infesting species) is

1 or 2 years (Finnegan 1958). Harman & Kulman (1967 b) have found that the sexual maturation of *P. strobi* is regulated by a diapause.

Many investigators have suggested that the adults of *Pissodes* species have a relatively long life-span (2—4 years) and maintain their ability to reproduce the whole time (e.g. Hierholzer 1954, McMullen & Condrashoff 1973). Bukzeeva (1965, 1968) stated that adult weevils of *P. notatus* generally survive 1 year, and occasionally 2. Carle (1967) found that the average life-span of females of this *Pissodes* species was 250 days.

A characteristic feature of many cone insects is that they do not emerge after the first winter, but remain in the larval stage for one or more years. Retardation has generally been explained as an adaptation to variations in the flowering intensity of the host tree (e.g. Bakke 1963). This kind of diapause was not observed in the life-cycle of the pine cone weevil during the present study. I suppose that diapause is not so important for the relatively long-lived pine cone weevil as for some other cone insects which live only a few weeks after emergence.

For determination of the rate of development and the length of the life-cycle of *Pissodes* species, controlled breeding experiments are usually necessary, since the various developmental stages may all be present in one tree at the same time. It is quite easy to study the life-cycle of the pine cone weevil and compare it with other Finnish species of *Pissodes* because, as this species deposits its eggs only in the young cones, the generations originating in various years can be distinguished from each other without trouble. The situation is far easier than in *Pissodes* species breeding in the stems, where, as Kangas (1938) found, the specimens of two different generations may occur in the rind of the same tree. Another advantage of *P. validirostris* is that the oviposition period is relatively short. As a result, the various developmental stages are quite distinct from each other in their seasonal occurrence. A tree attacked by the stem-infesting *Pissodes* weevils may survive for a relatively long time, and females can lay eggs on the tree all through the summer, and even the following year. Accordingly, the various developmental stages may be present simultaneously for a long period. A further asset of the pine cone weevil is the regularity of its seasonal life history, which is due to the fact that, in summer, conditions within the cones vary very little. In contrast, the breeding sites of a stem-infesting *Pissodes* species may be very diverse, owing to numerous variables, such as the position of the tree in the forest, the site of the specimen in the tree, whether the tree is standing or fallen, etc. Probably, even minor changes in conditions considerably affect the development of the pine cone weevil, as the experiments in breeding boxes indicate (cf. p. 25). If overwintering takes place in the larval stage diapause may occur during development.

In regard the seasonal occurrence of the various developmental stages and the length of the life-cycle, the pine cone weevil is like the tip-infesting *Pissodes* species. In this respect *P. validirostris* most nearly resembles *P. terminalis*, which breeds in the developing shoots of lodgepole pine. The regularity of the seasonal life history of *P. terminalis* is partly due to the short oviposition period.

5. DISPERSAL

How often the chronic damage caused by an insect pest calls for control measures depends greatly on how long the insect population takes to recover after such measures. In this respect the ability for dispersal is of great importance. Before the establishment of a seed orchard it would be helpful to know how quickly cone- and seed-destroying insects from breeding places in the surroundings will be able to reach the grafts.

Little has been published on the dispersal of *Pissodes* weevils. According to investigations conducted in North America (Sullivan 1953, 1961 a, Godwin et al. 1957, Dirks 1964, Harman & Kulman 1967 a, 1969), the spread of *P. strobi* is relatively slow, although some specimens may move 1.2 km a year (McMullen & Condrashoff 1973). A high proportion of the weevils remain on or near the trees in which they have overwintered. The adults of *P. notatus* do not move more than 40 m a season (Bukzeeva 1971).

Many insects, for instance bark beetles, have a swarming period during which they seek suitable breeding material. Dispersal in many species takes place during this mass flight. In *P. validirostris*, however, as the present study indicates, the weevils move to the breeding places individually and no mass flight occurs. However, the emergence from the winter quarters and subsequent moving to the breeding places can be regarded as a kind of swarming. How far these weevils travel during this period was studied in the following way. Weevils caught with the tanglefoot bands were marked with yellow paint on the elytra and released in a lodgepole pine stand. The stems around the point of release were equipped with tanglefoot bands to catch the marked weevils. 100 marked weevils were released on 21 May 1971 at 9 a.m. The tanglefoot bands were inspected at 3 p.m. the same day and once a day during the next 10 days.

Most of the recaptures were made at the first checking time. Altogether 70 % of the marked weevils were recaptured (Fig. 16). Although most of them had moved to the nearest tree, some specimens had travelled more than 10 m.

The dispersal of the pine cone weevil in late summer was studied in 1972. Two sets of marked weevils, young and old, were released on the bases of

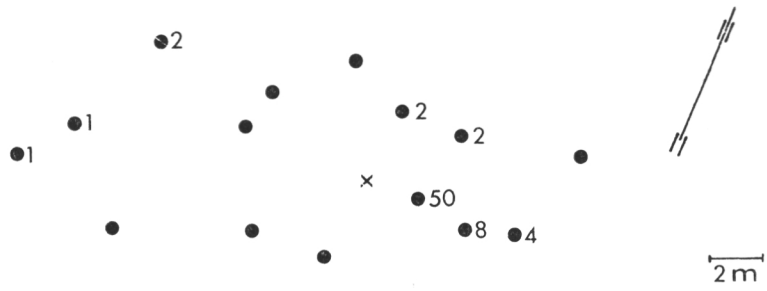

Fig. 16. Dispersal of marked weevils (100 specimens) from the release point (x) to the surrounding trees (●). A number beside a shaded circle means the number of marked weevils recaptured on each tree.

lodgepole pines on 18 May. In this experiment the trees used contained many new cones, and lack of cones would not have forced the weevils to leave the trees. The branches of the trees were not in contact with those of other trees, so that it was impossible for the weevils to crawl from one tree to another. As overcrowding might have had an influence, only 50 weevils were released on each tree. The young specimens had been reared the previous year from cones of *Pinus contorta*, and the old ones had been collected from the bases of standing trees in August. The weevils were released on the bases of eight trees, which were equipped with tanglefoot hoops on 4 July. The positions of the trees are shown in Fig. 17.

The first marked weevils were found in the tanglefoot hoops on 17 July, and the last on 20 October. The proportion of recaptures was distinctly higher among young weevils (35.5 % v. 16.5 %). Possibly, the old specimens died during the experiment in greater numbers than the young ones. A more likely explanation, however, is that the old weevils changed trees to a greater extent. The latter alternative is supported by the fact that a higher proportion of young weevils was recovered from the release trees (Table 4).

Most of the young specimens that were captured on another tree had gone to the nearest tree. In contrast, some of the old specimens had migrated for long distances. Weevils can move from one tree to another not only by flying but also by dropping to the ground and then crawling up the nearest tree. Some of the young weevils had evidently changed trees in this way, because several marked weevils were detected below the tanglefoot hoops. However, some of the old specimens were recaptured so far from the point of release that they had probably flown this distance.

It seems likely that, after emerging from the overwintering sites, in spring, weevils direct their course towards the trunk of the nearest tree. Throughout the summer they remain within a very limited area. Most of the young specimens (eclosion the previous autumn) spend the summer in the tree which

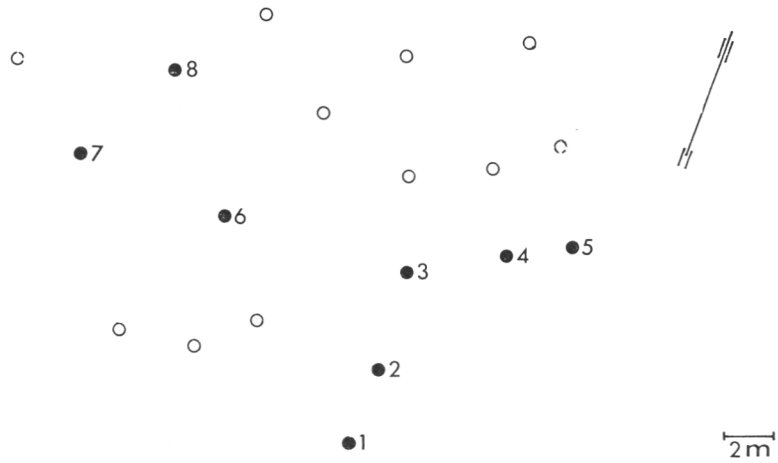

Fig. 17. Map of the forest used for studies on the dispersal of *Pissodes validirostris*. ● 1 = tree on which weevils were released and tree number; o = neighbouring tree. Cf. text and Table 4.

they climbed in the spring. Even the old weevils, although they apparently fly from one tree to another, do not disperse far. The extent to which they move probably depends greatly on the abundance of the cone crop.

Although no pine cone weevil was observed in flight during the present investigations, these weevils are capable of flying, because specimens found in early summer took wing when tossed into the air. Probably, however, there is no real swarming period, but mature weevils fly individually from one tree to another during the oviposition period whenever the temperature is favourable. The dispersal of the species is evidently due to the movements of the old mature weevils.

The flight and swarming periods of *Pissodes* weevils breeding in stems have been discussed in many papers. Although the adults of these insects are strong fliers, several authors write that they have rarely observed them in flight (e.g. Lorenz 1863, Wright 1960). According to Graham (1926), the adults of *P. strobi* are capable of flying long distances, but usually make short flights from tree to tree. The beetle of this *Pissodes* species can move from tree to tree by crawling on the ground (Dirks 1964). Stevenson (1967) stated that the adults of *P. engelmanni* can fly only after hibernation, since the flight muscles are poorly developed in autumn. The low flight activity of *Pissodes* weevils is evidently connected with the fact that the threshold temperature for flight is relatively high. For example, *P. piceae* can fly only when the temperature is above 18 °C (Hierholzer 1954), the corresponding value for *P. sitchensis* being 70 °F (21 °C) (Silver 1968).

Table 4. Dispersal of marked adults of *Pissodes validirostris* from tree to tree. Young weevils were released on the trees denoted with odd numbers, old weevils on those denoted with even numbers. Fifty weevils were released on each tree; dispersal is indicated by vertical re-distribution (cf. Fig. 17).

Tree no.	Tree no.							
	1	2	3	4	5	6	7	8
	number of weevils recovered							
1	13	—	—	1	—	1	—	—
2	2	4	2	—	—	—	—	—
3	—	—	17	—	—	1	—	—
4	—	—	—	5	—	1	—	—
5	—	1	2	1	14	1	—	1
6	—	—	—	1	—	6	2	—
7	—	1	—	—	—	—	19	1
8	—	—	—	1	—	1	—	4
total	15	6	21	9	14	11	21	6

Generally speaking, it appears that *Pissodes* species have no very distinct swarming period, but the adult weevils fly one by one during the breeding period. Species living in trunks must fly longer distances when seeking suitable breeding material than tip- and cone-infesting species, which can find breeding sites by crawling up the same tree from which they emerged the previous year. *Conophthorus coniperda* (Schwarz), a bark beetle breeding in the cones of *Pinus strobus*, flies from overwintering places in duff to the crown of the nearest tree, its horizontal dispersal being very restricted (H e n s o n 1966).

6. NATURAL CONTROL

Little is known about the factors that govern the numbers of pine cone weevils. When either direct or indirect control measures are to be undertaken, however, it is very important for the planner to be aware of the agents which affect the abundance of the insect population.

Observations on the mortality of the various developmental stages were made in cone samples collected during the growing season. Egg mortality cannot be estimated until the larvae have hatched. Therefore only samples collected in late June or early July can be utilized for these purposes. The total number of eggs equals the number of punctures, which each contain or have contained one egg. Since detailed examination of a cone is very time-consuming, only a few cone samples were used for studying the mortality of the eggs.

It was difficult to calculate the numbers of larvae destroyed by factors other than parasites. Immature larvae die immediately when cone samples are put into the refrigerator at —18 °C. Therefore it was usually impossible to decide whether a larva was alive or dead at the time when the cones were collected.

Another factor which made it difficult to count the number of dead larvae was that cones collected at the end of the larval period were very badly destroyed. In such cones it was almost impossible to find all the larvae that had died in the first or second instar. Therefore the results presented here are based chiefly on observations on third- and fourth-instar larvae.

Observations on the mortality of pupae were obtained from samples collected in September and October. Healthy pupae occurring during the pupal period proper in July and August are white. But if a pupa dies it begins to darken quite soon after death, so that dead pupae, even when they appeared quite undamaged, could easily be distinguished from healthy ones. The percentage of dead pupae was calculated from the total number of pupae, adults and exit holes.

For a study of the mortality among the adult weevils inside the cone, samples were collected in autumn and winter. Cones were stored outdoors so that any specimens still alive would survive until the sample was examined. Samples consisted of second-year cones, except the one collected at Punkaharju in March 1972, which contained cones from earlier years, too.

61. Parasites

Cones of Scots pine and lodgepole pine were collected in net bags in September for a study of parasites. The bags were stored in the field above the snow level during the winter. In mid-May the cones were placed in breeding boxes, which were kept in outdoor conditions during the emergence period. Specimens which failed to crawl into the glass jars were collected afterwards from the bottoms of the boxes.

Dissection of cones collected during the summer showed that some parasites may develop from egg to adult and emerge from the cones in the course of a single summer. For this reason cones were also gathered in mid-July and placed in breeding boxes immediately after collection.

Observations on the various developmental stages of the parasites were made in connection with cone dissection. Specimens that were in the pupal or adult stage in August or had already emerged from the cones were considered to belong to the summer generation. The various species of parasites could be distinguish fairly easily by their cocoons. For observations on their development after hibernation, larvae of the various parasites were placed in glass tubes plugged with cotton-wool. The tubes were inspected daily.

Altogether 4 parasites species were reared: *Scambus brevicornis* (Grav.) (Ichneumonidae), *Eubadizon atricornis* Ratz., *Coeloides melanostigma* Strand (Braconidae) and one recently described *Eurytoma* species, *E. annilai* Hedq. (Chalcididae) (see H e d q v i s t 1974). In addition, some specimens of *Rhopalicus* sp. (Chalcididae) were found when the cones were dissected. All these species feed on larvae of the pine cone weevil. Pupal parasites were not found in the course of this study.

Four larvae of an unknown endoparasite were found during investigations on the sexual maturity of adult weevils caught with tanglefoot bands in spring 1973. This parasite could not be identified, because no specimen was successfully bred to the ault stage. As far as I am aware, nothing has been published about the parasites of adult *Pissodes* weevils. Probably such parasites are very rare and do not have a great influence on the numbers of their hosts.

Since no difference was found between lodgepole pine and Scots pine concerning the time of emergence or sex ratio of the parasites, the data obtained from the 2 tree species were combined in Fig. 18.

Scambus brevicornis (Grav.)

The first specimens of *S. brevicornis* emerged from the cones in the beginning of June. The emergence period lasted about a month. There was no clear difference between the sexes concerning time of emergence or number of specimens. The first eggs were found relatively late in summer, — in

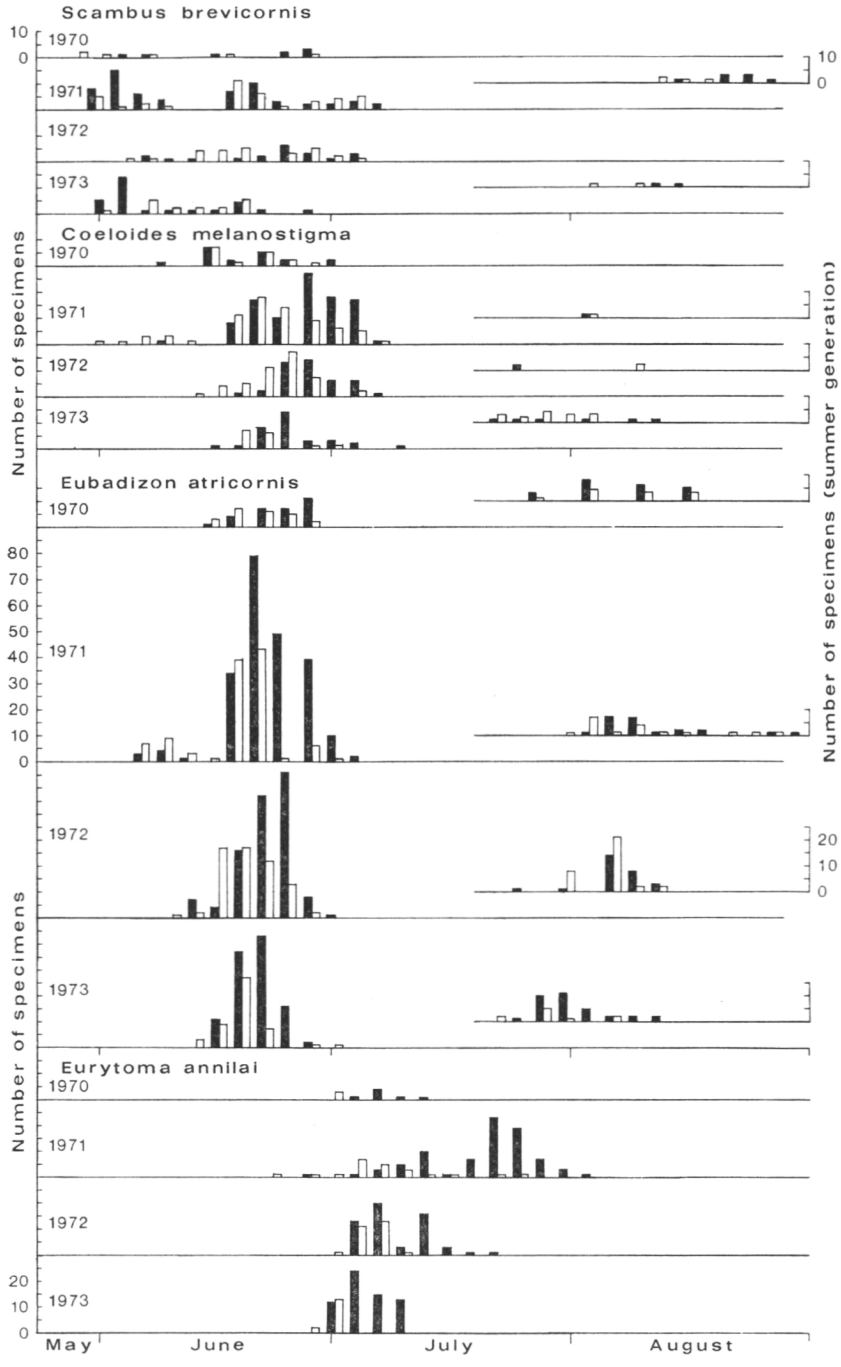

Fig. 18. Emergence of parasites of *Pissodes validirostris* from cones stored in breeding boxes. Black columns = females, white columns = males.

samples collected in early July. The egg is about 2 mm long and at the widest part about 0.3 mm in width, resembling a curved greenhouse cucumber. Eggs were common until late July.

The female lays her eggs individually in the tunnel of a fourth-instar larva of the pine cone weevil in the immediate vicinity of the host larva. Often, the weevil larva is just excavating the pupal chamber. On hatching, the parasite larva fastens on the host larva, living as an external parasite. The female may often deposit an egg on a pupa. However, the parasite larva cannot attack the host at this stage, and dies soon after hatching.

The first newly hatched larvae were found in mid-July and the first full-grown larvae at the end of July or beginnig of August. If the adults emerge during the same year, development is very rapid. The first pupae and adults were found in early August (Fig. 18). The larva spins a very thin cocoon on the wall of the pupal chamber of the weevil. The proportion of specimens that completed their development in one summer varied greatly from year to year (Table 5). Since *P. validirostris* produces few larvae in August, at least in southern Finland, it is likely that the female parasites that emerge in late summer lay their eggs on the larva of some other host. *S. brevicornis* is a very widespread and polyphagous species (Townes & Townes 1960).

Although *S. brevicornis* is partly bivoltine the species mostly passes the winter as the full-grown larva in the pupal chamber of the host. Pupation takes place the following spring, starting in mid-May. Emergence from the cones commences in early June. A life-cycle lasting longer than one year was not found at Tuusula. At Jurva, on the other hand, in the summer 1971 some larvae were retarded in the cones of 1970 and did not pupate until 1972. Accordingly, development from egg to adult lasted about 2 years.

Lovaszy (1941) reared specimens of *Pimpla terebrans* Ratz. (= *Dolichomitus terebrans terebrans* (Ratz.)) from cones of *Pinus silvestris* and *P. contorta* collected at Tuusula. The following ichneumonids have been reported as parasites of the pine cone weevil: *Epiurus* sp. (Mjöberg 1909); *Ephialtes sagax* var. *laticeps* Ratz. (Crooke 1948); *Ephialtes haemorrhoidalis* Tschk. (Canakcioglu 1959); *Ephialtes brevicornis* var. *euphrantae* (Schmiedeknecht) = *Pimpla euphrantae* (Schmiedeknecht) (Krol & Michalski 1961) and *Ephialtes brevicornis* (Grav.) = *Epiurus euphrantae* (Schmiedeknecht) (Smetanin 1970).

Several ichneumonids of the genera *Pimpla* and *Dolichomitus* (= *Ephialtes*) are known to parasitize other *Pissodes* species (Kangas 1938, 1941, Györfi 1941, Haeselbarth 1962, Stevenson 1963, 1967, Viedma 1964, Guryanova 1968, 1969, Karaman 1968, Stevenson & Petty 1968, Kishi 1970). It would be very interesting to make comparisions between specimens of these parasites reared from

different *Pissodes* species. The specimens reared by Lovaszy probably belonged to the same species as those obtained in the present study.

Coeloides melanostigma Strand

Most specimens of *C. melanostigma* (= *C. stigmaticus* Hellen) emerged in the latter half of June after overwintering (Fig. 18). Males appeared somewhat earlier than females, and were slightly more numerous. Ovipositing females were observed in the field throughout July. Nuorteva (1957) reported that both *C. melanostigma* and *C. abdominalis* Zett. fly in June and July (see also Schimitschek 1940). According to Haeselbarth (1962), a *Coeloides* species (presumably *C. bostrichorum* Gir.) that parasitize *Pissodes piceae* emerges in May and June about a week earlier than *Eubadizon atricornis*. In the experiments conducted at Tuusula *C. melanostigma* emerged somewhat later than *E. atricornis*.

The female lays her eggs on third- or fourth-instar larvae. However, the host larva has not yet started to excavate the pupal chamber. The *Coeloides* parasite of *Pissodes piceae* oviposits on the full-grown larvae, which has not yet begun to excavate the pupal chamber (Haeselbarth 1962).

The host larva is evidently paralysed during oviposition and does not continue tunnelling. The larva is an external parasite and finally spins a very strong, leathery cocoon. Its development must be very rapid, because the first cocoon were found as early as mid-July. The cocoon are commonly situated quite near the outer surface of the cone. Larvae of the pine cone weevil living in the centre of the cone were very seldom parasitized by this

Table 5. Emergence of the parasites of *Pissodes validirostris* during the first summer expressed as percentages of total emergence.

Species	Year	Breeding experiments		Cone samples	
		total no. of specimens	summer emergence %	total no. of specimens	summer emergence %
Scambus brevicornis	1970	25	4	106	17
	1971	33	33.3	122	32
	1972	—	—	50	14
Coeloides melanostigma	1970	33	0	51	5.9
	1971	35	5.7	88	4.5
	1972	—	—	16	6.3
Eubadizon atricornis	1970	126	27	428	27.1
	1971	161	21.1	219	21
	1972	210	26.2	136	28.7
Eurytoma annilai	1970	10	0	232	0
	1971	49	0	169	0
	1972	—	—	56	0

braconid. According to Haeselbarth (1962), a *Coeloides* species which parasitizes the larvae of *Pissodes piceae* cannot deposit eggs through bark more than 4 mm thick. The cocoons of *C. melanostigma* were usually covered with a very thick layer of pitch, and could only be detected by a careful search of the cone.

Emergence the same summer was scanty every year (Table 5). Most larvae overwintered in cocoons and emerged the following summer. Nuorteva (1957) thought it possible that this braconid has two generations a year, but there is no distinct difference between the flight periods of the specimens of these two generations. However, he found flying specimens in June and July and September but not in August. According to De Leon (1935), *C. dendrotoni* Cush. may develop from egg to adult in one summer, emerging in late July or August, but the great majority (95 %) pupate the following summer in May or June. As the present study showed, the situation is quite comparable in *C. melanostigma*. *C. abdominalis*, which parasitizes both *Pissodes* weevils and bark beetles, mostly completes its development during one summer (Schimitchek 1940, Nuorteva 1957).

Lovaszy (1941) supposed that the specimens of the first generation of *C. abdominalis* parasitize *Blastophagus* species and those of the second generation feed on *Pissodes* species. According to Haeselbarth (1962), *Coeloides* lays eggs on larvae of *Pissodes* parasitized by *Eubadizon atricornis* as well as on healthy larvae. There are not many larvae of the pine cone weevil in August, except those that are parasitized by *Eubadizon* and will overwinter. Possibly, the females of the summer emergence of *C. melanostigma* lay eggs on these parasitized larvae. Another possibility is that eggs are deposited on the larvae of other *Pissodes* species, which are probably more numerous in autumn. However, it is quite evident that *C. melanostigma* is partly bivoltine in Finland.

Smetanin (1970) wrote that *C. melanostigma* is a parasite of *P. validirostris*. Other hosts of this braconid are *P. notatus*, *P. pini*, *P. piniphilus* and *P. piceae* (Györfi 1941, Kangas 1941, Nuorteva 1957, Krol & Michalski 1961, Karaman 1968, Guryanova 1969, Bukzeeva 1970). *C. brevicaudis* was reported as a parasite of the pine cone weevil by Kangas (1941) and Györfi (1941), but Haeselbarth (1967) suggested that the species in question was *C. melanostigma*. According to Hellen (1957), *C. abdominalis* var. *brevicaudis* is the species parasitizing *P. validirostris* and *P. notatus*.

Eubadizon atricornis Ratz.

E. atricornis started to emerge a little later than *Scambus brevicornis*, but the whole emergence period was somewhat shorter (Fig. 18). Males

emerged a little earlier than females, but females always outnumbered males. Every year about 25 % of the specimens completed their development during one summer (Table 5), emerging in July or early August.

Haeselbarth (1962) made an extensive study of the biology of *E. atricornis* (*Brachistes atricornis* Ratz.) in Germany, where it lives as an endoparasite in the larvae of *Pissodes piceae*. He stated that a female is able to oviposit only in the eggs or in newly hatched larvae that are still in the egg punctures. After hatching, the parasite larva remains in the coelom of the *Pissodes* larva and develops very slowly until the host is in the final instar.

Similarly, when living in the larva of the pine cone weevil, the larva of *E. atricornis* develops very slowly at first. Even larvae that complete their development in one summer do not begin to grow rapidly until the host larva reaches the last instar. Finally, the parasite larva emerges from the host and lives externally on the weevil larva. The first cone samples containing larvae which had emerged from the hosts were found in cones collected in mid-July. Other larvae in the same cone sample were just spinning cocoons. Adult specimens in the cocoons were detected in cones gathered a week later, which indicates rapid development of the parasite. Thus the pupal period lasted only a few days. Adults started to emerge from the cones at the end of July (Fig. 18). Weevil larvae parasitized by *E. atricornis* were often very close to the cone surface, thus differing from healthy larvae, which penetrate into the axis of the cone for pupation. According to Haeselbarth, larvae of *Pissodes piceae* parasitized by *E. atricornis* remain closer to the bark surface than healthy ones. This facilitates the emergence of the parasites.

If emergence takes place the following summer, the parasite overwinters as a half-grown larva in the weevil larva. In the southern parts of Finland the hibernating larvae of *P. validirostris* almost without exception were parasitized by *E. atricornis*. In addition to the smaller size of the head capsule (Fig. 7), the parasitized fourth-instar larvae can easily be distinguished from healthy ones by their smaller size and transparent appearance.

In samples stored in glass tubes during the winter the larvae of *E. atricornis* emerged from the host larva in the latter half of May. The host was consumed in a few days, only its head capsule and thin cuticle remaining. After feeding, the larva began to spin a cocoon. Pupation took place 10 days later and emergence about 2 weeks after pupation.

Haeselbarth (1962) reported that the eggs of *Pissodes piceae* are laid during a relatively long period, from the end of May to the beginning of July, the emergence of *E. atricornis* thus coinciding quite well with the egg period of the host. In contrast, the oviposition period of *P. validirostris* is relatively short. Most adults of *E. atricornis* emerged after the greater part

of the larvae of the pine cone weevil had already hatched. However, the time of emergence of the parasites was studied in cones which had been stored in breeding boxes, and this may have retarded the rate of development of *E. atricornis*.

In Germany only a few specimens of *E. atricornis* develop from egg to adult during one summer, and Haeselbarth doubted whether they could then find eggs of *Pissodes piceae*. Nor are eggs of *P. validirostris* to be found in late summer. However, *E. atricornis* probably lives as a parasite in other *Pissodes* species, whose eggs are available to some extent in July and August. The proportion of adults that emerged during the first summer was so high every year in Finland that it is very hardly credible that the summer generation is unable to breed.

In the Soviet Union *E. atricornis* live as a parasite in the larvae of *P. validirostris* (Smetanin 1970), *P. notatus* and *P. piceae* (Lavrova 1967, Guryanova 1969). *Calyptus mucronatus* was reported to be a parasite of the pine cone weevil by Mjöberg (1909), Laidlaw (1930, 1933) and Crooke (1948). In summer 1972 I collected some cones of *Pinus silvestris* infested with *P. validirostris* in Gotland (where Mjöberg made his observations). Some adults of *E. atricornis* emerged from these cones before autumn. So it seems probably that the specimens reared by Mjöberg belonged to the species which is here called *E. atricornis*. According to observations made by Kangas (1938) and Hellen (1938, 1940, 1958) in Finland and by Crooke (1948) in England, *C. mucronatus* is a parasite of *P. validirostris*. A *Eubadizon* sp. was found to live as a parasite in the larva of *Pissodes notatus* in Turkey (Karaman 1968). Lovaszy (1941) reported that *Allodorus semirugosus* Nees. is a parasite of *P. harcyniae*, overwintering in the host larva. He stated that *Pissodes* larvae parasitized by this braconid do not differ from healthy ones in any respect. Laidlaw (1933) suspected (and so, according to him, did Thomson) that *A. semirugosus* is synonymous with *C. mucronatus*.

Eurytoma annilai Hedq.

Each year the adults of *E. annilai* clearly emerged later than the other parasites of the pine cone weevil (Fig. 18). Males began to emerge first, but the total number of females was much greater every year. Most adults emerged through the holes cut by the weevils or by other parasites. Opening of the cone scales also facilitated emergence from the cone.

The first eggs and newly hatched larvae were observed in cones collected in early July. However, eggs were found as late as mid-August. The egg of *E. annilai* is oval, about 0.4 mm long, dark, and covered with tiny hooks, which obviously help it to fasten on the host larva.

Full-grown larvae were found at the end of July. The larvae pass the winter in the cones and pupate the following summer. Larvae kept in glass tubes began to pupate in late May. It is very likely that the life-cycle of *E. annilai* takes a year, since no summer emergence was observed in the course of the present study. On the other hand, all specimens emerged after one hibernation. Nuorteva (1957) presumed that *E. arctica*, which parasitizes the larvae of many bark beetles, may have 2 generations a year. According to Taylor (1929), in *E. pissodis*, a parasite of North-American *Pissodes* weevils, 4 % develop from egg to adult during one summer, but even so this chalcid does not have 2 generations a year. Stevenson (1967) stated that *E. pissodis* is univoltine.

The eggs of *E. annilai* were found only in cones where fourth-instar larvae of the pine cone weevil had excavated wide tunnels. The eggs are often fastened to the larva of *P. validirostris* but they may lie in the tunnel at a considerable distance from the host larva. Obviously, the female, with her relatively short ovipositor, cannot reach hosts lying in the axis of the cone. Possibly the female lays eggs in the tunnels of the weevil larva and the newly hatched larvae try to find their hosts. Young larvae were often found in tunnels far from the nearest remnants of an egg. If there are holes cut by weevil larvae or adults of other parasites a female may enter the cone through one of these and deposit eggs beside the larvae located in the central part of the cone. Plenty of eggs were found in the axis of the cone. There was a good correlation between the number of weevil larvae per cone and the proportion of larvae parasitized by *Eurytoma*. Quite a few parasite eggs occurred in the cones, which externally appeared undamaged.

Most eggs were found on final-instar larvae which were lying in the pupal chamber, but many were on half-grown larvae, and some even on pupae. *Eurytoma* eggs frequently occurred on the same host larva as the eggs and larvae of *Scambus brevicornis*. Usually a female deposits a few eggs in the same place, and clusters of ten eggs are not uncommon (maximum 25 eggs in one group). Taylor (1929) stated that the American *E. pissodis* always lays only one egg on each host larva. It is very likely that the first larva to hatch destroys other eggs in the vicinity, because damaged eggs were often observed. Occasionally there were several young larvae on the same host but never more than one mature larva per host. Often a parasite larva did not consume the whole body of the host, and the remains of the weevil larva were easy to detect in the pupal cavity. If eggs are deposited on the pupa they are attached to the abdomen. It appeared from the present study that a parasite larva is unable to attack a pupa but dies soon after hatching.

The larva of *E. annilai* may parasitize the other parasites of the pine cone weevil, — in other words, it is a hyperparasite, too. In connection with cone dissection it was found that larvae, pupae and adults of other parasites

were destroyed by larvae of *Eurytoma*. Most hyperparasitic larvae occurred in the cocoons of *Eubadizon*, which contained only the antennae and legs of the braconid. *Eurytoma* larvae were occasionally found in the cocoons of *Coeloides*. Since there were no holes in the wall of the cocoon, it seemed probable that the *Eurytoma* larva had attacked the host larva before it span its cocoon. The other possibility is that a *Eurytoma* female had deposited an egg through the wall of the *Coeloides* cocoon.

Wachtl (Mayr 1879) reared one male of *E. wachtli* from a twig of *Pinus nigricans* which contained cones infested with the pine cone weevil. Györfi (1961) reported one specimen of *E. wachtli* reared from *P. validirostris*. *E. wachtli* is a parasite of *Magdalis rufa* Germ. and *M. violaceae* L., too (Mayr 1879, Györfi 1961). At Tuusula, Lovaszy (1941) obtained adults of *E. curculionum* Mayr from cones of *Pinus silvestris* and *P. contorta* attacked by *P. validirostris*. The specimens reared by Lovaszy probably belonged to the species called *E. annilai* in the present study.

E. pissodis, which parasitizes many *Pissodes* species in North America, has very similar habits to *E. annilai* (see Graham 1926, Taylor 1929, Stevenson 1967).

Some *Eurytoma* species were reported to live as hyperparasites. Nuorteva (1957) supposed that *E. arctica* may kill other parasites of bark beetles. According to Haeselbarth (1962), the larvae of *Eubadizon atricornis* are attacked by *Eurytoma* sp. *E. strigifrons* Thoms. and *E. appendigaster* Swed. are parasites of some braconids (*Apantheles*, *Microgaster*) (Nikolskaja 1963).

Rhopalicus sp.

The adults of the genera *Rhopalicus* were found a few times in samples collected in late July. They were quite close to the cone surface, and had probably attacked the first- or second-instar larvae of the pine cone weevil. Quite small exit holes, probably cut by *Rhopalicus*, were found in some cones, too. Development from egg to adult seems to take place during one summer. Because of its scarcity, *Rhopalicus* was quite unimportant as a factor in the bionomics of *P. validirostris*.

One female of *R. guttatus* (Ratz.) has previously been bred from the pine cone weevil in Finland (Hedqvist 1966). *R. suspensus* Ratz. was reported as a parasite of *P. validirostris* (Lovaszy 1941). *R. pulchripennis* (Crawford), a parasite of *Pissodes* weevils in North America, may emerge during the summer of attack (Taylor 1929, Silver 1968).

The proportions of the various species expressed as precentages of the total number of parasites are presented in Table 6. The values obtained

from the cone samples are based on the numbers of mature larvae, pupae, adults and exit holes. Since there was no great difference between Scots pine and lodgepole pine, data from these two tree species have been combined in the table. Obviously, the counts from cone samples collected in August and September indicate the relative abundance of the different parasites better than do the numbers of specimens that emerged in the breeding boxes. If cones are collected for counts of emergence in late autumn, the specimens of the summer emergence have already left the cones. On the other hand, if the cones are collected before summer emergence begins, the oviposition of the parasites may still be in progress. The relative abundances of the different parasites varies so greatly, however, that the influence of the time of counting is unimportant. Every year *Eubadizon atricornis* was the commonest parasite of the pine cone weevil, its number being roughly equal to the sum of the other species. Great annual variation occurred in the numbers of *Coeloides* and *Eurytoma*.

Data about the proportion of parasitized larvae of *P. validirostris* were obtained from cone samples collected in August, September and October. The presence of endoparasites was detected by dissecting the *Pissodes* larvae. The number of healthy specimens was the sum of unparasitized larvae, pupae, adults and exit holes of the weevils. Every larva, cocoon, adult or exit hole of a parasite was assumed to represent one parasitized specimen of the host. Accordingly, the values in Table 7 indicate the percentages of full-grown larvae that were parasitized.

The proportion of parasitized larvae in the cones was considerably greater in Scots pine than in lodgepole pine. No explanation for the difference was

Table 6. Variations in the ratios of the various parasites attacking the larvae of *Pissodes validirostris* expressed as percentages of the total number of parasites.

Locality	Year	No. of specimens	Percentages of			
			Scambus	*Coeloides*	*Eubadizon*	*Eurytoma*
Breeding experiments						
Tuusula	1970	114	12.3	29.8	49.1	8.8
Tuusula	1971	752	13.7	23.9	48.7	13.7
Tuusula	1972	388	12.4	17.5	54.4	15.7
Tuusula	1973	330	13.9	14.5	47.6	23.9
Cone samples						
Tuusula	1970	817	13.0	6.2	52.4	28.4
Tuusula	1971	582	21.0	15.1	34.9	29.0
Tuusula	1972	258	19.4	6.2	52.7	21.7
Punkaharju	1970	132	22.7	5.3	55.3	16.7
Juupajoki	1972	428	15.2	14.5	42.3	28.0
Pohja	1972	96	10.4	10.4	74.0	5.2
Hämeenkyrö	1972	37	37.8	—	54.1	8.1
Total		3 934	15.5	14.3	48.4	21.8

Table 7. Variations in the proportions of full-grown larvae of *Pissodes validirostris* destroyed by parasites.

Locality	Year	*Pinus silvestris*		*Pinus contorta*	
		no. of larvae	parasitized %	no. of larvae	parasitized %
Tuusula	1969	928	72.1	1 090	16.7
Tuusula	1970	376	84.0	3 694	43.3
Tuusula	1971	375	69.6	2 831	34.8
Tuusula	1972	190	81.6	171	46.2
Punkaharju	1970	121	76.9	200	19.5
Jurva	1971	123	62.6	—	—
Pohja	1972	135	71.1	—	—
Juupajoki	1972	—	—	874	49.0
Hämeenkyrö	1972	49	75.5	—	—
Total		2 297	74.2	8 860	37.4

found. The cones of *Pinus contorta* grow somewhat larger and become noticeably harder than those of *P. silvestris*, and parasites may be able to lay eggs better in the cones of Scots pine than in those of lodgepole pine. The percentage of parasitized larvae varied very little from year to year.

According to Mjöberg (1909), 82 % of the larvae of *P. validirostris* were attacked by parasites in a fairly small cone sample of *P. silvestris*. Crooke (1948) supposed that parasites play a large part in suppressing the population of the pine cone weevil.

In other *Pissodes* species mortality caused by parasites varies greatly, as the following list shows:

Host	Parasitism %	Author
Pissodes notatus	50	Kangas 1938
» »	10	Frediani 1957, Lavrova 1967
P. piniphilus	30—40	Kangas 1938
P. harcyniae	25	Kangas 1938
P. piceae	28	Hierholzer 1954
» »	60	Haeselbarth 1962
» »	55	Guryanova 1969
P. terminalis	34—70	Drouin et al. 1963, Stark & Wood 1964
P. engelmanni	29—36	Stevenson 1963, 1967
P. strobi	7—50	Graham 1926, Taylor 1929, Harman & Kulman 1968

The most effective parasites are reported to be *Eubadizon atricornis*, *Coeloides sp.*, *Dolichomitus terebrans* and *Eurytoma pissodis*. In *P. validirostris* the percentage of parasitized specimens is relatively high as compared with other species of the genus.

62. Predators

It was not easy to investigate the role of predators in reducing the numbers of the various developmental stages, because most predatory insects leave the cone during collection. Since an egg might have been destroyed several weeks before cone collection, causes of egg mortality were often very difficult to determine. Mites were often seen sucking the eggs of the pine cone weevil in cones collected during the oviposition period. For instance, mites had destroyed 3.3 % of the 1 167 eggs in a cone sample of *Pinus contorta* collected on 10 June 1970. In a sample collected on 10 July 1972, 12.9 % of the egg punctures contained only empty collapsed egg membranes. Probably these eggs had been destroyed by predators.

Caterpillars of *Dioryctria mutatella* Fuch living in the cones of Scots pine were sometimes observed to wound the larvae and pupae of *P. validirostris* and in this way to cause their death. As most of the caterpillars of this moth were very small during the larval and pupal periods of the pine cone weevil, the importance of this predator was slight.

According to Taylor (1929) and Stark & Wood (1964), caterpillars of *Dioryctria* sp. and larvae of clerid and cerambycid beetles prey upon the broods of *Pissodes* weevils. The most important predator of larvae and pupae in North America is the fly *Lonchaea corticis* Taylor (Graham 1926, Stevenson 1967, Silver 1968). Some birds (woodpeckers, tits (= chickadees) and nuthatches) may occasionally destroy a high proportion (90 %) of *Pissodes* larvae and pupae (Hierholzer 1954, Finnegan 1958).

The role of predators seems to be less important in reducing the numbers of the pine cone weevil than in controlling the populations of stem-infesting *Pissodes* weevils. This is because many of the predators of *Pissodes* larvae and pupae are insects which live under the bark.

63. Pitch flow

Egg punctures and feeding of larvae stimulate the flow of resin from the cones. In the cones of *Pinus contorta* collected on 10 July 1972, 5.6 % of the eggs had been killed by pitch exuding from the walls of the egg punctures. In the cones of *Pinus silvestris* egg mortality was much lower (Table 8), but even so the main reason for the death of eggs was exudation of pitch. Silver (1968) found that pitch flow killed from 3 to 13 % of the eggs of *P. sitchensis* in leaders destroyed by this weevil. According to him, the percentage may have been much higher in shoots where the attack was unsuccessful.

In several cases the mortality of larvae in cones of Scots pine was attributed to resin flow (Table 9). However, it must be kept in mind that even fi

the death of a larva is caused by some other factor, the tunnel may become filled with resin. In lodgepole pine, drowing in pitch was not so common as in Scots pine, in which third-instar larvae on boring into the axis of the cone, were often killed by pitch. In the fourth instar the larvae were not often destroyed by resin flow and mortality was lower than in other instars, apart from that caused by parasites. The number of pupae killed by resin was very small (Table 10).

Kangas (1938) stated that up to 63 % of the larvae of *Pissodes harcyniae* may be killed by pitch. According to Taylor (1929), 2.5 % of the full-grown larvae and pupae of *P. strobi* are destroyed by pitch flow. The larvae of many other *Pissodes* species (*P. terminalis*, *P. sitchensis*) were observed to die from the same cause (Drouin et al. 1963, Stark & Wood 1964, Silver 1968). Pitch flow is of greater importance in reducing numbers in *Pissodes* species which breed under the bark, because these species sometimes attack quite healthy trees, in which the resin ducts are still active.

64. Starvation

In the cone sample of *Pinus contorta* collected on 10 July 1972, 10.9 % of the egg punctures contained dead larvae. The eggs appeared to have hatched normally, but the small larvae had been unable to make their way into the tissue of the cone scale. Such larvae were very seldom found in cones collected earlier in summer. The inability of the larvae to bore into the cone may have been due to hardening of the tissues, which occurs gradually as the season progresses. In the cones of Scots pine newly hatched larvae were only occasionally observed dead in the egg punctures.

If there are many egg punctures in one cone, the outer layers of the cone scales very soon become so dry that the newly hatched larvae starve. In such cones only a few larvae can develop to the adult stage before the cone dries up, and it may happen that all the larvae die in the final instar. This kind of mortality is only of minor importance in *Pinus silvestris*, where the number of eggs per cone is much smaller than in *Pinus contorta*. Taylor (1929) reported that only 10 to 20 % of the first-instar larvae of *Pissodes strobi* find sufficient food to reach larval maturity.

65. Failure to emerge

The cones of *Pinus contorta* contained many adult weevils which had failed to emerge (Table 11). Most of the dead specimens were quite well developed but had perished when cutting the exit holes. Often the emergence hole was almost complete (the rostrum of the weevil was already out) but

the adult had then stuck in the opening of the hole. The work of boring an exit hole of adequate size in *P. contorta* was evidently beyond the powers of many of the weevils. This kind of mortality was almost never observed in the cones of *P. silvestris*, in which dead adults were mostly found in the pupal chamber.

Mortality in the cones of *P. contorta* collected at Juupajoki in 1972 was considerably lower than average. The cones in this sample were small and relatively soft, whereas those gathered at Tuusula and Punkaharju were normal in size and hard. Differences in size may be due to the fact that at Juupajoki the stand of *P. contorta* is situated on poor sandy soil (Siikakangas), but at Tuusula and Punkaharju the trees are growing on rich soil. The cones of Scots pine were much softer and therefore easier to dissect than those of lodgepole pine. It is evident that the size and hardness of the cone greatly influence the emergence of the adult weevils.

There was considerable variation between trees concerning the number of weevils that stuck during emergence. In the years 1970—1972 cones were collected from two clones of *P. contorta* at Tuusula. Each clone was represented by three grafts, so there were altogether nine samples from each clone.

In clone E 517 the number of stuck weevils was much greater than in clone E 519 (Table 12). There was no distinct difference between these clones in regard to the size of the cones, but the cones of clone E 517 were much harder and more difficult to dissect than those of clone E 519.

Dying in the emergence hole is not a common mortality factor among other *Pissodes* species. In *P. strobi*, however, from 7 to 9 % of the adults stick in the pupal chamber or in the emergence tunnel (Taylor 1929, Harman & Kulman 1968).

66. Developmental disturbances

In the cone sample of *Pinus contorta* collected on 10 July 1972, 11.9 % of the eggs failed to hatch. It seemed that embryonic development had not started in these eggs, most of which had collapsed and their contents had changed to yellow. Some of eggs in this category looked quite undamaged but no embryonic development had taken place. They were not healthy, newly deposited egg, since in the same sample there were no eggs which contained half-developed larvae. Probably these eggs were unfertilized. The proportion of undeveloped eggs in the cones was smaller in Scots pine than in lodgepole pine.

The proportion of unhatched eggs is relatively high in the pine cone weevil as compared with other *Pissodes* species. Taylor (1929) reported that almost all the eggs of *P. strobi* hatch. According to Finnegan (1958), only 2.1 % of the eggs of *P. approximatus* do not develop into larvae.

In the larvae, disturbances in development were difficult to verify. In the pupae, on the other hand, it could be seen that development sometimes stopped, even though there were no outward signs of injury. The head and thorax of some specimens had developed quite normally and had even reached the adult stage, but the development of the abdomen had stopped much earlier. This kind of disturbances may have been caused by eggs of *Eurytoma* deposited in the pupal chamber. Eggs of this pteromalid were sometimes observed on the abdomens of such pupae. Although the parasite larvae are unable to feed on the pupa (cf. p. 54), it seems that the development of the host is disturbed.

67. Extreme temperatures

On 8 and 9 July 1970 temperature was measured at Tuusula in both healthy and infested cones of Scots pine hanging on a tree. Temperature recordings were made with a thermo couple needle inserted into the cone (Ellab electric thermometer, type TE 5). The temperature ranged between 27 °C and 31 °C, being about 5 °C higher than in the air. No distinct difference was observed between healthy and infested cones. It appears that the temperature does not rise high enough in the cones as to kill the larvae immediately. However, a relatively high temperature hastens the drying up of the cones, so causing starvation of the larvae.

No detailed investigations were carried out on the mortality of the adults during the winter. However, in autumn 1971 a small sample of weevils (247 specimens that had emerged the previous year) enclosed in boxes were placed in the litter. By the following spring the mortality was 20 %.

In summer 1971 the tips of ten branches of *Pinus contorta* bearing cones infested with the pine cone weevil were enclosed in net bags. The bags were kept on the tree until the following spring, when they were examined. All the 157 weevils found in the bags had perished during the winter. The same spring (15—17 May) weevils were collected at the bases of five lodgepole pines and in the litter round these trees. Of the 143 weevils found 8 % were dead. In contrast to the sample from the bags, this sample included weevils from previous year. In the course of the present investigations it was observed that adult weevils often died during the experiments without any evident cause. MacDougall (1898 a) and Sullivan (1961 a) have also commented on the relatively high mortality of *Pissodes* weevils during various experiments. Although no exact conclusions about causes of death can be drawn from these observations, it is evident that weevils can overwinter successfully only under the snow cover.

McMullen & Condrashoff (1973) stated that adults of *Pissodes strobi* are able to hibernate on the trees on Vancouver Island in Canada.

According to C a r l e (1967), the adults of *P. notatus* cannot survive if the temperature is below —17 °C. D i r k s (1964) reported that mortality among the adults of *P. strobi* may be as high as 27—49 % in Maine, USA, during the winter.

68. Total effect of mortality factors

Although the factors which reduce the numbers of the pine cone weevil could not all be identified during the growing season, the total mortality of the various developmental stages was relatively easy to calculate. Tables 8, 9, 10, 11 and 12 show the mortality of eggs, larvae (excluding those para-

Table 8. Egg mortality of *Pissodes validirostris* in the cones of *Pinus silvestris* and *P. contorta*.

Date of cone collection	Number of		Mortality of eggs %
	cones	eggs	
Pinus silvestris			
5. VII. 1971	51	162	11.7
10. VII. 1971	54	220	12.3
total	105	382	12.0
Pinus contorta			
28. VI. 1971	33	355	35.5
5. VII. 1971	44	273	33.3
26. VI. 1972	21	427	41.5
10. VII. 1972	31	412	41.3
total	129	1 467	38.4

Table 9. Larval mortality in *Pissodes validirostris* (excluding parasitism).

Tree species	Number of			Mortality %
	trees	cones	*P. validirostris*	
Pinus silvestris	25	388	613	25.4
Pinus contorta	20	217	520	58.8

Table 10. Pupal mortality in *Pissodes validirostris*.

Locality	Year	*Pinus silvestris*		*Pinus contorta*	
		no. of *P. validirostris*	mortality %	no. of *P. validirostris*	mortality %
Tuusula	1969	209	1.4	904	0.4
Tuusula	1970	56	7.1	1963	1.8
Tuusula	1971	40	10	1 678	1.3
Tuusula	1972	31	0	169	0.6
Punkaharju	1971	—	—	92	9.8
Pohja	1972	39	2.6	—	—
Total		375	3.2	4 806	1.5

sitized), pupae and adults. As these tables indicate, in the various instars, excluding the pupal stage, mortality was considerably greater in the cones of *Pinus contorta* than in those of *Pinus silvestris*.

The total mortality before the emergence of the adults could be estimated accurately. It was relatively easy to calculate the number of eggs as well as the number of emergence holes per cone. Some inaccuracy was caused by cones in which all the eggs had been destroyed before they hatched. Such cones were very difficult to recognize in autumn, but they evidently formed a very small proportion, since none were found in the investigations on the number of eggs per cone.

As already stated (p. 18), the number of eggs per cone averaged 3.1 in Scots pine and 20.6 in lodgepole pine. The number of exit holes per cone was calculated from samples collected after mid-September. All cones inhabited by the pine cone weevil were included, regardless of whether there

Table 11. Adult mortality of *Pissodes validirostris* in the cones of *Pinus silvestris* and *Pinus contorta* expressed as percentages of the total number of adults and emergence holes.

Locality	Year	*Pinus silvestris*			*Pinus contorta*		
		no. of trees	no. of *P. validirostris*	mortality %	no. of trees	no. of *P. validirostris*	mortality %
Tuusula	1969	15	176	12.5	10	906	28.1
Tuusula	1970	25	351	4.8	20	2 297	23.9
Tuusula	1971	10	78	5.1	10	1 475	21.1
Tuusula	1972	10	92	6.5	5	168	17.3
Punkaharju	1971 [1])	—	—	—	10	83	38.6
Punkaharju	1971 [2])	—	—	—	10	986	27.5
Jurva	1971	5	40	10	—	—	—
Juupajoki	1972	—	—	—	10	448	6.3
Total			737	7.2		6 363	23.2

[1]) new cones, [2]) old cones

Table 12. Adult mortality of *Pissodes validirostris* in the cones of two different clones of *Pinus contorta*.

Clone no.	Graft no.	1970		1971		1972	
		no. of weevils	mortality %	no. of weevils	mortality %	no. of weevils	mortality %
E 517	1	126	18.3	84	26.2	210	21.4
	2	121	19.8	78	25.6	199	22.1
	3	85	32.9	149	34.2	234	33.8
	Total	332	22.6	311	29.9	643	26.1
E 519	1	162	18.5	269	16.4	431	17.2
	2	151	13.9	120	18.3	271	15.9
	3	272	11.0	520	15	792	13.6
	Total	585	13.8	909	15.8	1 494	15.1

were emergence holes or not. The number of pupated specimens (i.e. the total number of pupae, adults and emergence holes) and the number of adults (i.e. the total number of adults and emergence holes) were calculated from these samples (Table 13). The number of larvae per cone was difficult to count, since in a short time the living larvae destroyed the cone to such an extent that it was not easy to detect any larvae that had died earlier. However, the total number of larvae could be calculated more accurately from the egg mortality, which was 12.0 % in Scots pine and 38.4 % in lodgepole pine. So the number of the hatched eggs corresponds to the number of first-instar larvae.

During the egg stage the reduction of the progeny was much greater in lodgepole pine than in Scots pine (Fig. 19). In both tree species mortality was highest in the larval period. In the cones of *Pinus contorta* most larvae perished during the first three larval instars. Although many adults failed to emerge from the cones of *P. contorta*, the number lost in this way formed only a minor part of the reduction of the original progeny. However, the small difference in total mortality between the progenies found in Scots pine and lodgepole pine was due to the much higher adult mortality in the cones of *P. contorta*.

Parasites and drowning in pitch played important roles in the suppression of the population in the cones of Scots pine. The average number of parasitized specimens was 1.18 per cone, which corresponds to 38.1 % of the

Table 13. Number of pupae, adults and emergence holes of *Pissodes validirostris* per infested cone.

Locality	Year	Number of			No. of specimens/cone		
		trees	cones	*P. validirostris*	pupae	adults	emerg. holes
Pinus silvestris							
Tuusula	1969	20	422	130	0.31	0.30	0.27
Tuusula	1970	10	186	48	0.26	0.24	0.19
Tuusula	1971	15	291	131	0.45	0.43	0.41
Tuusula	1972	10	147	27	0.18	0.18	0.16
Pohja	1972	10	110	39	0.35	0.35	0.35
Hämeenkyrö	1972	5	45	10	0.22	0.20	0.20
Jurva [1]	1971	5	94	40	0.43	0.43	0.38
Total		75	1 295	425	0.33	0.32	0.30
Pinus contorta							
Tuusula	1969	15	448	907	2.02	2.02	1.45
Tuusula	1970	15	749	1 367	1.83	1.79	1.44
Tuusula	1971	15	654	1 475	2.26	2.23	1.78
Punkaharju	1971	10	596	1 088	1.83	1.80	1.29
Juupajoki	1972	10	217	453	2.09	2.06	1.94
Total		65	2 664	5 290	1.99	1.96	1.53

[1]) The number of pupae includes full-grown overwintering larvae

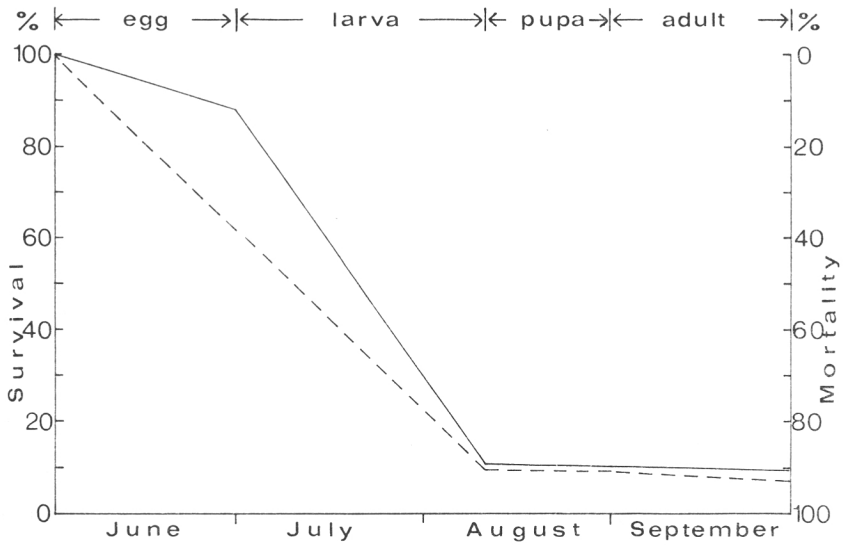

Fig. 19. Mortality of the progeny of *Pissodes validirostris* during the summer. Solid line = *Pinus silvestris*, interrupted line = *P. contorta*.

number of eggs per cone. In the cones of lodgepole pine there were 1.05 parasitized specimens per cone, which is only 5.1 % of the average number of eggs per cone. Starvation of larvae due to competition for food and drying up of the cone was the most important reason for reduction of the weevil population in *P. contorta*.

Although the percentage mortality was about the same in the two species of pine, five times as many weevils per infested cone emerged from lodgepole pine. If, moreover, we take into consideration that the proportion of cones infested by the pine cone weevil is about four times as great in *P. contorta* as in *P. silvestris* (cf. p. 68), the weevil density in lodgepole pine is twenty times as high as in Scots pine.

According to Taylor (1929), the average number of eggs laid by *Pissodes strobi* is 125 per leader, but only 6 (4.8 %) adults emerge. Losses are greatest (80—90 %) during the larval stage. Birds, small mammals, predators and parasites reduce the remainder by 30 %. The mortality of *P. terminalis* is greatest during the first three larval instars (Stark & Wood 1964). According to Silver (1968), the population of *P. sitchensis* diminishes most at the end of the larval period, the mortality being caused by predators and lack of food. Of the larvae of *P. piceae* that hatched, about 80 % were destroyed before emergence, chiefly during the larval period (Haeselbarth 1962). Guryanova (1969) supposed that parasites play only a small part in the fluctuation of *P. piceae* population, even though they reduce the number of weevils considerably every year.

7. INJURIES

The adults of the pine cone weevil, like those of other *Pissodes* species, attack pine shoots. Young trees damaged in this way may be weakened to such a degree that their trunks become susceptible to the injuries of weevil larvae or bark beetles, and the young trees may die (K a n g a s 1937). E c k s t e i n (1897) stated that in spring adults of pine cone weevils may damage young pine cones so badly that these later become deformed. K a n g a s (1938) and G y ö r f i (1956) noticed the same thing. Although the number of weevils was occasionally very high, especially on lodgepole pines, the damage caused by the adult weevils had no effect on the state of the trees either in seed orchards or in forests. Similarly, the feeding punctures cut in the cones by the adults were not of any economic importance. In England, C r o o k e (1948) found that *P. validirostris* may even breed in young shoots of Scots pine, but such behaviour is probably exceptional. In the present investigation the only injuries observed were done by larvae in the cones.

Observations on injuries to Scots pine caused by the pine cone weevil were made only in seed orchards, since this insect has little influence on the seed crop in natural stands (T r ä g å r d h 1939, S a a l a s 1949). Because only a few observations have been published on damage in lodgepole pine (K a r v i n e n & R i k k o n e n 1956, K r o l & M i c h a l s k i 1961, W e i s s e n b e r g 1972), the importance of this pest was investigated in stands of *Pinus contorta*, too.

From these studies on the injuries, estimates were made of the seed crop losses from year to year in seed orchards, and the differences in the extent of the damage between individual clones, between various provenances, and between Scots pine and lodgepole pine; in addition, the correlation between the number of damaged seeds and the number of larvae per cone was calculated. Cones of *Pinus silvestris* infested by larvae of *P. validirostris* may drop to the ground as early as August, and therefore investigations were conducted in the seed orchards of Scots pine in late July or early August. Cones damaged by larvae were quite easy to distinguish from healthy ones by the exudation of resin, and were not removed from the branches. Only

in doubtful cases were the cones dissected. Ladders were used in inspecting the cones. All cones round which there was a resin band caused by a weevil larva were classed as infested. If the larvae had died in an early stage without causing any visible damage, the cones were considered healthy. If there were less than 100 cones on a graft they were all inspected, but if the number of cones was greater the tree was examined branch by branch until the number of cones inspected exceeded 100.

Although the number of larvae in infested cones is usually much greater in lodgepole pine than in Scots pine, the cones of *Pinus contorta* (even when badly damaged) stay on the branches until the following summer at least. For that reason cones of lodgepole pine were collected for investigations of injuries in late autumn or winter. In each sample plot cones were collected from ten trees selected at random. Data on the number of seeds destroyed by larvae are based on samples taken in autumn.

71. Cone injuries

711. Extent of damage

The larvae of the pine cone weevil destroyed from 11 to 25 % of the cones of *Pinus silvestris* in seed orchards (except at Oitti and Jämsänkoski, where the proportion of infested cones was considerably smaller, Table 14). The injuries were heaviest in the orchards established on forest soil (Tuusula orchard 10, Punkaharju, Pohja).

The percentage of damaged cones at Jämsänkoski was especially low. The reason is that the larvae cannot develop to the adult stage during one summer, but hibernate and are removed from the orchard every year when the cones are collected in autumn. This evidently keeps the population level very low from year to year. Since the dispersal of *P. validirostris* is slow, the number of weevils invading the orchard during one summer is relatively small. Although detailed examinations of cones were made only in one orchard at Jämsänkoski, cursory inspections showed that the numbers of cones infested by the pine cone weevil were very small in the other orchards, too. It must be mentioned that the seed orchards at Jämsänkoski are surrounded by spruce stands, which may contribute to the low level of the *Pissodes* population.

The small proportion of cones damaged by the larvae of *P. validirostris* at Oitti is explained by the fact that the orchard has been established in a large flat area of cultivated soil, which is not a very suitable biotope for *Pissodes* weevils. Although the only systematic examinations of cones were made in summer 1970, the damage was estimated to be about the same in the two following years.

Table 14. Percentages of cones infested by *Pissodes validirostris* in seed orchards of *Pinus silvestris* and in cultivated stands of *Pinus contorta*.

Locality orchard/stand	Year	No. of clones	No. of trees	No. of cones	Infested cones %
Pinus silvestris					
Tuusula	1970	40	94	4 479	11.1
orchard 7	1971	40	103	4 758	14.9
	1972	40	102	5 246	17.5
	Total			14 483	14.7
Tuusula	1970	110	270	4 544	27.7
orchard 10	1971	110	284	8 170	25.8
	1972	110	296	11 323	16.3
	Total			24 037	21.7
Punkaharju	1970	55	105	2 669	24.3
orchard 1	1971	55	112	7 220	16.6
	Total			9 889	22.2
Jämsänkoski	1970	24	429	1 293	0
orchard 22	1971	24	517	3 555	0.4
	Total			4 848	0.3
Oitti					
orchard 17	1970	15	115	2 203	2.4
Pohja	1971	12	121	7 580	18.2
Pinus contorta					
Tuusula	1969	8	15	709	63.2
orchard 7	1970	8	15	1 133	66.1
	1971	8	15	812	80.4
	Total			2 654	69.7
Tuusula	1969		15	899	64.8
cultivation 65	1970		10	743	80.8
	1971		10	690	76.7
	1972		10	674	74.2
	Total			3 006	73.6
Punkaharju					
cultivation 99	1971		10	804	74.1
Juupajoki	1972		10	426	87.3

At Tuusula the number of infested cones in orchard no. 7, established on arable land, was much greater than at Oitti. However, the clearing is considerably smaller and surrounded by mixed forests. Probably the heavy infestation was also due to the presence in the orchard of grafts of *Pinus contorta*, in which the level of the weevil population was very high.

The average percentage of cones injured by *P. validirostris* was 3 or 4 times as great in lodgepole pine as in Scots pine. In regard to the extent of the damage, no distinct difference was found between trees in the forest and grafts of *Pinus contorta* in seed orchards. Neither was there any essential distinction between stands growing on different forest site types.

There was relatively little variation in the extent of weevil injuries from year to year. The population level of the pine cone weevil appears to be relatively stable from year to year. The density of the weevil population naturally depends on the number of cones. According to investigations carried out by the Department of Forest Genetics, the Finnish Forest Research Institute, the cone crop in 1972 was more than twice as great as in the previous year in orchard 10 at Tuusula; the respective value in orchard 7 was only 0.6. At Punkaharju, cone production was 6.4 times as great in 1971 as in 1970. However, the percentage of cones infested with *P. validirostris* did not vary as much as might have been expected from the variation in cone yield (Table 14).

The literature contains very little information about the extent of the damage caused by the pine cone weevil. In most of the relevant reports only the nature of the damage is described. However, very high percentages of infested cones were occasionally observed, as the following list shows:

Tree	Infested cones %	Author
Pinus silvestris	25	Mjöberg 1909
» »	50— 75	Escherich 1923
» »	7.7	Trägårdh 1939
» »	20— 30	Hedqvist 1952
» »	10— 15	Fodor 1973
Pinus contorta	100	Karvinen & Rikkonen 1956
» »	90	Krol & Michalski 1961
Pinus pinea	80	Baudin 1963, Romanyk & Bachiller 1965, Bachiller 1966, Cuevas & Bachiller 1969, 1970
P. silvestris, *P. nigra* *P. ponderosa*	75	Györfi 1956

Linnaniemi (1932) found large numbers of infested cones in Scots pine at Karjalohja, southern Finland, in summer 1930. In Turkey the most serious pest in the cones of *Pinus nigra* and *P. silvestris* is *Pissodes validirostris* (Canakcioglu 1969).

712. Variation between trees

Differences in susceptibility between the various groups of clones were investigated in the seed orchards of Scots pine at Tuusula (orchard 10) and at Punkaharju (orchard 1). The study was confined to clones which produced cones every year. In these trees the weevils had had an opportunity to breed for several years in succession, and the data from various years were combined.

Table 15. Percentages of cones infested by *Pissodes validirostris* in various groups of clones (E = south-Finnish clones, K = central-Finnish clones, P = north-Finnish clones, SU = Soviet Russian clones).

Locality orchard	Group of clone	No. of clones	No. of grafts	No. of cones	Infested cones %
Tuusula orchard 10	E	21	67	6 209	9.5
	K	30	72	7 635	20.4
	P	29	73	4 936	38.4
	SU	22	56	4 969	23.4
	Total	102	268	23 749	21.9
Punkaharju orchard 1	E	23	41	4 238	21.8
	K	8	24	2 612	14.7
	P	13	28	2 181	32.4
	SU	6	10	778	23.0
	Total	50	103	9 809	22.4

t-values	E/K	E/P	E/SU	K/P	K/SU	P/SU
Tuusula	3.77***	10.85***	3.61***	8.17***	0.22	7.11***
Punkaharju	2.55*	2.34*	1.22	4.35***	0.25	2.74**

* = 5 % level of significance
** = 1 % » » »
*** = 0.1 % » » »

At Tuusula the percentage of infested cones was highest in the north-Finnish and lowest in the south-Finnish clones (Table 15). Statistically significant differences were found between the various groups of clones, except between those of central Finland and the Soviet Union. At Punkaharju, too, the number of damaged cones was greatest in the north-Finnish clones.

At Punkaharju the rate of injuries caused by *P. validirostris* was investigated in 1970 and 1971 in a very young orchard (established in 1968) (Table 16). As might be expected, the cone crop from these grafts was very light. In 1970 not many of the cones were infested, but the following summer the percentage of damaged cones was about the same in the north- and central-Finnish clones as in the older grafts. In the south-Finnish clones the number of infested cones was small, but this was obviously due to the very poor cone production. The results indicate that pine cone weevils invade seed orchards as soon as the grafts begin to produce cones.

In the young grafts as well as in the older ones the percentage of infested cones was highest in the north-Finnish clones. In these young trees the cone crop was 2.3 times as great in 1971 as in the previous year, but the number of infested cones had increased 20-fold. In 1971 the central-Finnish clones produced only three-quarters of the cone yield of 1970, but the number of damaged cones was twice as high as in the previous year.

Table 16. Percentages of cones infested with *Pissodes validirostris* in young grafts of *Pinus silvestris* (E = south-Finnish clones, K = central-Finnish clones, P = north-Finnish clones, SU = Soviet Russian clones). Punkaharju.

Year	Group of clone	No. of. clones	No. of grafts	No. of cones	Infested cones %
1970	E	75	300	51	0
	K	55	220	96	10.4
	P	75	300	351	5.4
1971	E	75	300	40	5
	K	55	220	73	28.8
	P	75	300	818	40.6

In all grafts of some clones the percentage of infested cones was greater each year than in the trees of the other clones. The significance of this variation in susceptibility was tested statistically in the orchard at Pohja, where the sites of the grafts of the various clones had been assigned at random. The numbers of infested cones were counted in 12 clones, each represented by 12 grafts (12 blocks). However, some of the grafts had been destroyed, so that the average number of trees representing one clone was 9.

There were considerable differences between blocks (Table 17), obviously because the orchard is not situated on flat terrain. The proportion of infested cones was much smaller in the blocks (nos. 11 and 12) situated in a moist depression than in those (nos. 1 and 2) lying higher up the slope. Even between the different grafts of the same clone variation was great, probably owing to the differences between the blocks. However, in 18 cases the differences between clones were highly significant (27.3 % of the total number of comparisions) (Table 18). In clones E 139 and E 262 the percentage of infested cones was greater than the average value in every block but in clones E 741 and E 742 the opposite was the case. At Tuusula and Punkaharju it was found that in some clones the proportion of damaged cones was greater (or smaller) in every graft than the average for the orchard. There are grafts from the same parent tree growing both at Tuusula and at Punkaharju. Damage to these clones was about equal in the two localities. Some examples of clonal variation are presented in Table 19.

Differences in injuries caused by *Pissodes strobi* in strobus pines (*Pinus strobus*, *P. monticola*) were found between provenances and clones in investigations carried out in North America during several years (Wright & Gabriell 1959, Connola 1966, Gerhold & Soles 1967, Soles & Gerhold 1968, Garret 1970, 1972). However, no correlation was found between susceptibility to weevil damage and geographical latitude of provenance (Garret 1973). On the other hand, Holst (1955) and Teich & Morgenstern (1969) did not observed any distinctive

Table 17. Percentages of cones infested with *Pissodes validirostris* in grafts of *Pinus silvestris* in seed orchard at Pohja, 1972.

Clone no.	Block no.												Total	
	1	2	3	4	5	6	7	8	9	10	11	12	no. of cones	infested cones %
	Infested cones %													
E 19	—	29.5	—	2.4	—	5.8	0	4.1	30.2	10.5	0	—	409	11.7
E 27	—	7.0	—	—	0	0	20.0	0	14.9	—	0	26.1	401	11.0
E 31	51.3	73.0	—	39.8	—	7.1	26.8	—	0	46.1	3.8	3.8	643	37.0
E 69	42.2	—	23.3	—	35.2	6.8	40.7	—	—	22.5	13.9	16.7	754	26.7
E 108 ...	—	27.1	9.1	24.4	1.2	27.7	24.2	—	11.5	19.1	1.8	10.4	917	15.7
E 115 ...	—	12.0	—	8.4	3.1	—	8.3	0	—	—	5.2	0	447	6.3
E 139 ...	55.0	—	4.0	43.1	66.7	42.7	76.6	67.3	57.4	21.1	19.3	0	546	45.1
E 262 ...	—	37.2	34.8	27.8	—	40.0	53.4	31.6	—	47.4	—	10.5	926	36.9
E 264 ...	—	2.9	—	0	3.8	10.2	4.0	0	—	0	0	—	465	2.8
E 442 ...	12.3	—	10.7	—	13.1	4.4	13.5	3.8	10.1	4.4	9.1	0	788	8.2
E 741 ...	1.1	2.9	1.4	0	0	0	0	0	1.5	0	0	0	836	0.7
E 742 ...	0	0	0	0	0	0	—	1.5	0	1.4	—	0	448	0.4
Total	26.2	24.9	16.2	18.1	11.5	18.1	27.1	17.5	15.5	21.0	5.3	5.7	7 580	18.2

Table 18. Matrix of t-values for significance of differences between various clones of *Pinus silvestris*. Cf. Table 17. Pohja 1972.

Clone no.	Clone no.											
	E 742	E 741	E 442	E 264	E 262	E 139	E 115	E 108	E 69	E 31	E 27	E 19
E 19 ..	2.52*	2.44*	0.08	1.50	3.71**	4.30***	0.67**	1.27	2.53*	2.43*	0.54	—
E 27 ..	1.95	1.85	0.64	0.97	4.24***	4.88***	0.15	1.84	3.07**	2.98**	—	
E 31 ..	5.16***	5.25***	2.48*	3.97**	1.39	1.83	3.03**	1.25	0.18	—		
E 69 ..	5.18***	5.26***	2.59*	4.03**	1.18	1.58	3.11**	1.39	—			
E 108	4.02***	4.05***	1.26	2.86**	2.63**	3.19**	1.93	—				
E 115	1.72	1.60	0.78	0.79	4.25***	4.85***	—					
E 139	7.31***	7.56***	4.49***	5.92***	0.32	—						
E 262	6.42***	6.57***	3.83**	5.21***	—							
E 264	0.93	0.77	1.67	—								
E 442	2.75*	2.70*	—									
E 741	2.23	—										
E 742	—											

* = 5 % level of significance (56 % of cases)
** = 1 » » » » (41 » » »)
*** = 0.1 » » » » (27 » » »)

correlation in *Picea abies* (L.) Karst. between various provenances and attack by *Pissodes strobi*. According to Wright (1960) and Silver (1968), some Sitka spruce trees are more susceptible to attack by *Pissodes sitchensis* than others.

Attempts have been made to link the susceptibility or resistance of the trees with their morphological characters (Kriebel 1954). The specimens most susceptible to attack by *Pissodes strobi* are tall, rapidly growing trees with broad crowns (Graham 1918, Belyea & Sullivan 1956, Gara et al. 1971, Harman 1971). Fewer feeding cavities of this *Pissodes* weevil occur in trees with thin bark and cortical resin ducts near the surface (Stroh & Gerhold 1965). Buijtenen & Santa-

Table 19. Percentages of the cones infested with *Pissodes validirostris* in various grafts of the same clone of *Pinus silvestris*.

Parent tree no.	Locality	Graft no.	Year						Total	
			1970		1971		1972			
			no. of cones; infested cones %							
			no.	%	no.	%	no.	%	no.	%
Pinus silvestris										
E 636	Tuusula	1	46	52.2	75	54.7	59	66.1	180	57.8
		2	55	3.6	77	68.8	64	89.1	196	57.1
		3	98	35.7	86	48.8	81	63.0	265	48.3
	Punkaharju	1	24	58.3	182	50.5	—	—	206	51.5
		Total	223	33.6	420	54.3	204	72.1	847	53.1
K 29	Tuusula	1	53	1.9	46	2.2	66	1.5	165	1.8
		2	61	8.2	36	13.9	70	0	167	6.0
		3	25	0	20	0	40	2.5	85	1.2
		4	7	0	5	0	12	0	24	0
	Punkaharju	1	39	0	64	1.6	—	—	103	1.0
		2	38	13.2	126	11.9	—	—	164	12.2
		3	20	0	89	4.5	—	—	109	3.7
		4	7	0	25	4	—	—	32	3.1
		Total	250	4.4	411	6.6	188	1.1	849	4.7
P 312	Tuusula	1	12	66.7	36	33.3	83	26.5	131	32.1
		2	5	40	11	9.1	56	28.6	72	26.4
		3	35	74.3	50	78	98	25.5	183	49.2
	Punkaharju	1	18	16.7	160	21.9	—	—	178	21.3
		2	14	21.4	123	27.6	—	—	137	27.0
		3	23	21.7	193	36.8	—	—	216	35.2
		Total	107	43.9	573	33.5	237	26.6	917	32.9
Pinus contorta										
E 519	Tuusula	1	72	90.3	99	99.0	—	—	171	95.3
		2	93	84.9	52	92.3	—	—	145	89.0
		3	176	93.8	89	97.8	—	—	265	95.1
		Total	341	90.6	240	97.9	—	—	581	93.6
E 513	Tuusula	1	70	32.9	31	58.1	—	—	101	40.6
		2	44	40.9	36	41.7	—	—	80	41.3
		3	25	40	28	50	—	—	53	45.3
		Total	139	36.7	95	49.5	—	—	234	41.9

mour (1972) observed that the trees most resistant to the attack of the white pine weevil are those with a high content of non-crystallizing resin. In breeding experiments Plank & Gerhold (1965) did not find any correlation between the damage done by *Pissodes strobi* and the morphological characters of the various host trees.

Resistance to insect pests need not mean that the females cannot lay eggs, but will be high if these eggs or the larvae hatching from them are destroyed before any damage has taken place (Miller 1950). *Pinus mon-*

ticola, a close relative of *Pinus strobus*, is practically resistant to the damage of *Pissodes strobi*. Soles et al. (1970) supposed that the resistance mechanism either inhibits the adult weevils from occupying the trees or induces them to leave the trees.

Holst (1955) showed that the adults of *Pissodes strobi* avoid the smell of the white spruce (*Picea glauca* (Moench) Voss.). However, he did not find any difference in repellence between resistant and susceptible trees of Norway spruce. According to Anderson & Fisher (1956, 1960), the resistance of conifers to damage by the white pine weevil depends on the production of repellent essential oils. Marty & Motts (1964) supposed that variation in resistance is partly due to genetic differences, but that environmental factors are more important.

The present investigation gave no clues to the factors responsible for the differences in susceptibility between the various clones and various groups of clones, or between Scots pine and lodgepole pine. No correlation was observed between the morphological features of the trees and the amount of damage sustained. In some of the clones in which no cones were destroyed no indications of weevil activity (e.g. feeding punctures) were found, which suggests that the weevils had totally avoided these trees. In other clones egg punctures were numerous in the cones but the larvae had all died soon after hatching.

The grafts of north-Finnish clones start to grow a little earlier in spring than those of the south-Finnish clones. On the other hand, lodgepole pine begins to show activity at approximately the same time as the local south-Finnish clones of *Pinus silvestris*. Hence it seems unlikely that the differences in the distribution of weevil injuries can all be ascribed to phenological differences.

Differences in resistance are probably partly due to differences in the chemical composition of the trees. Juvonen & Hiltunen (1972) observed that the relative frequency of pines rich in 3-carene is greater in southern than in northern Finland. According to Selander et al. (1973), 3-carene is strongly repellent to the pine weevil, *Hylobius abietis* L.

Although the resistance of all grafts derived from the same parent tree is about the same, there is no evidence for the heritability of insect resistance (Gerhold & Stroh 1963). Holst (1955) reported that grafts and cuttings from a weevil-resistant Norway spruce were susceptible to the injuries of the white pine weevil.

It is likely, however, that some pine clones are practically resistant to the pine cone weevil. On the other hand, the cones of susceptible trees are not always infested by *P. validirostris*, because the occurrence of this weevil is greatly affected by environmental factors as well.

72. Seed damage

The value for the numbers of seeds destroyed as a result of weevil infestation are based on samples collected at Tuusula in late summer and autumn. Only undamaged seeds were taken into consideration, because it was often impossible to count the number of damaged seeds. The number of healthy seeds was compared with the average number of seeds produced by uninfested cones.

Generally, a proportion of the seeds were quite undamaged in cones infested with larvae of the pine cone weevil. If the larvae die before reaching the fourth stage, there are no seed losses. Especially in Scots pines there were many infested cones in which all the seeds were untouched. However, the clones differed in this respect. The percentages of infested cones in which the seeds escaped damage were as follows:

Year	*P. silvestris*		*P. contorta*	
	no. of cones	%	no. of cones	%
1970	276	35.1	749	14.4
1971	376	26.9	217	18.4
1972	213	30.5	223	22.4
total	865	30.4	1 189	16.7

Most of these cones contained only one weevil larva. But they did not yield any seed crop, although the seeds were undamaged, because the pitch flow inside the cone prevented the unfolding of the cone scales. In practice, the loss of seeds is as great as the proportion of infested cones.

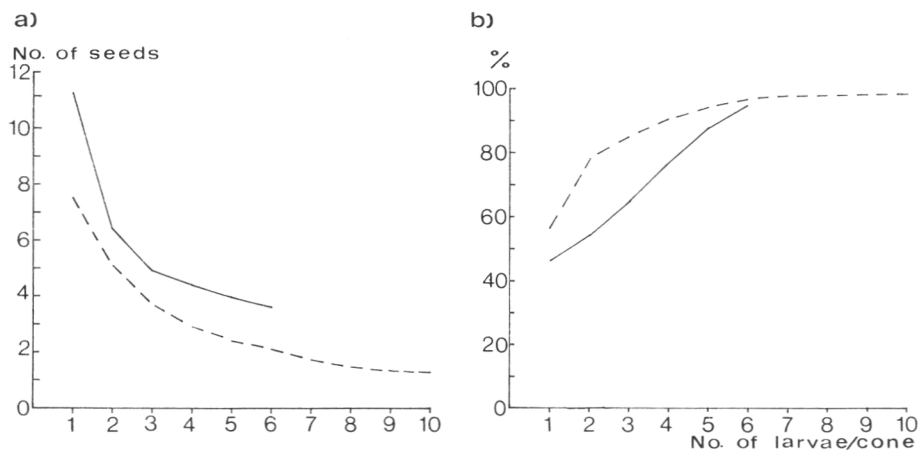

Fig. 20. — a) Correlation between the number of larvae per cone and the number of seeds destroyed by one larva. — b) Correlation between the number of larvae per cone and the percentage of seeds destroyed by the larvae. Solid line = *Pinus silvestris*, interrupted line = *P. contorta*.

If there was only one larva in a cone of Scots pine, the average number of damaged seeds was 11 (Fig. 20). The respective value in the cones of lodgepole pine was 7.5. There was a good correlation between the number of larvae per cone and the number of seeds destroyed. Differences between Scots pine and lodgepole pine were due to the fact that the average number of seeds per cone was 23.2 in *Pinus silvestris* but only 13.1 in *P. contorta*.

Although the fourth-instar larva feeds mostly on seeds, two seeds are enough for the completion of its development to the adult stage. If there are many larvae in the same cone, scales are their main nourishment in the final instar. No reliable information was obtained about whether larvae are able to complete their whole development without seeds or not. The larvae of other *Pissodes* species consume only phloem and sapwood, which are less nourishing than seeds. It is interesting that the larva of the pine cone weevil eats only cone scales during the first three instars. However, its feeding does not prevent the development of seeds. A larva begins to feed on seeds only when it is in the final instar. The fact that one cone may yield as many as 8 adults (in *Pinus contorta* even 13) may be due to this temperate consumption of seeds.

8. DISCUSSION

Since the results obtained in the course of the present study have already been discussed in detail in each section, only some general questions of importance in practical forest entomology will be considered here.

One of the most interesting points that has appeared from this study is that the pine cone weevil can reproduce much more successfully in lodgepole pine than in Scots pine. I am informed by North-American forest entomologists that this weevil does not occur in the natural range of the lodgepole pine in USA or Canada (see Barcia & Merkel 1972, Hedlin 1974). The greater susceptibility of *Pinus contorta* to the injuries of *P. validirostris* may be due to the fact that this pine species is not a natural host of the pine cone weevil. Susceptibility to injuries often increases if some plant is cultivated outside its natural range. Conversely, an animal species frequently does much more damage in newly occupied areas than in its original range. In both cases the imported species is not in equilibrium with its new environment. For example, the great numbers of eggs per cone and the high mortality of eggs and adults, indicate that the pine cone weevil is not very well adapted to live on lodgepole pine, despite its successful breeding in this new host.

However, the pine cone weevil can reproduce in the cones of *Pinus pinea* as well as in those of *P. contorta*, although the former is probably one of the »original» hosts of *P. validirostris*. The pine cone weevil does not attack the cones of another North-American pine species, *Pinus banksiana* Lamb., which is a near relative of *P. contorta*. It seems that some pine species are more suitable than others for the reproduction of the pine cone weevil. According to many handbooks of forest entomology (Escherich 1923, Trågårdh 1939, Saalas 1949, Schwerdtfeger 1970), Scots pine is the main host of *P. validirostris*. However, this *Pissodes* weevil breeds considerably better (and causes more damage) in the cones of *Pinus contorta* and *P. pinea* than in those of *P. silvestris*. If the pine cone weevil were to be introduced into North America it would become a serious cone pest in the stands of *P. contorta* there. Moreover, some other North-American pine species might prove to be susceptible to the attack of *P. validirostris*. It is interesting that in North America the white pine weevil (*Pissodes strobi*),

which attacks leaders of various coniferous trees, causes serious damage in plantations of Norway spruce originating from Europe (Holst 1955). If this weevil were to be introduced into Europe it would probably cause grave economic losses in the plantations of *Picea abies*.

Another interesting question is what causes the relatively high population density of the pine cone weevil in seed orchards of Scots pine from year to year. Although no statistics were available about the numbers of infested cones in natural stands of *Pinus silvestris*, it could be shown that the average percentage of damaged cones was much higher in orchards than in forests. According to Kangas (1938), *P. validirostris* is one of the rarest species of *Pissodes* in Finland. In the eastern United States *Pissodes strobi* did not become a serious problem until plantations of the white pine were established in abandoned fields (Belyea & Sullivan 1956). Various activities of this *Pissodes* weevil (feeding, mating, oviposition, development, etc.) are highly dependent on physical factors of the environment (temperature, humidity, light, wind) (Sullivan 1959, 1960, 1961 b, Gara et al. 1971). Damage is most severe in open, even-aged and relative thinly planted pure stands of *Pinus strobus*, which offer the most favourable conditions for the breeding of the white pine weevil.

Seed orchards closely resemble such plantations. If *Pissodes validirostris* requires the same sort of environment as *P. strobi*, as we may suppose, seed orchards are very suitable for the development of the pine cone weevil. In the course of the present study it was noticed that, in natural stands, infested cones are most likely to be found on relatively low, branchy trees growing in sheltered places in full sunlight. In such places the population density of the pine cone weevil was high year after year.

Belyea & Sullivan (1956) suggested that numerically the population of the white pine weevil is relatively stable, differing in this respect from many other forest insects, which are characterized by strong fluctuations. The populations of many cone insects are highly dependent on the annual cone crop, which varies very greatly in most coniferous trees (Hedlin 1964). However, Scots pine produces a fairly good cone crop relatively often in Finland (Sarvas 1964). According to experiences obtained so far, seed orchards produce cones even when the cone yield in natural stands is very poor. Furthermore, the longevity of the adults, which is exceptional even among cone insects, prevents a strong depression of the population during poor cone years.

Physical conditions in seed orchards change gradually with the growth of grafts and this may reduce vulnerability to the injuries of the pine cone weevil. Injuries from *Pissodes strobi* begin to decrease in young white pines when they reach the height of 10 m or the age of 20 years (Graham 1926, Belyea & Sullivan 1956). This probably because physical

factors in the plantation become progressively less favourable for the maintenance of the weevil population (O v e r h u l s e n et al. 1972). As shown above, weevil injuries can be substantially reduced by dense planting, growing pine in mixed stands with other species, or shading the young trees with a deciduous overstorey (P o t t s et al. 1942, M a r t y & M o t t s 1964). The damage caused to Sitka spruce by *Pissodes sitchensis* can be controlled by the same measures (W r i g h t 1960).

Although conditions in a seed orchard change somewhat as the trees grow older, they will always differ considerably from those prevailing in a forest. Hence the pine cone weevil will be a chronic pest in pine seed orchards.

In Scots pine, injuries due to *P. validirostris* can clear be kept to a minimum by utilizing the observations on its biology reported here. In the lodgepole pine, on the other hand, the proportion of infested cones is repeatedly so great that indirect control methods cannot be expected to reduce the damage to a tolerable level. Although relatively resistant clones of *Pinus contorta* can be found, cultivation of these trees for seed production is unlikely to be economically profitable. The only course that can be recommended is the use of some chemical methods. Detailed results of tests now in progress on chemical control will be published later.

Is seed orchards the Scots pine hardly seems worth undertaking direct chemical control. By establishing seed orchards of the local clones farther south several advantages can be gained, such as better ripening of seeds and a heavier cone crop (S a r v a s 1970). Most of the advantages of this southward transfer can be obtained by moving the grafts of north-Finnish plus trees from northern to central Finland. There is no point in establishing seed orchards of north-Finnish races farther south, because this may lead to weakening of the general vitality of the clones. As shown by the present study, the cones of north-Finnish clones were much more heavily infested with pine cone weevil in southern than in central Finland. For reduction of weevil damage to the minimum the seed orchards of north-Finnish clones should be establish in central Finland.

It seems evident that the extent of weevil injuries is greatly dependent on the characteristics of the soil and terrain in seed orchards. In southern Finland pine seed orchards can be kept satisfactorily free of weevil damage by establishing them on realtively flat arable areas exposed to wind rather than on hilly ground with forest soil. Another reason why rolling terrain is unsuitable for seed orchards is that in such areas there are often depressions where the frost peril is great.

As the present study showed parasites play an important part in the control of the pine cone weevil in seed orchards. This observation should be borne in mind in autumn when the cone crop is harvested. In southern Finland the effectiveness of the parasites can be intensified by leaving the

infested cones in the orchards, for the adult weevils have already left the cones by the end of September and infested cones contain only parasite larvae including parasitized weevil larvae. In central Finland, however, the situation is entirely different. Healthy weevils overwinter in the cones as larvae, and annual collection and removal of infested cones from seed orchards will greatly reduce the population density of the pine cone weevil. Since the dispersal of the weevils is slow and the oviposition period relatively short, the number of weevils cannot increase very much during one summer. In the central parts of Finland weevil hazards can be adequately controlled if the infested cones are collected and carried away from the seed orchard every autumn.

Because the density of the pine cone weevil population is much higher in lodgepole pine than in Scots pine, grafts of *Pinus contorta* growing in a seed orchard provide good breeding material for this weevil and maintain the weevil population at a high level. Therefore weevil injuries can be reduced by not cultivating lodgepole pines in or near Scots pine seed orchards.

Preliminary observations suggest that clones differ considerably in susceptibility to weevil injuries. However, the frequency of very susceptible clones is not high. Since these trees produce relatively few cones and afford breeding possibilities for the weevils, these susceptible clones (plus trees) should be eradicated from seed orchards and excluded from the forest tree breeding programme.

It would be interesting both theoretically and practically, to study to what extent the susceptibility of a clone to weevil injuries depends on its chemical composition. A fuller knowledge of the differences between different trees might enable us to recognize susceptible trees or tree species with the help of chemical analyses. Since injuries caused by the pine cone weevil can be controlled sufficiently by the means mentioned above, an examination of the chemical properties of all plus trees might be uneconomic. But in the field of forest genetics it may become necessary to study the chemical characteristics of clones as far as possible, and this knowledge can then be applied to the control of injuries caused by insects in seed orchards.

9. SUMMARY

1. The extent of injuries caused by *Pissodes validirostris* was investigated in Scots pine seed orchards and in stands of the lodgepole pine, the aim being to ascertain how far the damage can be controlled by indirect measures. Since little was known about the biology of the pine cone weevil, it was necessary to study the life history, dispersal and natural control factors, which are all important when indirect control methods are employed. Investigations were carried out in several pine seed orchards and in stands of *Pinus contorta* in southern and central Finland in the years 1969—1973.

2. In southern Finland adults of the pine cone weevil started to emerge from their winter quarters in early May. They crawled up the trunks and reached the second year-cones.

3. Mating and oviposition took place in May and June, larvae were found in June and July, pupae from mid-July to mid-August, and new adults began to emerge from the cones in mid-August, and proceeded to feed on the young shoots.

4. Adults of the old generation started to come down from the trees in mid-July and hid in crevices at the base of the trunk or in the litter, but those of the new generation did not descend until September. Most weevils had retreated to winter quarters by late September. The majority reached their hibernation sites creeping down the stem.

5. In southern Finland most specimens of the new generation overwintered as adults, but in central and northern Finland in the larval stage. Development was resumed in spring and the adults emerged the following summer in July.

6. Imagos of the new generation did not become sexually mature the following summer until the oviposition period was over. Thus in the south of Finland the life-cycle is 2 years. In central Finland the emergence of new adults occurred chiefly the second summer, which means that the duration of the life-cycle is 2 or 3 years.

7. The adults of the pine cone weevil are relatively long-lived. In spring the proportion of immature adults was less than half the total number of the population.

8. Dispersal in the pine cone weevil is relatively slow, since a high proportion of the adults remain on or near the trees where they hibernate.

9. The most important causes of mortality were parasites, predators, pitch flow, starvation, failure during emergence and developmental disturbances. Egg mortality was about 10 % in Scots pine but nearly 40 % in lodgepole pine.

10. Five parasite species were observed to feed on the larvae of *Pissodes validirostris: Scambus brevicornis*, *Coeloides melanostigma*, *Eubadizon atricornis*, *Eurytoma annilai* and *Rhopalicus* sp. In Scots pine 75 % of the weevil larvae were destroyed by parasites, in lodgepole pine 40 %. Starvation of larvae due to competition for food and drying up of the cone was the most important reason for reduction of the larvae in *Pinus contorta*.

11. Pupal mortality was very low. In *Pinus contorta* about 20 % of the adults died inside the cones before emergence, but in *P. silvestris* less than 10 %. In Scots pine about 9 % of the original progeny (number of eggs) reached the adult stage. In lodgepole pine the corresponding value was about 7 %.

12. In southern Finland the percentage of cones infested with the pine cone weevil averaged about 20 % in seed orchards of Scots pine. In central Finland the number of damaged cones in such orchards was very low. The extent of injuries is affected by the terrain. About 75 % of the cones of *Pinus contorta* were infested with *Pissodes validirostris*.

13. Damage caused by the pine cone weevil in pine seed orchards can be reduced by a) establishing orchards on relatively large flat fields, b) growing grafts of north-Finnish plus trees in central but not southern Finland, c) keeping the orchards and their immediate surroundings clear of *Pinus contorta*, d) collecting and removing infested cones every autumn in central Finland but leaving them *in situ* in southern Finland.

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KÄPYPIKIKÄRSÄKKÄÄN (*PISSODES VALIDIROSTRIS* GYLL., COL., CURCULIONIDAE) BIOLOGIA JA VAHINGOLLISUUS ERITYISESTI MÄNNYN SIEMENVILJELMILLÄ

Tutkimuksen tarkoitus on selvittää käpypikikärsäkkään biologiaa ja tämän hyönteisen aiheuttamia tuhoja kotimaisen männyn siemenviljelmillä ja Murrayn männyn metsiköissä sekä tutkia, missä määrin tuhot ovat vältettävissä ilman varsinaisia torjuntatoimenpiteitä. Tutkimukset suoritettiin Etelä- ja Keski-Suomessa sijaitsevilla siemenviljelmillä ja Murrayn männyn metsiköissä vuosina 1969—1973. Lajin biologiaa koskevat selvitykset tehtiin suurimmaksi osaksi Metsäntutkimuslaitoksen Ruotsinkylän kokeilualueessa.

Käpypikikärsäkäs lähtee liikkeelle talvehtimispaikoistaan toukokuun ensimmäisellä viikolla ja siirtyminen puuhun tapahtuu kiipeämällä runkoa pitkin ylös oksistoon. Munia esiintyy touko- ja kesäkuussa, toukkia kesä- ja heinäkuussa, koteloita heinäkuun puolivälistä elokuun puoliväliin ja uudet aikuiset kuoriutuivat kävyistä elokuun loppupuolella tai syyskuun alussa.

Vanhat yksilöt alkavat laskeutua puusta talvehtimispaikkoihin puitten tyville ja karikkeeseen heinäkuun puolessa välissä, mutta uuden sukupolven aikuiset vasta syyskuussa. Vilkkainta siirtyminen talvehtimispaikkoihin on syyskuun lopulla. Talvehtiminen tapahtuu Etelä-Suomessa suurimmaksi osaksi aikuisena mutta Keski- ja Pohjois-Suomessa ensimmäisen kerran toukkana. Talvehtineet toukat aikuistuvat heinäkuussa.

Uuden sukupolven aikuiset tulevat lisääntymiskykyisiksi syntymänsä jälkeisenä kesänä vasta niin myöhään, etteivät ne enää kykene laskemaan munia lähes täysikasvuisiin käpyihin. Sukupolviajan pituus on siis Etelä-Suomessa suurimmaksi osaksi kaksivuotinen. Keski- ja Pohjois-Suomessa aikuistuminen tapahtuu valtaosaltaan vasta toisena kesänä, joten sukupolviajan pituus on siellä kaksi tai kolme vuotta. Kärsäkkäät ovat suhteellisen pitkäikäisiä, joten aikuisista yksilöistä kuuluu vähemmän kuin puolet edellisenä kesänä syntyneeseen sukupolveen. Aikuiset liikkuvat yhden kesän aikana suhteellisen rajoittuneella alueella, joten niiden leviäminen on verrattain hidasta.

Munista tuhoutuu kotimaisen männyn kävyissä noin 10 % mutta Murrayn männyn kävyissä lähes 40 %. Toukka-ajan lopussa on alkuperäisestä uudesta sukupolvesta (munien määrä) jäljellä vain 10 %. Koteloitten tuhoutuminen on hyvin vähäistä. Murrayn männyssä aikuisista kuolee kävyn sisään noin 20 % mutta kotimaisessa männyssä alle 10 %. Munista kehittyy uloskaivautuviksi aikuisiksi kotimaisessa männyssä noin 9 % ja Murrayn männyssä noin 7 %.

Käpypikikärsäkkäällä todettiin viisi toukkaloista: *Scambus brevicornis*, *Coeloides melanostigma*, *Eubadizon atricornis*, *Eurytoma annilai* ja *Rhopalicus* sp., jotka tuhoavat toukista kotimaisen männyn kävyissä noin 75 % mutta Murrayn männyssä vain 40 %.

Etelä-Suomessa käpypikikärsäkkään toukat tuhosivat kotimaisen männyn siemenviljelmillä keskimäärin 15—20 % kävyistä. Tuhojen määrässä esiintyi varsin huomattavia kloonien välisiä eroja. Pohjois-suomalaisissa klooneissa tuhoutuneita käpyjä oli selvästi enemmän kuin keski-suomalaisissa, ja huomattavasti enemmän kuin eteläsuomalaisissa klooneissa. Eniten tuhoja todettiin kumpuilevilla kangasmailla sijaitsevilla ja vähiten tasaisilla entisillä pelloilla olevilla viljelmillä. Keski-Suomessa sijaitsevilla viljelmillä tuhoja ei esiintynyt käytännöllisesti katsoen ollenkaan. Tämä johtuu suurimmaksi osaksi siitä, että kävyissä toukkina talvehtivat kärsäkkäät tulevat vuosittain poiskuljetetuksi siemenviljelmältä käpysatoa korjattaessa. Murrayn männyn kävyistä kärsäkkäät tuhosivät Etelä-Suomessa 75 % kasvupaikasta riippumatta.

Käpypikikärsäkkään kotimaisen männyn siemenviljelmillä aiheuttamia tuhoja voidaan vähentää seuraavilla toimenpiteillä. 1. Perustetaan viljelmät suhteellisen suurille, tasaisille peltoaukeille, jotka eivät ole käpypikikärsäkkään luontaisia elinpaikkoja. 2. Viljellään pohjois-suomalaisten kantapuiden vartteita Keski-Suomessa. 3. Poistetaan viljelmältä hyvin alttiiksi osoittautuvat kloonit ja vältetään Murrayn männyn kasvattamista siemenviljelmillä tai niiden välittömässä läheisyydessä, koska ne tarjoavat hyvät lisääntymismahdollisuudet kärsäkkäille. 4. Kerätään Keski-Suomessa kärsäkkään asuttamat kävyt pois viljelmältä syksyllä käpysatoa korjattaessa, koska ne sisältävät terveitä kärsäkästoukkia, mutta jätetään kärsäkkään vioittamat kävyt viljelmälle Etelä-Suomessa, missä ne sisältävät ainoastaan loistoukkia.

VERHOPUUSTON VAIKUTUS METSIKÖN LÄMPÖOLOIHIN POHJOIS-SUOMESSA

MATTI LEIKOLA

THE INFLUENCE OF THE NURSE CROP ON STAND TEMPERATURE CONDITIONS IN NORTHERN FINLAND

SUMMARY

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ALKUSANAT

Kun Pohjois-Suomen metsien uudistamiskysymyksien tutkimista 1960-luvun lopussa ryhdyttiin Metsäntutkimuslaitoksessa voimakkaasti tehostamaan, hahmoteltu tutkimusohjelma käsitti kaksi osaa: metsänviljelyn runkotutkimuksen sekä kymmenen eri kysymyksiin keskittyvää erikoistutkimusta. Näistä yksi oli kysymys verhopuuston vaikutuksesta metsien uudistamiseen. Käytännön syistä ongelma jaettiin kahteen osaan. Nyt käsillä oleva tutkimus, joka hyväksyttiin Metsäntutkimuslaitoksen työohjelmaan v. 1970, käsittelee mikroilmastollisten mittausten tuloksia. Varsinaisten metsänviljelykokeiden tulokset julkaistaan toisaalla.

Tutkimuksen kenttäkoealojen perustamisvaiheessa metsäteknikko Pekka Suolahti avusti mittauslaitteiden asentamisessa ja valvoi kesän 1970 mittaustoimintaa. Hän on myös piirtänyt julkaisun kuvat. Vuosina 1971—1973 mittaustoiminnan valvonta oli metsäteknikko Jaakko Rokkosella, joka on myös johtanut tulosten alustavaa käsittelyä. Aineiston lopullista käsittelyä on johtanut metsäteknikko Timo Ylitalo. Englanninkielisen tiivistelmän on kääntänyt metsänhoitaja, Ph D Kim v. Weissenberg. Käsikirjoituksen ovat lukeneet professorit Max. Hagman, Olavi Huikari ja Paavo Yli-Vakkuri. He ovat tehneet työhön arvokkaita ja varteen otettuja huomautuksia ja parannusehdotuksia.

Lausun parhaat kiitokseni kaikille edellä mainituille, erityisesti kentällä työskennelleille mittausapulaisille. Olen myös kiitollisuudenvelassa edesmenneelle professori Risto Sarvakselle tarkoitukseen sopivan koealan luovuttamisesta tutkimuksen käyttöön.

Helsingissä, helmikuussa 1975

Matti Leikola

SISÄLLYSLUETTELO

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1. JOHDANTO

1960-luvun ilmastollisesti epäedulliset vuodet aiheuttivat suurta tuhoa varsinkin Pohjois-Suomen männyn istutustaimistoille (mm. Etholén 1972). Tuhoutuneiden tai vaurioituneiden taimistojen tarkastelun perusteella käytännön metsäammattimiesten keskuudessa vakiintui yleisesti käsitys, että paitsi kuusen, myös männyn viljelytaimistot olivat menestyneet koivuverhopuustojen alla paremmin kuin aukeilla aloilla. Niinpä metsähallituksen ohjeen mukaan (Ohjekirje... 1969) metsäaurausalueiden jätepuustoa ei yleensä ollut syytä raivata ennenkuin siinä vaiheessa, jolloin siitä olisi selvää haittaa nousevalle taimistolle. Poikkeuksena olivat vain tiheät haapavesakot. Myös yksityismetsissä noudatettiin samaa menettelyä (esim. Pohjois-Suomen... 1970).

Edullisen tuloksen otaksuttiin perustuvan mm. verhopuuston ilman lämpöoloja parantavaan vaikutukseen tästä johtuvine seurausvaikutuksineen. Verhopuuston onkin jo kauan tiedetty tasaavan kasvukauden aikana esiintyviä äärilämpötiloja (Geiger 1965 ym.). Varsinkin milloin kysymyksessä on ollut maanpinnan ulossäteilystä johtuva halla, tiheän verhopuuston taimia suojaava vaikutus on yleisesti tunnustettu (esim. Multamäki 1942, Schnelle 1963, Leikola ja Pylkkö 1969). Tällä kertaa kysymys hallan torjumisesta ei kuitenkaan ollut olennainen — hallaahan ei Pohjois-Suomen männynviljelyaloilla juuri esiinny — vaan koko kasvukauden aikaisesta ilman lämpöolojen mahdollisesta muuttumisesta taimille edullisemmiksi.

Tutkimuksen tarkoituksena on ollut selvittää kysymystä verhopuuston vaikutuksesta metsikön lämpöoloihin Pohjois-Suomessa. Erityisesti on keskitytty seuraaviin ongelmiin:

— Miten verhopuusto vaikuttaa metsikön vuorokautisiin äärilämpötiloihin.

— Miten verhopuusto vaikuttaa metsikön vuotuisiin lämpösummiin.

— Miten verhopuusto vaikuttaa maan pintakerroksen lämpöoloihin.

Kysymystä tarkastellaan pitäen mielessä koko ajan metsänhoidon näkökohdat. Yksityiskohtaisesta mikroilmastollisesta analyysistä on tässä yhteydessä pidättäydytty.

2. TUTKIMUSAINEISTO JA -MENETELMÄ

21. Tutkimusalue

Tutkimusalueeksi valittiin Metsäntutkimuslaitoksen Kivalon kokeilualueessa ns. Sainkivalossa sijaitseva hieskoivikko (66° 20.5′ P, 26° 37.5′ I, 170 m mpy). Alue on laaja ja tasainen, jonkin verran soistunut kangas. Vuonna 1961 metsikköön oli asetettu 5 siemenenkeruusuppiloa ja vuonna 1965 lämpötilan mittausmasto latvuksen yläreunan tasolle sekä 3 anteesinmittausmastoa latvuksen tasalle. Metsänhoidon tutkimusosaston siemensatoja kukkimiskoealana koivikko toimi vv. 1961—1973 numerolla XVII. Metsikön puusto oli mitattu ensimmäisen kerran v. 1950 ja sen jälkeen vuosina 1958, 1961 ja 1967. Vuonna 1967 koivikko harvennettiin varovasti, jolloin siitä poistettiin 2 k-m³. Tutkimusmetsikön (kuva 1) ja sen puuston tärkeimmät tunnukset on esitetty taulukossa n:o 1.



Kuva 1. Sainkivalon hieskoivikko vertailualana käytetyltä aukealta käsin nähtynä. Valok. heinäk. 1970.

Fig. 1. The birch stand at Sainkivalo seen from the adjacent open control area. Photo in July 1970.

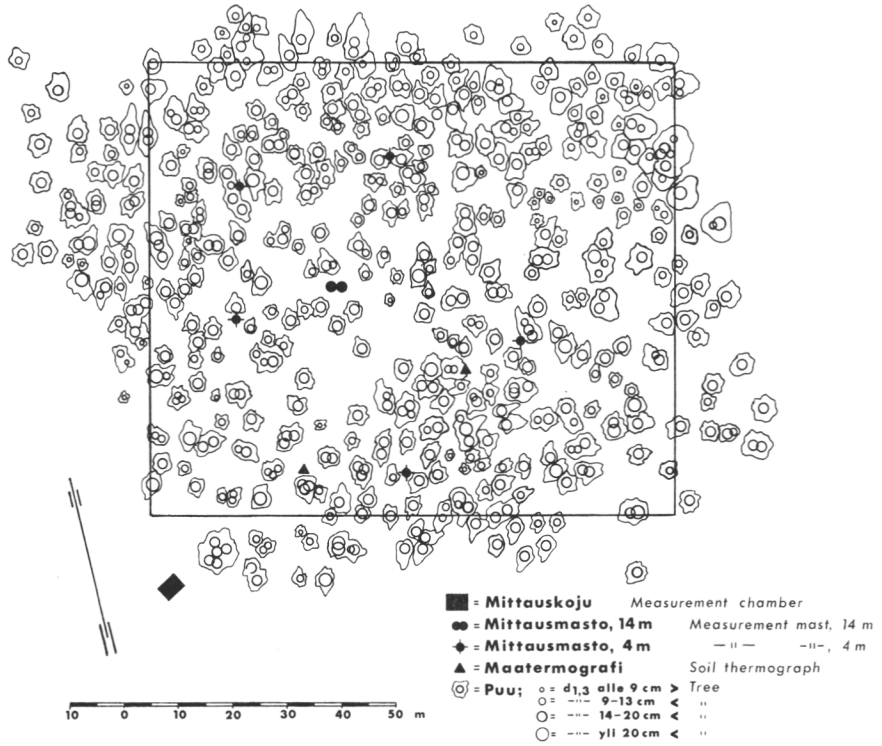
Taulukko 1. Tutkimusmetsikön tärkeimmät tunnukset.
Table 1. Important characteristics of the stand

Metsikkötunnus *Characteristics*		Mitt. vuosi *Year of measurements*
Metsikön ala — *Area*	n. 1 ha	
Puulajisuhteet: — *Tree species:*		
— *Betula pubescens* Ehrh.	100 %	1967
Runkoluku — *No of stems*	54 kpl/ha	»
Valtaläpimitta — *Dom. diameter*	18.4 cm	»
Valtapituus — *Dom. height*	14.3 cm	»
Kuutiomäärä, kuorin. — *Volume, with bark*	52 k-m³/ha	»
Puuston ikä (kantoarvio) — *Age (estim. from stumps), years*	n. 110 v	»
Latvuspeittävyys, Cajanuksen putkella,[1]) 200 hav. — *Crown closure, Cajanus' cylinder,*[1]) *200 observ.*	33 %	1968
Metsätyyppi — *Site type according to Cajander* [2])	pMT (soist.)	1967
Humuksen paksuus, 10 pistoa — *Thickness of humus, 10 tests*	32 mm	1961
Kivisyys ind., 30 pistoa [2]) — *Stoniness ind., 30 tests* [3])	24 cm	1961

[1]) Sarvas (1953).
[2]) Cajander (1949).
[3]) Viro (1952).

Kesällä 1970 hakattiin koivikon vieressä kasvanut noin 2 ha:n laajuinen männikkö aukeaksi, ja sekä kertynyt puutavara että hakkuutähteet raivattiin alalta välittömästi. Aukeata alaa käytettiin lämpötilan mittauksessa em. koivikon vertailualueena.

Metsikköilmastollisissa tutkimuksissa, varsinkin milloin kysymyksessä on kahden erilaisen alueen lämpöolojen vertailu, on vertailupohjan valintaan kiinnitettävä suurta huomiota (esim. Ångström 1936). Tässä suhteessa voidaan todeta, että molemmat alueet olivat täysin tasaisella maalla ja aivan toistensa vieressä, joten mainittavia topografian tms. aiheuttamia systemaattisia eroja tuskin saattoi odottaa. Aukean alan koko ylittää selvästi mm. Geigerin (1941) antamat ohjearvot, ja noin 80 m:n levyinen vaippa voitiin jättää ympäröivien metsiköiden vaikutuksen alla olevaksi vyöhykkeeksi. Vaikka liian pienet aukeat alat on usein mainittu ns. ilmastopariasemien käytön erääksi virhelähteeksi, ja usein painotetaan aukean alan koon vaikutusta sen lämpöoloihin, voidaan tässä tutkimuksessa käytettyä aukeata luonnehtia ns. suureksi uudistusaukoksi, jonka keskiosissa mikroilmastollisia reunavaikutuksia ei enää esiinny (esim. Göhre ja Lützke 1961).



Kuva 2. Latvuskartta, joka osoittaa lämpötilan mittausmastojen sijainnin koivikossa.
Fig. 2. Crown map of the birch stand showing the location of the measurement masts.

22. Lämpötilan mittaus

Ilman lämpötilan mittaamiseksi pystytettiin alkukesällä 1970 viisi 4 m:n korkuista mastoa eri puolille koivikkoa ja viereisen aukean alan keskelle kaksi 6 m:n korkuista mastoa (kuva 2). Mastot tuettiin liikkumattomiksi harusvaijerilla ja varustettiin 1 m:n pituisilla 2 × 2″ paksuisilla poikkipuilla, joihin säteilysuojuksilla varustetut lämpötilan mittausanturit kiinnitettiin. Aukealle alalle pystytettiin lisäksi puinen Ilmatieteen laitoksen standardisääkoju 2 m:n korkeuteen. Kojuun asetettiin termografi ja mittauksen tarkistusanturit.

Mittauskorkeuksiksi valittiin koivikossa 0.5 m, 2 m ja 4 m, ja näitä mittaustasoja täydennettiin aukealla alalla 6 m:n korkeudella. Lisäksi mitattiin ilman lämpötilaa koivikossa latvuksen yläreunan tasalle, 14 m:n korkuisen maston huippuun sijoitettiin termografin avulla.

Lämpötilan pääasiallisimmaksi mittausmenetelmäksi valittiin termoelementtimittaus. Käytetyt termoelementtikaapelit olivat 1.3 mm:n läpimittaista

muovipäällysteistä kupari- ja konstantaanijohtoa. Mittauslaitteena käytettiin Rubicon Instruments Inc.'n valmistamaa potentiometriä, malli 2715 B, mittaustarkkuus 15 μv +23°C lämpötilassa. Termoelementtianturit muodostettiin juottamalla kupari- ja konstantaanijohtimet noin 2 cm:n matkalta yhteen hopeajuotoksella. Mittauskojuna palveli lasikuituinen, lämmitettävä 2 × 2 × 2 m:n työmaasuoja. Vuosina 1972—1973 käytettiin mittauksessa anturikanavien vaihtoon Croydon Precision Instruments'in valmistamaa valintakytkintä, malli SP2/P/MB. Potentiometrin lukemisessa käytettiin apuna suurennuslasia.

Termoelementtimittauksen perusjaksona palveli vuorokausi, jonka aikana ilman lämpötila mitattiin juoksevasti aina joka toinen (parillinen) tunti. Mittaukset tehtiin säännöllisesti kahtena viikonpäivänä: tiistaina ja torstaina (vrt. Leikola 1974).

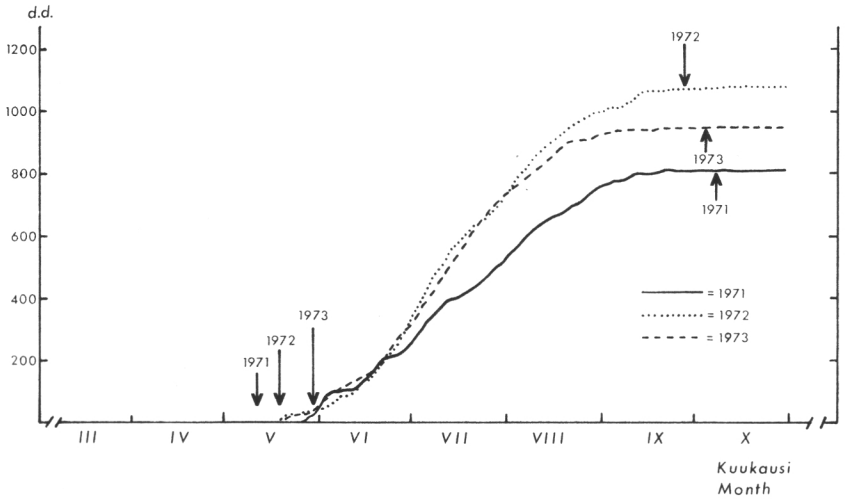
Termoelementtianturit suojattiin ohuesta alumiinista valmistetuilla, molemmista päistään avonaisilla, lieriönmuotoisilla, 5 cm:n pituisilla ja Ø 4 cm:n säteilysuojuksilla, jotka maalattiin sisältä mustiksi. Näitä mittausmastojen poikkipuiden päihin vaakasuoraan asetettuja suojuksia täydennettiin kesällä 1971 Ilmatieteen laitoksen ohjeiden mukaan vielä toisilla, edellistä suuremmilla, samanmuotoisilla alumiinisuojuksilla. Vapaa ilmanvaihto katsottiin turvatun, ja kuitenkin anturit olivat suojassa sekä tulo- että ulossäteilyltä (Franssila 1961, Pech 1964, Bjor 1967 ym).

Lieriönmuotoisen säteilysuojuksen aiheuttama säteilyvirhe riippuu tietenkin jonkin verran mm. tuulen suunnasta. Esim. Multamäen (1942) suorittamassa vertailussa virhe vaihteli n. 0.1—0.2°C tuulen suunnasta ja voimakkuudesta riippuen. Tuulen suunnan vaikutus pyrittiin Sainkivalossa eliminoimaan siten, että kunkin mittauskorkeuden anturin suojus sijoitettiin ilmansuuntiin nähden satunnaisesti ja tulosten käsittelyssä käytettiin vain usean (aukealla kahden ja metsikössä viiden) anturin antamia keskimääräisiä lukemia.

Maan lämpötilaa mitattiin koivikossa ja aukealla alalla kahdessa pisteessä termoelementtien avulla ja kahdessa pisteessä kaksianturisia maatermografeja (Lambrecht n:o 257) käyttäen. Mittaussyvyydet olivat 5 cm ja 10 cm elävän sammalpeitteen ja humuksen rajapinnasta mitattuna. Mittausmenettely oli samanlaista kuin tutkimusalueen ilman lämpötilan mittauksessa ja samoina vuosina Kivalossa suoritetuissa maan lämpötilan mittauksissa, joita on yksityiskohtaisemmin selostettu toisaalla (Leikola 1974).

Samassa yhteydessä kuin lämpötilan mittaukset tehtiin, merkittiin myös muistiin mittaushetkellä vallinnut pilvisyys (asteikolla 0—8), tuulen suunta ja nopeus (m/sek.) sekä vallitseva sää Ilmatieteen laitoksen säämerkeillä (mm. Säähavainto-opas 1951).

Vuotuiset **mittauskaudet** olivat termoelementtimittauksen osalta seuraavat:



Kuva 3. Vuotuinen lämpösumma (d.d.) koivikon latvuston yläreunan tasalla vuosina 1971—1973. Mittauskaudet maaliskuun alusta lokakuun loppuun. Muun mittaustoiminnan aloittamis- ja lopettamisajankohdat on merkitty nuolilla.

Fig. 3. The annual temperature sum (d.d.) at the upper level of the canopy of the birch stand in 1971—1973. Measurement periods from the beginning of March until the end of October. The beginning and the end of the rest of the measurements are indicated with arrows.

Mittaus-vuosi	Mittaus alkoi	Mittaus päättyi
1970	15.7.	30.9.
1971	11.5.	7.10.
1972	18.5.	28.9.
1973	29.5.	4.10.

Latvuksen yläreunan tasalle sijoitettu mittauspiste oli toiminnassa vuosittain maaliskuun alusta lokakuun loppuun.

Silmävaraisten havaintojen ja karikemittausten mukaan koivikon lehtien vuosittaiset puhkeamis- ja varisemisajat olivat seuraavat:

Vuosi	Lehdet hiirenkorva-asteella (pituus n. 20 mm)	Lehdet varisivat (10 %—90 %)
1971	1.6.	13.9—3.10
1972	4.6.	11.9—2.10
1973	1.6.	7.9—3.10

Vuosien 1971—1973 mittauskaudet kattoivat tämän mukaan koko sen ajan, jolloin koivikko oli lehdessä. Ennen mittauskauden alkua ja sen loppumisen jälkeen kertyi latvuksen yläreunan tasalla olevan mittauspisteen

mukaan jonkin verran tehoisan lämpötilan summaa (kuva 3), mutta tuona aikana metsikön ja aukean säteily- ja lämpöolot muistuttavat siinä määrin toisiaan, että näiden alojen vertailussa tästä syystä syntyvä mahdollinen virhe katsotaan yleensä suuruudeltaan erittäin pieneksi (esim. Lütz ke 1961, Odin 1964, Baumgartner 1967).

23. Aineiston käsittely

Lämpötilan mittauspöytäkirjoista laskettiin aluksi termoelementtimittauksen antamat vuorokausikohtaiset ääriarvot, jotka oletettiin sellaisinaan vuorokautisiksi minimi- ja maksimilämpötiloiksi. Metsikön viiden ja aukean alan kahden rinnakkaisen ilman lämpötilan mittausmaston havainnot yhdistettiin jokaisessa vertailussa mittauspaikan ja -korkeuden keskimääräisiksi lukemiksi. Yleensä käytettiin kuukauden tai koko kesän tarkastelujaksoja, mutta myös vuorokausikohtaisia lämpötilan eroja tarkasteltiin yksityiskohtaisemmin.

Termografien antamat lukemat merkittiin piirturinauhoilta muistiin juoksevasti käyttäen kahden tunnin havaintoväliä. Piirturin lukemat korjattiin tarkistuslämpömittarien lukemien perusteella lasketuilla kertoimilla ja korjatut havainnot käsiteltiin edelleen kuten termoelementtimittausten havainnotkin.

Vuotuiset lämpösummat laskettiin tuntikohtaisen (d.h.) periaatteen mukaisesti valiten kynnysarvoksi tähän tarkoitukseen yleisimmin käytetyn lämpötilan +5°C. Tuntikohtaiset lämpösummat jaettiin vielä 24:llä. Menettely oli samanlainen kuin Kivalon maanmuokkausalan lämpötilan mittaustulosten käsittelyssä (Leikola 1974). Latvuksen yläreunan tasalla olleen lämpötilan mittauspisteen lämpösummat laskettiin kuitenkin käyttäen d.d. -periaatetta (lämpösummasta ja sen laskennasta esim. Sarvas 1966).

Jäljempänä esitettäviä lämpösummia tarkasteltaessa on pidettävä mielessä, että niissä ei oteta huomioon vuorokautisten lämpöolojen koko vaihtelua, vaan ainoastaan kynnyslämpötilan ylittävä osa, jolla on puiden elintoimintojen kannalta havaittu olevan ekologista, erityisesti fenologista merkitystä (esim. Schnelle 1955, Sarvas 1972). Lämpösumman avulla ei siis voi tarkastella esim. verhopuuston vaikutusta lämpöoloihin mikroilmastollisena käsitteenä, vaan tulkinta on koko ajan biologisella pohjalla saaden koko mielekkyytensä puiden elintoimintojen intensiteetin riippuvuudesta lämpötilasta ja sen kestoajasta.

Taulukko 2. Vuosien 1971—1973 lämpösummat (d.d.) sadanneksina pitemmän mittauskauden keskiarvosta eräiden lämpötilan mittausasemien mukaan.

Table 2. The temperature sums of the years 1971—1973 as per cents of the averages of longer observation periods according to some weather stations.

Lämpötilan mittausasema *Weather station*	1971	1972	1973	Keskiarvo (100) *Mean*	
				d.d.	Mittausvuod. *Observ. years*
Sainkivalo, latvuksen yläreuna — *Sainkivalo, upper level of the canopy*	88	118	104	914	1960—1973
Rovaniemi, Apukka 66°35′P, 26°01′I 105 m mpy	92	118	105	904	1951—1973
Sodankylä, observat. 67°22′P, 26°39′I 178 m mpy	91	122	106	813	1950—1973
Keskimäärin, noin — *Average, appr.*	90	119	105	—	—

24. Mittausvuosien edustavuus

Kun lämpötilan mittauksia koivikossa ja aukealla alalla tehtiin koemielessä loppukesällä 1970 ja koko kesäkauden ajan vain vuosina 1971—1973, on kysymys näiden kolmen päähavaintovuoden edustavuudesta tärkeä tulosten yleistettävyyttä ajatellen. Taulukossa 2 on vertailtu havaintovuosien lämpööloja muutamilla havaintoasemilla Metsäntutkimuslaitoksessa laskettujen vuotuisten lämpösummien perusteella. Sainkivalon hieskoivikon latvuksen yläreunan tasalla on tehty mittauksia 8 vuoden ajan, ja Ilmatieteen laitoksen havaintoasemien lämpösummat perustuvat Apukan osalta 27 ja Sodankylän osalta 28 vuoden havaintoihin.

Vuosi 1971 on tämän mukaan ollut selvästi keskimääräistä kylmempi, kun taas vuosi 1972 on ollut runsaasti keskimääräistä lämpimämpi. Viimeinen havaintovuosi, 1973, on ollut hieman keskimääräistä lämpimämpi, mutta se edustaa silti jokseenkin hyvin normaaliksi katsottavaa lämpösumman suuruusluokkaa.

3. TUTKIMUSTULOKSET

31. Metsikön äärilämpötilat

Taulukossa 3 on esitetty aukean alan ja koivikon keskimääräiset vuorokautiset äärilämpötilat kolmen havaintovuoden aikana. Tarkasteltaessa aluksi eri korkeuksilla mitattuja äärilämpötiloja havaitaan maksimilämpötilojen olevan niin metsässä kuin aukeallakin 4—6 m:n korkeudessa alimman ja nousevan siirryttäessä vertikaalisuunnassa lähemmäksi maan pintaa. Vastaavasti ovat 4—6 m korkeudessa mitatut metsikön ja aukean alan minimilämpötilat korkeimmat ja alenevat siirryttäessä alaspäin lähemmäksi maan pintaa. Sekä metsikön että aukean alan lämpöolot ovat siten havaintokauden aikana noudattaneet mallia, joka on luonnollinen tulo- ja ulossäteilytyypin vallitessa: maanpinnan läheisen ilmakerroksen lämpöolot ovat äärevät, mutta ne tasaantuvat siirryttäessä ylemmäksi (esim. Franssila 1949).

Kuvassa 4 on vertailtu toisiinsa koivikon ja aukean alan äärilämpötilojen välisiä keskimääräisiä eroja. Suuntaus on kaikkina havaintovuosina samanlainen: päivittäiset minimilämpötilat ovat metsikössä noin 0.5—1.0 C-astetta korkeammat kuin aukealla alalla vastaavalla korkeudella, ja päivittäiset maksimilämpötilat ovat metsikössä vuorostaan suunnilleen saman verran alemmat kuin aukealla. Ilman lämpöolot ovat toisin sanoen aukealla äärevämmät kuin metsikössä, ja äärevyys kasvaa mitä lähemmäksi maan pintaa siirrytään (vrt. esim. Baumgartner 1956, Göhre ja Lützke 1956).

Vertailevin mittauksin on voitu varmistaa yleinen, teoreettisesti perusteltavissa oleva käsitys, että puiden ollessa lehdettöminä metsikön ja aukean alan äärilämpötilojen välinen ero on pienempi kuin puiden ollessa täydessä lehdessä (esim. Lützke 1961, Chroust 1968). Kuvassa 5 on vertailtu koivikon ja aukean alan maksimi- ja minimilämpötilojen välisiä eroja kolmen havaintovuoden kaikkina mittauspäivinä. Kovin selvää muutosta ei puiden lehteen tulo kesäkuun ensimmäisellä viikolla tämän mukaan ole aiheuttanut, ja syntyneiden erojen vaihtelu onkin ennemmin laskettava suursään aiheuttamien säätyypin muutosten tiliin (esim. Sirén 1955). Jo vanhastaan onkin tiedetty, että pilvettömällä säällä, heikon tuulen valli-

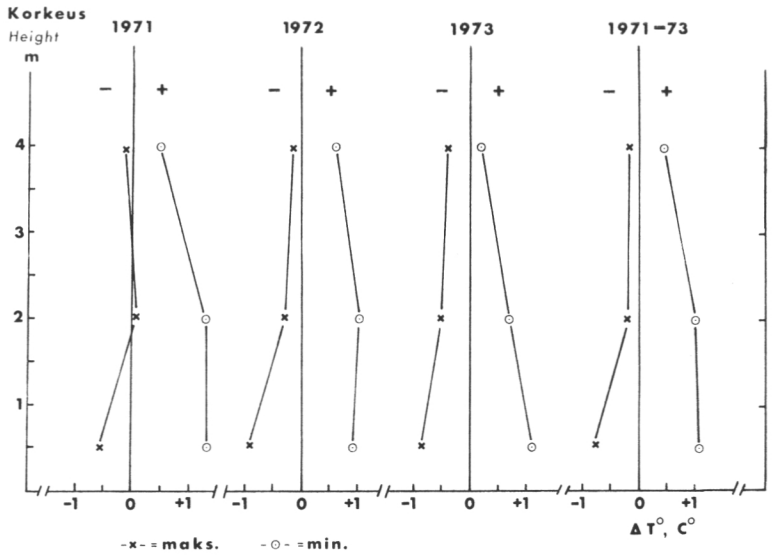
Taulukko 3. Aukean alan ja koivikon keskimääräiset äärilämpötilat havaintokausina 1971—1973.

Table 3. The average max. and min. temperatures in the open and in the birch stand in 1971—1973.

Mittauskorkeus *Measurem. height*	Maks./min. lämpöt. *Max./min. temperature*	1971		1972		1973		1971—1973	
		Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*
		Keskimääräinen äärilämpötila, °C *Average max./min. temperature, °C*							
6 m	Maks.— *Max.*	16.90	—	18.26	—	17.31	—	17.5	—
	Min. — *Min.*	5.56	—	7.72	—	5.89	—	6.4	—
	Erotus — *Differ.*	11.34	—	10.54	—	11.42	—	11.1	—
4 m	Maks.— *Max.*	16.82	16.69	18.63	18.54	17.86	17.44	17.8	17.6
	Min. — *Min.*	4.83	5.33	7.25	7.85	5.48	5.71	5.9	6.3
	Erotus — *Differ.*	11.99	11.36	11.38	10.69	12.38	11.73	11.92	11.26
2 m	Maks.— *Max.*	16.86	16.95	19.08	18.75	18.21	17.71	18.0	17.8
	Min. — *Min.*	3.80	5.09	7.12	8.09	4.52	5.18	5.1	6.1
	Erotus — *Differ.*	13.06	11.86	11.96	10.66	13.69	12.53	12.90	11.68
0.5 m	Maks.— *Max.*	18.03	17.46	20.32	19.33	19.01	18.09	19.1	18.3
	Min. — *Min.*	3.26	4.54	6.35	7.28	3.47	4.52	4.4	5.4
	Erotus — *Differ.*	14.77	12.92	13.97	12.05	15.54	13.57	14.76	12.85

tessa metsikön ja aukean lämpöolojen erot muodostuvat selviksi, kun taas sateisella ja sumuisella säällä tai tuulen (vaihdon) sekoittaessa ilmamassoja, eroja ei lainkaan muodostu tai ne ovat erittäin vähäisiä (Geiger 1965, Mitscherlich 1971 ym.).

Muutamissa tapauksissa, kuten esim. vuoden 1972 maksimilämpötilan kohdalla, esitetty malli toteutuu kuitenkin kauniisti: kesäkuun alkupuolelle saakka ovat metsikön ja aukean alan lämpötilan erot maanpinnan läheisyydessä hyvin vähäiset, mutta puiden ollessa täydessä lehdessä kesäkuun puolivälistä aina syyskuun loppupuolelle saakka metsikön maksimilämpötilat ovat selvästi alhaisemmat kuin aukean alan. Aivan mittauskauden lopussa, kun kaikki lehdet ovat pudonneet puista, metsikön maksimilämpötilat ovat vuorostaan hieman korkeammat kuin aukean alan.

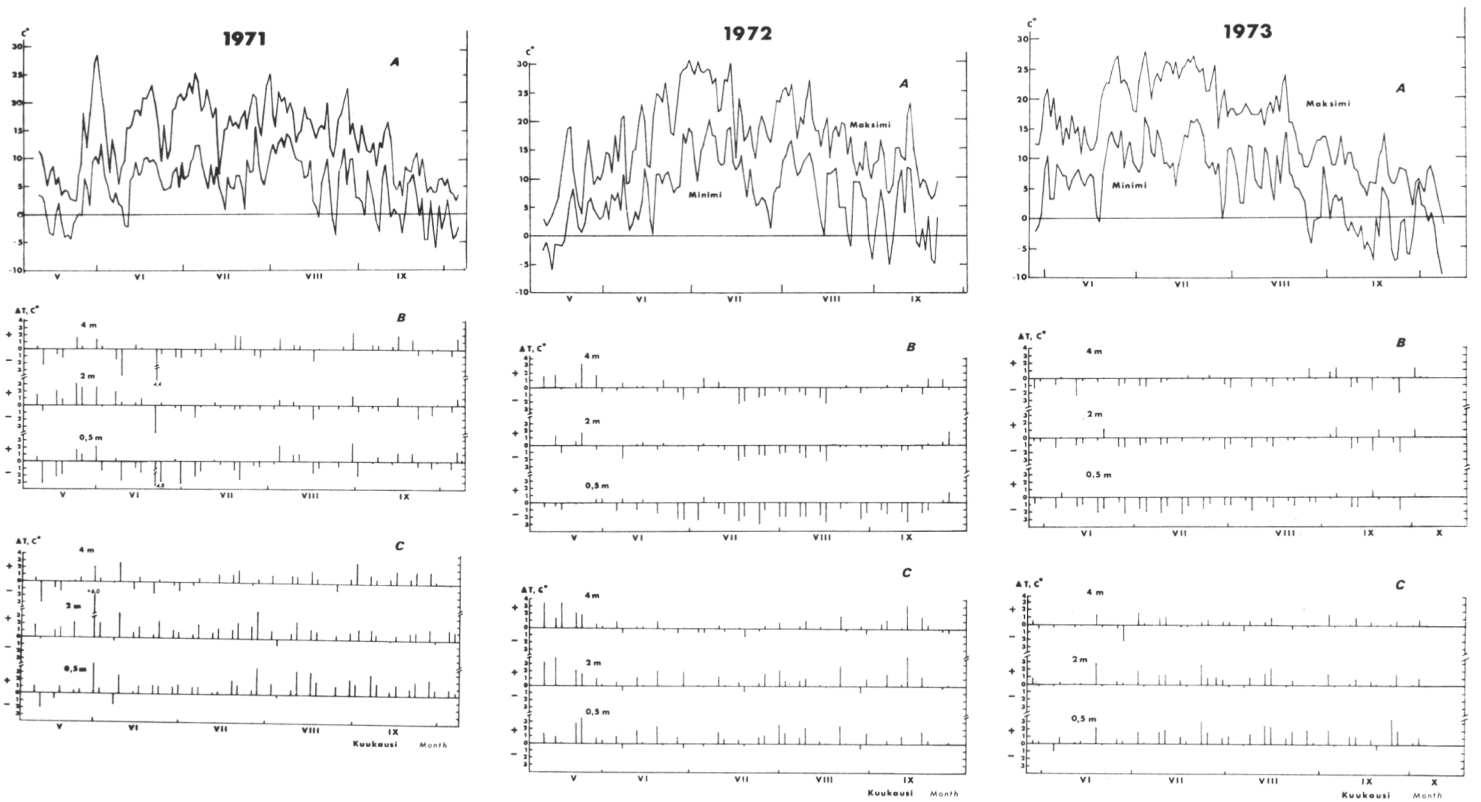


Kuva 4. Koivikon ja aukean alan äärilämpötilojen väliset keskimääräiset erot havaintokausina 1971—1973.
+ = koivikko lämpimämpi, — = koivikko kylmempi.

Fig. 4. The average differences between the daily air max. and min. temperatures in the birch stand and in the open in 1971—1973.
+ = The birch stand is warmer, — = The birch stand is colder.

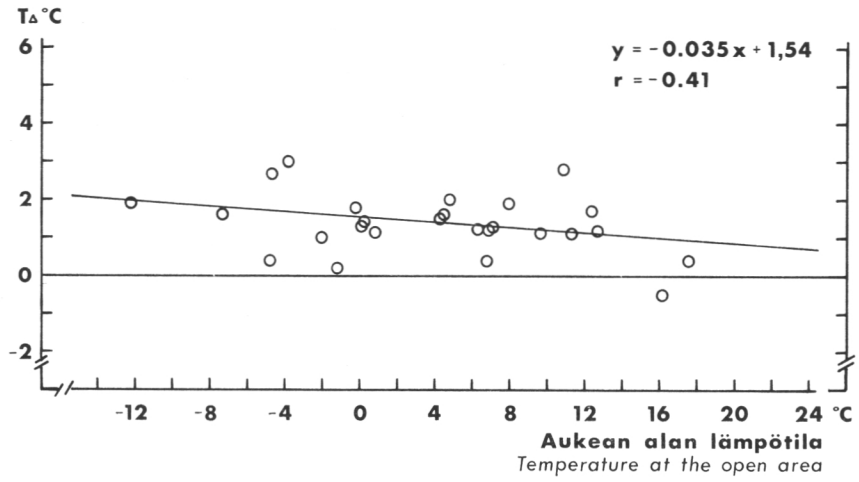
Normaalisti koivikon ja aukean alan äärilämpötilojen väliset erot ovat olleet korkeintaan 2°—3°C suuruusluokkaa, ja esim. yli 4°C erot ovat vain muutaman kerran vuodessa esiintyviä poikkeuksia.

Tarkemman selvyyden saamiseksi verhopuuston vaikutuksesta vuorokautisiin minimilämpötiloihin, mittaustulokset ryhmiteltiin kolmeen luokkaan mittaushetkellä vallinneen pilvisyyden ja tuulen voimakkuuden mukaan. Kuvassa 6 on esitetty kaikkien kolmen vuoden havainnoista laadittu yhdistelmä pilvettömistä (pilvisyys 0—1) ja tyynistä (tuulen voimakkuus 0—2 m/sek.) öistä. Metsikön ilman minimilämpötilaa kohottava vaikutus on tämän mukaan jokaisessa tapauksessa yhtä lukuunottamatta positiivinen, ja heikossa negatiivisessa riippuvuusuhteessa aukealla alalla mitattuun ilman minimilämpötilaan. Korrelaatiokertoimen arvo eroaa 0:sta 95 %:n luotettavuudella, mikä ilmaisee mm. että ilman minimilämpötilan ollessa kesäkauden aikana alhaisen, ulossäteily on ollut voimakkaampaa kuin minimilämpötilan ollessa tätä korkeamman. Metsikön vaikutus säteilyoloihin on näin ollen myös näkynyt selvemmin lämpötiloissa.



Kuva 5. Koivikon ja aukean alan äärilämpötilojen vaihtelu 0.5 m:n korkeudessa havaintokausina 1971—1973. A = päivittäiset maksimi- ja minimilämpötilat aukealla alalla. B = koivikon ja aukean alan päivittäisten maksimilämpötilojen väliset erot. C = metsikön ja aukean alan päivittäisten minimilämpötilojen väliset erot.

Fig. 5. The variation of the daily max. and min. temperatures at height of 0.5 m. in the birch stand and in the open in 1971—1973. A = The daily max and min. temperatures in the open. B = The differences between the daily max. temperatures in the birch stand and in the open. C = The differences between the daily min. temperatures in the birch stand and in the open.



Kuva 6. Koivikon ja aukean alan päivittäisten minimilämpötilojen välisen eron (T △) riippuvuus aukealla alalla mitatuista minimilämpötiloista. Mittauskorkeus 0.5 m, havainnot pilvettömällä ja tuulettomalla säällä.

Fig. 6. The dependence of the difference (T △) between the daily max. and min. temperatures in the birch stand and in the open on air temperature measured in the open. Measurement height 0.5 m., observations in clear and calm weather.

32. Metsikön lämpösumma

Taulukkoon 4 on koottu aukean alan ja koivikon kuukausittaiset lämpösummat eri korkeuksilla mitattuina. Lämpösummien välisiä keskimääräisiä eroja on havainnollistettu kuvassa 7. Metsikön ja aukean alan lämpöoloissa on havaittavissa selvä vuodenaikojen mukainen kehitys: varhain keväällä metsä on hieman lämpimämpi kuin aukea ala, alkukesällä aukea ala on vuorostaan selvästi lämpimämpi, mutta loppukesällä metsikkö osoittautuu jälleen lämpimämmäksi. Lopputulos, so. havaintokauden lämpösumma, osuu maanpinnan lähellä metsässä taimien kannalta edulliseksi, mutta kun siirrytään vertikaalisuunnassa ylöspäin rungostokerrokseen ja latvuksen alarajan tasalle, ero on taimien kannalta metsälle epäedullinen. Erot ovat vuotuisten lämpösummien suuruuteen verrattuna kuitenkin perin vaatimattomat, vain 0.5—2.5 %. Tämä merkitsee sitä, että kasvukauden aikana metsikön ja aukean lämpösummien välillä on tosin eroa, mutta tämä ero on niin pieni, että esim. eri vuosien lämpösummien vaihtelu peittää sen jopa kymmenkertaisena. Eri vuosien yksityiskohtainen tarkastelu ei muuta tätä yleistä johtopäätöstä.

Useat tutkijat ovatkin kiinnittäneet huomiota tähän ilmiöön arvioidessaan vuotuisten keskilämpötilojen perusteella saamaansa tulosta. Niinpä esim. O d i n (1964, 1974) ilmoittaa kolmen vuoden mittausten perusteella,

Taulukko 4. Kuukausittaiset lämpösummat (d.h./24) aukealla alalla ja koivikossa havaintokausina 1970—1973.

Table 4. The monthly temperature sums (d.h./24) in the open and in the birch stand in 1970—1973.

Korkeus *Height*	Kuukausi *Month*	1970		1971		1972		1973		Keskimäärin *Average* 1971—1973	
		Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*
6.0 m	Toukok. *May*	—	—	63	—	49	—	13	—	42	—
	Kesäk. *June*	—	—	281	—	353	—	264	—	299	—
	Heinäk. *July*	347	—	276	—	462	—	444	—	394	—
	Elok. *Aug.*	320	—	266	—	312	—	173	—	250	—
	Syysk. *Sept.*	97	—	63	—	93	—	44	—	67	—
	Lokak. *Oct.*	—	—	21	—	—	—	6	—	9	—
	Yht. *Total*	764	—	971	—	1 269	—	945	—	1 062	—
4.0 m	Toukok. *May*	—	—	82	74	47	55	13	14	47	48
	Kesäk. *June*	—	—	293	279	350	356	291	282	311	306
	Heinäk. *July*	340	333	289	276	479	456	449	443	406	392
	Elok. *Aug.*	319	330	253	279	315	313	174	176	247	256
	Syysk. *Sept.*	94	109	54	68	90	111	48	48	64	76
	Lokak. *Oct.*	—	0	15	22	—	—	5	7	7	10
	Yht. *Total*	753	766	987	998	1 281	1 290	979	969	1 082	1 086
2.0 m	Toukok. *May*	—	—	61	83	54	55	14	14	43	51
	Kesäk. *June*	—	—	273	290	358	353	281	281	304	308
	Heinäk. *July*	335	332	274	286	467	455	448	442	396	394
	Elok. *Aug.*	322	319	267	272	310	315	171	172	249	253
	Syysk. *Sept.*	96	101	60	62	90	115	48	48	66	75
	Lokak. *Oct.*	—	—	15	21	—	—	5	7	7	9
	Yht. *Total*	753	751	946	1 014	1 278	1 295	967	963	1 064	1 091

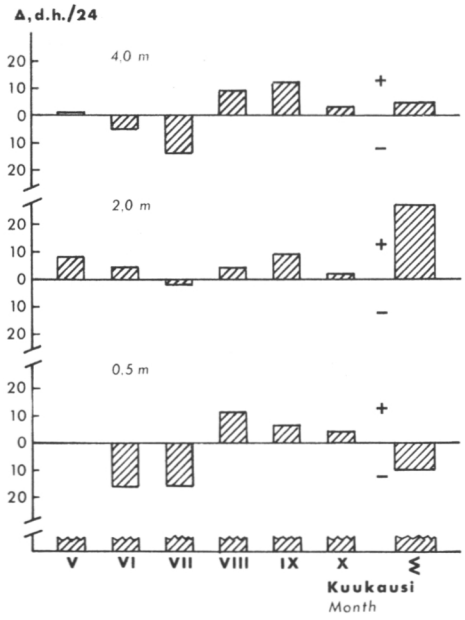
Korkeus *Height*	Kuukausi *Month*	1970		1971		1972		1973		Keskimäärin *Average* 1971—1973	
		Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*
0.5 m	Toukok. *May*	—	—	80	79	57	57	14	14	50	50
	Kesäk. *June*	—	—	311	291	357	348	300	282	323	307
	Heinäk. *July*	333	332	302	282	472	449	436	435	403	387
	Elok. *Aug.*	326	315	258	277	308	308	157	170	241	252
	Syysk. *Sept.*	94	99	52	63	105	112	48	47	68	74
	Lokak. *Oct.*	0	0	10	23	—	0	6	5	5	9
	Yht. *Total*	753	745	1 013	1 016	1 299	1 275	961	952	1 091	1 081

että aukkoinen tunturikoivikko ei vaikuta merkitsevästi ilman lämpöoloihin koko kesäkauden lämpötilan keskiarvoina arvostellen. Samaan tulokseen päätyy Baumgartner (1956) vertaillessaan tiheän verhopuustokoivikon ja aukean alan välisiä keskilämpötiloja kesäkauden aikana.

Franssila ja Järvi (1974) toteavat, että Lokan altaan maastossa sijainnutta ilmastoasemaa ympäröivä erittäin harva metsä ei sanottavasti vaikuttanut asemalla vallitseviin lämpöoloihin. Lütz ke (1961) ilmoittaa, että tiheässä metsikössä lämpötilan vuosikeskiarvot olivat hänen mittaustensa mukaan kaikilla mittauskorkeuksilla 1.0°—0.3°C alhaisemmat kuin aukealla alalla (katso myös Mitscherlich 1971, ym. 1965).

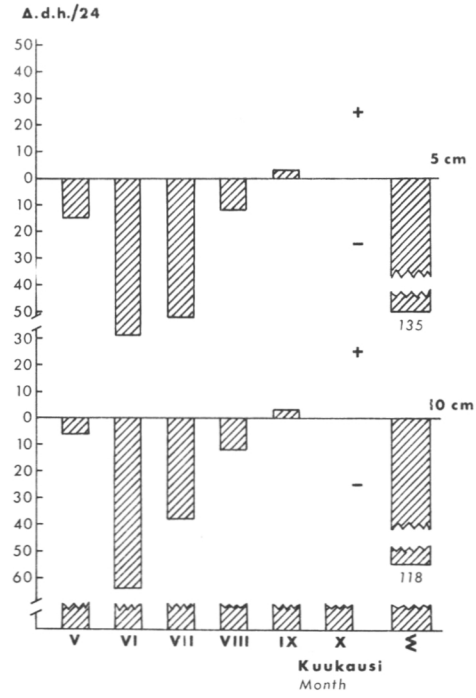
33. Maan lämpöolot

Kuvassa 9 on esitetty maassa 5 cm:n syvyydellä mitattujen päivittäisten minimi- ja maksimilämpötilojen kehitys kasvukauden aikana aukealla alalla sekä koivikon ja aukean alan äärilämpötilojen väliset lämpötilan erot. Havaintokausien aikana on molempien alueiden sekä minimi- että maksimilämpötilojen välisten erojen kehitys hyvin samanlainen. Varhain keväällä, kun puissa ei vielä ole lehtiä, maan äärilämpötilat ovat metsässä korkeammat kuin aukealla alalla, mutta suunnilleen kesäkuun alusta alkaen aukean alan äärilämpötilat ovat selvästi korkeammat. Syyskesällä, kun yöt viilenevät ja puiden lehdet alkavat varista, molempien mittausalueiden maan äärilämpötilat ovat likimain samansuuruiset, ja myöhään syksyllä



Kuva 7. Koivikon ja aukean alan ilman lämpösummien väliset erot havaintokausina 1971—1973.

Fig. 7. The differences between the temperature sums in the birch stand and in the open in 1971—1973.

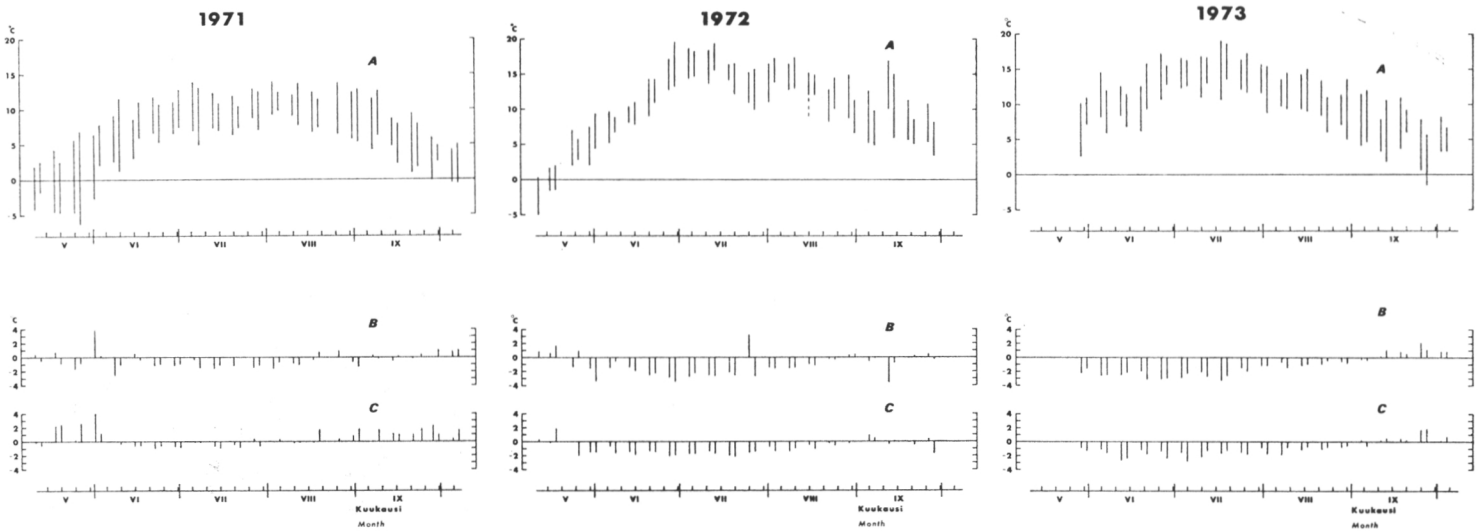


Kuva 8. Koivikon ja aukean alan maan lämpösummien väliset erot havaintokausina 1971—1973.

Fig. 8. The differences between the temperature sums of the soil in the birch stand and in the open in 1971—1973.

maan äärilämpötilat ovat koivikon alla jälleen korkeammat kuin aukealla alalla. Tämä äärilämpötilojen eron vaihtelu voidaan sitoa varsin hyvin koivikon lehvistön kehitysvaiheisiin, vaikka lumipeitteen erilaisuudella, roudan sulamisella yms. on luonnollisesti osansa varsinkin alkukesän maan lämpöoloihin (esim. Ångström 1936, Yli-Vakkuri 1960).

Taulukkoihin 5 ja 6 on koottu aukean alan ja koivikon maan lämpösummien vuotuinen kehitys kahdella eri mittausmenetelmällä, termoelementeillä ja maatermografeilla mitattuna. Kuvassa 8 on esitetty aukean alan ja metsikön erot. Seuraavat piirteet ovat maan lämpösumman osalta olennaisimmat: metsikön ja aukean alan maan suurin lämpösumman ero muodostuu kesä-heinäkuussa. Tähän verrattuna ovat touko-, syys- ja lokakuussa syntyneet lämpösummien erot perin vaatimattomat. Lämpösummien eron kuukausikohtainen kehitys muistuttaa suuresti edellä selostettua äärilämpötilojen välisen eron kehitystä. Alkukesällä se on vähäinen, mutta kasvaa keskikesään siirryttäessä ja jälleen pienenee siirryttäessä edelleen syksyä ja



Kuva 9. Koivikon ja aukean alan maan äärilämpötilojen vaihtelu 5 cm:n syvyydellä havaintokausina 1971—1973. A = päivittäiset maksimi- ja minimilämpötilat aukealla alalla. B = koivikon ja aukean alan päivittäisten maksimilämpötilojen väliset erot. C = metsikön ja aukean alan päivittäisten minimilämpötilojen väliset erot.

Fig. 9. The variation of the daily soil max. and min. temperatures at depth of 5 cm in 1971—1973. A = The daily soil max. and min. temperatures in the open area. B = The differences between the daily max. temperatures in the birch stand and in the open. C = The differences between the daily min. temperatures in the birch stand and in the open.

Taulukko 5. Maan kuukausittaiset lämpösummat aukealla alalla ja koivikossa havaintokausina 1971—1973. Mittaus termoelementeillä, syvyys 5 cm.

Table 5. The monthly temperature sums of soil (d.h./24) in the open and in the birch stand in 1971—1973. Measurement with thermocouples, depth 5 cm.

Kuukausi *Month*	1971		1972		1973		Keskim. 1971—73 *Aver. 1971—73*		
	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Erotus *Differ.*
Toukok. *May*	—	—	2	1	6	3	3	1	2
Kesäk. *June*	58	46	167	144	191	122	139	104	35
Heinäk. *July*	150	127	324	262	289	233	254	207	47
Elok. *August*	156	150	247	221	180	159	194	177	17
Syysk. *September*	38	54	104	95	54	60	65	70	-5
Lokak. *October*	—	—	—	—	3	4	1	1	0
Yht. — *Total*	402	377	844	723	723	581	656	560	96

talvea kohden. Koivikon ja aukean alan maan lämpösummien välinen ero on, toisin kuin ilman lämpösumman osalta oli laita, melko huomionarvoinen; noin 15—20 % aukean alan koko vuoden lämpösummasta. 10 cm:n syvyydessä on mitattu pienempi lämpösumma kuin 5 cm:n syvyydessä, mutta eri alueiden välinen lämpösumman ero on molemmilla syvyyksillä suhteellisesti samaa suuruusluokkaa.

Vertaillessaan maan lämpöoloja aukealla ja erilaisissa metsissä ovat kaikki tutkijat saaneet maan lämpöolot metsässä johtonmukaisesti kylmemmiksi kuin aukealla alalla (esim. Sirén 1955, Baumgartner 1956, Lützke 1961, Mitscherlich ym. 1965). Vaikka tämän ilmiön suurin syy on epäilemättä näiden kahden paikan maan pinnalle lankeavassa erilaisessa säteilytaseessa, on myös syytä kiinnittää huomiota metsikön ja aukean alan pintakasvillisuudessa sekä humuksen paksuudessa ja laadussa aina väistämättä vallitseviin eroihin. Mittaustekniseltä kannalta olisi syytä vaatia täysin samanlaista pintakasvillisuutta, paljaaksi raivattua maanpintaa tms. kaikille vertailun kohteena oleville aloille, mutta käytännössä tämä on täysin luonnonvastainen tilanne, jonka antamien tulosten käyttäminen ja soveltaminen edelleen metsänhoidon tarpeisiin on hyvin hankalaa. Vielä on syytä muistaa, että esim. taimien juuristojen syvyyden ei tarvitse olla sama aukealla alalla ja viereisessä metsikössä, vaan puiden juuret hakeutuvat itsenäisesti niille edullisiin maakerroksiin (esim. Paavilainen 1966, Lähde ja Siltanen 1973).

Taulukko 6. Maan kuukausittaiset lämpösummat aukealla alalla ja koivikossa vuosina 1971—1973. Mittaus maatermografeilla.

Table 6. The monthly temperature sums of soil (d.h./24) in the open and in the birch stand in 1971—1973. Measurement with thermographs.

Syvyys *Depth*	Kuukausi *Month*	1971		1972		1973		Keskimäärin *Average*		
		Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Aukea *Open*	Koiv. *Stand*	Erotus *Differ.*
5 cm	Toukok. *May*	—	—	9	—	55	19	21	6	15
	Kesäk. *June*	38	9	166	101	191	108	132	73	59
	Heinäk. *July*	115	76	302	248	261	198	226	174	52
	Elok. *August*	163	157	225	226	166	136	185	173	12
	Syysk. *September*	60	69	97	104	25	20	61	64	-3
	Lokak. *October*	—	1	2	1	—	—	1	1	0
	Yht. — *Total*	376	312	801	680	698	481	626	491	135
10 cm	Toukok. *May*	—	—	7	—	13	—	7	0	7
	Kesäk. *June*	30	10	157	84	201	100	129	65	64
	Heinäk. *July*	108	79	306	234	214	200	209	171	38
	Elok. *August*	135	136	248	212	147	144	177	164	13
	Syysk. *September*	52	61	105	108	30	27	62	65	-3
	Lokak. *October*	—	—	1	2	—	—	0	1	-1
	Yht. — *Total*	325	285	824	640	605	471	584	466	118

4. TULOSTEN TARKASTELUA

Jo viime vuosisadan puolimaissa useaan Euroopan maahan perustettiin ns. ilmastopariasemia metsän mikroilmastollisten vaikutusten selvittämiseksi. Näihin kuului yleisimmin yksi metsikköön ja yksi läheiselle aukealle alalle 2 m:n korkeuteen perustettu mittauspiste, joiden antamia mittaustuloksia vertaamalla pyrittiin ennen kaikkea kartoittamaan kysymystä metsikön vaikutuksesta ilman ja maan lämpö- ja kosteusoloihin (Baumgartner 1967 ym.). Myöhemmin on tosin osoitettu melkoisia heikkouksia mittauksen kohteeksi valittujen aukeiden alojen ja metsiköiden valinnassa, lämpötilan mittausmenetelmissä ja ennen kaikkea riittämättömällä tuuletuksella varustettujen mittarikojujen käytössä (esim. Franssila 1949, Lützke 1961, Geiger 1965), mutta esim. tulokset metsikön vaikutuksesta ilman ja maan lämpötilaan ovat osoittautuneet pääpiirtein oikeiksi. Metsikkö tasaa varsinkin kesäaikana ilman ja maan lämpötilojen ääriarvoja, mutta keskiarvoina ilmaisten metsikkö on joka vuodenaikana kylmempi kasvupaikka kuin aukea ala.

Viime vuosikymmeninä on varsinkin lämpötilan automaattinen mittaustekniikka kehittynyt suuresti ja koealueiden harhattomaan valintaan on kiinnitetty runsaasti asiaankuuluvaa huomiota. Metsikön ja aukean alan lämpöolojen vaihtelusta aikanaan saatu kuva on säilynyt ennallaan, mutta metsikön ja aukean alan keskimääräiset lämpötilat ovat osoittautuneet lähes samansuuruisiksi; aukkoisen tai harvan metsän vaikutus esim. kesäkauden lämpötiloihin on osoittautunut pienemmäksi kuin keskimääräiset lämpötilan mittauksen virherajat (esim. Baumgartner 1956, Odin 1974). Tämä tulos on yhdenmukainen nyt suoritetun lämpösummaan perustuvan laskelman kanssa. Toiveita metsikön keskimääräisten lämpöolojen muuttamiseksi verhopuuston avulla taimien kannalta suotuisaksi ei tämän perusteella juuri näytä olevan.

Tätä taustaa vasten tuntuu tässäkin tutkimuksessa aukealla alalla ja metsikössä saatu maan lämpösummien suuri ero ensi silmäykseltä vaikeasti selitettävältä. Ilmiö johtuu kuitenkin ennen kaikkea siitä säteilyerosta, joka varsinkin kesäkauden aikana muodostuu metsikön ja aukean alan välille.

Aukealle alalle lankeavasta säteilystä vain pieni osa pääsee vaikuttamaan täystiheän metsikön latvuskerroksen muodostavan toimivan pinnan alapuolella (esim. Mitscherlich ym. 1965, Perttu 1970). Onkin luonnollista, että varsinkin alkukesällä kun auringon ja ilmakehän tulosäteily on voimakkaampaa kuin maanpinnan ulossäteily, aukean alan maan pintakerros lämpenee nopeammin kuin metsän. Sen sijaan ilman lämpötilaan tulo- tai ulossäteily vaikuttaa suoraan melko vähän. Jos ilman lämpötilan mittauksessa käytetyt anturit on suojattu hyvin säteilyltä, on mittaustoiminnan kannalta oikeastaan samantekevää, onko niiden yläpuolella vain yksi toimiva pinta (säteilysuojus) vai kaksi pintaa (säteilysuojus ja metsikön latvuskerros). Vain se lämpötila, joka ilmassa fysikaalisena aineena on, välittyy lämpötilan mittauslaitteen kautta rekisteröitäväksi.

Näin selittyvät myös mm. puustoltaan hyvinkin erilaisissa metsiköissä mitatut hyvin vähäiset ilman lämpötilan erot (esim. Mitscherlich ym. 1965). Onkin tämän vuoksi syytä palauttaa mieliin ne rajoitukset, joita pelkillä ilman lämpötilan mittauksen tuloksilla on arvosteltaessa esim. verhopuuston vaikutusta sen alle perustettavan taimiston elinympäristöön. Metsikköön tai aukealle syntyneet taimet ovat myös itsenäisinä kappaleina aina alttiit säteilyn ja vastasäteilyn kaikille vaikutuksille, mikä voi muuttaa niiden lämpötilaa useita C-asteita (esim. Raschke 1960, Schnelle 1963, Leikola ja Pylkkö 1969). Taimien verson kasvusolukkojen lämpötilaa voi mitata vain suoraan näihin solukkoihin kohdistuvalla mittaustoiminnalla, jota ilman lämpötilan mittaus ei korvaa. — On kuitenkin samalla korostettava, että juuriston kasvuedellytyksiä voidaan täysin tyydyttävästi kuvata maan lämpötilaan kohdistuvilla mittauksilla, sillä juuristot tunnetusti noudattavat melko tarkkaan niitä ympäröivän maan lämpötiloja (esim. Lyr ja Hoffmann 1967).

Tässä yhteydessä ei ole syytä ryhtyä tarkastelemaan perusteellisesti verhopuuston käytön asemaa metsänhoidollisena menetelmänä tai kaikkia niitä ekologisia vaikutuksia, joita verhopuustolla on sen alla kasvatettavaa taimistoa ajatellen. Muutamia erityisesti ilman ja maan lämpöoloihin liittyviä kysymyksiä on kuitenkin syytä valaista tämän tutkimuksen antamien tulosten valossa.

Verhopuuston käyttöä perustellaan usein metsänuudistusaloilla esiintyvien, taimille haitallisten ja jopa vahingollisten äärilämpötilojen torjunnalla. On totta, että kasvukauden aikana Pohjois-Suomessakin saattaa esiintyä niin alhaisia lämpötiloja, että kuusen ja jopa männyn taimetkin vahingoittuvat (esim. Eiche 1966, Andersson 1968). Tämä on kuitenkin normaalioloissa harvinaista, mikäli siemenen alkuperä on oikein valittu. Mahdollisuudet vaikuttaa verhopuuston avulla hallanvaaraa vähentävästi ovat nimenomaan Pohjois-Suomessa vähäiset. Lapin oloissa tiheäksikin katsottava lehtimetsä on siksi aukkoinen, että latvukseen ei synny yhte-

näistä toimivaa pintaa, vaan verhometsään jää vertikaalisuunnassa kanavia, joita myöten kylmää ilmaa helposti painuu rungostokerrokseen (esim. Göhre 1963). Suurin osa Pohjois-Suomessa esiintyvistä sinänsä jo harvinaisista keväthalloista on tyypiltään ns. advektiohalloja, jotka johtuvat kylmän ja kuivan ilmamassan purkautumisesta arktisilta alueilta maahamme (esim. Venho 1966). Tällaisia halloja vastaan verhopuuston käytöstä on vain vähän apua, ellei näihin yhdisty ns. ulossäteilytilannetta.

Pahinta tuhoa on Lapissa aiheutunut suotuisien ja epäsuotuisien sääsuhteiden onnettomista yhteensattumista. Tyypillinen on ollut tilanne, jolloin kylmän alku- ja keskikesän jälkeen seuraa lämmin loppukesä ja sen jälkeen jo syyskuussa yhtäkkiä ankarat pakkaset ja pysyvän lumipeitteen tulo. Tällaisia tuhoaaltoja tiedetään Pohjois-Skandinaviassa sattuneen mm. vuosina 1902—1903 ja 1968—1969 (esim. Mikola 1952, Eiche 1966). Mikä on verhopuuston osuus tällaisten katastrofituhojen heikentäjänä ei ole aivan selvää, mutta tämän tutkimuksen tulosten valossa ei sillä voi olettaa olevan taimistoon suurtakaan suojaavaa vaikutusta. On kuitenkin muistettava, että metsikön vaikutukseen talvisiin lumi- ja tuulioloihin ja tätä kautta esim. Eichen (1966) kuvaamiin jälsivaurioihin ei aineisto tarjoa mitään selvää päättelyn lähtökohtaa.

Ilman maksimilämpötilojen aiheuttamia suoranaisia haittoja on Suomessa todettu vain siemenillä ja sirkkataimilla (mm. Vaartaja 1954). Jo varttuneemmalle taimistolle haitallisen korkeita lämpötiloja, jotka vaatisivat esim. verhopuuston käyttöä, ei meillä tiedetä esiintyvän. Sen sijaan verhopuuston vaikutukset metsikön ilman hiilidioksiidipitoisuuteen, maan kosteuteen jne. saattavat osoittautua edullisiksi, vaikka ne tuskin korvaavat sitä haittaa, mikä verhopuuston kilpailusta taimistolle aiheutuu (vrt. Pohtila 1975). Tämän perusteella on syytä suositella verhopuuston käytön rajoittamista Pohjois-Suomessa mahdollisimman vähiin; vain sellaisiin tapauksiin, joissa siitä on todellista kiistatonta hyötyä, kuten ilmastollisesti arkoja puulajeja tai provenienssejа kasvatettaessa, torjuttaessa voimakasta pintakasvillisuutta jne. Tällöinkin on pidettävä huolta siitä, että verhometsä todella täyttää tehtävänsä, eikä sitä korvata harvalla ja aukkoisella jätepuustolla, jonka korjaaminen voi myöhemmin tuottaa ylimääräisiä kustannuksia ja taimistolle aiheettomia kasvutappioita. On muistettava, että verhopuusto varjostuksellaan ja juuristokilpailullaan aina hidastaa sen alla kasvavan taimiaineksen kehitystä.

5. TIIVISTELMÄ

Tutkimuksen tarkoituksena on ollut selvittää kysymystä verhopuuston vaikutuksesta metsikön lämpöoloihin Pohjois-Suomessa. Kysymystä on tarkasteltu ennen kaikkea metsänhoidon näkökulmasta. Tutkimusalueeksi valittiin MTL:n Kivalon kokeilualueessa sijaitseva hieskoivikko, jonka lämpötilaa mitattiin vuosina 1970—1973 ilmassa 0.5 m:n, 2 m:n ja 4 m:n korkeudella sekä maassa 5 cm:n ja 10 cm:n syvyydellä. Tuloksia verrattiin viereisellä aukealla alalla vastaavilla korkeuksilla mitattuihin lämpötiloihin.

Tutkimuksen päätulokset olivat seuraavat:

— Ilman minimilämpötilat olivat hieskoivikossa keskimäärin noin 0.5°—1.0°C korkeammat ja maksimilämpötilat vuorostaan saman verran alemmat kuin aukealla alalla. Metsikön minimilämpötilaa kohottava vaikutus oli tyynellä ja kirkkaalla säällä positiivinen ja heikossa negatiivisessa riippuvuussuhteessa aukean alan ilman minimilämpötilaan.

— Ilman lämpösumma oli 0.5 m:n korkeudella koivikossa suurempi kuin aukealla alalla, mutta 2 m:n ja 4 m:n korkeudella tätä pienempi. Erot olivat kuitenkin suuruudeltaan hyvin vähäisiä.

— Maan minimi- ja maksimilämpötiloissa oli havaittavissa selvä vuotuinen kehitys: varhain keväällä äärilämpötilat olivat koivikossa korkeammat kuin aukealla alalla, keskikesällä matalammat, mutta myöhään syksyllä jälleen korkeammat.

— Maan lämpösumma oli koivikossa huomattavasti pienempi kuin aukealla alalla. Ero muodostui pääasiassa kesä-heinäkuussa.

Tulosten tarkastelussa kiinnitetään huomiota mittausteknisiin seikkoihin, kuten säteilysuojuksiin jne. Yleisesti ottaen todetaan, että mahdollisuuksia muuttaa kasvupaikan lämpöoloja verhopuuston avulla keskimäärin suotuisammiksi ei ole; päinvastoin verhopuuston alle muodostunut mikroilmasto on keskimäärin aukeata alaa viileämpi. Tämän vuoksi olisi verhopuuston käyttö rajoitettava Pohjois-Suomessa vain tapauksiin jolloin sitä todella tarvitaan, koska hallan ja pintakasvillisuuden torjunta täällä ei yleensä ole ongelma. Jos verhopuustoa kuitenkin käytetään, on pidettävä huolta siitä, että se on riittävän tiheä, jotta aukoton toimiva pinta muodostuu latvustoon.

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7. SUMMARY

The object of the study was to investigate the effect of the nurse crop on stand temperature in northern Finland. The following problems have been especially focused upon:

— The effect of the nurse crop on the daily maximum and minimum temperatures of the stand.

— The effect of the nurse crop on the annual number of degree days in the stand.

— The effect of the nurse crop on the temperature in the topsoil.

The problems have been analyzed mainly from a silvicultural viewpoint.

The research area was located in the Kivalo Experimental Forest of the Finnish Forest Research Institute. The stand of *Betula pubescens* Ehrh. in Sainkivalo (N 66°20.5′, E 26°37.5′, elev. 170 m) was chosen. The area is a large and even, somewhat waterlogged, upland mineral soil. The most important characteristics of the stand (Fig. 1) have been presented in Table 1.

In the summer of 1970, a pine stand of approximately two hectares next to the birch stand was clear cut, and the area was subsequently used as a control. For air temperature measurements five 4 m high poles were erected in the beginning of the summer of 1970 in various parts of the birch stand, and two 6 m high poles were erected in the center of the clear-cut area (Fig. 2). The poles were immobilized with wires to the ground, and 2″ × 2″, 1 m long cross bars were attached to them. The temperature sensors, protected by radiation shelters, were attached tothe bars. A standard weather chamber was placed 2 m above the ground on the clear-cut area. A thermograph and temperature-control sensors were placed in the shelter. The measurements were conducted at heights of 0.5 m, 2 m, and 4 m in the birch stand and, in addition to these, at 6 m on the clear-cut area. In addition, the air temperature was measured at the upper level of the canopy by a thermograph on the top of a 14 m high pole.

Measurements were taken mainly by thermocouples 1.3 mm in diameter of plastic-coated copper and constantan wires. The instrument was a Rubicon Instruments Inc. potentiometer, model 2715B, accuracy 15μv at +23°C. Measurements were made every second even hour during the 24-hour period every Tuesday and Thursday (cf. L e i k o l a 1974). The thermocouple sensors were placed into radiation shelters of thin aluminum tubing open in both ends, 5 cm long and 4 cm in diameter, painted black on the inner side. During the summer of 1971, similar but larger shelters, recommended by the Finnish Meteorological Institute, were used in addition to those described above.

The soil temperature was measured in the birch stand and on the clear-cut area at two points with thermocouples and at two points with Lambrecht No. 257 soil thermographs. The depths were 5 and 10 cm below the living moss layer and the humus. The method of measurement was the same as for the air and the same as that used for the soil temperature measurements in Kivalo reported in detail elsewhere (L e i k o l a 1974). According to visual observations and measurements of litter fall, the annual bud-break and leaf-fall dates were as follows:

Year	Leaves ca. 20 mm long	Leaves fallen (10 %—90 %)
1971	June 1	Sept. 13—Oct. 3
1972	June 4	Sept. 11—Oct. 2
1973	June 1	Sept. 7—Oct. 3

Consequently, the annual periods of measurement in 1971—1973 (Fig. 3) covered the whole time during which the birch stand was in leaf. According to Table 2, the year 1971 was clearly colder than average, and the year 1972 was much warmer than average. The last year of measurement, 1973, was slightly warmer than average, but in spite of that, it represents fairly well the average order of magnitude of the number of degree days.

Results. The temperatures of both the stand and the clear-cut area have followed a model typical for conditions of insolation and radiant emission: the temperatures close to the ground are extreme but less so higher up (Table 3). The daily minimum temperatures in the stand are about 0.5°—1.0°C higher compared to the clear-cut areas at similar heights, and the daily maximum temperatures are again about the same number of degrees lower compared to the clear-cut area (Fig. 4). The time of bud break during the first week of June has not caused very great changes (Fig. 5). To obtain a better understanding of the effect of the nurse crop on the daily minimum temperatures, the results were classified into three groups according to the cloudiness and wind velocity at the time of measurement (Fig. 6). According to this, the increasing effect of the stand on the minimum air temperature has been, in all cases except one, positive and has had a slightly negative correlation with the minimum air temperature at the clear-cut area. The correlation coefficient is $\neq 0$ with 95 % probability.

There is a clear annual trend in the temperatures of the clear-cut area and the stand: In the early spring the stand is somewhat warmer than the open area; in early summer the clear-cut area is clearly warmer, but in late summer the stand is again warmer (Table 4). The end result, *i.e.* the temperature sum, is favourable to the seedlings close to the ground in the stand; but going vertilically upwards towards the layer of stems and the lower level of the canopy, the difference is unfavourable to the young trees in the stand (Fig. 7). The differences, compared to the magnitude of the annual temperature sums, are rather small, only 0.5—2.5 %. This means that during the growing season there is some difference in the temperature sums between a birch stand and a clear-cut area, but this difference is so small that *e.g.* the annual variation of temperature sums is ten times larger. A detailed examination of each year does not change this general statement.

During the years of measurements, the trend of the differences between the soil minimum and maximum temperatures between the two areas was very similar (Fig. 9). Early in the spring, when the trees still have no leaves, the extreme temperatures of the soil in the stand were higher compared to the clear-cut area, but from about mid-June the extreme temperatures of the soil in the clear-cut area were clearly higher. In the fall, when the nights are colder and the leaves start to drop, the extreme temperatures of the soil on the two areas were about the same. Late in the fall the extreme temperatures of the soil were again higher in the stand compared to the clear-cut area. These changes in the differences between the extreme temperatures can easily be tied to the developmental stages of the leaves in the canopy, even if differences in snow cover, thaw of the ground frost *etc.* naturally exert an influence, especially on the early summer temperatures. The following features are characteristic for the temperature sum of the soil (Tables 5 and 6, Fig. 8). The largest difference in the temperature sums occurred during June-July. Compared to this, the differences

occurring in May, September, and October were very small. The trend of differences in the temperature sums for each month was very similar to the previously described trend. In the early summer the difference was small, but it increased towards midsummer and decreased again towards the fall and winter. The difference between the stand and the clear-cut area in the temperature sums for the soil was, in contrast to that of the air, about 15—20 % of the total annual temperature sum of the open area.

Discussion. The average temperatures of a stand and an opening have usually been foud to be about the same; the effect of an open or uneven stand on, *e.g.* the summer temperatures, has been found to be smaller than the average confidence limits of the measurements (*e.g.* Baumgartner 1956, Odin 1974). This result is in agreement with the observations now made on temperature sums. According to this, there does not seem to be any hope of changing the average temperature conditions of a stand by means of a nurse crop in order to favour seedlings.

Consequently, the large difference in soil temperature sums observed between the stand and open area seems at first sight difficult to explain. The phenomenon depends primarily, however, on the difference in radiation which occurs between the stand and the clear-cut area, especially during the summer. If the air temperature sensors are well-protected against radiation, there is no difference in the result, if they are protected by one layer (the radiation shelter) or by two (radiation shelter and the nurse crop). Only the temperature of the air itself is registered by the thermocouples. Therefore, we must recall the limitations presented by using results obtained only with air temperature measurements to study the effect of a nurse crop on the environment for the seedlings planted under it. The seedlings in the stand or on the clear-cut area are independent bodies exposed to all the effects of radiation and counter-radiation, which can change their temperatures several degrees C. The temperature of the growing meristems of a shoot of a seedling can be measured only by sensors applied directly to these meristems. Air temperature measurements are only a substitute for such measurements. At the same time it must be pointed out that growth conditions for the root system may be described quite satisfactorily by measurements of the soil temperature since the temperature of the roots follows quite closely the temperature of the soil around them.

The use of a nurse crop is often regarded as beneficial on the basis of its reducing effect on extreme temperatures harmful or lethal to the seedlings. It is true that in northern Finland during the growing season such low temperatures may occur that the seedlings of spruce and even pine are damaged. This, however, occurs very seldom during normal conditions, if the provenance of the seed is chosen correctly. The main part of the spring frost occurring in northern Finland is of the advection frost type, caused by cold and dry air coming to Fennoscandia from Arctic regions. A nurse crop helps very little against such frost unless a situation of radiant emission occurs simultaneously.

Therefore, the use of nurse crops in northern Finland should be used very sparingly and only in cases where it may provide undisputable benefits, as when raising non-hardy provenances or species or when controlling strong ground-cover competition. Even then, one must take care that the nurse crop really fulfills its function and that an open and uneven remnant stand is not substituted for it so that the harvesting may later cause excess costs or needless growth reduction for the young trees.