METSÄNTUTKIMUSLAITOS

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Importance of Soil Temperature, Height of Water Table, and Microclimate as Growth Factors of Pine, Spruce, and Birch.

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Preface.

This study is part of the program of the Forest Research Institute of Finland. It has been financed from Institute founds and from American Agricultural Research Grant No. E8-FS-36/FG-Fi-116, made under U.S. Public Law 480. The main part of the planning and supervision of the study is the work of Kimmo Paarlahti, Lic.For., as the assistant of the undersigned.

The idea for the study came from an earlier investigation completed by the Swamp Forestry Department of the Institute in 1955, in which the banding method was used. In that year, regular measurements of some 500 trees were begun in 54 localities. Graphs drawn of these measurements revealed some astonishing facts about the beginning of tree growth in the different localities. In 1958, we began to check the preliminary data from this material by means of artificially produced changes in growing conditions. The first change we made was to cool the ground around the trees by covering the soil with straw. In a subarctic climate, the consequence of this step are considerable. Upon receipt of the agricultural research grant from the USA, the experimental areas were enlarged to test the effects of water regulation, fertilization and artificial changes in air temperature. Throughout all of this time, the 500 trees in the basic material established in 1955 have been measured continually.

We intend to continue the research mainly by mathematical means, enlarging our basic material still further to test the general applicability of the results and their significance in the light of fluctuations in natural growing conditions. We intend to employ water regulation to test the ability of different species to withstand floods, as well as investigating their root systems and microbiology.

A 16 mm colour film has been made of the study, financed by Filmiyhtymä Oy and planned and filmed by the undersigned, showing the experimental areas, the organization of the study and the principal results.

Throughout the study Mr. Eero Pelkonen, supervised the field work, installed the measuring apparatus and performed the measurements. We owe a special vote of gratitude to his and his assistants' enthusiasm and attention to detail. I would like to add my own thanks for good work done, often under difficult conditions.

For computing the results, thanks are due mainly to Pentti Kanerva, M. For., during the initial period of the study, and Matti Eronen, B. Sc. during the final stage. Their interest, willing cooperation and skill in finding answers to the most difficult questions have contributed very greatly to the success of the operation. Of the many people who have assisted in handling the material, I would particularly like to thank Leo Lintu, M. For., and Pirkko Iso-Heikkilä, M.A.

The accompanying report has been translated into English by Karl-Johan Ahlsved, M. For.

Helsinki, 30th June 1965

Olavi Huikari

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1. Introduction

The stand increment in forests depends on the growth of the individual trees. In attempting to understand the fundamental nature of growth, it is necessary to stress the importance of the ecological factors. Tree growth has been studied by numerous investigators, in all the climatic conditions of the world. Most of these investigations have been devoted to phenomena which were observed over rather long periods of time, revealing the essential features in the lifelong development of different species of trees. The shortest period of observation customary in studies of this kind is one year. The clearly visible annual rings have made it possible to carry out simultaneously all the measurements needed for the portraying of the growth, which has enabled the investigations to be extended to the whole lifetime of trees. Laitakari (1920) and Mikola (1950) have carried out investigations of this kind in Finnish conditions. Mikola's studies were very thorough, dealing with the matter from many angles. When the progress of growth during a single growing season is under observation, methods must be used which make it possible to follow the process of growth over this shorter period of time. It is therefore necessary to

develope a measuring method suitable for research of this kind. The first such investigation was probably carried out by Friedrich (1897). In 1892-95 he studied nine sample trees of eight species

In addition to the ecological factors the genetic very often also have a preponderant influence on tree growth. In general trees grow during the warm season and as the weather gets colder, the growth is retarded or completely stopped. Ilvessalo (1942) has proved that the diameter growth of pine and spruce starts earlier than that of birch.

It has been shown that the diameter growth continues later into the summer than the height growth; the growing time of the roots is longer than that of the aerial parts of the tree. The seasonal periodicity of the height growth is mainly determined by hereditary factors, whereas the diameter growth depends principally on ecological factors (Kramer and Kozlowski, 1961).

In general trees do not grow throughout the entire possible growing season. Kramer (1957 b) has proved that the growth of pine, even under the favourable conditions prevailing in greenhouses, occasionally stops. It is also known that height growth in tropical trees can take place 3, 4, 5, or 6 times a year, or even more frequently. The reason for this irregular pattern of growth has not been definitely established. Hemberg (1949) believes that it depends on the inhibiting effect of mineral compounds absorbed by the trees. Kienholz

(1934, 1941) explains that growth as a rule lasts only 30 days, even if favourable conditions allow a longer period. This question has also been studied by Meginnis (1934), Schreiner (1940), Young and Kramer (1952), Harris and Boynton (1952), Merril and Kilby (1952), and Kramer (1958 b). Shrinkage and swelling of different kinds in tree stems during different times of the year have been discussed by, among others, Haasis (1933), Fielding and Millett (1941), Byram and Doolittle (1950), and Clark and Gibbs (1957).

In several tree species it has been observed that the cambium cells divide throughout the summer, although diameter growth does not take place (Priestly 1930). Young and Kramer (1952) have noticed that the diameter growth starts later than the height growth, but they have not observed any differences concerning the initial moment of growth at different heights of the stem. Diurnal changes in stem thickness have been studied by Mac Dougal (1921, 1938), who found out that tree stems shrink during the day and swell towards daybreak. Kramer (1957 b) has observed that the best increment is obtained when there are great differences between diurnal and nocturnal temperatures; the increment is least if there are no such differences. Merriam (1898) noted that the temperature during the growing season sums up, thus creating growth belts. A temperature of 10° C causes a two- or threefold intensification of biochemical phenomena (Daubenmire, 1938). According to Friesner (1942 b),

the supply of water is of major importance for the diameter growth. Mikola (1950) has also proved that there is correlation between diameter growth and moisture content in the soil.

Fritts (1958) found out the correlation between soil moisture and the increment, particularly obvious in the fall when soil moisture is small. Richards and Wadleigh (1952) observed that soil moisture already has a growth-retarding effect before the soil is saturated with water. According to Kenworthy (1948), excess moisture retards height growth 68 % and diameter growth 50 % under similar conditions. Stanhill (1957) also noticed that 66 trees out of a total of 80 had already reacted to the moisture before the wilting point was reached.

Kramer (1952) found out that height growth depends to a greater degree on the precipitation during the preceding year than the rainfall during the year of the growth. If soil moisture during the spring growing period is sufficient, rain does not influence the height growth. If the amount of precipitation is small, the growth can be correlated with the amount of rainfall. The radial growth has been proved to be more dependent on the annual precipitation than the height growth. Investigations by Glock (1937), carried out in Arizona, have revealed that the precipitation has a definite effect on the increment during the growing season.

As different investigations concerning the effect of growth factors on tree increments are carried out in considerably different climatic conditions, the results

obtained may vary. In the region of coniferous forests with a snow and soil frost climate, it is important for the development of forestry to carry out growth factor investigations under precisely these climatic conditions, because in this region, e.g., the soil and air temperature can be growth factors with effects differing from those in warmer conditions. It is also important to clarify the mutual relationships between soil hydrology and nutritional conditions of the soil. These factors must be dealt with separately by means of experiment arrangements which make it possible to present the separate effects of each, when they act as determining growth factors.

Growth factor arrangements on a field scale have been used only to a lesser extent. Utilization of swamps for forestry purposes is, in fact, activity entirely based on artificially induced changes in the substratum, and thus demands special investigational means.

2. Establishment of Experiment Areas

21. Location

The location of the areas is shown on the maps in Figs. 1 and 2. The Vilppula areas lie at 62° 3'N, 24° 34'E, and the Kivalo areas at 66° 27'N, 26° 50'E. The Vilppula areas are located at Jaakkoinsuo in Vilppula Experiment Area of the Forest Research Institute. The Kivalo spruce-swamp area is at Alajärvi and the pine-swamp area is at Sattasuo. These two areas belong to the Kivalo Experiment Area of the same Institute. Both Vilppula and Kivalo lie towards the north of the Eurasian coniferous zone, which in Europe is dominated by pine (Pinus silvestris), spruce (Picea abies), and silver and white birch (Betula verrucosa and Betula pubescens). According to the local zone classification of Finland, Vilppula is situated in the northern part of the South Finland arboreal zone and Kivalo on the borders of the North Finland and Ostrobothnia arboreal zone. In altitude, both areas vary between 119 - 166 metres above sea level (see Table 1).

22. Climate

Table 1 shows main climate differences between Vilppula and Kivalo; it gives mean figures on the weather between

1921-50. As can be seen, the mean temperature at Vilppula is somewhat higher than at Kivalo, although the difference is not very great. The 0° C isotherm in spring reaches Kivalo some ten days later than Vilppula, whereas the autumn 0° C isotherm passes over Kivalo an average of 20 days before it comes to Vilppula. Despite the later occurrence of the thaw at Vilppula, the 5° C isotherm is in spring approximately 10 days earlier and the thermic season lasts 25 days longer there than at Kivalo.

23. Description of experiment areas

At both in Vilppula and Kivalo we have established two experiment areas for the purpose of this study, one on a pine swamp and the other on a spruce-and-birch swamp. Our figures on pine growth refer only to the pine swamp plots. Similarly the spruce and birch results have been obtained on the spruce-and-birch plots at Vilppula and Kivalo (ViR and KiR, ViK and KiK - see sect. 23).

The Vilppula pine area is in a cottongrass pine swamp very poor in nutrients and the spruce area in a somewhat richer Myrtillus spruce swamp. The Kivalo pine area is in an herb-rich pine swamp that is fairly rich in nutrients, and the spruce area in a very rich herb-spruce swamp (see Table 3).

Table 3 shows the average acidity and total nutrient content of the swamp types represented by our experiment areas, according to Vahtera (1955). It confirms that ViR is the poorest and KiK the richest in nutrients. All four areas are poor in phosphorus and potash.

All the areas had been ditched earlier using very broad strips. Table 2 shows the years in which they were ditched, the thickness of the peat layers and the dates on which water level regulation was practised specifically for this study.

To test the botanical homogeneity of the areas, descriptions of their ground vegetation were made in 1962 and 1963; eight squares measuring 1 sq. metre were tested on each plot. The original ground vegetation and the results of our homogeneity tests are given in Appendix 3.

The stock growing on the areas is shown in Tables 4-8. At Kivalo it was measured between 25th - 27th October and at Vilppula between 19th - 20th October 1961. The growing stock is also illustrated in Figs. 3-10.

24. Artificial changes in air temperature

To elucidate the effect on increment of the air temperature around the shoots, plastic greenhouses were built at Vilppula in the spring of 1962 and the spring of 1964,

and at Kivalo in the spring of 1963. (Figs. 11 and 12). Each greenhouse covered three pines about 4-5 metres in height. Continual measurements were made of the height and diameter growth of the trees. In each greenhouse there was a maximum-and-minimum thermometer and a thermohygrograph to register the air temperature, and a group of mercury thermometers in the ground to indicate the ground temperature (cf. sect. 32). The findings in the Vilppula greenhouses in 1962 made it clear that moisture absorbed by the trees from rain water had a marked effect on their vital processes. For this reason, the trees were watered with sprinklers at regular intervals in 1963-64. To avoid loss of heat through radiation at night, the greenhouses were heated with oil stoves.

The greenhouses enable us to keep the average diurnal temperature of the air surrounding the shoots 5-8° higher than the external air temperature.

The ground temperature in the greenhouses was roughly the same as that of the control areas outside.

For controls, we used pines of similar age and size growing in the open air in the immediate vicinity of the greenhouses.

25. Artificial changes in ground temperature

To alter the heat economy of the ground we tried to make the ground frost in winter go as deep as possible, and

during the growing season we delayed the melting of the snow and ground frost for as long as we could. In 1962 and 1963 we did this by removing the snow cover from our cold-ground plots to permit the frost to penetrate deeper into the ground. When the snow began to melt in spring, we deliberately covered the cold-ground plots with snow, and thus succeeded in delaying the ground thaw for a considerable period of time (Figs. 13-16).

Earlier studies (Huikari, 1961) indicated that the best way to delay the ground thaw was to cover the plots with some material that would prevent the snow and frost from melting. To find the best material, we carried out special tests in the winter and spring of 1961 and 1962. For this purpose, we established 20 cold-ground parcels measuring 4 x 4 metres each. Snow was removed from them throughout the winter of 1961/62 and replaced before the spring thaw in 1962 and the parcels were covered with board, straw, sawdust, plastic crêpe and aluminium foil (Figs. 13-16). The 20 parcels were divided into two groups, in each of which there were 4 replicates. The state of the snow and ground frost thaw in every parcel was examined six times between 23rd May and 6th July. The results are shown in the Fig. 17. They indicate that the best material for delaying the ground thaw is straw, as used by Huikari (1961).

To achieve greater ground temperature differences than we could get without covering the ground, certain plots were rendered colder than natural in winter and spring 1964 by covering them with straw at Vilppula and with sphagnum peat at Kivalo. To ensure a valid comparison between the increment on the cold-ground plots and the control plots - i.e. to prevent the ground vegetation killed off by the covering from affecting the increment on the cold-ground plots - the control plots at Vilppula were covered with similar straw the previous autumn in order to kill off their ground vegetation. The straw at Vilppula was 15 cm thick, the peat at Kivalo 10 cm. Times of soil frost melting on the cooled and control plots are shown in Table 9.

26. Water regulation

To elucidate the effect of ground water depth on increment, the water level in the surrounding ditches was regulated to depths of 10, 30, 50, and 70 cm around different plots. At Vilppula, one pine swamp plot was regulated to a water level of 0 cm. The ground surface level for the measurement of ditch-water depths was determined from the average of the ground surface levels noted at the ground water holes dug in three rows on the plots. On some of the plots thus water-regulated, the soil fertility were then improved

by fertilization and the ground temperature by artificial cooling and the use of covering materials. The size, location, and different treatments of the test plots are shown in Figs. 18-21. The regulated pine swamp plots at Vilppula numbered 13, spruce swamp plots 4, and both types measured 40 x 15 metres each. At Kivalo, there were 12 pine swamp plots measuring 50 x 10 metres, and 8 spruce swamp plots of 40 x 15 metres. The water level in the ditches was regulated first by conducting water to the areas from higher ground via ditches or pipes and then adjusting the water in the ditch in each plot to the level designted with the aid of dams (Fig. 22).

The ditches around the plots measured 1 metre deep by 20-30 cm wide. In winter, the dams were covered with conifer needles and snow to prevent them from freezing and enable them to function throughout the year. The ground water level under the plot was affected not only by the water level in the ditch but also by the water permeability of the peat, which was determined by the "auger hole" method at the ground water holes on the parcels (9 per parcel) in summer 1964. The results per area and per layer depth are given in Table 10 in the form of index figures, the highest permeability value (that found in the 0-10 cm layer in the Vilppula spruce swamp area) being counted as 100. These figures show that the two Kivalo areas were very similar in

water permeability and that the Vilppula pine swamp area differed from them markedly only in the 0-10 cm layer. The biggest difference was found in the Vilppula spruce swamp area, where high water permeability were noted down to a depth of 30 cm. In the other three areas, there was a very sharp reduction in water permeability between 10-30 cm (cf. Huikari, 1958).

Fig. 23 shows the ground water ratios at different levels in the plots regulated in 1964. The delineators indicate the number of times the ground water was measured at different depths on each plot. They also give the average ground water depth during the observation season in the form of median values for the different observations. The median values in the Vilppula pine swamp area were 13, 40, 54, and 62 cm, those in the spruce swamp area 10, 29, 53, and 64 cm. At Kivalo the pine swamp values were 10, 25, 41, and 55 cm and the spruce swamp values 4, 34, 41, and 57 cm. Judging by the median values the ground water regulation was very succesful, although a few deviations from the regulation levels desired were noted. The distribution of the observations at different levels makes it plain that - generally speaking - the deeper the regulated water level in the ditches, the greater is the variation of ground water level. This is due to poorer water permeability at deeper levels.

27. Regulating soil nutrients

To compare the soil improvement brought about by fertilization with natural hydrological conditions, fertilizers were applied in all the areas except the Vilppula spruce swamp area, where we were unable to establish plots for the study of fertilization; the soil there is naturally rich with nutrients in any case. P and K fertilizations were applied in the Vilppula pine swamp area on 8 September 1961 and in both areas at Kivalo on 6 October 1961. Nitrogen was added at Vilppula on 10 May 1962 and at Kivalo on 29 May 1962. The location of the fertilized plots is shown in Figs. 18-21. In performing the operation, we took particular care to see that in no case did the water flow from a fertilized plot into an unfertilized plot, as can be seen from the maps. (P = 500 kg of "Kotka" phosphate (23 % P_2O_5) per hectare, K = 200 kg of potassium sulphate (50 % K_2O) per ha., N = 400 kg of calcium ammonium saltpetre (25 % N) per ha.)

28. Abbreviations used

C= Cooled; snow removed in the fall and the rest stamped down. In early spring the removed snow was spread back on the area.

F= Fertilized; KP-fertilization 1961, and N-fertilization 1962.

Ki= Kivalo experiment area.

KiK= Herb-rich spruce swamp in Kivalo.

KiR= Herb-rich pine swamp in Kivalo.

S= Straw-covered (in Vilppula), and Sphagnum-peat-covered (in Kivalo).

T= Temperature plots, where the influence of soil temperature was studied.

U= Untreated plots, where only the water table was regulated.

Vi= Vilppula experiment area.

ViK= Myrtillus spruce swamp in Vilppula.

ViR= Cottongrass pine swamp in Vilppula.

0, 10, 30, 50, 70 = distances in centimetres from the ground surface to the adjusted water table in ditches.

3. Measurements

31. Weather observations

Air temperatures, air humidity and precipitation in the experiment areas during the periods of observation were measured using the equipment described below. In some cases, we supplemented these with readings from stations in the net of the Finnish Meteorological Office. For Kivalo we used observations from Rovaniemi Airport (39 km W.N.W. of Kivalo) and from the North-Finland experimental station of the Agricultural Research Centre at Apukka (32 km W.N.W. of Kivalo). For Vilppula we supplemented our data with meteorological readings from the Helsinki University Forestry Training Station at Hyytiälä (28 mk S.S.W. of Vilppula) and the Luonetjärvi Airport (71 km N.E. of our areas). From the airfield stations of Rovaniemi and Luonetjärvi we obtained sun radiation values and from Apukka and Hyytiälä we received diurnal temperature means and maximum and minimum temperatures.

32. Air and ground temperature measurement, precipitation meters and groundwater holes

We measured air temperatures with maximum-and-minimum thermometers fitted with radiation protectors, in each of the four areas (Fig. 24). Reading were taken regularly throughout

the observation seasons. These thermometers were set at a height of 1 metre from the ground. Each area had one thermal hygrograph giving continuous recordings of air temperatures and humidity. These were set two metres from the ground in standard meter cabinets provided by the Finnish Meteorological Office. The thermohydrographical temperature readings were corrected from mercury thermometers in the same cabinets.

To ascertain differences in ground temperature between plots treated in different ways, each plot had mercury thermometers installed at depths of 5, 10, 15, 20, and 40 cm in the ground(Fig. 25). Each group of thermometers was fitted with an aluminium-sheeting radiation protector. Ground temperatures were read three times a week during the observation season, at the same as stem circumferences were measured.

Each area had 10 precipitation meters (Fig. 26) at ground level. An extra meter was then installed in a clearing outside the area. These meters had a collection area of 100 sq.cm, witha container below from which the water was poured into measuring cylinders. Precipitation was measured at the same time as the ground temperatures were recorded.

To check the groundwater level, each plot had nine groundwater holes, as shown in Fig. 27, located at points in the plot indicated in Figs. 18-21. The depth of the groundwater level was measured to an accuracy of 1 cm, using a measuring pile set with 0 at ground level. The height of these piles was calibrated every spring in order to eliminate

changes in their length caused by ground frost. Ground water depths were measured at the same time as ground temperatures and stem circumferences.

33. Measuring increment

The height increment of the pines was measured during all the observation seasons, that of the spruces at Vilppula during only one season. The height increment of the pines was determined using a measuring rod and binoculars.

Changes in stem diameter were measured by the banding method developed by the Swamp Forestry Department of the Forest Research Institute, and in general use since 1955. Details of this method are illustrated in Figs. 29-31. Beforesetting the band in place, most of the rough edges of the barkare carefully removed (Fig. 28). A plastic strip (Fig. 29) is then wrapped around the stem and over it is set a measuring band fitted with a spiral spring (Fig. 30). The band is furnished with two measuring holes into which are thrust measurement points fitted with dials (Fig. 31). Regarding the accuracy of this method, see section 41. To note changes in circumference, measurements were made at intervals of 3-4 days before the growing season began, three times a week during the season, and twice a week after it. The first measurements were usually taken by the middle of April at the latest, and the last around the middle of September. We also made a few control measurements later on in the autumn.

34. Roots, microbiology and surface vegetation

A special study was made to ascertain the depth distribution of root systems on plots with different ground water levels. Its method and results are given in Appendix 1.

Biological activity in the soil and its depth distribution was studied on some plots of varying ground water levels, using a method based on the speed of cellulose decomposition developed by the Swamp Forestry Research Department. The method and results of this are given in Appendix 2.

Descriptions of the ground vegetation on the plotsin the study were made in 1962 and 1963 in a manner explained in subsection 23. In 1963, these descriptions were made only of the plots on which the ground water level had been regulated, but no fertilization or surface cover applied, since the latter treatments radically alter the ground vegetation. The vegetation analyses and homogeneity tests are presented in Appendix 3.

4. Banding Method Used to Measure Stem Circumferences.

41. Accuracy of measurements.

The effect of the strength of the spring was studied in 1955, when the method was being developed, and again during the measurements we took between 18th April - 29 th September 1964. Three trees - a pine, a spruce and a birch - we used. Around each, four bands, varying in tautness, were placed next to each other. Sum curves of the measurements taken with these bands indicate that their degree of tautness does not affect the results, for the total increments measured by the different bands varied by less than 10 per cent. Furthermore, on two of the trees, for which only the curves relating to the weakest and strongest springs were drawn, the measurements varied in different directions. On the third tree, curves for all four bands were drawn, but these did not show any regular variations resulting from the effect of spring tautness.

If, in addition, the sum of the reductions noted in the stem thicknesses of these trees is examined, it can be seen that the springs reacted in the same way as they did to circumference growth. The bands were numbered 1, 2, 3, and 4 - 1 being the weakest, 4 the strongest - and the sum of the shrinkages referred to are tabularized as follows:

	1	2	3	4
pine	180 mm^{-2}	148 mm^{-2}	184 mm^{-2}	224 mm^{-2}
spruce	308 "	420 "	316 "	252 "
birch	172 "	72 "	48 "	92 "

The figures reveal no systematic variations according to the strength of the spring. The differences can be regarded as purely random.

To estimate errors in measurement, we first examined the effect of air temperature on the length of the band and, consequently, on the readings it gave. As the band is made of a metal with a low heat expansion coefficient, it can be expected that errors due to differences in temperature at the times of measurement would be fairly small. If a band is placed around a stem 18 cm in diameter, and the temperature difference in the metal at two separate measurements is 15° C, the variation in the length of the part of the band around the stem will be 0.01 mm, because the heat expansion coefficient of steel is 0.000012 (1/1°C). Thus the variation in band length is about half of the measurement accuracy of the method, so it can be ignored.

Also studied were inaccuracies in measurement due to the tree itself. We based this on control measurements made at Vilppula in summer 1964. Four trees of each of the three species were selected at random and around each were placed four adjacent bands. Changes in circumference were then band-measured at intervals of 3-4 days during the whole season of 1964. It could be expected that the measurements on a single tree would be the same. On this basis, an estimate was made to the accuracy of a single measurement.

First of all we transferred our results to graphs. In each tree species we selected one of the four specimens and marked the coordinates for it. Individual observations were

marked with an x, so that the x on the abcissaxes always represented the sum of the growths measured by the four bands on the same tree. The expression $x-\frac{1}{4}(x)^2$ for the ordinate axes then represented the dispersion of the gross readings indicated by the bands. The result demonstrated that the dispersion was practically uncorrelated to the amount of the growth.

To ascertain the error of individual measurements, we calculated the average deviation in the growth readings given by bands 1, 2, 3 and 4 per observation day. The mean θ of these average deviations was taken as an estimate of the error. θ came out as follows:

pine θ = 0.0620 mm

birch θ = 0.0615 mm

spruce θ = 0.0684 mm

The errors in pine and birch were roughly equal, those in spruce slightly greater. This is because spruce reacts more to changes in the weather, as is borne out by the cumulative growth curves given on page.

Many of the errors found in the different species were due to the fact that the growth at the level of each of the adjacent bands varied. On comparing the total growth registered by adjacent bands during the whole growing season, we found considerable differences between them.

To determine the error in the total growth during the growing season, we calculated the average deviations in total growth registered by bands 1, 2, 3 and 4 on all four trees in each species, using the method described above. The mean

values of the average deviations came out as follows:

pine θ_s = 0.408 mm

birch θ_s = 0.534 mm

spruce θ_s = 0.424 mm

On comparing these figures with the errors $\theta^{(n)}$ noted in n measurements, as obtained from the approximate formula $\theta^{(n)} = n\theta$, they are found to be all roughly the same in magnitude, since $\theta^{(n)}$ averages out at 0.410 mm. Further examination, however, reveals that the average deviations in total growth measurements are in almost direct correlation to the corresponding total growth. In other words, the relative error is a constant, and it is even almost a constant for all the tree species, as can be seen from the following error percentages:

pine 2.9 % of total growth

birch 3.2 % " " "

spruce 3.2 % " " "

We also studied the error in growth measurements made at intervals of two hours, which is useful when investigating diurnal growth rhythms, for example. On two days around the middle of the growing season - 24th June and 1st July - we calculated the means θ_n of the average deviations in measurements made at two-hourly intervals:

pine θ_n = 0.0198 mm

birch θ_n = 0.0247 mm

spruce θ_n = 0.0275 mm

Here, too, as with measurements taken at intervals of

a few days, the error proved to be greatest in spruce.

In making these measurements, we tried to eliminate some of the causes of error. For example, incidental shifting of the band after it has been fixed did not affect the results, since the measurements were begun some time later, after the band had had time to settle into place. The estimates we obtained for the errors can thus be considered fairly reliable, in spite of the limited number of measurements made.

The accuracy of the method, indicated above, refers to the consistency of measurements on the same tree. Systematic causes of error in the banding method, such as changes in the properties of the band due to the lapse of time and to weather factors are not brought out by this method.

42. The trees as objects of measurement

421. Diurnal and other changes in stem diameter.

It has long been known that there are regular fluctuations in stem diameter within a single day: stems are at their thickest and thinnest at certain times of the day. Fig. 32 shows a series of measurements we made over a 24-hr period during this study. We found regular diurnal fluctuations in stem diameter: the latter increases steadily between 18.00 and 14.00 hrs. of the following day and then diminishes between 14.00 - 18.00 hrs. The phenomenon is due to the intake and evaporation of water connected with the vital processes of the tree. Further investigation of the nature and significance of this process would surely be very rewarding, but at the present stage of this study we have not undertaken a more detailed treatment of the material collected.

To eliminate the effect of this diurnal fluctuation, we began our measurements at exactly the same time and measured all the trees in the same order every day. This ensured that every tree in the study was measured at the same time of the day, so that consecutive measurements would be comparable.

Stems also vary in diameter with the temperature. In addition, the bark swells and shrinks with changing humidity. A special enquiry has revealed that these fluctuations are not significant within the limits of accuracy of our study.

422. Diameter growth reactions of trees of different crown layers.

In 1955, data were collected on the diameter growth reactions of 161 pines of different crown layers at Parkano, in South Finland. These data are presented in Fig. 33. It can be seen that the trees of the first crown layer have the strongest reactions, those of the second one almost as strong, while those of the third and fourth layers have a growth reaction only a third as great as that of the first layer. The curves show that the trees of all layers react in the same way to the different factors affecting growth during the growing season. Mathematical treatment of the material indicates that the changes in the reactions from one layer to another are systematic. A comparison between the average diameter variation series per crown layer reveals systematic differences between the series. Variations in external factors cause corresponding reactions in pine diameter increment, and these reactions differ either because the growth rhythm in the different trees varies slightly or because the ratio between the strength of the reactions varies at different times during the season.

Since the trees of the first crown layer are the best fitted to react to the growth factors prevailing on the site, we continued the measurements only on these trees or in cases where first-layer trees are not available in adequate quantities on second-layer trees growing with as much open space around them as possible.

423. Diameter growth reactions at different heights in the stem.

Figs. 34, 35 and 36 show some findings of a study we made of pine, spruce and birch specimens to test their diameter growth reactions at different heights along their stems. In our pine specimens, we found that the diameter growth reaction begins first at a height of 5-7 metres, and last of all at one metre from the ground. Seasonal diameter growth in pine is greatest at 7 metres, and in spruce, at 5 metres. Diameter growth in spruce begins particularly strongly. The phenomenon is roughly the same in birch, but not so obvious, for diameter growth begins almost simultaneously at all heights along the stem.

All our measurements were made at the commonly used height of 1,3 metres. This was considered feasible because growth reactions at given heights in the stem are obviously comparable between different trees. In evaluating the results, however, it should be borne in mind that growth in pine sometimes begins in the top half of the crown two weeks earlier than at the bottom of the stem. This indicates that the commencement of the growing season depends on processes that start in the crown and move downwards at a rate of roughly half a metre a day. The fact that growth begins practically simultaneously at all heights in the birch stem should be borne in mind when the factors affecting the commencement of growth are studied in the future.

5. Commencement of growth

51. Height increment

In this study, measurements of height growth have been confined almost entirely to pine. The observations cover all the years of the study and all the pines measured. Owing to technical difficulties, we have been unable to measure the height increment of spruce, except at Vilppula in 1961. No measurements of height growth in birch have been taken at all. The measurements were made at intervals of two or three days.

Tables 11 and 12 show the date on which height growth began every year. The figures indicate the number of trees in which the growth began on each date of observation.

It can be seen that the dates on which different specimens began to grow vary by some two weeks. General commencement of growth, too, varies from year to year. The height increment of spruce noted for 1961 only began on 19th - 22nd May, which was more than two weeks later than pine.

From Tables 11 and 12 it is possible to calculate rough averages of the dates on which growth began every year. The commencement dates given below refer to these average dates.

The average dates on which growth began in the Vilppula pine swamp area were as follows:

	Unfertilized specimens	Fertilized specimens
1961	5.5	(5.5)
1962	5.5	5.5
1963	6.5	6.5
1964	27.4	25.4

Growth at Kivalo began later than at Vilppula. We have no figures on the commencement of height growth in 1961, the first year of our study, since the observations were only started there in early June, after the growth had begun. The figures we have are given in Table 12, which provides a comparison with Table 11 (Vilppula). The average commencement dates of height growth in pine at Kivalo in 1962-64 were as follows:

	Unfertilized specimens	Fertilized specimens
1962	23.5	24.5
1963	16.5	16.5
1964	11.5	11.5

Height growth in pine began 10-17 days later at Kivalo than at Vilppula.

511. Air temperature

To study the correlation between the beginning of height growth and air temperature, we used plastic greenhouses to increase the air temperature around pines growing at Vilppula and Kivalo, and compared the growth of these trees with that of pines in the open air near them. Fig. 36 shows that the growth of the pines studied began in both the greenhouses and out-of-doors at roughly the same time, but that the period of most rapid growth began at both Vilppula and Kivalo about a month earlier in the greenhouses than outside.

In an effort to find a critical sum of air temperatures determining the commencement of height growth, we added together the sums of all temperature-hours over 5° C up to the

time height growth began. They came out as follows:

	1962	1963	1964
		temp. hours	
Vilppula		332	656
Kivalo	1582	2187	238

Such sharp differences show that these simple sums of temperature-hours do not suffice to explain the beginning of the growing season.

Tables 13 (Vilppula) and 14 (Kivalo) present diurnal maximum and minimum temperatures on the three days before and after the average date of commencement of growth in the pine-swamp areas.

Both in Vilppula and in Kivalo, a strong increase in the height growth can be observed soon after the mean daily temperature has, for the duration of the growing season, exceeded 10° C.

According to Fig. 36, the artificial increase in temperature produced by the greenhouses demonstrates that the commencement of the effective season for height growth is dependent on the development of diurnal average temperatures. This is borne out by the height growth, precipitation, diurnal temperature averages and minimum temperatures shown in Figs. 38 - 41.

512. Precipitation and soil hydrology

In 1961, Kivalo experienced dry weather for two weeks between May 29th and June 12th, after the beginning of the height growth season. The first time the terminal shoots

were measured during this period - June 2nd - their length averaged 25 mm. By the end of the dry period on June 12th, their average length was about 74 mm. Four days later (June 16th), after 370 ml/sq.dm of rain had fallen on June 14th, the average length of the shoots was 104 mm. The average growth per day between the different days of observation at this time was as follows:

	mm/24 hrs
3-5.6.	3.5
6-9.6.	4.2
10-12.6.	7.1
13-16.6.	7.1
17-19.6.	5.2

This indicates that height growth accelerated during the whole of the dry period and that the subsequent rain did not increase the rate of acceleration.

Figs. 37-40 show the height increment, precipitation, average and minimum air temperatures per observation date in 1961, 1962, 1963, and 1964. From the delineators for 1961, it can be seen that the most rapid height growth began after the average air temperature had risen permanently to over 10°C, even though there were long periods without rain. The importance of diurnal air temperature average over 10° C for rapid height growth has already been noted in subsection 24 on plastic greenhouses and it seems to be confirmed by the data in Figs. 38-41. Thus precipitation does not appear to have such an important effect on the commencement of height growth as air temperature.

Neither does the commencement of height growth seem to be dependent on the ground water table. One exception to this generalization, however, can be seen on the plot on which the ground water was at ground level (0 cm). On this plot in the Vilppula pine swamp area, height growth began considerably later than on the other plots there. But for subsequent fertilization, the trees on it would have died. At this time of the year the ground is still very wet in any case, so it is understandable that, on the other plots, this factor did not affect the date on which height growth began.

513. Soil temperature

Height growth began at the same time on the cold-ground plots as on the normal ones - generally at the end of April or beginning of May. Soil temperatures then are almost the same on both kinds of plots. Later on in the summer, clear differences in soil temperatures can be noted. In the summer of 1964 a maximum difference of 9° C between the cold-ground plots and the normal control plots was noted.

At a depth of 5 cm, the soil temperature was found to vary between -1° - $+2.5^{\circ}$ C at the beginning of height growth. Tables 15 and 16 show the development of soil temperature around this time at both Vilppula and Kivalo. The temperatures shown here are the averages on the normal plots.

Soil temperatures 5 cm deep at the beginning of the height growth were the same at Vilppula and Kivalo. The growing season at Vilppula begins about two weeks earlier than at Kivalo. When height growth in spruce began at Vilppula in

1961, the soil temperature on the normal plots was about +6° C at a depth of 5 cm.

Tables 17 and 18 give the soil temperatures at a depth of 40 cm on the cold-ground plots at Vilppula and Kivalo at the beginning of height growth.

The depth of the ground frost and the state of the ground thaw appear to have no direct effect on the beginning of growth, as can be seen from Table 19.

Table 19 shows the thickness of the snow, and the depth of ground frost and thaw on the cold-ground and control plots in the Vilppula and Kivalo pine swamp areas at the beginning of height growth, 1962-64. It will be seen that in many years there were sharp differences in soil temperatures around this time.

514. Soil nutrients

In 1961, 1962, and 1963, height growth began on the same date on the fertilized plots and the unfertilized control plots. In 1964 it began on the fertilized plots at Vilppula on April 25th, though the average date of commencement for untreated plots was April 27th. Fertilization has a powerful effect on the amount of growth. Height growth in pines begins earlier on very rich sites than on those that are poor in nutrients. Our growth curves reveal a clear difference between the early stages of growth in fertilized and unfertilized trees: right from the start, it is consistently greater in the fertilized specimens.

515. Miscellaneous observations on height growth

At the same time we studied the initial dates of height growth, we measured the buds of terminal shoots on plots treated in different ways in different years. Our findings are given in Table 20.

The terminal buds on the Kivalo pines were notably smaller before the beginning of growth than were those of the Vilppula pines at the corresponding time. In general, the bud size appears to have diminished between 1961-1964, according to the average figures presented in Table 20. The terminal buds on the fertilized plots at Vilppula differ from all the others in their rapid growth. The figures in the table may cover a swelling in the buds that was so slight as not to be noted as growth. In this case, fertilization led to a quicker ripening of the buds, which subsequently caused the earlier beginning of growth already noted.

In all years, the buds on the fertilized trees at Kivalo were bigger than those on their controls.

In this study, both the fertilized and the cold-ground plots have their own separate controls. The non-cooled cold-ground controls lie adacent to the cooled plots to provide a valid comparison to them.

52. Diameter increment

The banding method was used to ascertain the time at which diameter growth began. This moment is much harder to determine accurately than the commencement of height growth, despite the accuracy of the banding method, for circumference

measurements involve variations and fluctuations that are very difficult to correlate with growth.

The period of diameter growth is here defined as that period during which 80 per cent of the total growths occurs, lopping off the periods during which the first and last 10 per cent of the growth takes place. In Table 21, which was prepared on this basis, the diameter growth of Vilppula pine is indicated as having begun at the end of May or beginning of June. This was also true for the spruce at Vilppula, except in 1964; in that year, it grew exceptionally rapidly in diameter after a sudden warming of the air, and then growth ceased altogether for two weeks during a chilly period, and finally continued as before. In birch, diameter growth has always begun considerably later than in pine and spruce - during the first half of June.

Diameter growth in pine began about a week earlier at Vilppula than Kivalo (Table 21). In 1962 and 1963, it began in spruce five days later at Kivalo than at Vilppula. In 1964 there was a considerable difference in the dates, because the heat wave that caused the exceptionally early commencement of diameter growth at Vilppula did not occur at Kivalo.

Birch began its diameter growth ten days later at Kivalo than at Vilppula in 1962, one day earlier in 1963 and 17 days earlier in 1964 (Table 21).

521. Air temperature

Diameter growth begins when the diurnal temperature average has been over 10° C for some time. It does not always begin at the same time in every tree species. Likewise,

diameter gowth begins at different times at the various altitudes of the stem, especially in pine and spruce, as noted above in section 423. In 1961, when the mean diurnal temperature at Vilppula suddenly rose to over 20° C in the spring, having previously been 6-7° C, growth began simultaneously in all species. In spruce, however, signs of incipient growth had been noted during observations made before the sudden rise in temperature. This was probably bacause the spruce, reacting more readily to rain, had utilized the 0.6 mm of precipitation that had occurred in the meantime. Previously, no precipitation had been recorded at the initial moment of growth. In 1963, spruce and pine growth began slowly after May 11th.

Diameter growth in birch began only after May 20th, in 1963. The beginning of birch growth was evidently delayed by the low minimum temperature, which fluctuated a little above or below 0° C on the observation days. The quicker reaction in birch to changes in temperature can also be seen in the 1964 curves for Vilppula. In that year the temperature dropped sharply after growth had begun. This occurrence is cleary reflected in the growth curves for birch, but pine and spruce showed no such strong reactions. The very strong early rise in the growth curve for spruce in the same year between 17th - 27th April is due largely to the high maximum temperatures; the temperature during this period rose as high as 17° C, and was accompanied by warm and heavy showers.

In Fig. 42 it can be seen that raising the air temperature by means of plastic greenhouses has not

affected the initial dates of diameter growth either at Vilppula or at Kivalo. Neither can any such changes be noted in the rest of the material.

522. Precipitation and soil hydrology

Precipitation accelerates diameter growth at all stages of the growing season. This can be seen very clearly, for instance, in the growth curves for Kivalo in 1963, where a dry period occurred right at the beginning of the growing season, between 22nd - 27th May (Fig. 48-50). After that, some 16,5mm of rain fell in two days, and the average air temperature rose about 3° C. The increase in diameter growth in pine during these two days amounted to almost 1/3 of the total growth during the whole of that summer, and in spruce to about 1/5 of the total growth. In birch, the growth only amounted to 1/28 of the total summer growth, since birch displays no reaction to precipitation so early in the season, before its leaves have come out. The 1962 curves for Kivalo also show a rise and fall in the spruce and pine growth due to fluctuations in precipitation in the early stages of the season, and here again, the changes in birch stem diameter are much smaller. The precipitation was very probably sufficient to start the growth, but it only speeded up around 17th June, when the average diurnal temperature rose above 10° C for the rest of the growing season.

No differences in the effect of soil hydrology on the various kinds of plot have been noted at the beginning of diameter growth.

523. Ground temperature

At the time diameter growth began, there was a difference of 2-3° C between cold-ground and normal plots at a depth of 5 cm (Table 22).

No difference was found between the initial dates of growth, despite the considerable differences in ground temperature shown in Table 22. There were considerable differences in ground temperature at the beginning of diameter growth in different years.

It has been demonstrated earlier (Huikari 1961) that the dates on which diameter growth in spruce, pine, and birch begin do not depend upon the ground temperature prevailing at the time.

524. Soil nutrients

Diameter growth in pine begins on fertilized plots earlier than on others. The greater the effect of fertilization on the amount of diameter growth, the clearer is its effect on the timing. A good example is provided by the growth curves for pine at Vilppula in 1963 and 1964 (Figs. 43a and 44b). In 1964 the difference in the initial moment of growth was as much as three weeks, in 1963 1 - 1 1/2 weeks.

At Kivalo, where the effect of fertilization was slower an less marked in other respects, too, the differences in the time of growth beginning were not so great (Fig. 48). In spruce and birch the differences can

scarcely be observed, due to the slight reaction capability of the trees (Fig. 49).

53. Pine flowering

Table 23 gives the average time for the annual beginning of flowering on the Vilppula plots, the interval between the beginning of height growth and that of flowering, the sum of the diurnal temperature averages during this period, and the temperature sum calculated both as the sum of the diurnal averages exceeding 5° C, and as the sum of temperature hours over 5° C up to the time of flowering. It can be seen that although the number of days between the beginning of the height growth and that of flowering varies considerably, the temperature sums are very similar from year to year. Obviously, therefore, flowering is closely related to air temperature.

Pine flowering and pollenation began at the same time on normal, cold-ground and fertilized plots, but they were much stronger and lasted longer on the fertilized plots than on the normal ones.

Table 24 gives the ground temperatures at the beginning of the flowering on Vilppula pine swamp plots treated in different ways, and water-regulated to depths of 5, 15, and 40 cm. When flowering began in 1964, the ground temperatures 5 cm deep varied between +1.9° C and +11.3° C. Thus the beginning of the flowering does not appear to be correlated to ground temperatures, at least within these limits.

Flowering also began simultaneously on plots whose ground temperatures varied between -0.3° C and +8.3° C at a depth of 15 cm. and -0.8° C and +6.7° C at 40 cm.

From readings at the Luonetjärvi weather station, given in kilocalories per sq.cm. per day, we have calculated the quantity of sun radiation that occurred between the onset of height growth and the beginning of flowering in the Vilppula pine swamp area:

year	kilocalories
1961	13.700
1962	21.100
1963	14.100
1964	19.800

Thus, here again there appears to be no clear correlation between the start of flowering and total sun radiation during this period.

6. Duration of growing season

61. Height growth

Our results show that height growth in pine ceases at the warmest time of the summer - at the end of June or some time in July, depending on the weather. The time varies by several weeks in the same locality from year to year. The following table shows the dates on which pine height growth stopped at Kivalo and Vilppula in 1961-64.

Year	Vilppula	Kivalo
1961	19.6	7.7
1962	5.7	13.7
1963	22.6	23.6
1964	2.7	7.7

In the four years covered by this study, the above dates varied by 16 days at Vilppula and 20 days at Kivalo. The duration of the height growth was as follows:

Year	Vilppula	Kivalo
1961	45 days	-
1962	61 "	50 days
1963	47 "	38 "
1964	66 "	67 "

611. Air temperature

To find a correlation between the duration of height growth and air temperature, we added up the sum of the temperatures observed during the height-growth period.

Table 25, which applies to the Vilppula pine-swamp area, gives the number of days that height growth lasted each year, the sums of the diurnal temperature averages during this time, and the temperature sums - both those based on the diurnal average temperatures, and those calculated as temperature-hours according to readings taken at intervals of two hours. The table also contains the same data for plastic greenhouses and their controls in 1964. Table 26 gives similar figures for the pine-swamp area, plastic greenhouses and control plots at Kivalo.

Both these tables indicate that the duration of height growth is very closely correlated to the sum of temperature-hours over 5° C. The duration of height growth in the plastic greenhouses in 1964 was as follows:

	Dates of growth	Duration in days
Kivalo		
greenhouse	5.5 - 22.6	48
control	9.5 - 18.7	70
Vilppula		
greenhouse 2	24.4 - 13.6	50
control	24.4 - 29.6	60

The duration of growth in the greenhouses and the control trees differed by 16 days at Vilppula and by 22 days during the two observation years at Kivalo. The sums of the average diurnal temperatures during the growing period added together do not differ from each other percentage-wise as much as the number of days duration. The smallest difference was in the sums of temperature-hours over 5° C.

Sun radiation values for Vilppula and Kivalo were obtained from the weather stations at Luonetjärvi and Sodankylä. The total radiation values during height growth are presented in Table 27. The figures for Kivalo were smaller than those for Vilppula. Radiation per day was roughly the same in both localities, the difference in the sums of the radiation values being due to the difference in the number of growing days.

612. Precipitation and soil hydrology

No correlation whatever was found between precipitation and the duration of height growth. This is because so much of the total precipitation comes in the form of heavy showers that large quantities of water run off, and are not utilized by the tree.

Individual trees vary greatly as to the dates upon which their height growth ceases. By distributing this dispersion between in plot and inter plot components it is possible to test for correlations between different forms of plot treatment and the terminal date of height growth.

In 1961, there was no difference at either Kivalo or Vilppula, as regards the time at which height growth ended. In 1962, there was no difference at Vilppula, but at Kivalo growth ended significantly earlier on plots with a ground water table of 10 cm than on those in which the ground water was 30 cm deep, and very significantly earlier than on the 50 cm and 70 cm plots.

The average dates of termination of height growth on the water-regulated plots were as follows:

KiRU 10	KiRU 30	KiRU 50	KiRU 70
9.July	14.July	15.July	14.July

In 1963, there was no correlation between ground water depths and the date of growth termination at Kivalo. At Vilppula, the 10 cm plots differed almost significantly from the 30 and 70 cm plots, but not at all from the 50 cm plots.

613. Ground temperature

Table 28 reveals the terminal points for annual growth in sample plots treated in various ways. The figures indicate that the height growth ceased at about the same time in both the cooled plots and the control plots, although the soil temperature at 5 cm depth in the cooled plots was 7-9^{0} C lower than in the control plots at this time; as the height growth began at about the same time, cooling did not affect the duration of height growth.

614. Soil nutrition

Table 28 makes it plain that fertilization prolongs the growing season as well as increasing the total increment. This, of course, presupposes correct fertilization in which the substances are applied in the right ratios to soil that is otherwise deficient in them. The prolongation of the growing season due to fertilization can have a negative effect if the fertilization is such as to cause malequilibrium in the nutrients.

The Swamp Forestry Department of the Forest Research Institute has established a very large and diversified fertilization test series at Leivonmäki near Vilppula. The results of these tests indicate that excessive nitrogen fertilization causes buds to reburst in the same year, causing the buds to freeze in the fall. The same phenomenon has been noted on test plots with an acute deficiency of phosphorus.

By 1963 the effect of fertilization began to be visible: at Kivalo it prolonged the growing season by four days. At Vilppula, too, fertilized trees grew some four days longer than the control trees. In 1964 the corresponding prolongation was 7 days in Vilppula and 3-4 days in Kivalo. As the height growth in pine on the fertilized sample plots started 2 days earlier than on the unfertilized plots, the overall prolongation in Vilppula amounts to 9 days.

62. Diameter growth

During the preparatory work for this study in 1955, the growth reactions of 133 pines in the Liesneva area, not far from Vilppula, were studied, and preliminary computations made on the effect of weather on variations in diameter growth. Special attention was paid to the length of dry periods before the date of measurement and their effect on diameter variations.

The value for the variation in pine circumference was calculated by deducting the weighted mean of the immediately preceding and following band readings from the band reading of the day of observation. The variation series for circumference growth in 1955 was calculated from the variation series per tree by iteration, using the correlation

of each tree to the sum series as the weight for its series. The series was computed for June 6th - October 19th, 1955. Weighting was considered necessary because the material included trees of all crown layers, so the strenght of their growth reactions varied.

In computing the variation series for circumference growth in 1954, we did not use the correlation coefficients as weights, because nearly all the test trees were of the same crown layer. The variation series was calculated for the period May 25th - August 28th, the time during which the pines were growing.

If a series of this kind is used to elucidate the effect of some weather variable (x) on fluctuations in circumference, it should be borne in mind that every variation value in it involves three band readings, and thus also includes the effect of the weather variable at the times of the readings. If the effect of the weather variable on stem circumference islinear, its effect on the variation value can be obtained by calculating the series corresponding to the circumference variation values from the x series, and comparing the weather series thus adjusted with the variation series for circumference.

In addition to the duration of the dry period mentioned earlier, we studied the correlation of circumference variations with rain, relative air humidity, and average, maximum and minimum air temperature.

621. Air temperature

Basing our calculations on the 1955 measurements, we studied the correlation between the variations in pine

circumference and those of the maximum and minimum air temperatures. The correlations with the maximum temperatures on the day of measurement and the day preceding it were slightly negative. Those between the circumference variations and the maximum temperatures noted two and three days before the measurement were practically zero. On the other hand, variations in minimum air temperatures on the day of measurement and the day before it showed a clearly positive correlation with the variations in circumference. There was also a slight positive correlation with the minimum temperatures registered two days earlier.

At Vilppula, circumference measurements were taken at intervals of two or three days in 1964. Average air temperatures calculated for the corresponding intervals were put into a variation series. The variation series for the minimum temperature was calculated from a series, the terms of which were the means of the minimum diurnal temperatures noted on the observation days (2-3 day intervals). The variation series for the maximum temperatures was similarly obtained.

Variation series were also calculated for the circumference of birch and spruce. In the case of pine, separate series were computed for fertilized and non-fertilized trees, since the intensity of growth on these differs considerably. The coefficients of the correlation between the circumference variation series and the maximum, minimum and average temperature series are given in the following table:

	Maximum	Minimum	Average
Pine			
ViRU	-0.203	0.291	-0.029
ViRF	-0.012	0.499^{xx}	0.336^{x}
ViRTS	-0.089	0.334^{x}	0.036
ViRTCS	-0.075	0.341^{x}	0.035
ViRU10	-0.128	0.121	0.138
ViRU70	-0.112	0.384^{x}	0.077
ViRF10	-0.061	0.367^{x}	0.205
ViRF70	-0.086	0.488^{xx}	0.377^{x}
plastic house	-0.124	0.118	0.047
control	-0.108	0.405^{x}	0.191
Spruce	-0.158	0.208	0.050
Birch	-0.147	0.379^{x}	0.159

Of the three variation series on temperature investigated, variations of minimum temperature are found to correlate most closely to those of the stem circumference of pine, spruce, and birch. The variations in average temperature also show a positive correlation, in general, but this becomes significant only in the case of the fertilized trees. All the variation series on circumference that we have studied correlate negatively with the variations of maximum temperature, but not significantly so. Here the correlation coefficients for the fertilized trees are slightly closer to zero than those of the normal trees. The reactions of the greenhouse trees correlate less closely to corresponding

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x Denotes significance at the 5 % level.
xx Denotes significance at the 1 % level.
xxx Denotes significance at the 0.1 % level.

air temperature variations than those of trees growing in the open. With regard to the correlation coefficients presented above, it should be noted that they have been calculated separately for each weather factor, ignoring their interdependence. For the variation series on fertilized and unfertilized trees, we have also calculated partial correlation coefficients, from which we have eliminated this interdependence. In calculating the partial correlation coefficients, precipitation and relative humidity were taken as variables in addition to the above. These partial correlation coefficients are shown in the following table:

	maximum temperature	minimum temperature	mean temperature
ViRU	0.092	0.460	-0.012
ViRF	0.178	0.254	0.344

Particularly striking is the greater correlation of fertilized trees with average temperature. But high minimum temperatures (night temperatures) seem to have a greater influence on variations of circumference in normal trees than on the fertilized trees.

The partial correlations with the variations of maximum temperature proved to be positive. This demcnstrates that high maximum temperatures in themselves do not have a negative effect on diameter growth. The aforementioned negative correlations are due to the negative correlation between maximum temperatures, on the one hand, and precipitation and relative humidity on the other ($r_1 = -0.405$, and $r_2 = -0.294$).

The correlations of our three weather variables with the circumference variations in trees on cold-ground plots

and plots that were covered but not cooled were similar way to those with normal trees. Figure 42 reveals that the diameter increment began and ended at the same time in both the greenhouses and on the control trees. Thus the artificial increase in the air temperature did not influence the duration of the diameter growth.

622. Precipitation and soil hydrology

Basing our calculations on the observations in the preliminary survey of 1955, we studied the correlation between stem circumferences and the duration of dry periods occuring just before measurement. Here we first examined the correlation between the duration of dry weather and tree growth. Obviously, more water is available for trees when it rains and immediately afterwards. During a dry period, it falls off - sharply at first, then more and more gradually. Evidently the effect of the utilizable rain water on circumference growth is similar, producing a largely concave downwards curve on the graph.

The curve in Fig. 45 was considered to be a suitable transforming curve to illustrate the effect of the duration of dry weather; it was formed of values indicating the amount of rainwater available for the trees. The points of the graph have been used when the dry weather duration values have been concerted into influence values. From this series we calculated a variation series corresponding to that of stem circumference. This correlation with variations of stem diameter is illustrated in Fig. 46a, and it is clearly positive.

In Fig. 46a, the observations are illustrated by three groups of points, representing early summer, middle summer and late summer. It can be seen that the smoothed curves for the points for these three different periods differ in their regression coefficients; the later the summer period, the smaller the regression coefficient. In other words, given variations in the amount of rainwater available for the trees cause greater variations in stem diameter in early summer than in late summer. The intensity of growth also varies as a function of time in the same way, lending support to the assumption that the size of the variation depends on the stage of the growing season.

This phenomenon led us to seek an index for the intensity of tree growth. To do so, we took the current growth determined as a derivative of the smoothed cumulative growth curve. The correlation between circumference and the variation values for the rain water available to the trees, weighted by this index, is shown in Fig. 46b. This correlation is clearly closer than that illustrated in Fig. 46a, where the values are not index-weighted. The coefficient of the correlation comparising the weighted values came out to $r = 0.90$.

The following are the correlations between the circumference variation series for 1964 and the variation series for precipitation and relative humidity.

	Precipitation	Relative humidity
Pine		
ViRU	0.657^{xxx}	0.606^{xxx}
ViRF	0.645^{xxx}	0.416^{xx}
ViRTS	0.716^{xxx}	0.609^{xxx}

	Precipitation	Relative humidity
Pine		
ViRTCS	0.688^{xxx}	0.602^{xxx}
ViRU10	0.676^{xxx}	0.681^{xxx}
ViRU70	0.636^{xxx}	0.524^{xxx}
ViRF10	0.683^{xxx}	0.511^{xx}
ViRF70	0.568^{xxx}	0.339^{x}
plastic house	0.206	0.061
control	0.734^{xxx}	0.544^{xxx}
Spruce	0.607^{xxx}	0.544^{xxx}
Birch	0.378^{x}	0.248

They indicate that rain is a strong factor in stem circumference variations. The correlations involving relative humidity are also significant. Precipitation and relative humidity naturally correlate with each other very closely. The correlation between their variation series is 0.739. The partial correlations, involving the effect of the three temperature variables presented earlier and one of the variables explanating moisture are as follows.

	precipitation	relative humidity
ViRU	0.373	0.487
ViRF	0.684	0.254

From this, it appears that the circumference of fertilized trees varies less with relative humidity than does that of unfertilized trees, in agreement with the simple correlation coefficients studied earlier. On the other hand the

correlation with precipitation variations is much greater in the fertilized trees than in the non-fertilized ones.

In the first of the above tables, correlation coefficients were also calculated separately for fertilized and control plots with ground water regulation to depths of 10 cm and 70 cm. It might be supposed that circumference variations in trees on the drier-regulated plots would correlate more closely with changes in relative humidity. The coefficients show that this is not the case.

Although the correlation between the variations appearing in the greenhouse trees and the precipitation outside is not significant, its coefficient ($r = 0.206$) is still the largest of all the correlations between the greenhouse trees and weather factors.

Variations in stem circumference on the cold-ground plots and the non-cooled, straw-covered plots correlate with precipitation and relative humidity in very much the same way as those of the normal trees.

The reaction of spruce to changes in moisture conditions appears to be similar to that of pine, but in birch it is considerably weaker. The correlation between birch growth and changes in relative humidity does not reach the significant mark.

Figures 43, 44, and 47-50 reveal that the duration of the diameter growth was the same for all tree species on sample plots differing as regards water economy, but in other respects treated in the same way.

623. Soil temperature

Figures 43b, 44a, 47, and 51-53 reveal that the diameter growth takes place at the same time on the cooled sample plots and the control plots. Thus the decrease in soil temperature has not affected the growing period.

624. Soil fertility

Figures 43a, 44b, and 48 reveal that the diameter growth on fertilized sample plots in pine swamps at Vilppula and Kivalo started earlier than on the unfertilized plots, but terminated at the same time. Thus fertilization has increased the period of growth.

This could not be observed in spruce and birch at the Kivalo sites (Figures 49 and 50). This may be a consequence of the fact that the trees in these areas are sufficiently old that their reaction capabilities have greatly diminished.

625. Periodic variations

Pine, spruce, and birch differ from each other as regards their sensitivity to growth reactions caused by a variety of factors. Figs. 48a, 49a, and 50a reveal that birch does not react with as great a sensitivity to, for instance, dry periods, as pine and spruce. In pine and spruce, periods when growth ceases altogether evidently very often because of drought are more clearly noticeable. Specifically it can be observed that such periods of growth

cessation were encountered in spruce and pine at Kivalo during two dry spells in 1963. It can also be clearly observed that the period of cessation was not so distinct in the 30 cm and 50 cm plots as in the 70 cm and 10 cm plots. In trees with a strong increment this periodicity in growth is not as clear as in trees whose growth is poorer.

The soil temperature seems to have an effect on periodicity, as soil frost which remains in the soil for a longer time obviously ensures water availability during the dry periods.

In spruce, a distinct increase in growth, caused by rains, can be observed. The reaction of the spruce to the dry periods differs from the pine in that no shrinking occurs in the stem of spruce, which keeps its former diameter (Fig. 48a and 49 a).

7. Increment and growth

71. Mathematical treatment

Radial growth has been calculated from banding measurements. Each year, four days' observations in spring and autumn were selected with the aid of graph delineators, and the circumference growth was calculated from the difference between their mean values. By dividing this by 6.28 we obtained the radial growth figures presented in Tables 41-44 in Appendix 4. The corresponding tables (39-40) for height increment give terminal shoot lengths in millimetres.

The effect of water regulation and other artificial measures on increment can be seen in Tables 39-44. Comparison between the plots, however, is hampered by a lack of homogeneity among the four main areas. Thanks to the substantial correlation between annual increments, we have been able to eliminate this factor in our computations. Two-way covariance analyses have proved to be a very suitable method of computation. One factor that hindered our analyses of height growth was that each year some of the test trees were changed. For this reason the degree of freedom had had to be reduced.

The following is a short survey of circumference growth measured at Vilppula in 1962. The basic year in the covariance analyses is 1961, the first year of our study.

If y_{ijk} is taken as the increment in 1962, it can be presented by the equation:

$$y_{ijk} = m + t_i + b_j + c\ (x_{ijk} - \bar{x}) + e_{ijk}$$

in which m = the average general increment

t_i = the effect of the artificial measures

b_j = the effect of the ground water depths

x_{ijk} = increment of the same trees in 1961.

The last term e_{ijk} follows the normal distribution, but independent of t_i and b_j. The correlation between the variable y_{ijk} and the constant x_{ijk} is assumed to be a linear one.

Table 29 gives the sums (in 0.01 mm) of circumference growth per plot. The figure in top right corner of each square denotes the number of trees submitted to the combination of treatments in question. Of the increment sums below this, the upper sum is the figure for 1962, and the lower that for 1961.

From the original increments and the increment sums per plot in Table 29 it is possible to calculate the corrected sums of the squares and products shown in the following table.

Source of variance	f	$\sum (y_i-\bar{y})^2$	$\sum (y_i-\bar{y})(x_i-\bar{x})$	$\sum (x_i-\bar{x})^2$
Plots	11	392'008	256'671	445'815
Error	84	1'458'349	1'061'934	1'361'223
Ground water depths	3	38'252	48'414	179'038
Treatments	2	62'199	-40'695	31'915
Interaction	6	291'557	248'952	234'862
Total	95	1'850'357	1'318'605	1'807'038

If we denote the sums of squares and products for error by Exx, Eyy, and Eyx respectively, the regression coefficient of y on x, or adjustment factor c, is given by

$$c = \frac{Eyx}{Exx} = \frac{1'061'934}{1'458'349} = 0,78013$$

We may now calculate the residual error sum of squares. As we see, the original error s.s. is 1'458'349, with 84 d.f.
To remove the effect of the regression on the initial growth numbers we subtract

$$\frac{E^2yx}{Exx} = \frac{1'061'934^2}{1'458'349} = 828'449$$

$$Eyy = \frac{E^2yx}{Exx} = 1'458'349 - 828'449 = 629'900$$

This difference, 629'900, is the residual s.s. for error with 83 d.f., since 1 d.f. must be subtracted for the additional parameter c. The residual mean square $s^2_{y \cdot x}$ is

$$\frac{629'900}{83} = 7589,16.$$

The original mean square is 17'361,30 and so the use of covariance has approximately doubled the accuracy of the experiment. To test if there are significant differences between the plots we must first calculate the residual s.s. for the plots. This is found by subtracting the residual s.s. for error from that for plots + error

888'164 - 629'900 = 258'264

The F-test of the adjusted plot means is given by the ratio of the residual mean squares.

$$F = \frac{258'264}{11 \cdot 7589} = 3.094$$ (significant at the level 99 %, with f 11 and 83)

The covariance adjustment to the i:th plot total of y is

$$- c\ (T_{ix} - r_i \bar{x})$$

where T_{ix} is the plot total of x, r_i is the number of replicates and $\bar{x}$ the general mean of x. Adjusted plot means are shown in Table 30.

To test the significance of the differences among the various depths of the water table and among the various treatments, we must calculate the F-values from the table below.

	$\sum (y_i-\bar{y})^2$	$\sum (y_i-\bar{y})(x_i-\bar{x})$	$\sum (x_i-\bar{x})^2$
Error	1'458'349	1'061'934	1'361'223
Water tables + error	1'496'601	1'111'348	1'540'261
Treatments + error	1'520'548	1'021'239	1'393'138
Interaction + error	1'749'906	1'310'886	1'596'085

Because the difference between two adjusted plot means, or totals, depends on the estimated adjustment factor c, we must increase the residual error mean square $s^2_{y \cdot x}$, if we compare the adjusted values with eachother. There are so many comparisons that we use the same correction for them all. This Finney's approximation is given by

$$s^2_{y \cdot x} \left(1 + \frac{txx}{Exx}\right) = 7589 \left(1 + \frac{40'529}{1'361'223}\right) = 7813$$

where txx is the plot mean square for x. Now we get the F-values

Water tables: $F = 2.766^{+}$

Treatments: $F = 9.088^{+++}$

Interaction: $F = 0.925$

These numbers show that there are significant differences between treatments, and that they are similar at all water table depths, because the interaction term is not significant. Results of this and other covariance analysis calculations are shown in Tables 31-38.

72. Air temperature

721. Vilppula

Fig. 37 shows the effect the plastic greenhouses had on the height growth of pine at Vilppula. From these curves it appears that, on the average, the diurnal temperature means in the greenhouses were 5° C higher than those outside. Height growth began earlier and lasted a much shorter time in the greenhouses than outside. The figures on this growth are as follows:

	1961	1962	1963	1964
	Height growth, mm			
Plastic greenhouse 1	447[x]	320	254	374
Control 1	370	261	234	253

[x] Greenhouse not erected until 1962

	Height growth, mm	
	1963	1964
Plastic greenhouse 2	257[x]	325
Control 2	263	284

In 1964 both greenhouses appeared to have affected a slight improvement in growth. In 1963, Greenhouse 1 seemed to have had a clearly negative effect. It appears that their effect on radial growth was less advantageous than on height growth (Table below). This may be due to inadequate irrigation in the greenhouses.

	1962	1963	1964
	Radial growth, mm		
Plastic greenhouse 1	1.00	0.54	0.80
Control 1	1.70	1.57	1.78
Plastic greenhouse 2			1.14
Control 2			1.17

The results indicate that under the test conditions prevailing at Vilppula, air temperature is not a critical factor for height and diameter growth in pine.

722. Kivalo

Figs. 37 and 42 show the height and radial growth of pine in the plastic greenhouse and its control. The following figures give the quantity of growth:

Greenhouse not erected until 1964

	1962	1963	1964
		Height growth, mm	
Greenhouse	421[x]	266	387
Control	390	217	288

	1963	1964
	Radial growth, mm	
Greenhouse	1.64	1.19
Control	1.44	1.80

In 1962, the year the greenhouse was erected, height growth was greater in trees, which later came under plastic than it was in the control trees. However, the figures indicate that it did, in fact, improve height growth. The differences in the average growth were 31 mm in 1962, 49 mm in 1963, and 99 mm in 1964 in favor of the greenhouse trees. As at Vilppula, however, diameter growth in 1964 was considerably weaker.

73. Precipitation

731. Vilppula

The table below shows that pine growth at Vilppula has been least during the most rainy year. Spruce increment, too, was least during the most rainy season. Birch grew best during the most rainy season.

[x]Greenhouse not erected until 1963.

The results were obtained from a basic series (1-55) at Vilppula, in which no changes in the growth factors were made.

	1961	1962	1963	1964
	Circumference growth, mm			
pine	7.99	9.01	8.72	8.65
spruce	12.80	14.29	14.67	13.35
birch	11.17	8.23	10.00	9.37
	Precipitation during the growing time, mm			
pine	231	123	94	94
spruce	200	155	96	113
birch	200	127	71	62

However, the total precipitation does not give a correct picture of precipitation as a growth factor, because an even distribution of the precipitation during the growing season has a very different effect on the growth process than alternating dry periods and periods of greater than usual precipitation. Figs 43 44 and 47 indicate that dry periods have a srongly negative effect on growth. In pine this often takes the form of an actual shrinkage of circumference. Strongly growing trees on fertilized plots do not suffer from drought as much as trees on poorer ground.

732. Kivalo

The effect of dry periods can be seen very clearly in the trees at Kivalo (e.g. in Figs. 48, 49, and 50). The growth curves for pine indicate that dryness halts growth and considerably reduces stem diameter in the specimens already growing under the poorest conditions. On our more productive plots, positive growth continued during the dry time, and in 1964 it went on longer and stronger on the straw covered plots than on the non-covered or otherwise poorly productive plots. Fertilization and artificial cooling with straw were found to increase the moisture in the surface layers of the soil, thus promoting and prolonging the period of effective growth, both at Vilppula and at Kivalo. On the 10 cm water-regulated plots, however, growth was poor despite the fertilization and soil covering; the effect of dry weather on these plots is very clear.

One conclusion is that, under growing conditions such as in Finnish Lapland, ditches should be deep enough and close enough to each other to the depth of the table at least 30 cm deep, but that from the end of June onwards, steps should be taken to counteract the effect of overdrainage. Probably, the only way to do this is by irrigation.

74. Soil temperature

741. Pine at Vilppula

Artificial ground cooling in 1962 and 1963 did not produce significant changes in the height growth of pine

at Vilppula (Table 31). Ingeneral, height growth on the cold-ground plots was smaller than on the controls.

As regards diameter growth, the growth values, in the covariance computation, in which the year 1961 was used as basic year, were smaller on the cold-ground plots than on their controls at all ditch depths except at 70 cm (ViRC 70 plot), at which the artificial cooling did not cause a negative reaction of the diameter growth. This phenomenon is not significant in degree, but on comparing the various ditch depths it can be seen that the negative effect of artificial cooling on diameter growth falls off steadily as the ditch depth increases.

In 1962 and 1963 one end of the cold-ground plots was cooled by removing the snow during the winter; no covering materials were used in the following spring, so that the snow melted relatively rapidly with the spring rains. Ground thaw also began from the surface, with the moss layer and first few centimetres of soil melting considerably earlier than the frost deeper down. Under such conditions, the root tips, which lie mainly in the surface layer of the soil (Kalela 1957, Heikurainen 1959), may already have been in thawed soil at the time the shoots began to grow, and may themselves have started to grow. To ensure that the surface layers of the soil remained cold for as long a time as possible and to prevent the snow and ground thaw from beginning with the surface layers, artificial cooling was practised in winter 1963/64 with the aid of a straw covering (see sect. 25). The controls of the cold-ground plots were covered with straw the previous autumn in order to control the other effects of straw covering. The artificial cooling by means of straw cover had an almost significant negative effect on the height growth in pine as compared with the height growth on the straw-covered control plots.

Cooling with a straw (or Sphagnum-peat) covering, which naturally produced other side effects of covering, permitted a highly significant increase in diameter growth compared with the non-covered control plots. On the uncooled covered plots, too, growth was very significantly greater than it was on the control plots. The sum of the growth values on the covered cold ground plots was less than that of the uncooled covered plots, but the difference was not significant.

Covering was found to have a very significant positive effect on growth, regardless of whether the soil was cooled or not. It seems therefore to be an advantage to cover the soil with the same material as is used to prevent snow and ground frost from melting, simply in order to improve it. Even though this measure has no practical value at the present time, owing to the high cost of suitable materials, an investigation could well be made of the correlation between the advantage of such a method and other growth factors. As things are, it can be noted that on the ViRTS 70-plot pine increment was very significantly greater than on the control plots. The increase of growth on the ViRTS 70-plot was greater even than on the fertilized ViRF 70-plot, though the difference here was not significant. The positive effect of covering the diameter growth in pine, also can be observed at the other water depths. All in all, covering raised diameter growth by almost 50 per cent, compared with control plots. The biggest effect was on the plots with ditch depths of 70 cm. A comparison of growth figures on different dates shows that this is because the artificial delay in the snow and ground thaw raises the moisture in the soil later on during the dry part of the summer, when 70 cm regulation ditches otherwise

cause overdrainage.

From our findings it can be seen that, within the limits of the present study, the soil temperature during the growing season is not an as important factor for growth as the soil hydrology, and is not capable to cover the differences in fertility.

742. Birch and spruce at Vilppula

Ground cooling had a positive effect on birch diameter growth at all ground water depths in 1962 and 1963, taking 1961 as the basic year for covariance analyses (Table 33). The effect of ground cooling with straw on birch diameter growth in 1964 was almost significant. The results indicate that the increased moisture provided by straw covering and cooling had a positive effect on the trees especially in the 50 cm and 70 cm plots.

The improvement in birch diameter growth due to straw covering was significant when compared with the growth in 1963. This effect, as also in spruce, is most evident on the 50 cm and 70 cm plots.

It is remarkable that the increase in diameter growth in spruce, differing from that in pine and birch, even at 10 cm water depth was highly significant, due to cooling and straw covering.

743. Pine, spruce, and birch at Kivalo

In 1964 cooling diminished the height growth very significantly, in comparison to the figures for 1963, on all experiment members; it was 29 % less than height growth on the control plots

On the pine swamp area at Kivalo it was noted that even in the course of the first summer diameter growth decreased after cooling (Table 36), to a almost significant degree. In the summer of 1963 the decrease was very significant, with 1961 used as the basic year in the calculations. When the cooling was undertaken in 1964 and made more effective by a Sphagnum-peat covering, a significant decrease in the diameter growth was not obtained.

The effect of soil temperature on the increment of pine, spruce, and birch was investigated in the pine swamp and spruce swamp areas at Kivalo in 1963 and 1964. For this purpose, circular sample plots were set up close to the hydrological experiment areas. The treatment on these was the same as on the other heat economy sample plots (CS, S, and U). The means (in mm) of the figures indicating height growth in pine according to the results of the original measurements were as follows:

	CS	S	U
1963	105.4	132.2	110.8
1964	98.7	137.9	133.0

The values for 1964, adjusted by covariance according to 1963 are the following (in mm):

	CS	S	U
1964	105.2	128.1	136.2

Cooling eventually retards height growth, but in this instance it was not clear enough to be significant.

The original results of measurements of radial growth in pine on circular sample plots were (in mm):

	CS	S	U
1963	0.73	0.70	0.57
1964	1.05	0.96	0.74

The radial growth values for 1964, adjusted by covariance according to 1963 figures were (in mm):

	CS	S	U
1964	0.98	0.93	0.85

The results indicate the development of the radial growth between the first and the second years of treatment. Subjected to cooling and covering, as well as covering alone, the radial growth, contrary to the height growth, increased. The differences, however, do not attain statistical significance.

The original mean values for the annual radial growth in spruce are as follows (in mm):

	CS	S	U
1963	0.86	0.51	0.87
1964	1.28	0.95	1.20

The radial growth figures for 1964, adjusted by covariance according to 1963, are the following (in mm):

	CS	S	U
1964	1.18	1.14	1.10

Cooling and covering seem to affect the diameter growth in spruce, as well as in pine, in a favourable way, although the growth-increasing effect of the covering seems slight.

The original means for the radial growth in birch are (in mm):

	CS	S	U
1963	0.98	0.99	0.55
1964	1.09	1.01	1.03

The radial growth figures for 1964, adjusted by covariance according to 1963 are (in mm):

	CS	S	U
1964	1.18	1.06	0.94

Even in birch the diameter growth was greatest on the cooled and covered sample plots and on those which were only covered. As the effect of cooling and covering tends in the same direction, the difference, caused by cooling, is not significant in comparison with the control plots.

75. Soil hydrology and fertility

751. Pine at Vilppula

Except on the ViRF 0 -plot, the ground water level did not influence the height growth of pine in 1962, when the average of the terminal shoots was only 52 mm (Table 39).

In 1963, the development of the ViRF 0 and ViR 10 - plots lagged noticeably behind that of the others. The increment of the ViRU 10 - plot is almost significantly smaller than that of the ViRU 70, after covariance adjustment (Table 31). On the other plots the height growth, as in previous years, was larger, the greater the ditch depth employed. The differences in growth, however, were not significant, due to the poor fertility. Only in the fertilized plots, in which this minimum factor had been compensated for, were significant increment increases achieved. The largest increments were obtained on ViRF 50 and ViRF 70, both of which differed significantly from ViRF 10. ViRF 30, on which the increment was smaller than on the abovementioned plots, differed from ViRF 10 significantly after covariance adjustment.

During the final year of experimentation, increasingly effective drainage brought about greater height growth on all the plots with different treatment. On ViRF 0 the height increment was only 9 mm. The ViR 10 - plots lagged very significantly behind the other plots, and ViR 30 almost significantly behind ViR 70, with the differences in the 1962 growth taken into account.

The effect of fertilization on the height increment was

rather slight for 1962 (Table 39), since fertilization with K and P took place only in the fall of 1961; in 1962 its effects were limited to increasing the size of the needles and their chlorophyl content. But in 1963 the height increment on the fertilized plots was twice that on the control plots. At different ground water depths the coefficients for the increase in growth were: ViRF 10 - 1.9, ViRF 30 - 2.3, ViRF 50 - 2.2, and in ViRF 70 - 1.8. In the third year (1964) the effect of the fertilization was still more pronounced; the average height increment was 4.2 times greater on the fertilized plots than on the control plots; the coefficients for the various ground water depths were: ViRF 10 - 8.9, ViRF 30 - 4.5, ViRF 50 - 3.9, and in ViRF 70 - 3.0. The effect of the fertilization was clearly greatest on the ViRF 10 - plot, and least on the ViRF 70 plot. The slight increase in pine increment on ViRF 0 was undoubtedly also due to fertilization.

Already in 1962, the diameter growth varied at different ground water depths (Table 30), evidently due to fertilization. As the lack of nutrients was no longer a minimum factor, the tree was able to produce wood with greater efficiency; the determining factor was now the ground water level. The radial growth was greatest in the ViR 50 - plots, which differed almost significantly from the moister ViR 10s and ViR 30s. The ViR 70 plots were almost significantly more favorable for growth than the ViR 10s, after the 1961 conditions had been reestablished. Even on the fertilized ViRF 0 - plot, the average radial growth amounted to 0.63 mm.

The most noticeable change in 1963, as compared with the previous year, was the similarity in the development

of the ViR 30s and the ViR 50s. The slightest growth still took place on the ViR 10s, which differed from the ViR 30s and ViR 50s very significantly, and from the ViR 70s almost significantly. On these latter plots, an injurious overdrying had already become evident, with growth reduced from its earlier level. On ViRF 0, two pines died, and the average radial growth did not even exceed 0.43 mm.

Noticeable differences in growth among the unfertilized plots did not occur until 1964. Prior to 1964, the development of the stands improved, it is true, when the ditch became greater, but only the ViR 70s and the ViR 10s differed from each other to an almost significant extent, following covariance adjustment to the 1961 level. On the fertilized plots, the radial growth was very significantly smaller on ViRF 10 than on ViRF 30 and ViRF 50, and almost significantly smaller than on ViRF 70. The largest annual growth was obtained on ViRF 50 and ViRF 30, between which there was no significant difference. The development of ViRF 70 lagged behind the aforementioned two plots differing significantly from ViRF 50 and almost significantly from ViRF 30. The slightest growth was naturally encountered on ViRF 0: its average amounted to 0.54 mm. The increase in radial growth over the previous year was due to the fact that several pines died, and their replacements on the plot were specimens of a greater vitality.

The effect of the fertilization on radial growth was rapid. As early as 1962 the differences between the fertilized and unfertilized plots became significant. In 1963 and 1964 the divergence from the control plots increased to

a very significant degree in all areas, with varying drainage effectiveness. The salutary effects of fertilization were most evident on ViRF 30 and ViRF 50.

On unfertilized plots, the deeper the ground water was located, the greater the radial growth, but when fertilization was added, a depth of 50 cm was the most favorable, followed by 30 cm and 70 cm, in that order. The relatively disadvantageous quality of the 70 cm depth was revealed only after fertilization, when the soil hydrology became the minimum factor.

The results of the investigation reveal that under conditions corresponding to those in the Vilppula pine swamp area, the greater increment is obtained when the water is located 50 cm below the surface of the ground, in ditches 15 m apart; at both greater and lesser water depths, the increment grows smaller. If ditch depths which allow the water table to sink lower than a depth of 50 cm are employed in Sphagnum-peat, the prospects are for an injurious overdrying.

752. Spruce and birch at Vilppula

The ditch depth experiment areas set up in spruce- and birch-covered swamps at Vilppula were on sites so rich in nutrients that fertilization was not considered necessary. The sample plot series included ditch depths of 10, 30, 50 and 70 cm.

Tables 33 and 34 reveal the radial growth figures. In the growth figures for 1963, adjusted by covariance, no significant differences were noticed (Table 33). The growth

figures for 1964 adjusted by covariance to the basic year 1961, reveal that the growth in birch was the better, the deeper the water table in the ditches surrounding the plots was located. The difference is significant between the ViK 10 - and ViK 70 - plots and almost significant between ViK 10 and ViK 50. The growth on ViK 30 was almost significantly poorer than on ViK 50 and ViK 70. The figures for 1964, adjusted by covariance indicate the development of the growth throughout the investigation period, and clearly reveal the dependence of growth on the depth of the ditch.

In the growth of spruce it can be observed (Table 34) that regulation of the water depth in the ditches surrounding the sample plots led to an increase in the radial gorwth during 1962, which on the 50 cm plot was greater, to a highly significant degree, than on the 10 cm plot, following adjustment by covariance to the 1961 level. On ViK 30 and ViK 70 the radial growth was also significantly greater than on ViK 10. The growths on the 30 cm, 50 cm, and 70 cm plots did not differ significantly from each other. Covariance calculation of the growth figures for 1963 in relation to the basic year, 1961, did not bring out significant differences at different ditch depths. In 1964, too, no differences could be observed between the different ditch depth plots. The total radial increment for the years 1962-64, adjusted by covariance, was somewhat greater on ViK 50 than on the other water depth sample plots. Thus, the behaviour of spruce in the spruce swamp area is similar to that of pine in the pine swamp area.

753. Pine at Kivalo

Regulation of the water depth in the ditches in the Kivalo sample plots was slower to affect the radial growth in pine than was the case at Vilppula (Table 36). Even the effect of fertilization seems to have been delayed, and was perceptible in 1963 only on the KiRF 30 - and KiRF 70 - plots, on which the difference, in comparison with the control plots, is very significant, with 1962 figures used as the basic values. The height growth, too, was very significantly more rapid on KiRF 70, and almost significantly so on KiRF 30, as compared with 1962; this was a consequence of fertilization (Table 35).

In 1964 the height growth increased significantly on all experiment members, thanks to fertilization. It was greatest on the 50 cm and the 70 cm plots, after a covariance adjustment in which the figures for 1962 were used as basic values. When 1963 figures were used as basic values, the results for 1964 were not significant. In 1964 the diameter growth exceeded the figures for the control members on KiR 50 and KiR 70 very significantly, in comparison with the figures for 1962, and on KiR 50 very significantly in comparison with the figures for 1963. KiRS 10 lagged behind the other experiment members very significantly, with the growth figures for 1962 used as basic values. On the KiRU experiment members, the greatest height growth was obtained on sample plot KiRU 30, followed, in descending order, by KiRU 70, KiRU 10 and KiRU 50, where the growth was least. Differences, however, were rather small. In respect to diameter growth,

KiRU 50 was the best, followed by KiRU 70, KiRU 30, and the weakest, KiRU 10.

In 1962 and 1963, no significant differences were noted between the different ditch depth sample plots, either as regards height growth or diameter growth without fertilization. On the fertilized plots it could be observed that KiRF 70 fared best in comparison with the other experiment members, with KiRF 50 in second place. The most unfavourable in respect to diameter growth was KiRF 10, where the effect of fertilization was negative every year. As regards height growth, KiRF 30 was almost significantly better than KiRF 50 in 1963, with 1962 figures used as basic values. Examination of height growth for 1964, using 1963 as the basic year, reveals that the trees on fertilizated plots, at all ditch depths, grow better than those on the unfertilized, although the difference did not reach the limit of significance. The growth on the fertilized plots was about 10 % stronger than on the control plots. The height growth on the KiRF 30-plots lagged almost significantly behind that on KiRF 50 and KiRF 70. There were no significant differences between the other sample plots.

When the differences between the different plots in 1962 have been excluded from the growth figures for 1964, it can be observed that the increment on the fertilized plots was significantly higher than on the control plots. The growth-increasing effect of fertilization becomes evident on KiRF 50 and KiRF 70. The differences between the plots are not significant.

In 1964, the diameter growth on KiRF 50 and KiRF 70

exceeded the control values very significantly in comparison with the year 1963.

754. Birch and spruce at Kivalo

In the Kivalo experiment area, fertilization was also performed in spruce swamp, although the natural site is rather rich in nutrients. The fertilization was considered necessary to improve the mobilization of nutrients which, under normal conditions, is weaker in Kivalo than in Vilppula, due to the colder climate. The diameter growth of birch in 1963 exceeded the growth figures for 1962, both on the fertilized and the unfertilized plots at all ditch depths, except for the 10 cm depth, where growth on the control plots declined from 1962 to 1963. In 1964 the growth further increased on the KiK 50- and KiK 70- plots, but decreased on the KiK 30- and KiK 10- plots (Table 37). In 1963, the development on the KiK 10-plots was significantly poorer than on the other plots, between which no significant difference was noted. In 1963, the gorwth-increasing effect of the fertilization was significant at all ground water depths, except for the KiK 70-plots. The result was obtained by covariance calculation, using the figures for 1962 as basic values. In the fertilized experiment members it was observed (the same held true on the Vilppula pine swamp experiment areas) that KiKF 30 and KiKF 50 were foremost in growth, with KiKF 70 lagging behind KiKF 50. The experiment members KiKF 30, KiKF 50 and KiKF 70, did not differ significantly from each other with respect

to the strength of their radial growth. KiKF 10 grew significantly less than KiKF 50 and KiKF 70, but it did not differ significantly from the experiment member KiKF 30, when the year 1962 was used as basic year in the covariance calculation.

With regard to the growth of spruce, there were no significant differences between KiK 10, KiK 30, KiK 50, and KiK 70 (Table 38). Fertilization increased the growth almost significantly. After fertilization, the development was strongest in the experiment member KiKF 50, in 1963, followed respectively, by KiKF 30, KiKF 70 and KiKF 10. In the unfertilized part of the experiment, KiKU 70 showed the poorest results. The growth-increasing effect of the fertilization on spruce was evident in the 1964 growth of all experiment members, and was, according to covariance calculation with the 1962 figures used as basic values, highly significant. The differences between the sample plots KiK 10, KiK 30, KiK 50, and KiK 70 were not significant, because the distribution was very great. The growth on KiK 10 was clearly smaller than on the other sample plots, followed by KiK 70, KiK 50, and KiK 30, where the growth was the greatest. On KiKF 30 the growth was noticeably greater than on the other fertilized plots.

We may infer from the foregoing that shallower ditches should be used in North Finland than in South Finland.

755. Distance between ditches

Investigations on the water economy of peat soils (cf. Huikari 1959 a and b) have indicated that peat soils are

generally of poor water permeability, and that as a consequence, the ditch depth has no great effect on the mobility of water at the sites. On the other hand, it has been observed that the distance between the ditches has a very strong effect on water mobility.

Figs. 59 and 60 show the results obtained from two strip-width experiment areas in which the hydrology and stand increment of swamps, previously drained for forestry purposes, have been studied. In Fig. 59 it can be seen that in a pine swamp area in Parkano, not far from Vilppula, the growth of pine has been clearly dependent on the distance of the ditches from each other. The growth has increased the narrower the ditch spacing used. Results of investigations in the Mortti experiment area, not far from Kivalo, are presented in Fig. 60. They reveal that the effect of ditch spacing is approximately the same as in Parkano. The narrower the ditch spacing used, the greater the increment becomes. Fertilization has increased the growth in the experimental ditching area at Mortti for all strip widths, but even in the fertilized areas the increment was greatest on the narrowest strips.

For the changing of swamps into productive forest land, this fact is of great importance, as are the results obtained from the hydrological experiment areas. Both of these investigations show how ditching should be carried out, in order to achieve the best possible results at the lowest cost.

8. Summary

This study, begun in 1955, is part of an investigation by the Swamp Forestry Department of the Forest Research Institute of the relative importance of different factors in the growing process in trees. The investigations were made almost exclusively on trees growing in swamps which had been drained for forestry purposes. At first investigation was carried out by measuring site factors of trees and their increments, on various sites. In 1958 we began our investigations of soil temperature, utilizing a technique for the artificial cooling of the soil. From 1961 on, changes in air temperature, soil hydrology, and soil fertility were made, in addition to soil cooling, to clarify the relative importance of different site factors on growth. The realization of this enlarged investigational program was made possible by a grant from the United States government, E8-FS-36/FG-Fi-116. The results presented in this report are chiefly from the investigations carried out in 1961-64.

General weather conditions in Finland are excellent for investigations of this kind. It was possible to utilize the winter and soil freezing in the artificial cooling of the site. The relatively chilly spring provided an excellent contrast to regulated greenhouse conditions. As the project was carried out on swampy sites, ditching made it possible to create large permanent differences in the hydrology of the site. In sites naturally poor in nutrients, fertilization was used.

The investigation was carried out in Finland, at Vilppula,

in the southern part of the coniferous forest region, which has a snow and soil frost climate, and at Kivalo, in the northern part of the same region. The annual mean temperature is 3-4° C at Vilppula and 0-1° C at Kivalo.

For the purposes of the investigation, growth factor conditions were changed, at special experiment areas set up in 1960-61. In some of the ditches surrounding the sample plots, the water table was kept at the level of the ground surface, while at others it was located at a depth of 10, 30, 50, and 70 cm from the ground surface; some of the sample plots were fertilized and others were artificially cooled. In addition, the air temperature around some sample trees was increased by means of plastic greenhouses. The results which were obtained from the investigation were analysed with the aid od statistical methods.

In respect to the correlation between the initial moment of height growth and the air temperature, we observed that the increment begins at about the same time both in the greenhouses and in the trees outside, and that the period of strongest height growth took place about one month earlier in the greenhouses than outside, both at Vilppula and Kivalo. The duration of the height growth could be observed to be rather closely correlated to the total number of temperature-hours over 5° C. As regards the total height increment, no great changes were observed as a consequence of the increase in air temperature at the Vilppula experiment area. But at the Kivalo area we noticed that the increase in the air temperature had caused a slight increase in the height growth. The increase in the air temperature achieved in the plastic greenhouses did not change the initial moment of the diameter growth

either in Vilppula or in Kivalo. With respect to the air temperature it could be observed that the variation in the minimum temperature had the most direct correlation to variations in the circumference of pine, spruce, and birch. The correlation to the variation in the mean temperature was generally positive, too, but it was significant only in fertilized trees. Variations in the circumference were related to the fluctuations in maximum, minimum, and mean temperatures in both the cooled and the uncooled strawcovered sample plots in the same way as to the control trees. The diameter growth started and ended at the same time in the greenhouses and outside, indicating that the artificial increase in the air temperature did not have any influence on the duration of diameter growth. In the plastic greenhouses at Vilppula, the diameter growth in pine was noticeably poorer than in the control pines. Likewise in the conditions prevailing at Kivalo, the diameter growth was smaller in the greenhouses than outside.

The flowering of pine was observed to be closely related tp the development of air temperature. In pine the temperature sum values for the period between the initial moment of height growth and the beginning of flowering are very close to each other every year. Flowering of the pines began at the same time in the normal, cooled, and fertilized sample plots. In the fertilized sample plots, flowering and pollination was much stronger than on the control plots and there the flowering also lasted longer. The initial moment of flowering did not seem to be dependent on soil temperature.

The precipitation could not be observed to have as dominating an effect on height growth as does air temperature. The

initial moment of height growth does not seem to be dependent on the ground water level, except for trees growing on sample plots where the ground water reaches the ground surface. In such cases the height growth began later. Throughout the growth process, rains improved the increment. As regards the initial moment of the diameter growth, no differences were noticed in sample plots with different water economies.

Between the amount of precipitation and the length of time during which height increment takes place no correlation was noted. In the 10 cm ditch depth experiment member, height growth ended significantly earlier than in the 50 and 70 cm experiment members. The pines growing on fertilized experiment members reacted to precipitation more strongly than the trees growing on unfertilized experiment members. The variations in the circumference of fertilized trees were less dependent on the relative air moisture than those of the unfertilized trees.

The reaction of the trees on the sample plots with a 70 cm ditch depth to the changes in air moisture conditions did not exceed that of the trees on the sample plots with a 10 cm ditch depth. The variation of the circumference in trees on the cooled and uncooled sample plots corresponded to the variations in precipitation and relative air moisture just as did normal trees. The reactions of spruce to the changes in moisture conditions seemed to be about the same as pine. The birch, however, reacted noticeably less strongly. The ecological arrangements on the site did not influence the time when diameter growth takes place. Dry periods effect the diameter increment significantly by diminishing the diameter growth. In pine a reduction in the circumference may even take place.

The healthy trees in the fertilized areas do not suffer from the dry periods as much as the trees in unfertilized areas. The increase in the moisture content of the topmost soil layers, brought about by the straw covering, plus the fact that the surface layers remain moist later in the summer, increased the diameter increment and prolonged the period of strong growth in both the Vilppula and Kivalo investigation areas. Even in the sample plots with a 10 cm ditch depth, the effects of the dry periods are noticeable, in spite of fertilization and covering.

A greater ditch depth induces a greater height growth. In the investigation area at Vilppula, on a substratum of Sphagnum-peat, the greatest diameter increment in pine was achieved with the water at a depth of 50 cm in ditches 15 metres apart. In spruce and birch the diameter growth was of almost the same size in the sample plots with 30, 50, and 70 cm ditch depth, under conditions prevailing in a spruce swamp at Vilppula. Under conditions prevailing in a pine swamp at the Kivalo experiment area, the growth of pine was highest when the ditch depth was 50 or 70 cm. On the unfertilized experiment members, the highest growth was obtained at a 50 cm ditch depth.

The initial moment of the height and diameter growth in spruce, pine, and birch could not be observed to have a direct relation to the soil temperature. Neither have the differences in soil temperature affected the length of time during which height and diameter growth take place. We could achieve no significant changes in the height growth of pine at Vilppula in 1962 and 1963 by reducing the soil temperature. In general, however, we observed that the height increment

was less on plots with a reduced soil temperature than on the control plots. At Kivalo no regular effect on the height increment could be observed after the cooling of the site in 1962 and 1963. In 1964, however, the cooling having been made more effective by the covering, the height growth at Kivalo was very significantly reduced compared to the plot which had been covered but not cooled. In Vilppula, too, this effect was almost significant.

At the Vilppula experiment area, the diameter growth in pine was smaller in the cooled sample plots than in the control plots, in spite of the plot with 70 cm ditch depth.

By means of the more effective cooling achieved through the use of a straw and sphagnum-peat cover, a very significant increase in diameter growth was achieved, in comparison with the uncovered control sample plots in the pine swamp area at Vilppula. In the experiment areas in pine and spruce swamps at Kivalo, the diameter growth of pine, spruce, and birch was greater on the cooled and covered areas than on the covered areas, and diameter growth was greater on both the areas than on the uncovered and uncooled control plots. The growth-increasing effect of the covering is already noticeable in the year in which the covering took place, while, again, the effect of fertilization really becomes evident only during the following year.

The studies which are briefly presented in the appendices 1, 2, and 3 and which concern the vertical distribution of the root systems of pine and of microbiological decomposition activity, and the ground vegetation and homogeneity of the experiment areas, were also carried out in the experiment areas at Vilppula and Kivalo.

9. Literature

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10. Figures (1 - 60)

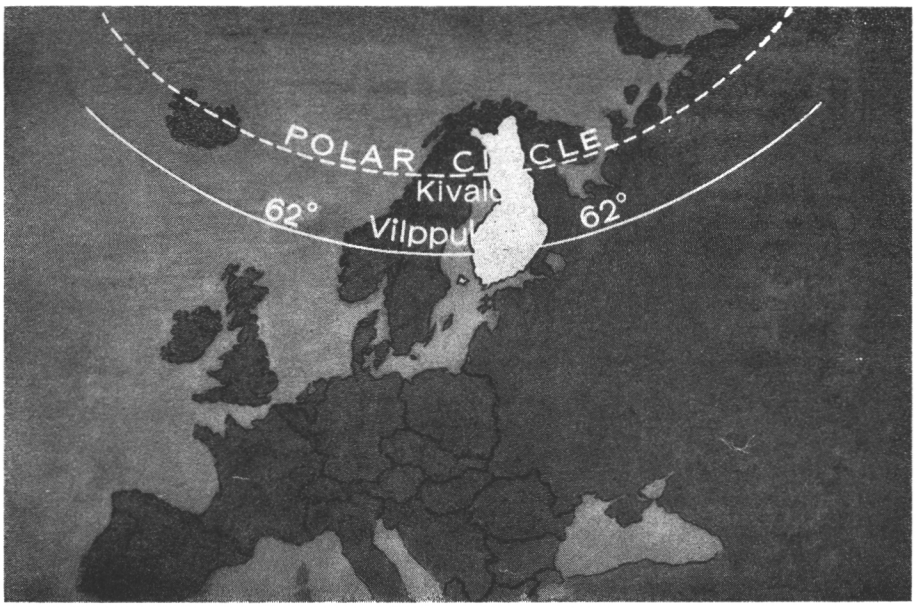

Figure 1.

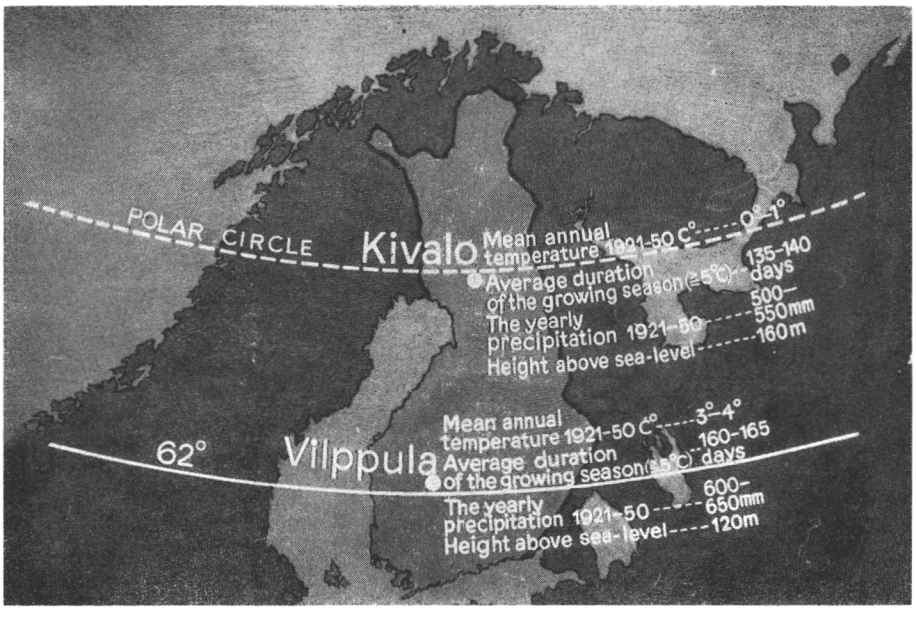

Figure 2.

Figures 1 and 2. Location of experiment areas

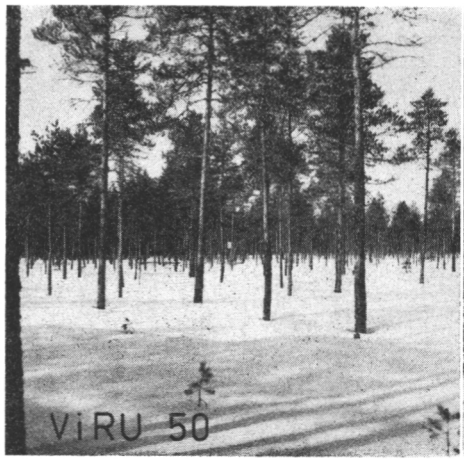

Figure 3.



Figure 4.

Figures 3. and 4. Stands on pine swamp areas in Vilppula



Figure 5.



Figure 6.

Figures 5. and 6. Stands on spruce and birch swamp areas in Vilppula



Figure 7.



Figure 8.

Figures 7. and 8. Stand on pine swamp areas in Kivalo



Figure 9.



Figure 10.

Figures 9. and 10. Stands on spruce and birch swamp areas in Kivalo



Figure 11.

Plastic house constructed for purposes of air temperature regulation

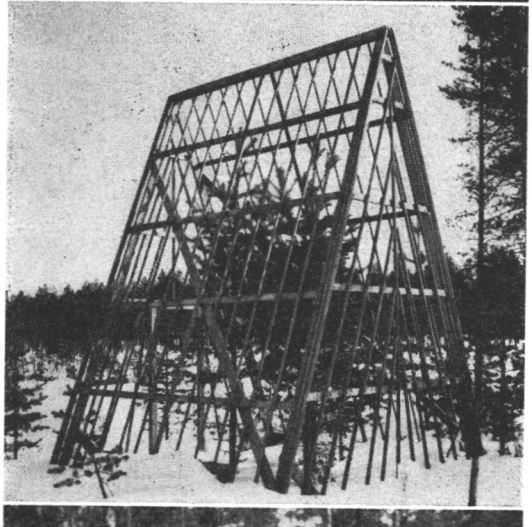

Figure 12.

Same in winter, plastic removed



Figure 22.

The water level regulated by means of dams



Figure 13.

To increase the freezing of the soil, snow is shovelled away from the areas to be cooled.



Figure 14.

Shortly before the snow begins to melt, it is shovelled back on the cooled area and covered with straw.

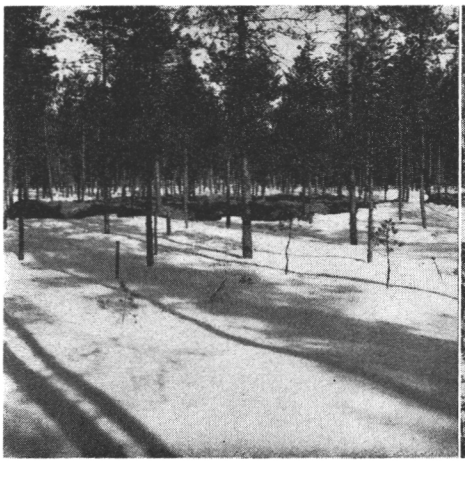

Figure 15.

Finished straw-covered and cooled sample plot.



Figure 16.

After the snow has already melted in the surrounding area there is still a thick snow layer under the straw cover.

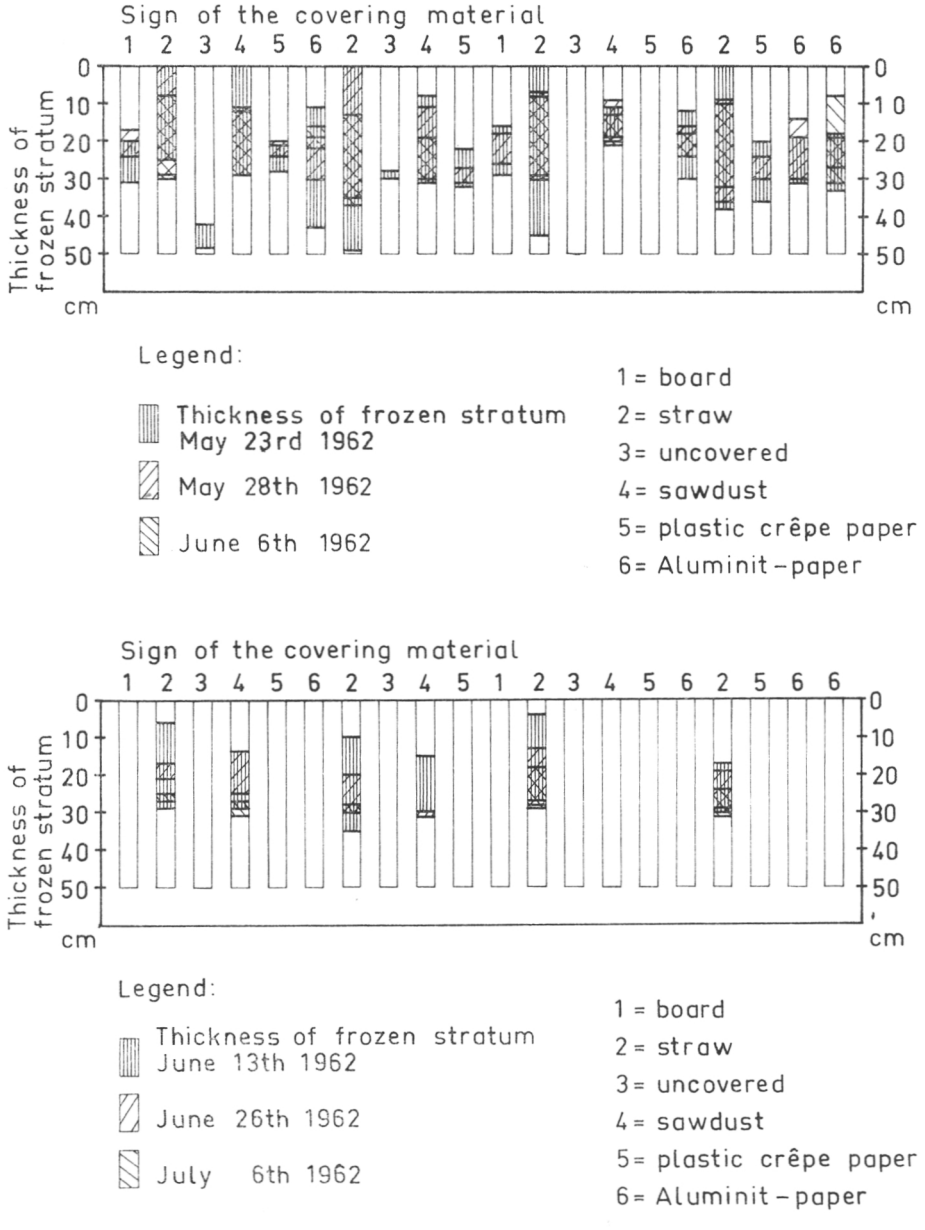

Figure 17. Occurrence of soil frost in sample plots covered with different materials, May 23rd, 28th, June 6th, 13th, and July 6th, 1962

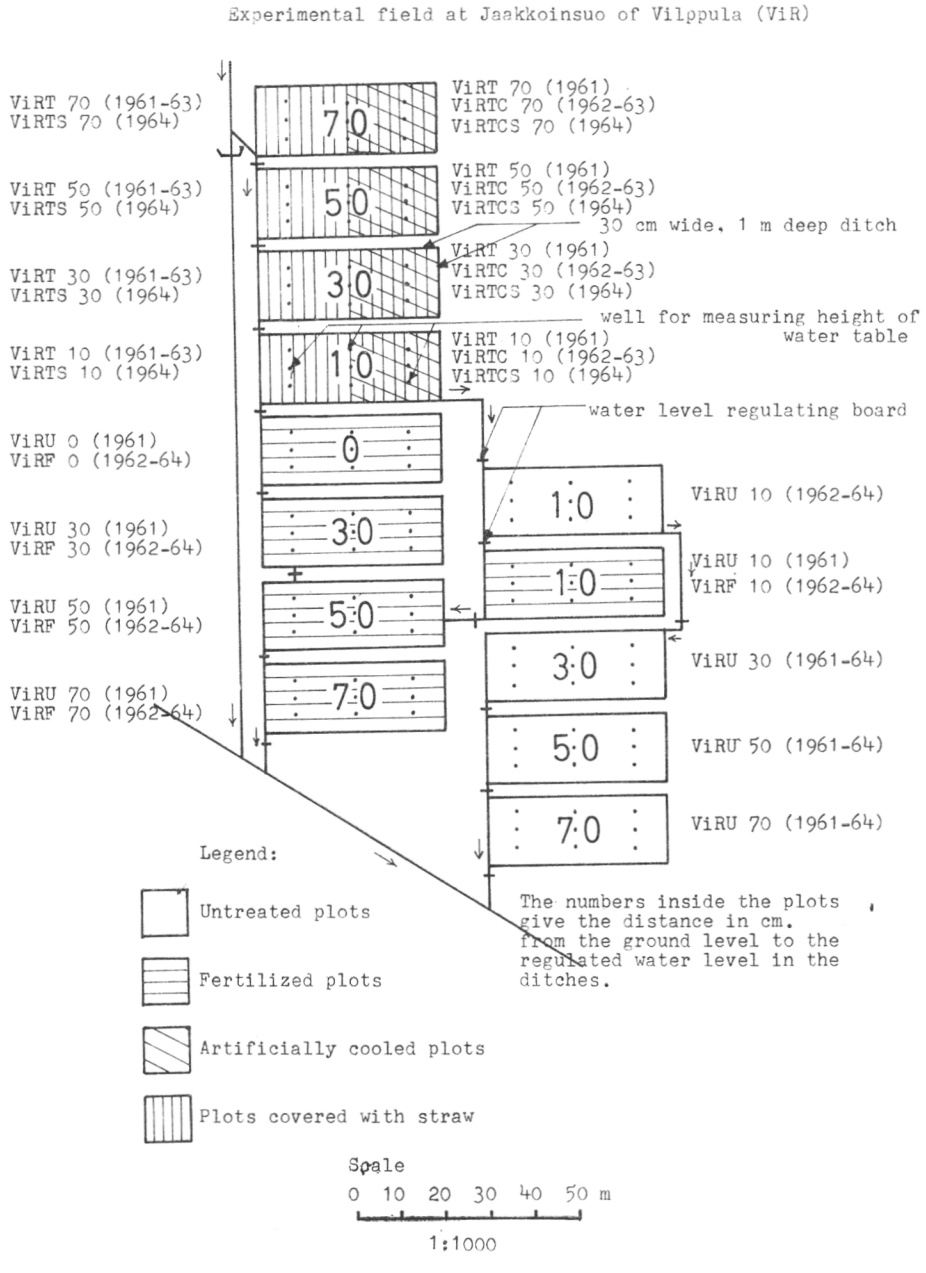

Figure 18. Experiment area at Jaakkoinsuo, Vilppula (ViR)

Experimental field at Jaakkoinsuo of Vilppula (ViK)

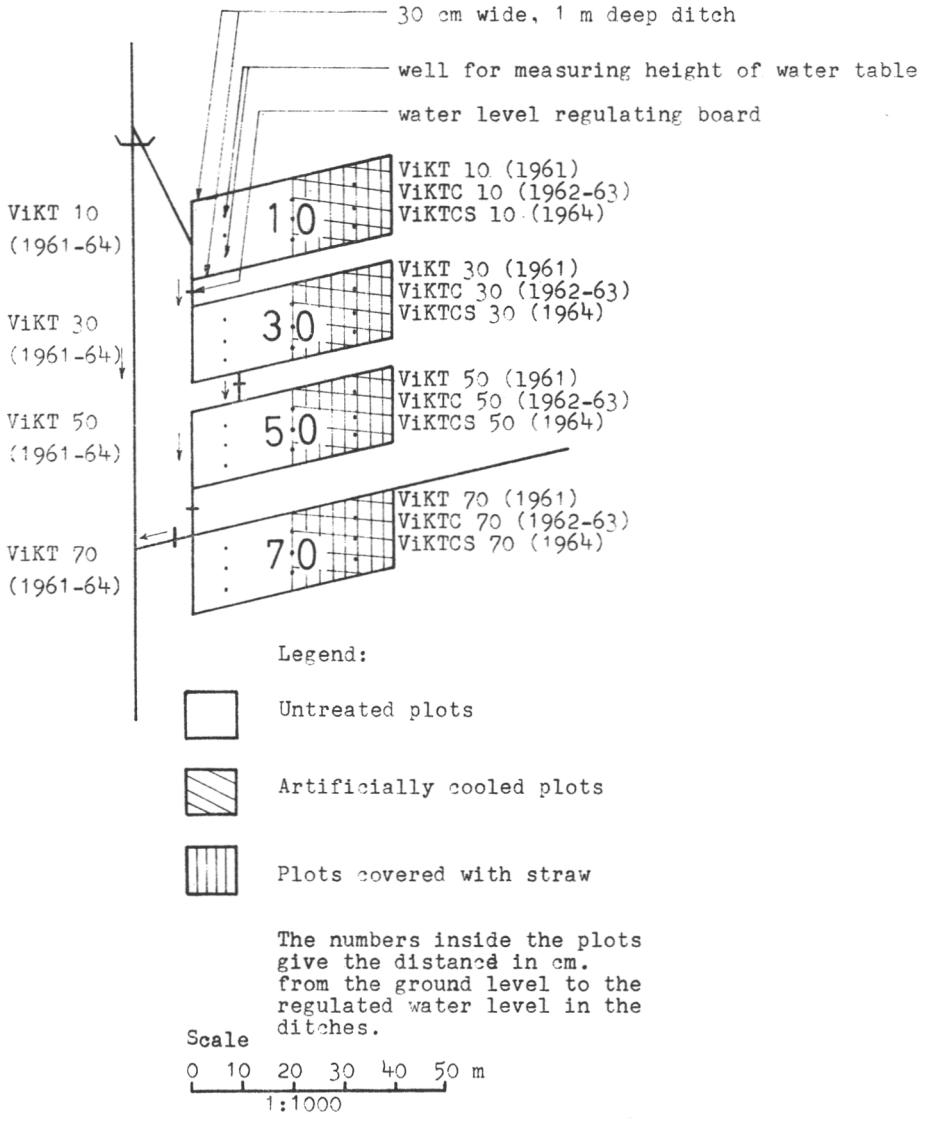

Figure 19. Experiment area at Jaakkoinsuo, Vilppula

(ViK)

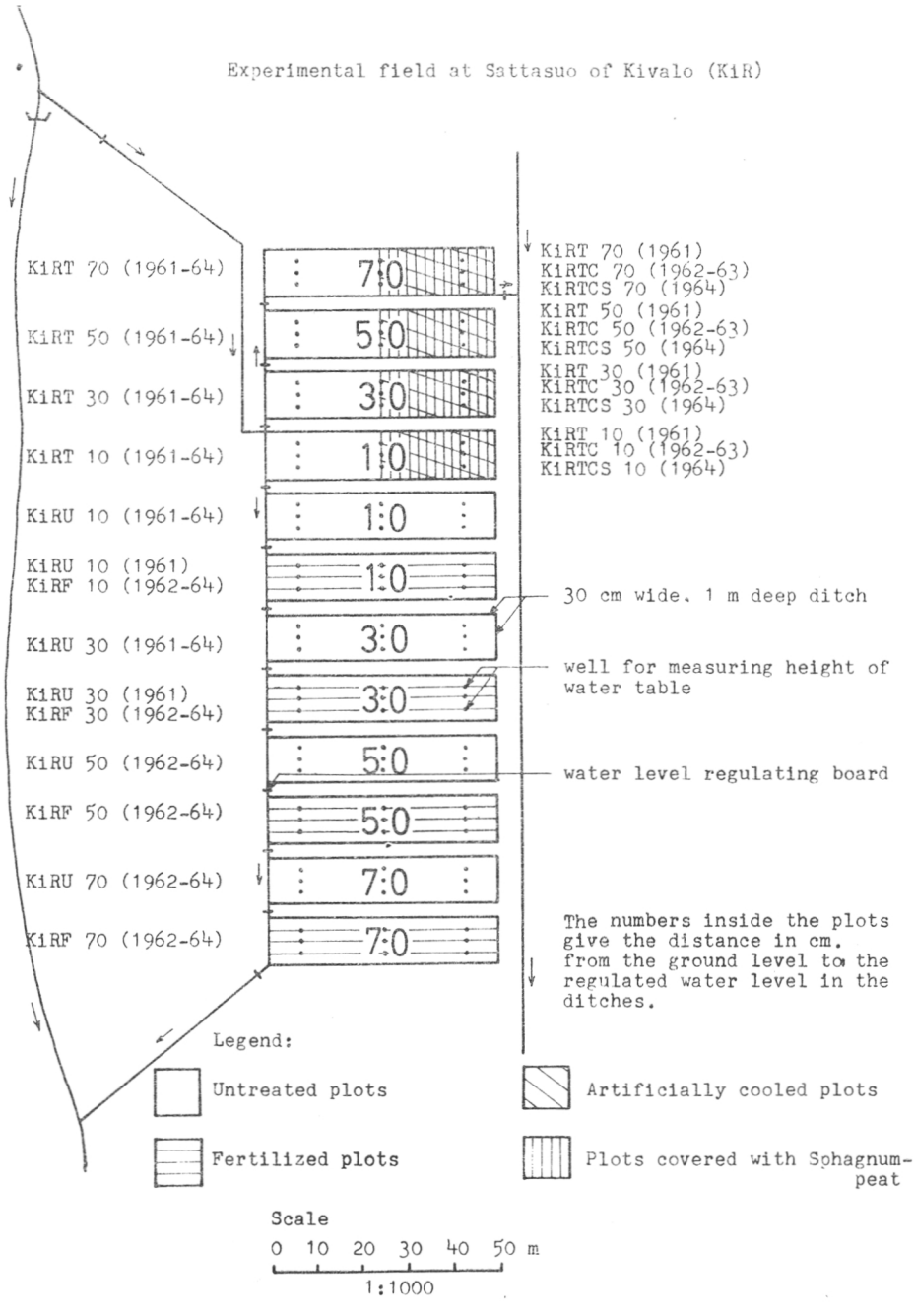

Figure 20. Experiment area at Sattasuo, Kivalo (KiR)

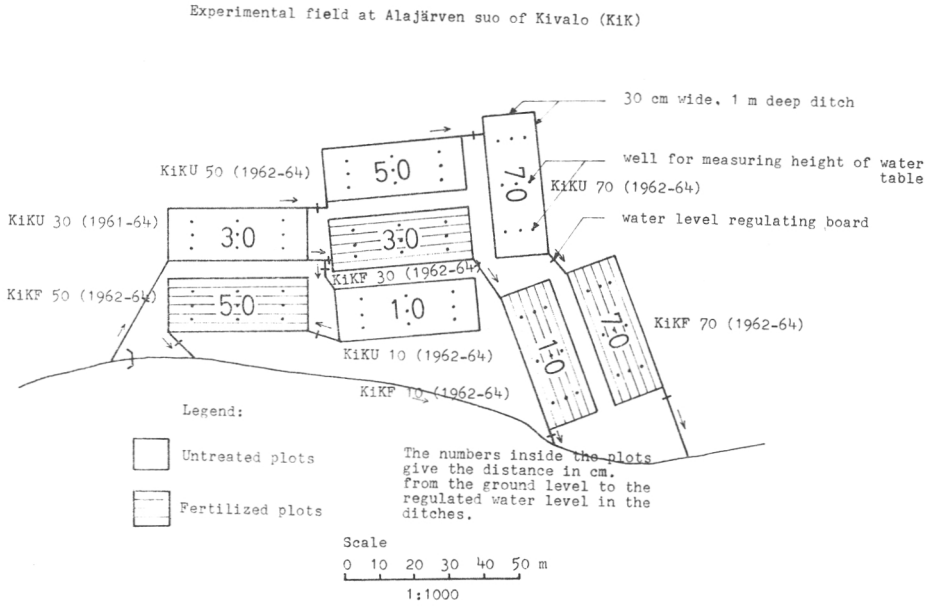

Figure 21. Experiment area at Alajärven suo, Kivalo

(KiK)

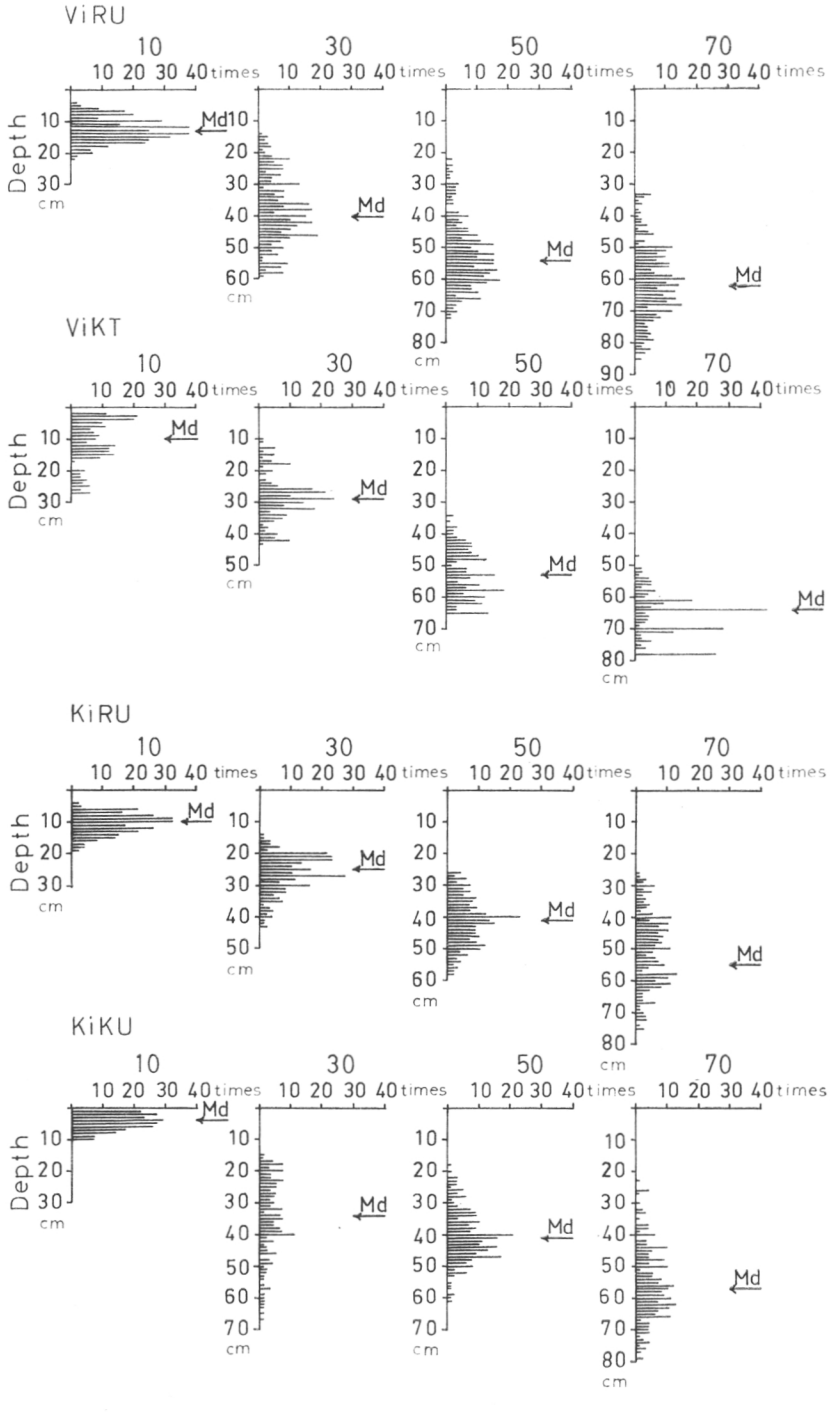

Figure 23. Figures revealing how many times the ground water has been observed at different depths during the observation period in 1964 Md = median



Figure 24.

Max.-min. thermometer for measuring air temperature.

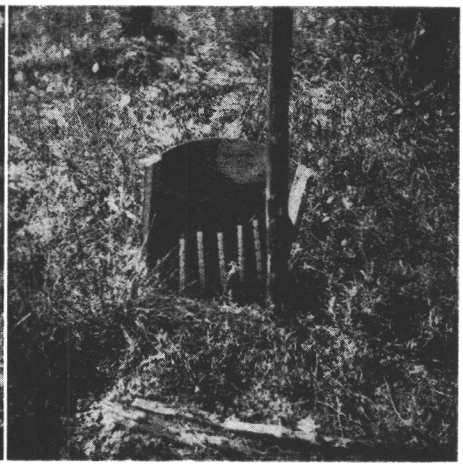

Figure 25.

Ground thermometers with radiation shield.



Figure 26.

Precipitation meter. Area 100 sq.cm.

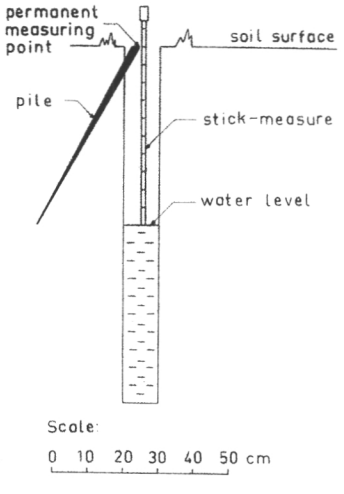

Figure 27.

Well for measuring the height of ground water table.



Figure 28.



Figure 29.

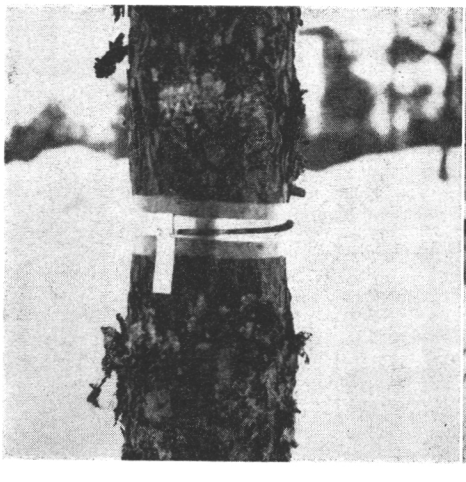

Figure 30.

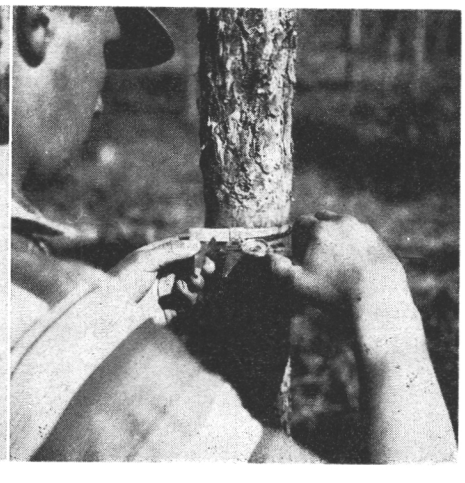

Figure 31.

Taking of measurements.

Figures 28 - 30. Installation of circumference bands.

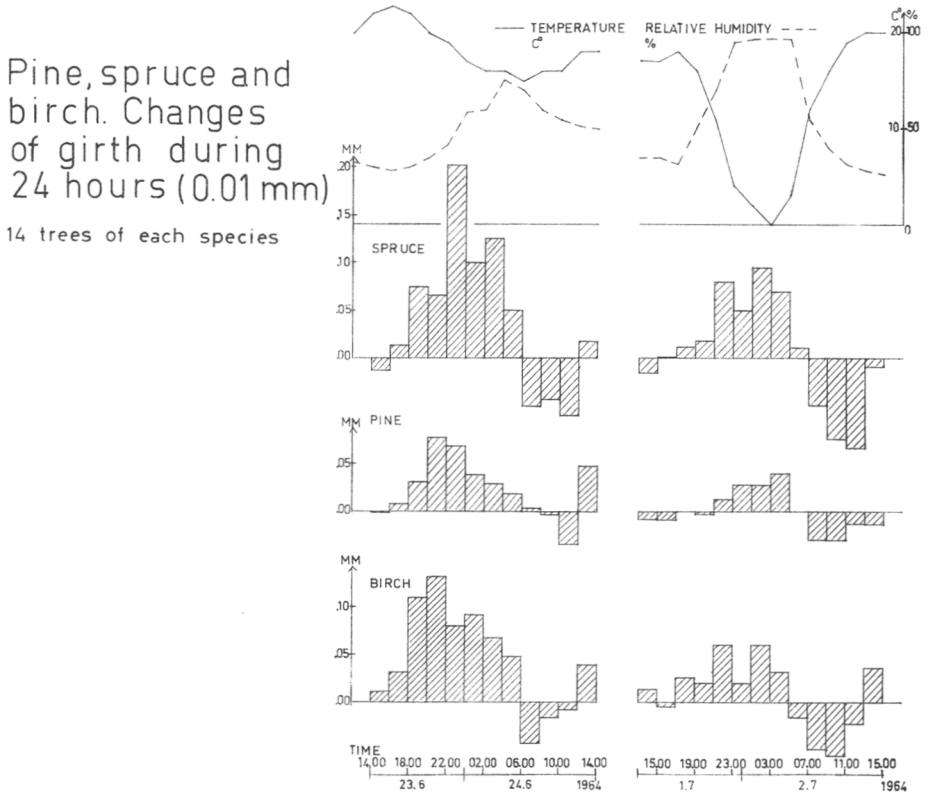

Figure 32. Diurnal changes in the circumference of stems at breast height. Pine, spruce, and birch.

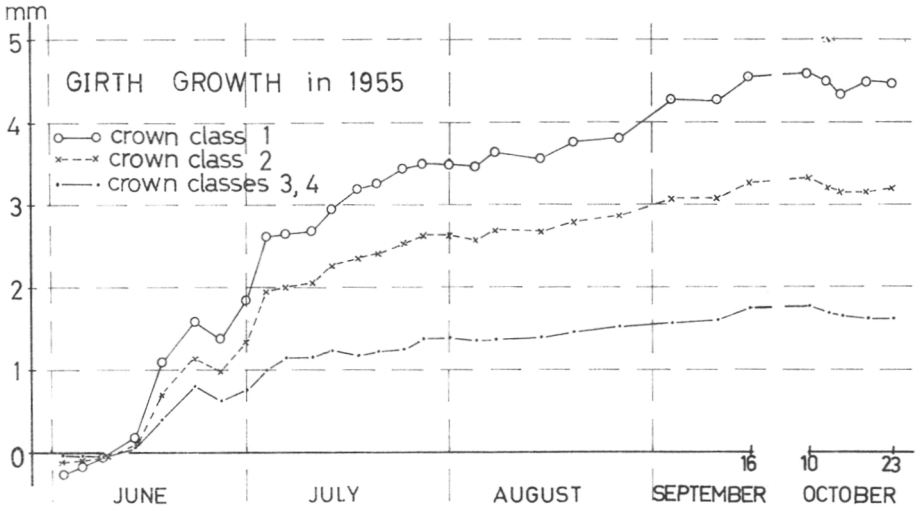

Figure 33. Mean series of ring band measurements of different crown classes

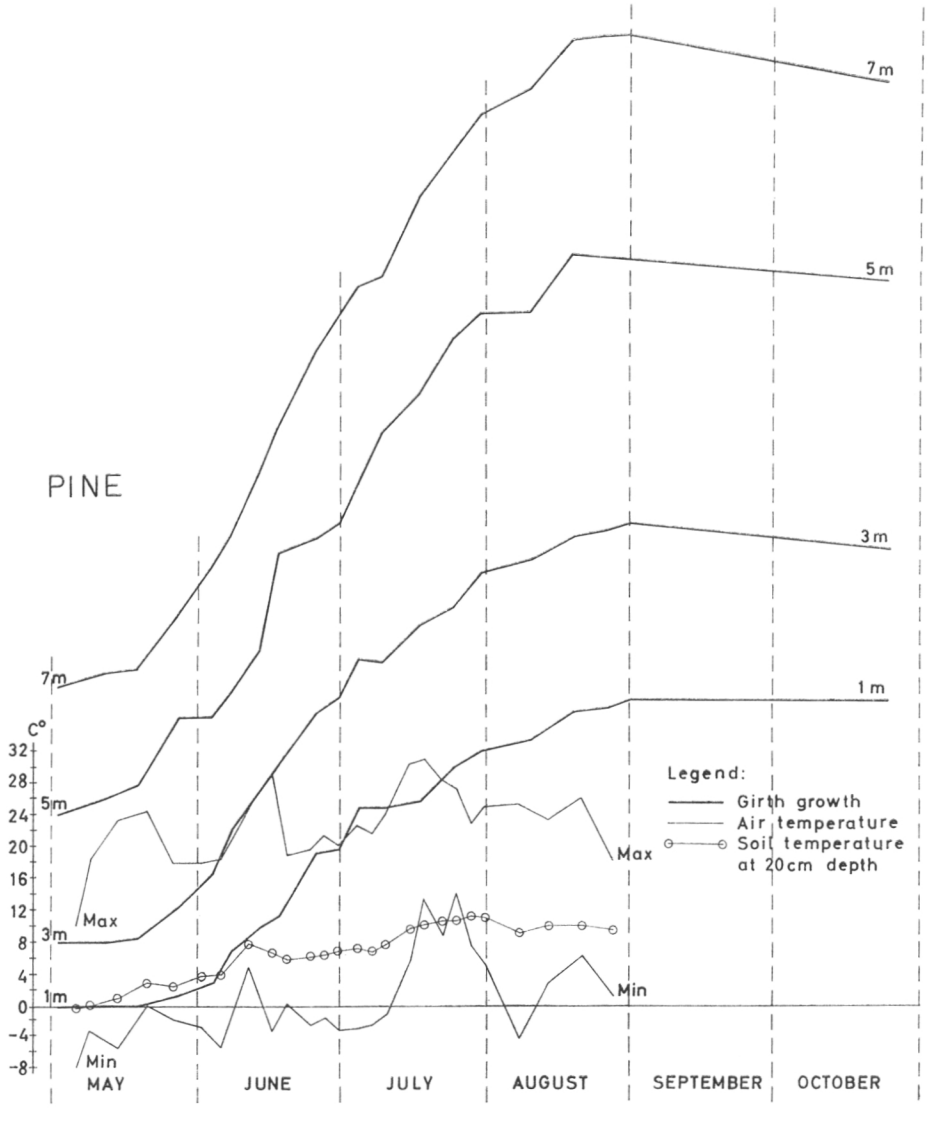

Figure 34. Circumference (girth) growth at different altitudes of pine stems

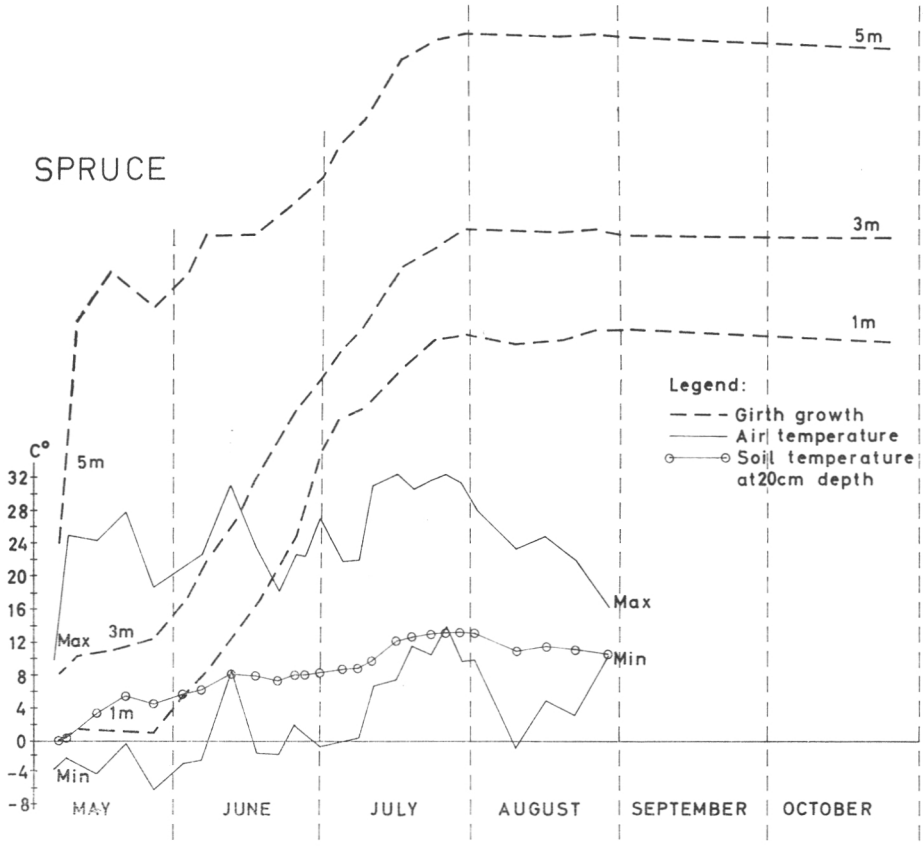

Figure 35. Circumference (girth) growth at different altitudes of spruce stems

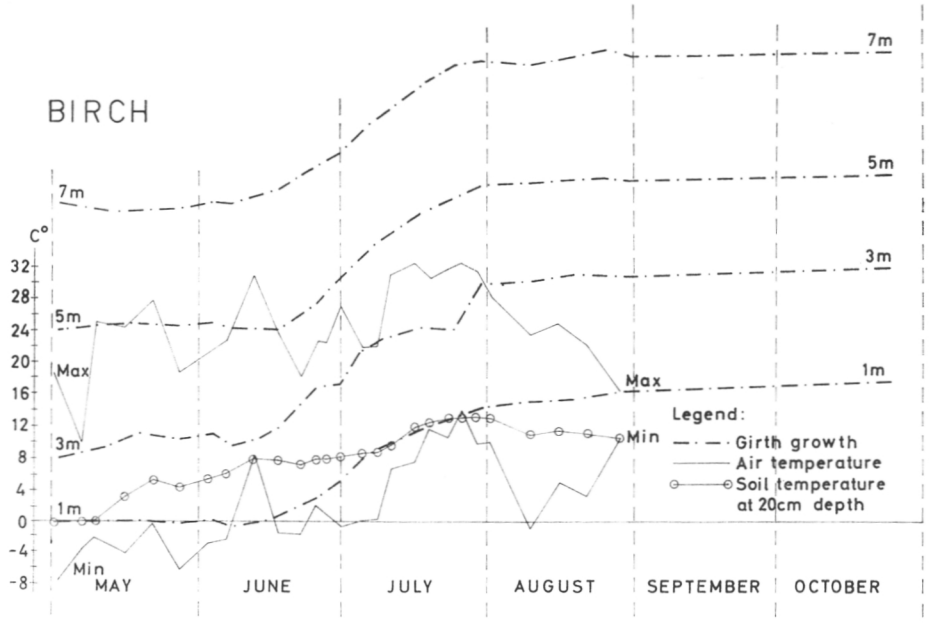

Figure 36. Circumference (girth) growth at different altitudes of birch stems

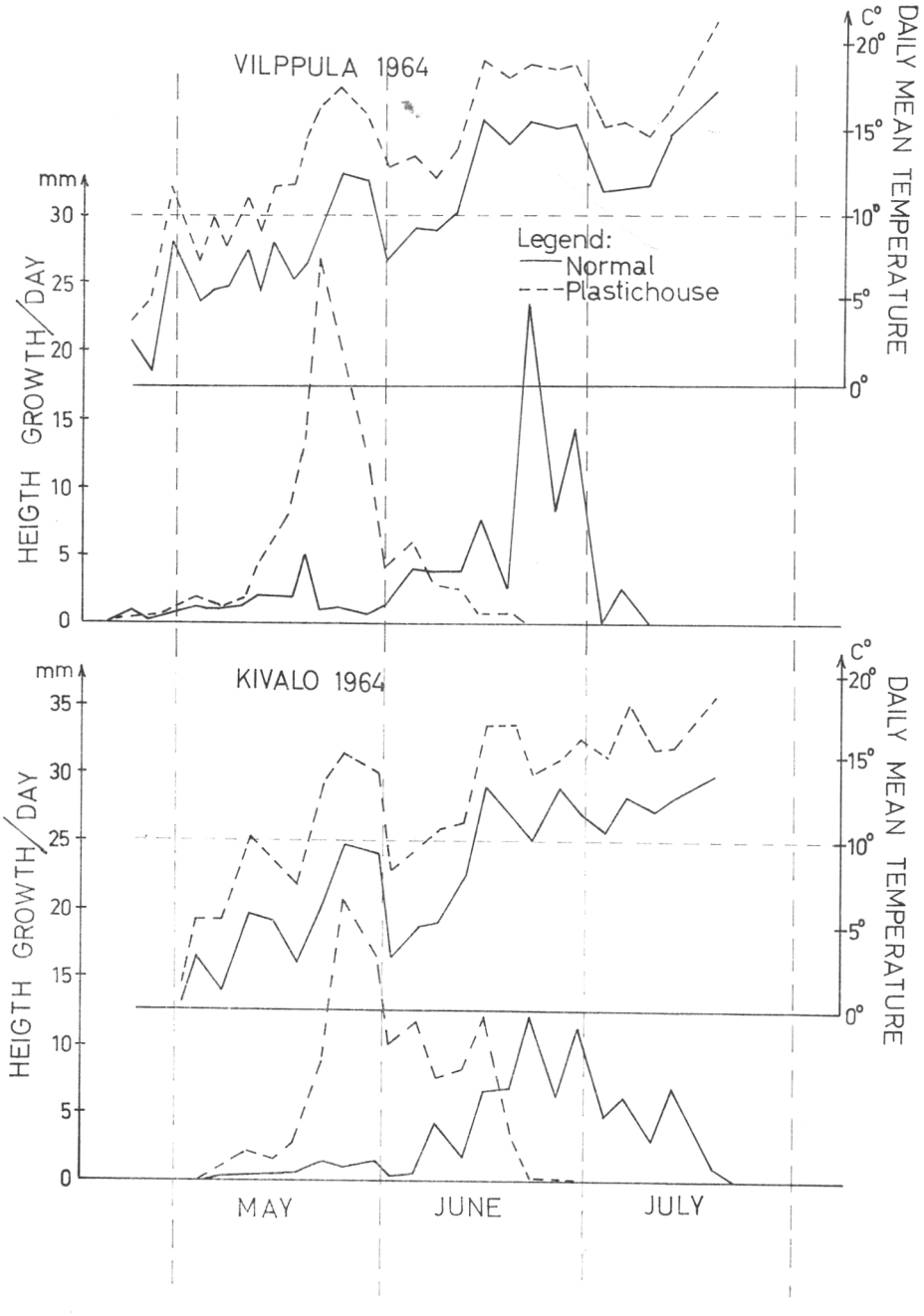

Figure 37. Height growth of pine in the plastic house and on the normal plot in 1964 at Vilppula and Kivalo

ViR. Height growth, precipitation and average and minimum temperatures

a. In 1961

b. In 1962

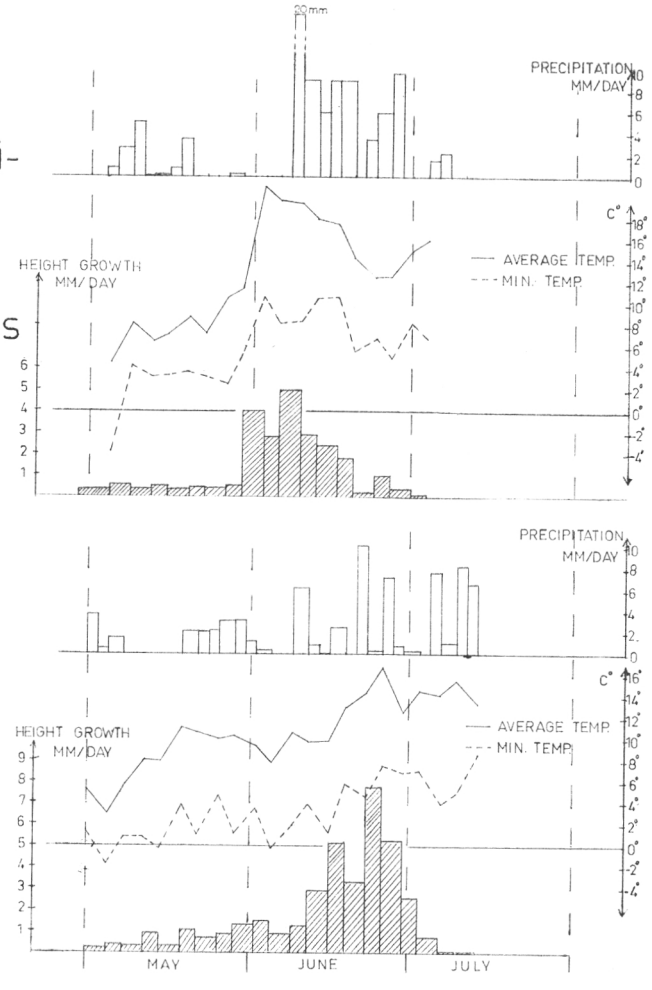

Figure 38. Relation of the height growth in pine to precipitation, mean temperature, and minimum temperature in 1961-1962. ViR.

ViR. Height growth, precipitation and average and minimum temperatures

a. In 1963

b. In 1964

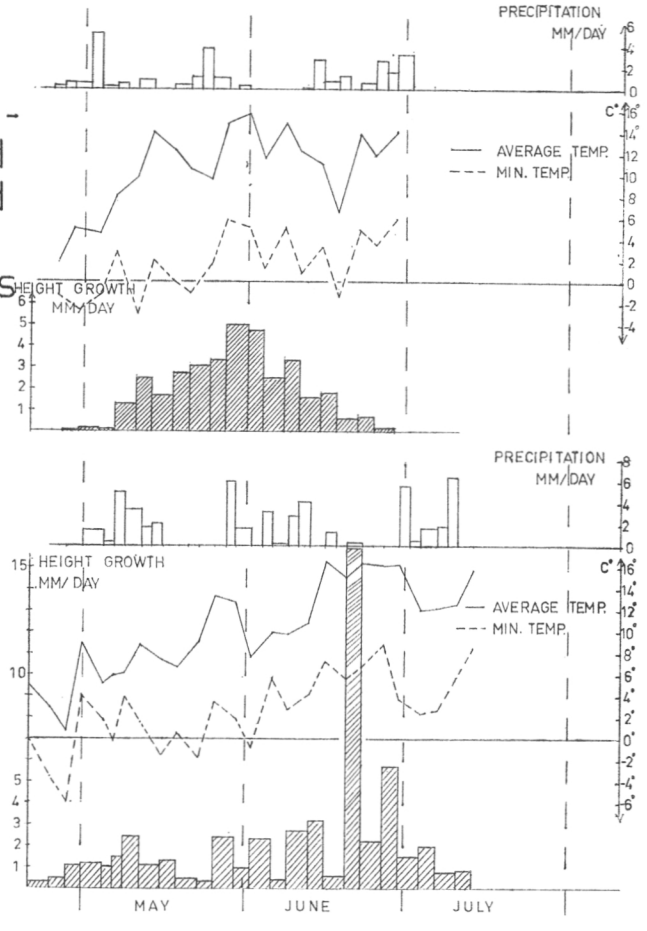

Figure 39. Relation of the height growth in pine to precipitation, mean temperature, and minimum temperature in 1963-1964. ViR.

KiR. Height growth, precipitation and average and minimum temperatures

a. In 1962

b. In 1963

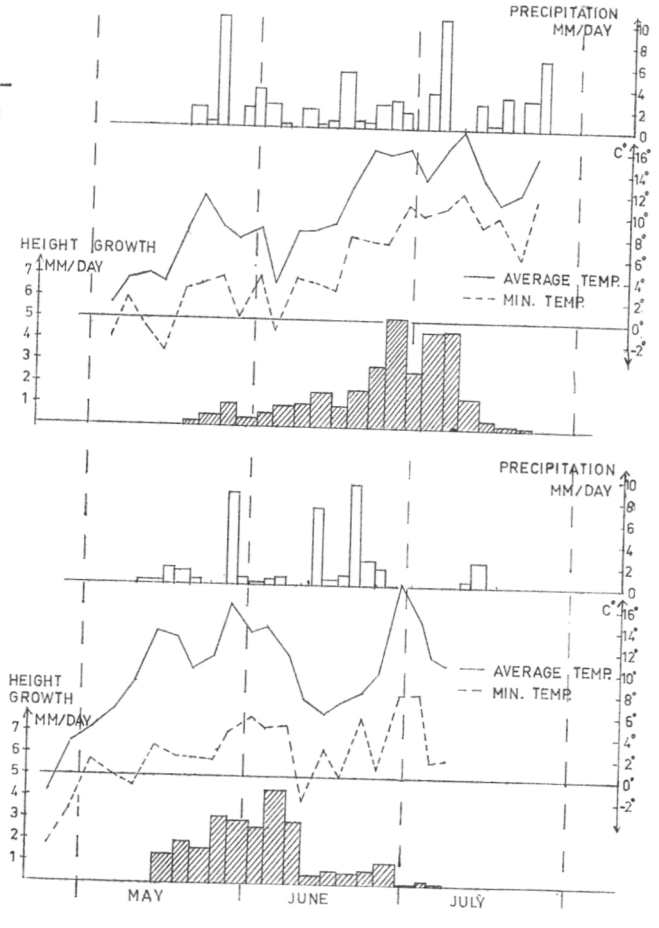

Figure 40. Relation of the height growth in pine to precipitation, mean temperature, and minimum temperature in 1962-1963. KiR.

KiR. Height growth, precipitation and average and minimum temperatures

In 1964

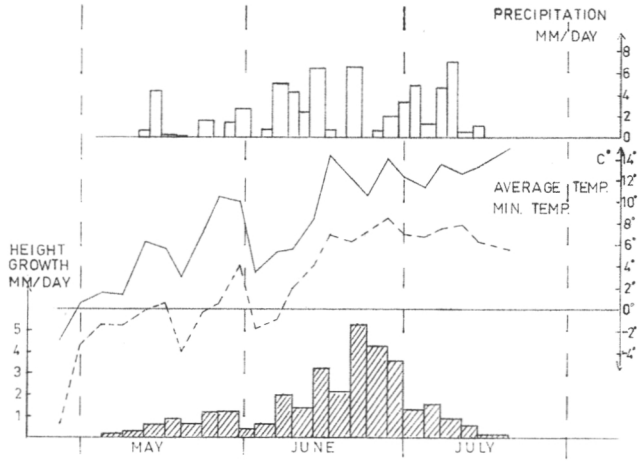

Figure 41. Relation of the height growth in pine to precipitation, mean temperature, and minimum temperature in 1964. KiR.

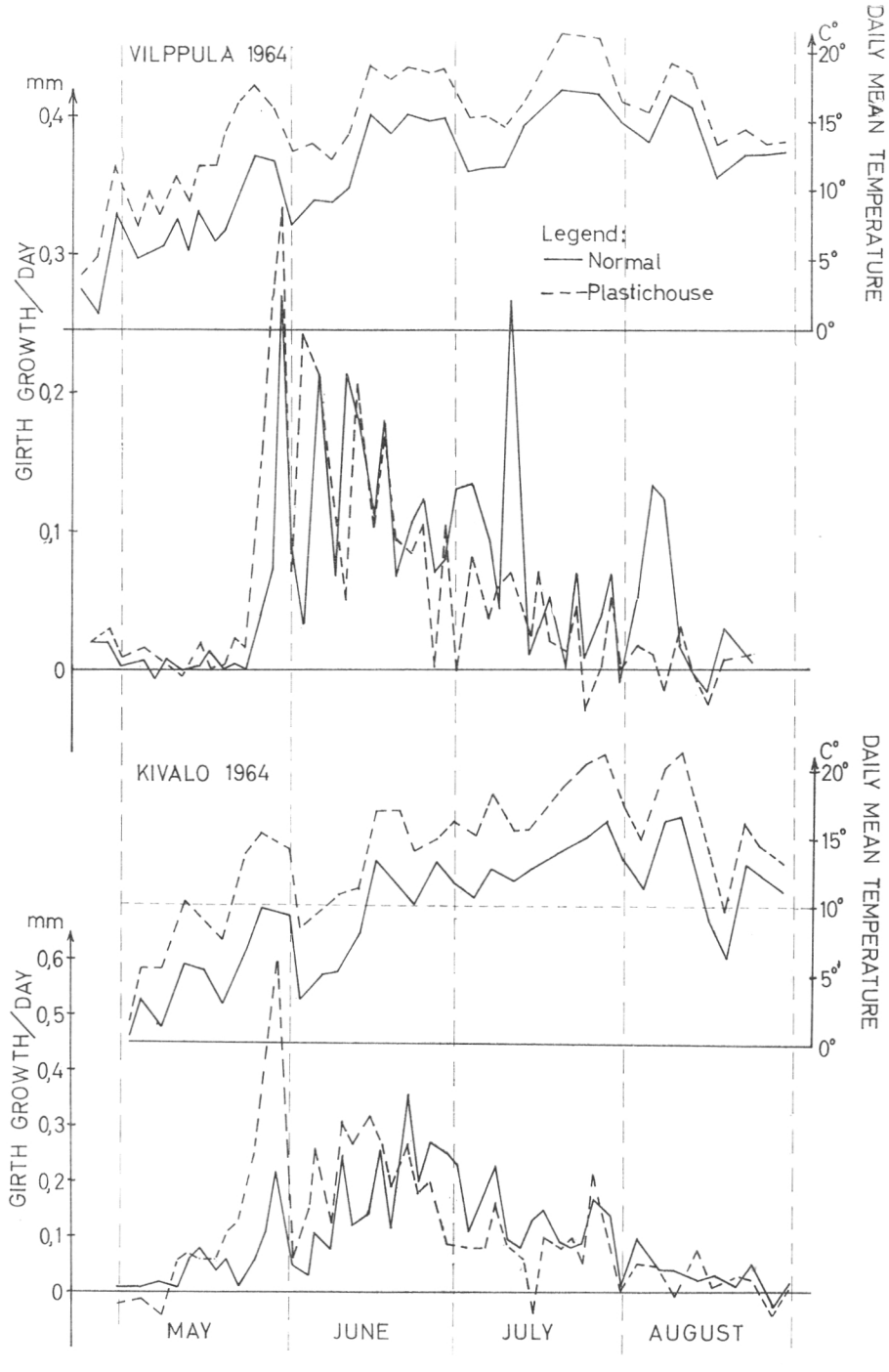

Figure 42. Circumference (girth) growth of pine in the plastic house and on the normal plot in 1964 at Vilppula and Kivalo

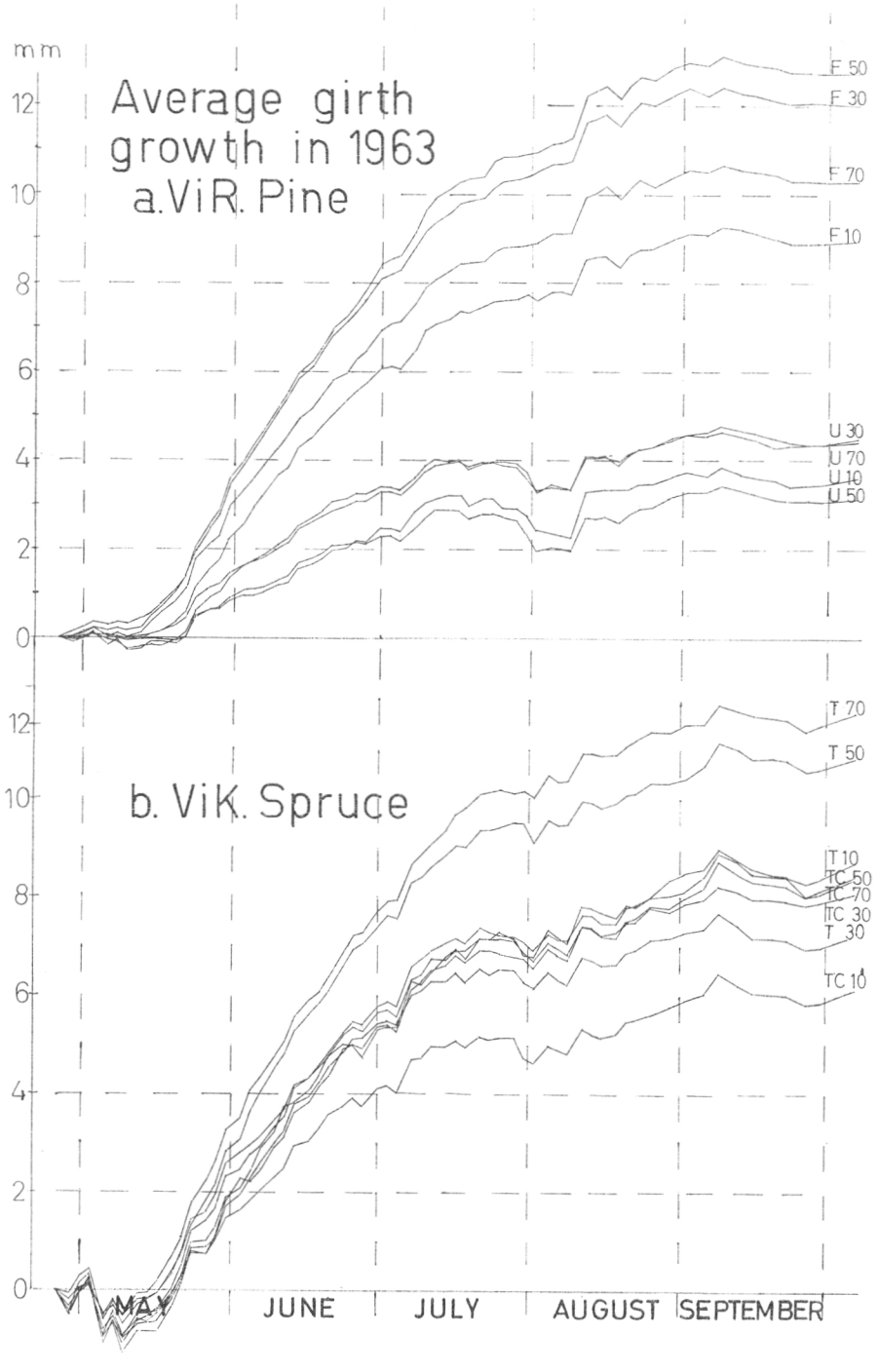

Figure 43. a) Average circumference growth of pine in fertilized and normal sample plots (1963). ViR.

b) Average circumference growth of spruce in cooled and normal sample plots (1963). ViK.

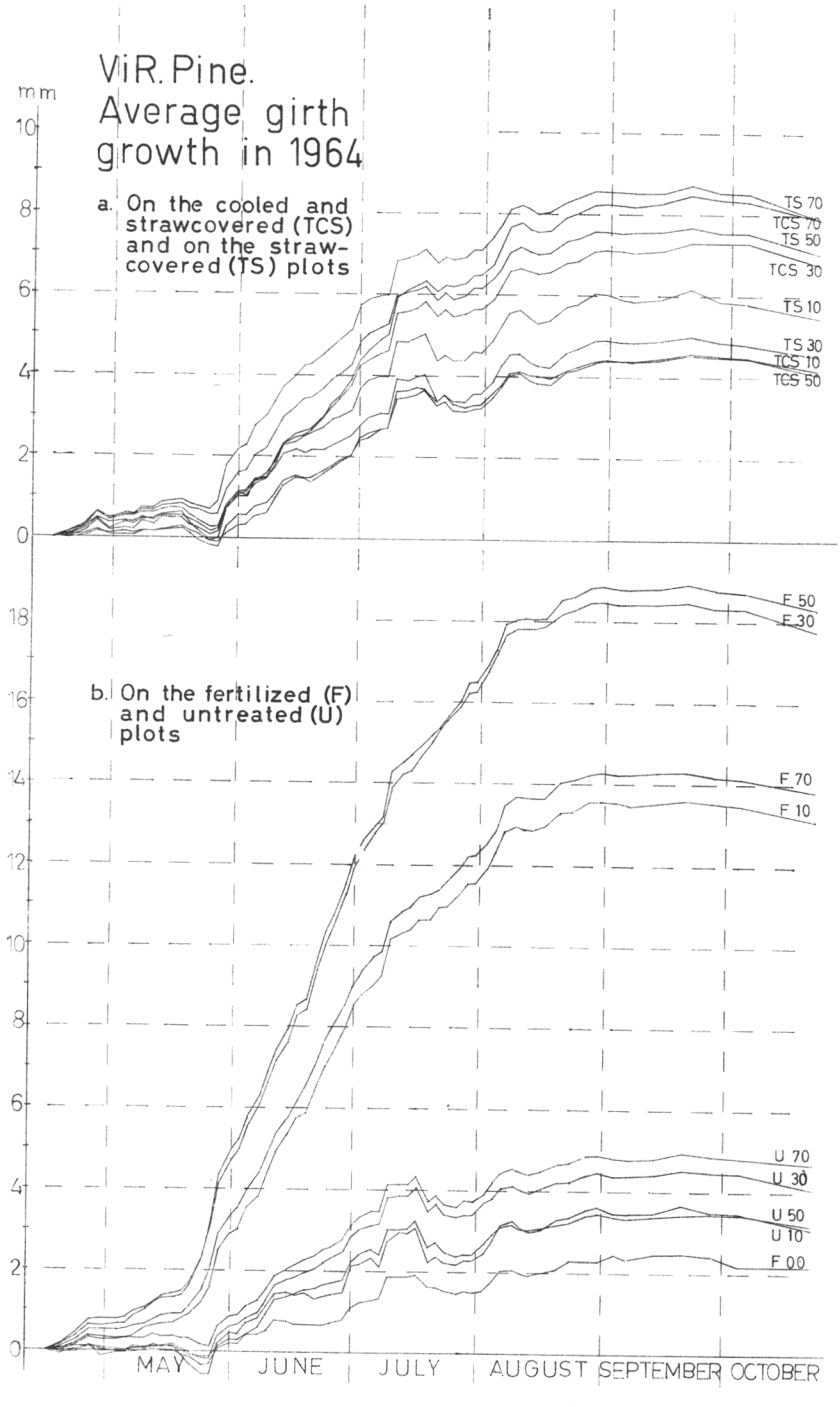

Figure 44. Average circumference growth of pine (1964). ViR.

a) in the cooled and covered and the covered sample plots

b) in the fertilized and the normal sample plots

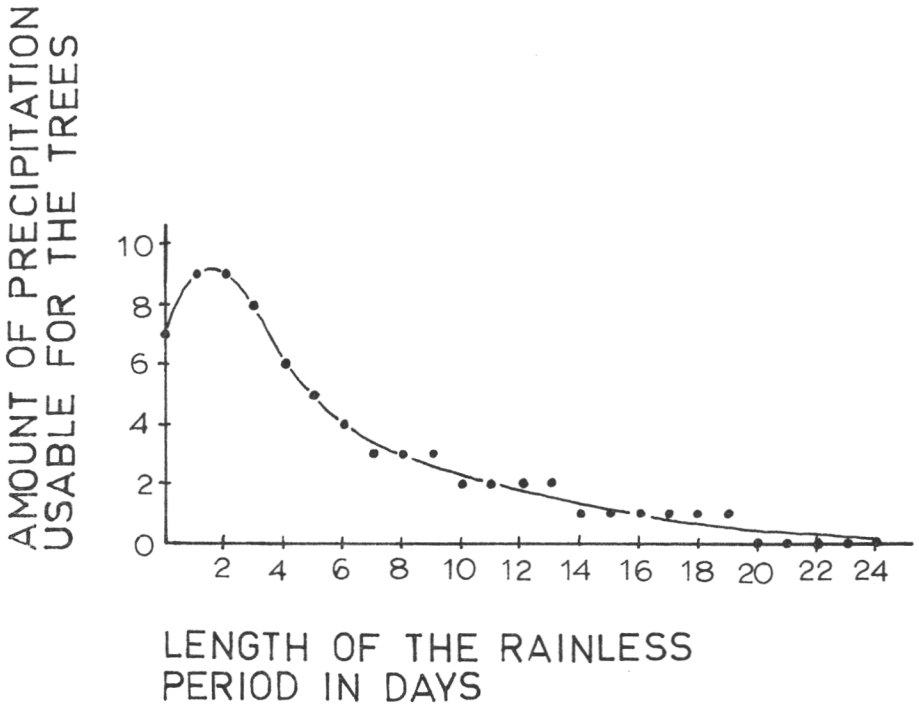

Figure 45. Transforming curve for the length of the rainless period. The points indicate values used in the calculation.

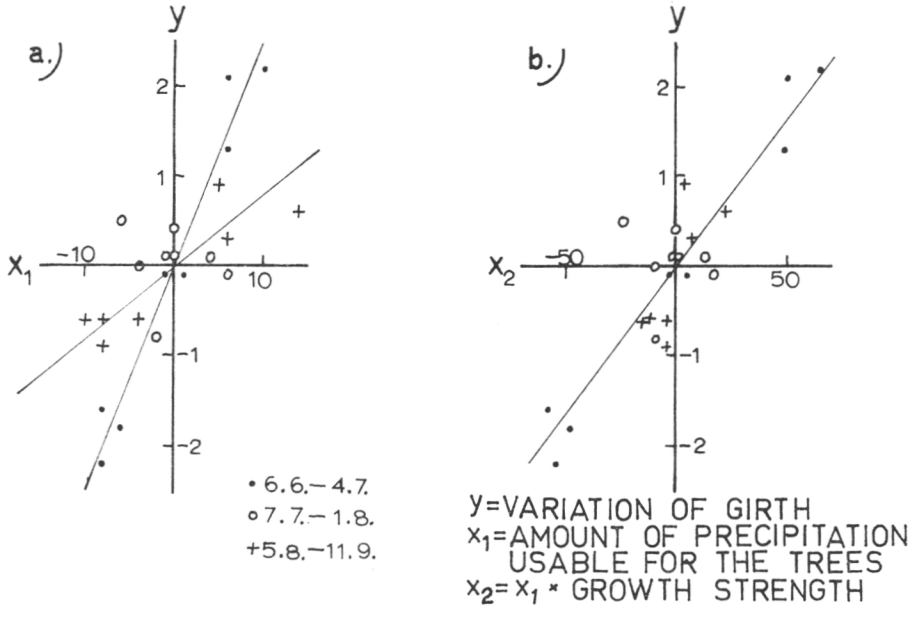

Figure 46. Effect of the amount of precipitation usable by the trees on the variation of the circumference in pine.
Sample plots 1-16.

a) The same weight used at different times during the growing season.

b) The growth strength used as weight.

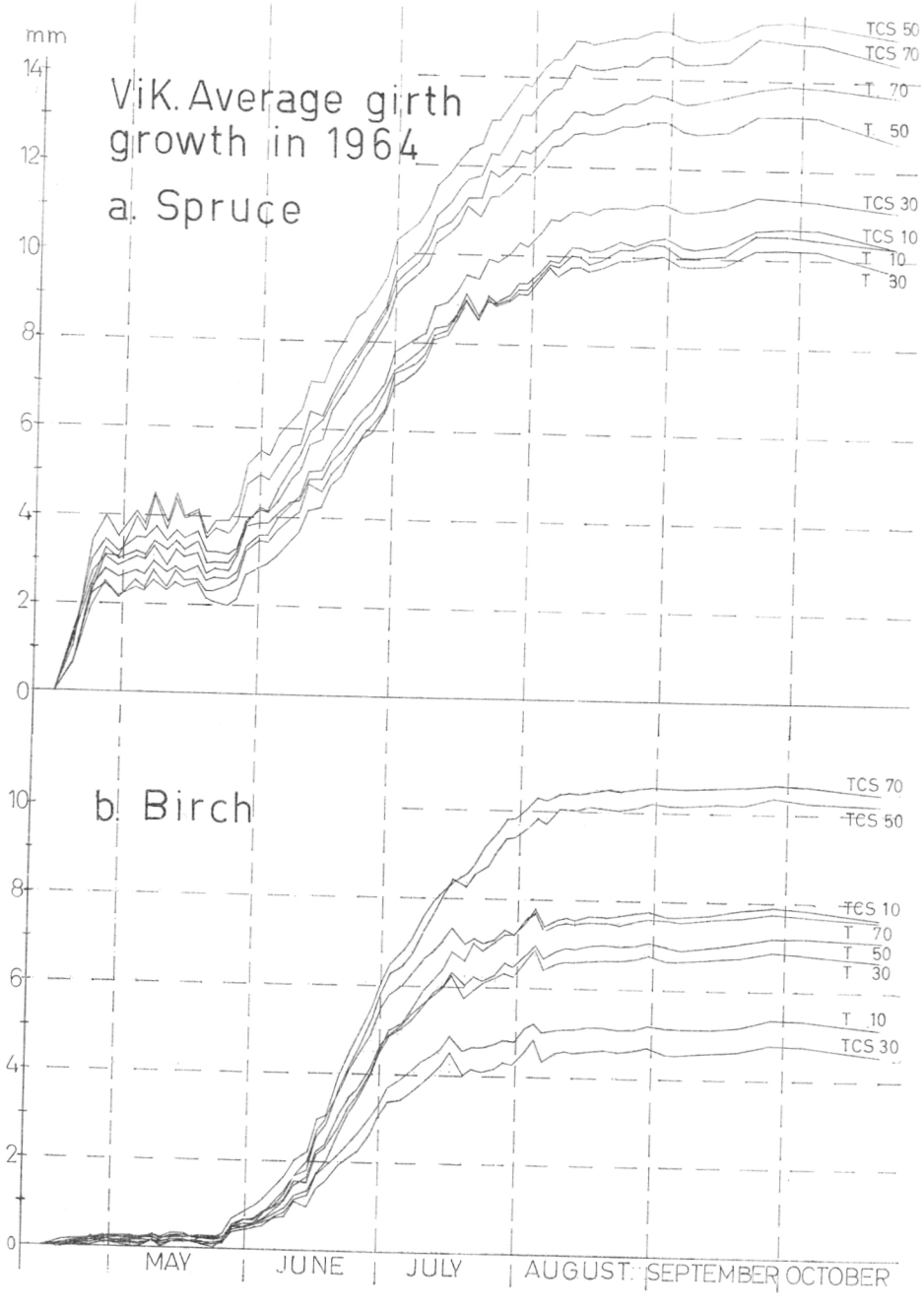

Figure 47. Average circumference growth in the cooled and covered, and the normal sample plots in 1964. ViK.

a) Spruce

b) Birch

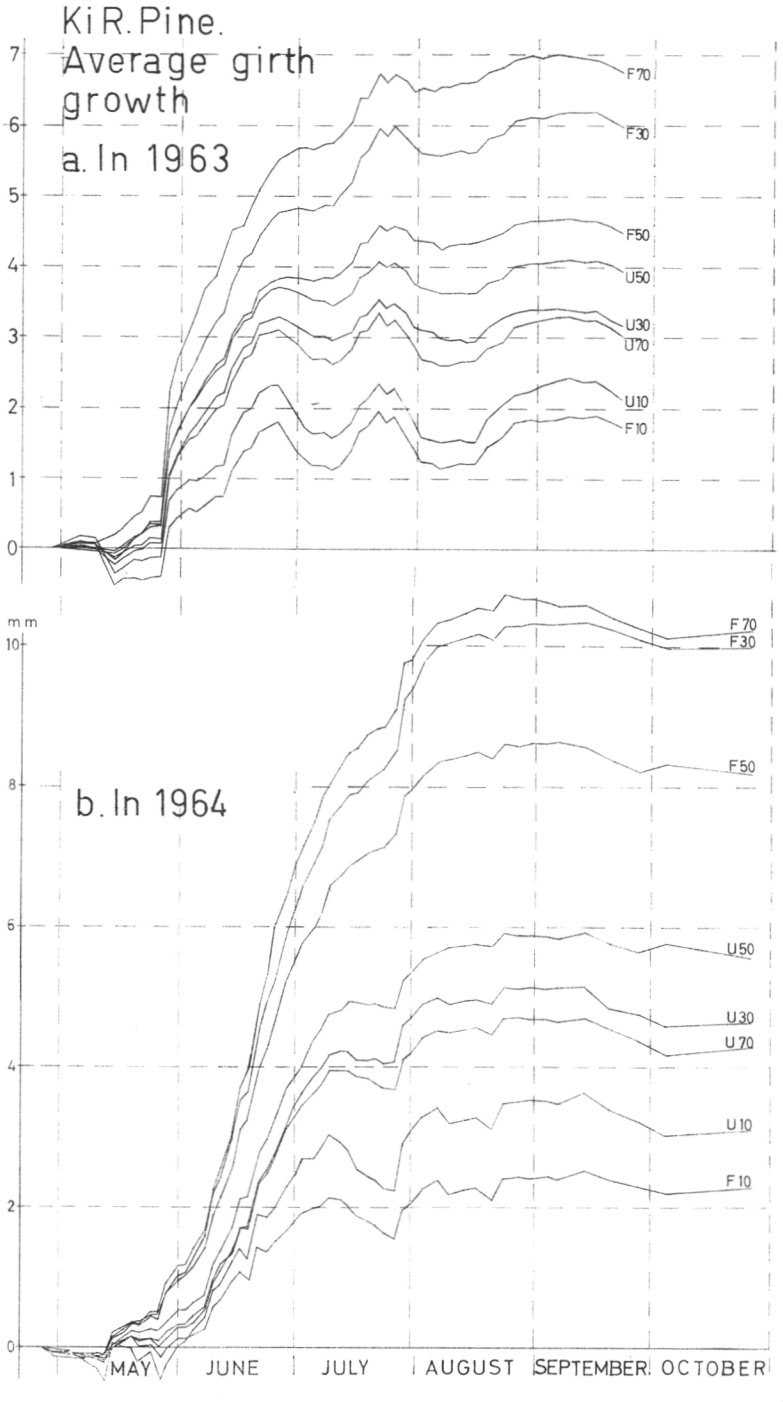

Figure 48. Average circumference growth of pine in the fertilized and the normal sample plots. KiR.

a) in 1963

b) in 1964

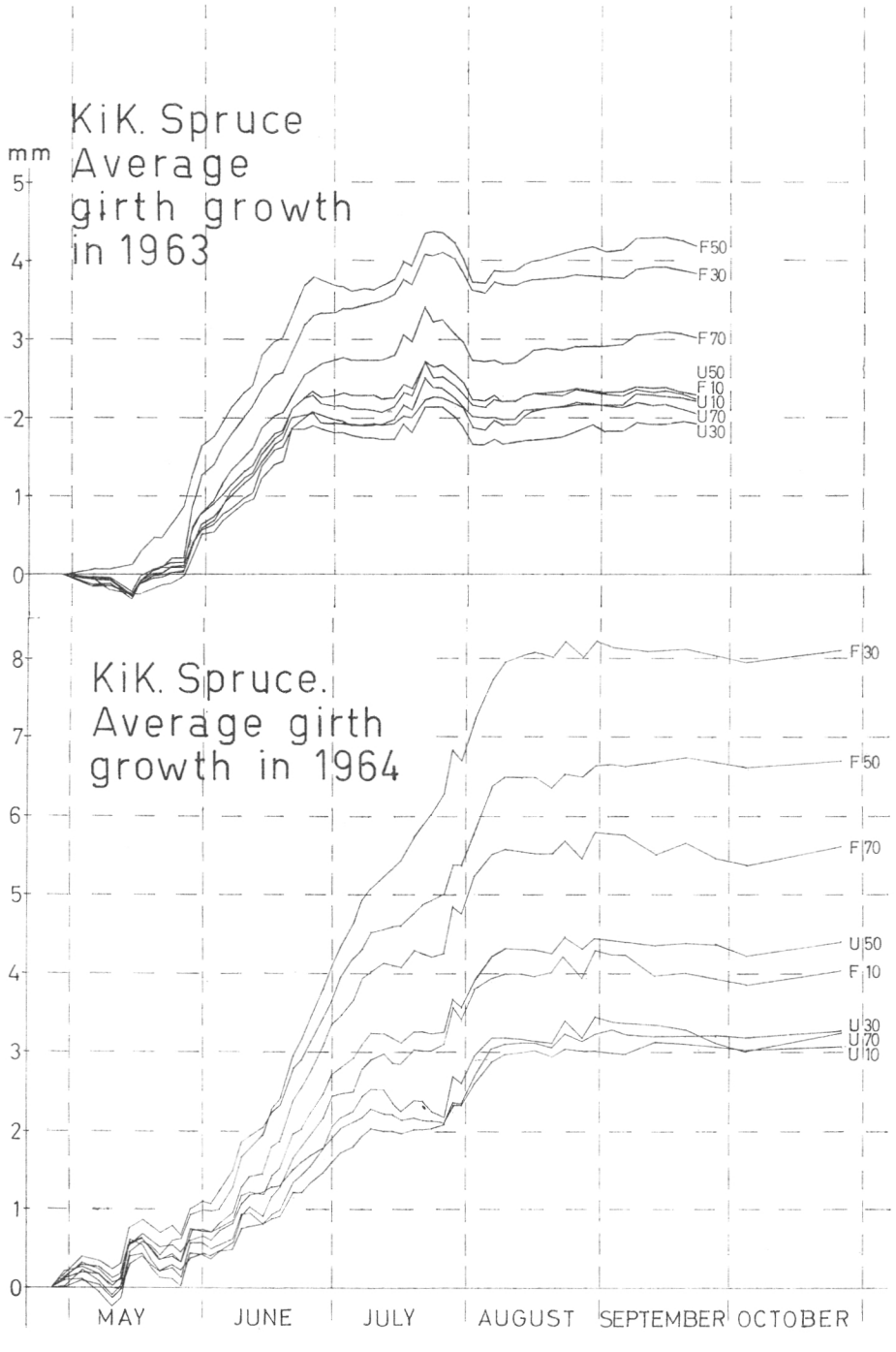

Figure 49. Average circumference growth of spruce in the fertilized and the normal sample plots. KiK.

a) in 1963

b) in 1964

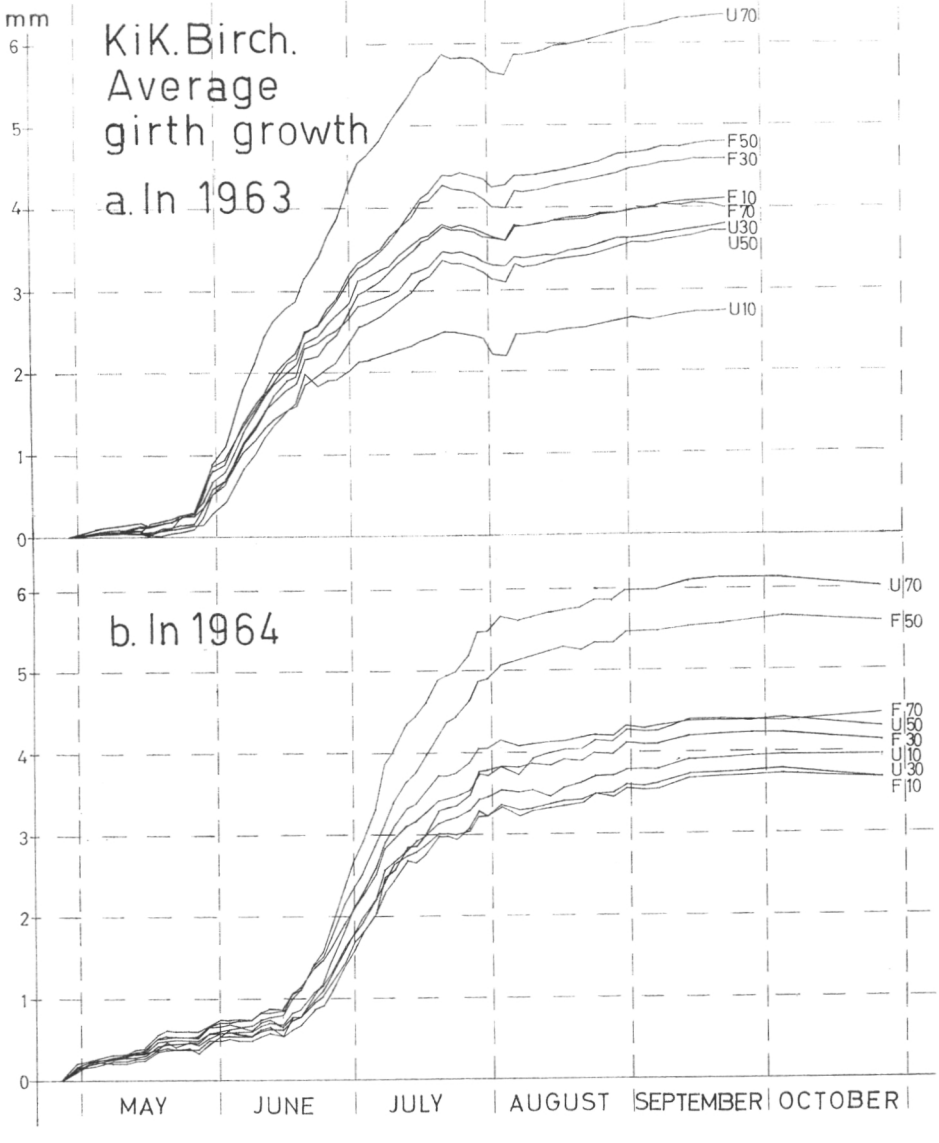

Figure 50. Average circumference growth of **birch** in the fertilized and the normal sample plots. KiK.

a) in 1963

b) in 1964

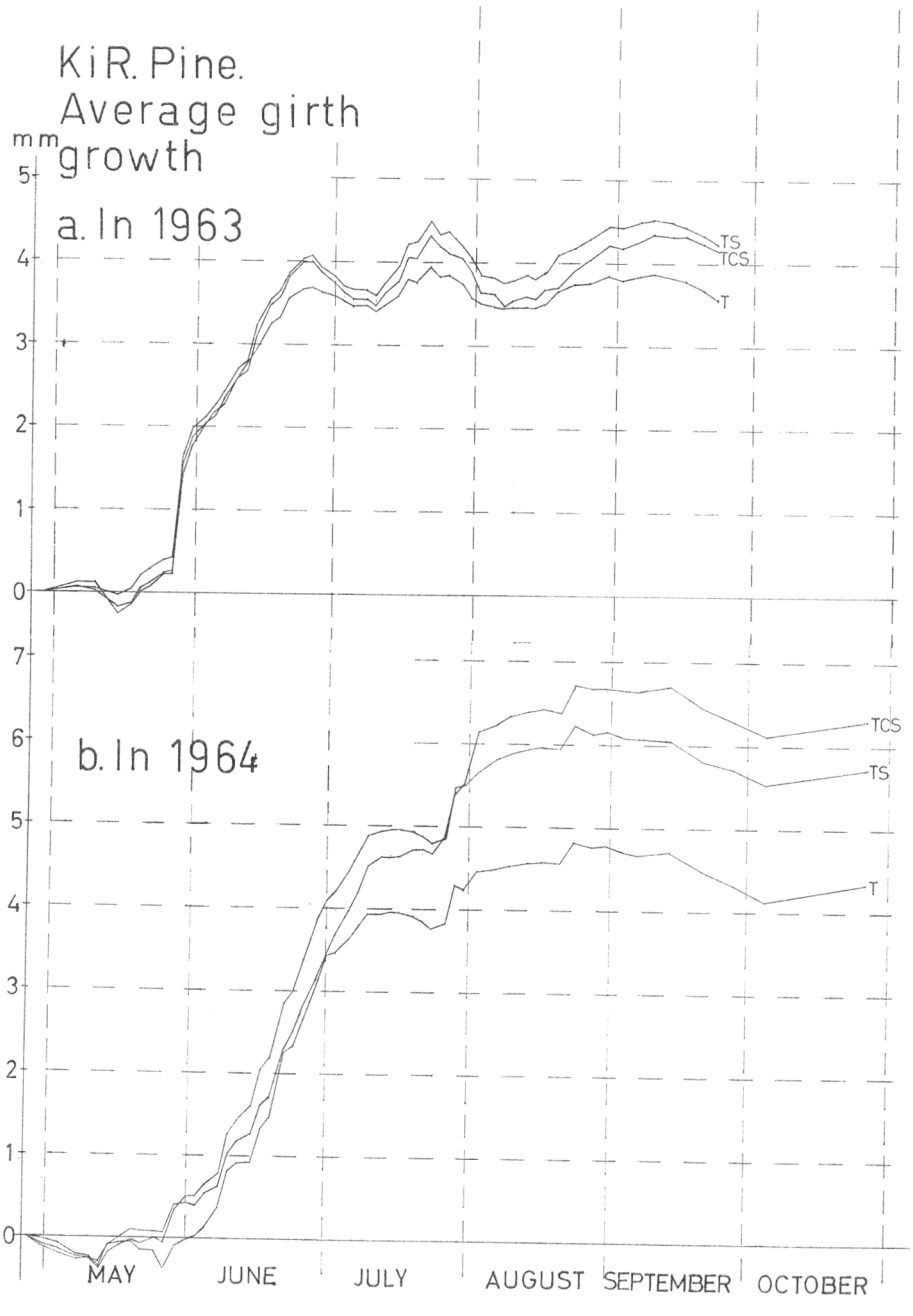

Figure 51. Average circumference growth of pine in the covered, the cooled and covered, and the comparison sample plots in 1963 and 1964. The circular sample plots. KiR.

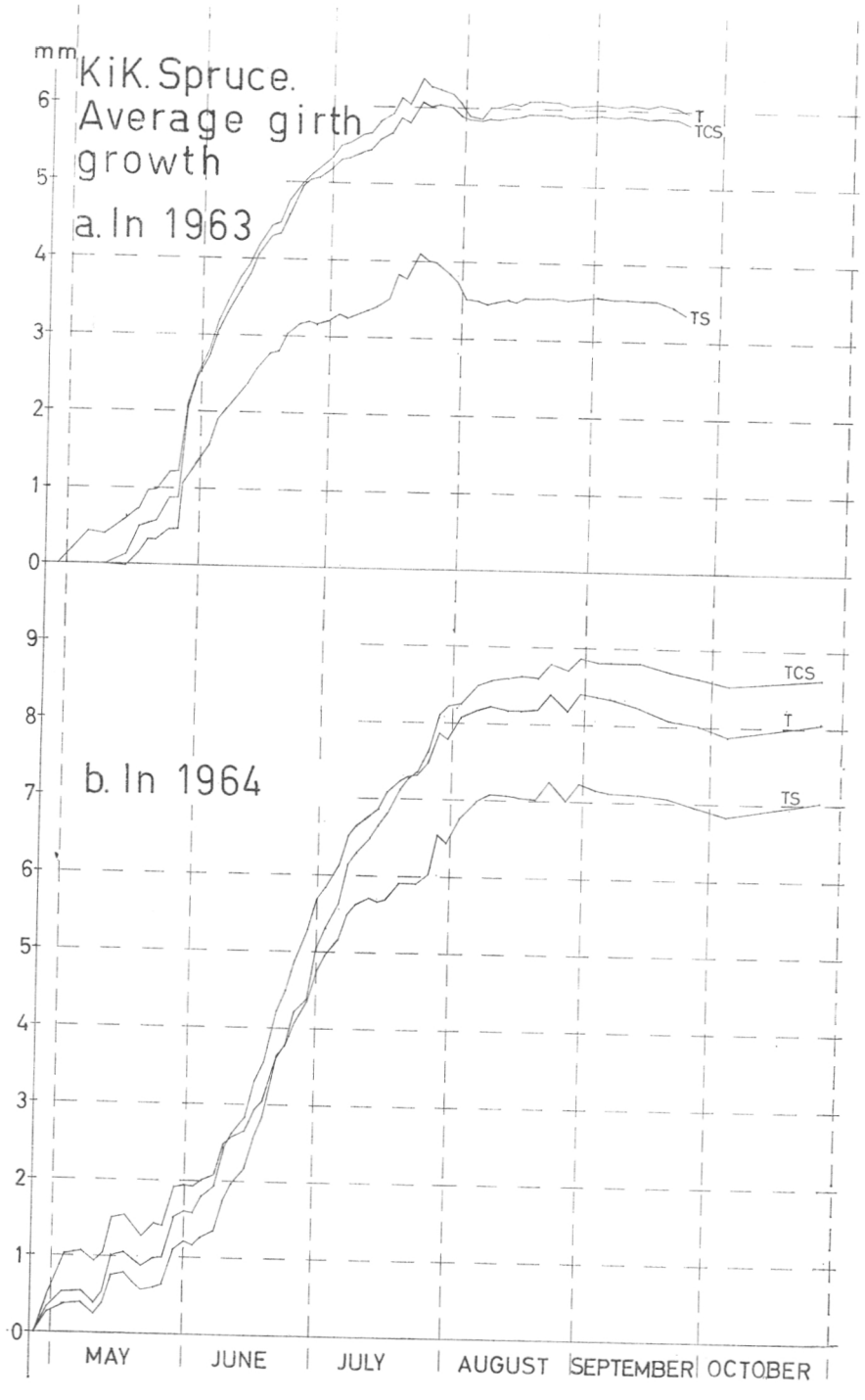

Figure 52. Average circumference growth of spruce in the covered, the cooled and covered, and the comparison sample plots in 1963 and 1964. The circular sample plots. KiK.

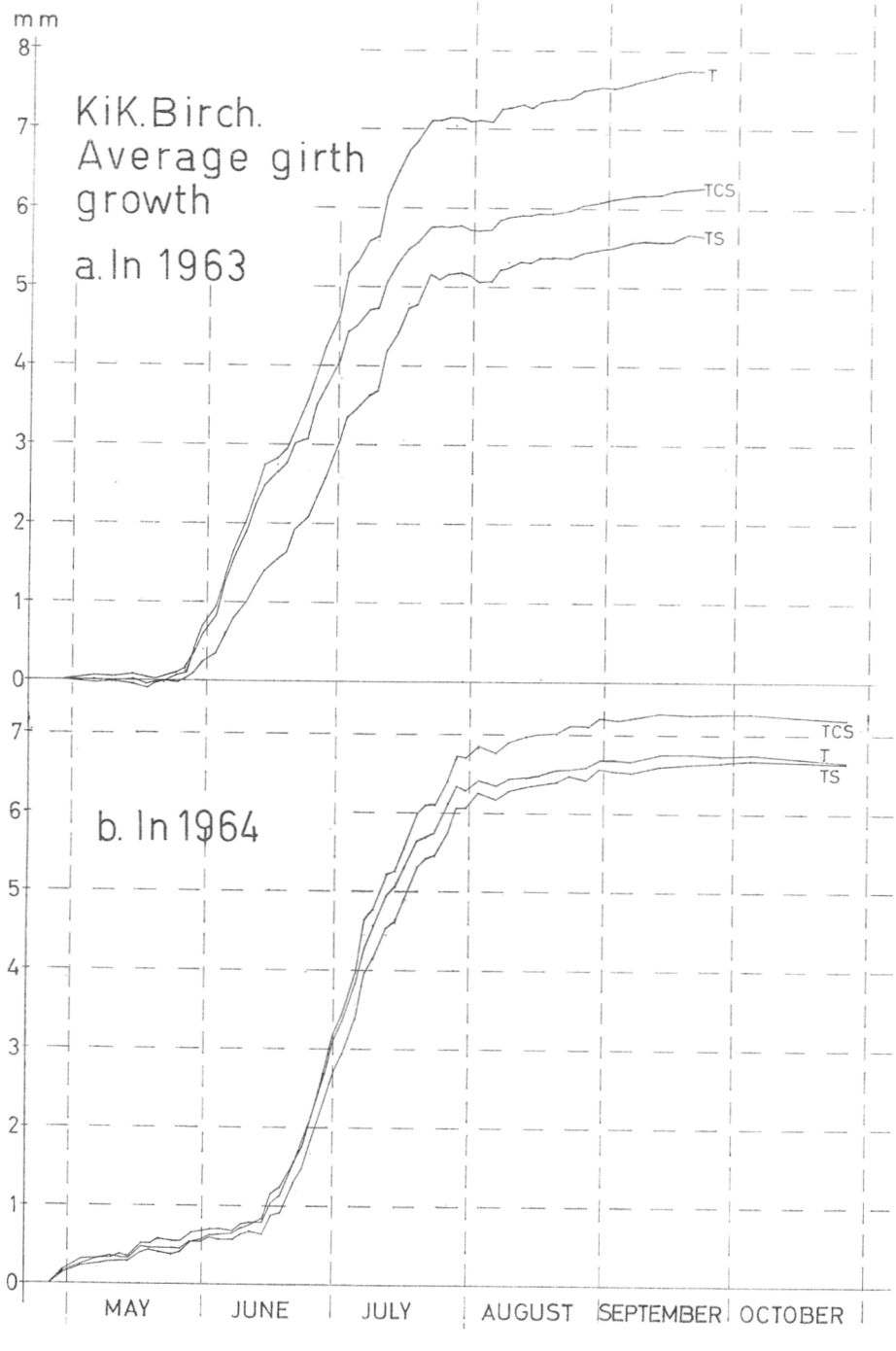

Figure 53. Average circumference growth of birch in the covered, the cooled and covered, and the comparison sample plots in 1963 and 1964. The circular sample plots. KiK.

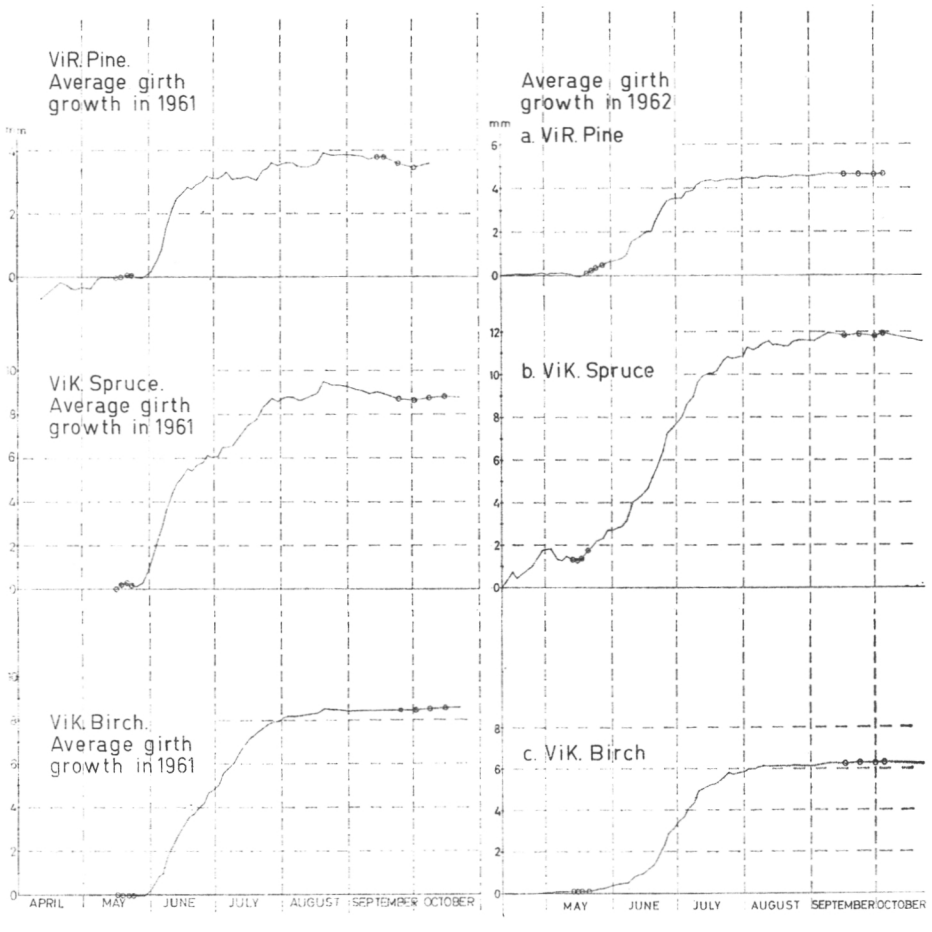

Figure 54. Cumulative circumference growth in 1961 and 1962. Pine, spruce, and birch. Vilppula.
The total increment is calculated by subtracting the average of the four May measurements from the average of the four Sept.-Oct. measurements (eight measurements indicated by circles).

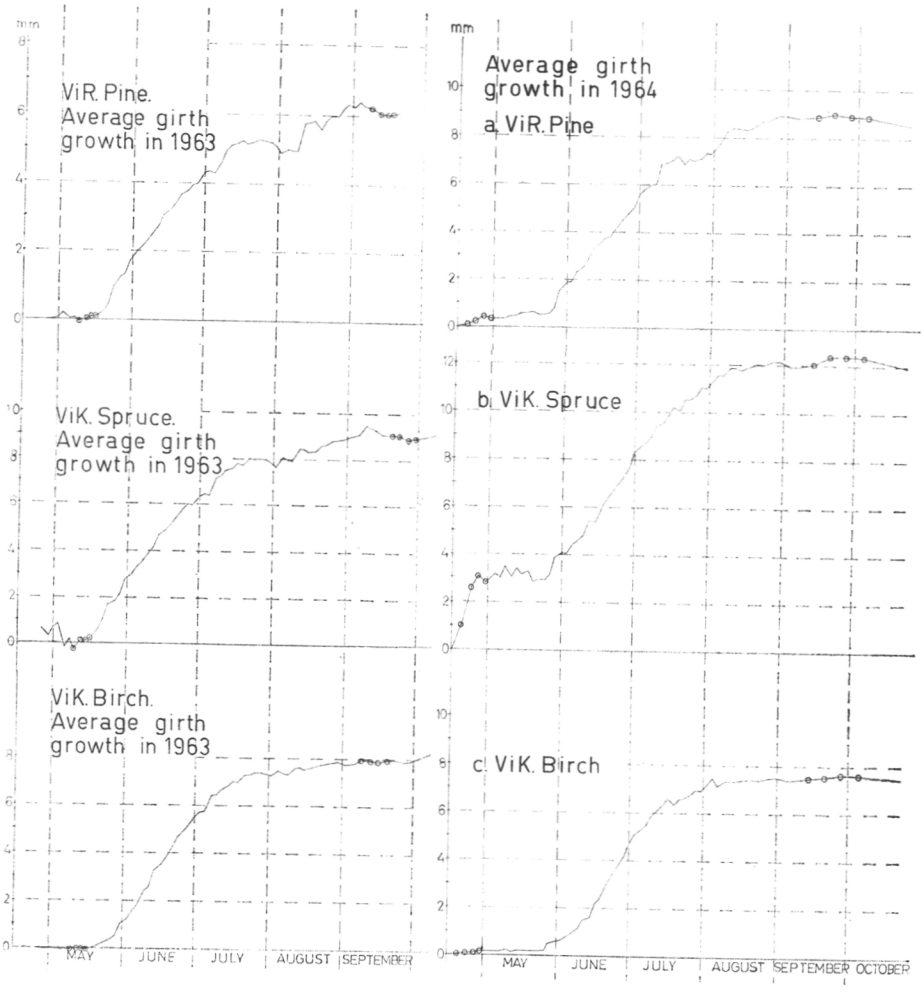

Figure 55. Cumulative circumference growth in 1963 and 1964. Pine, spruce, and birch. Vilppula. The total increment is calculated by subtracting the average of the four May measurements from the average of the four Sept.-Oct. measurements (eight measurements indicated by circles).

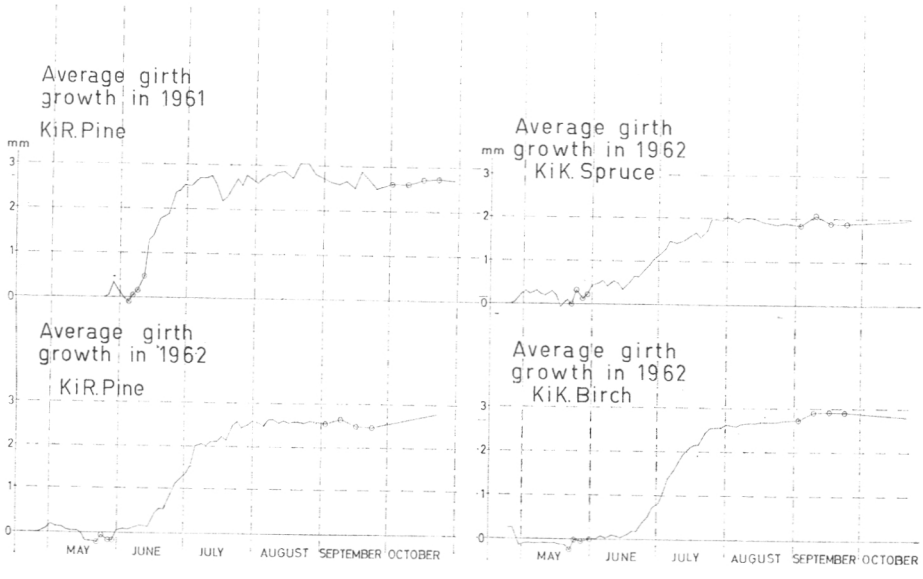

Figure 56. Cumulative circumference growth in pine (1961), and in pine, spruce, and birch (1962). Kivalo. The total increment is calculated by subtracting the average of the four May measurements from the average of the four Sept.-Oct. measurements (eight measurements indicated by circles).

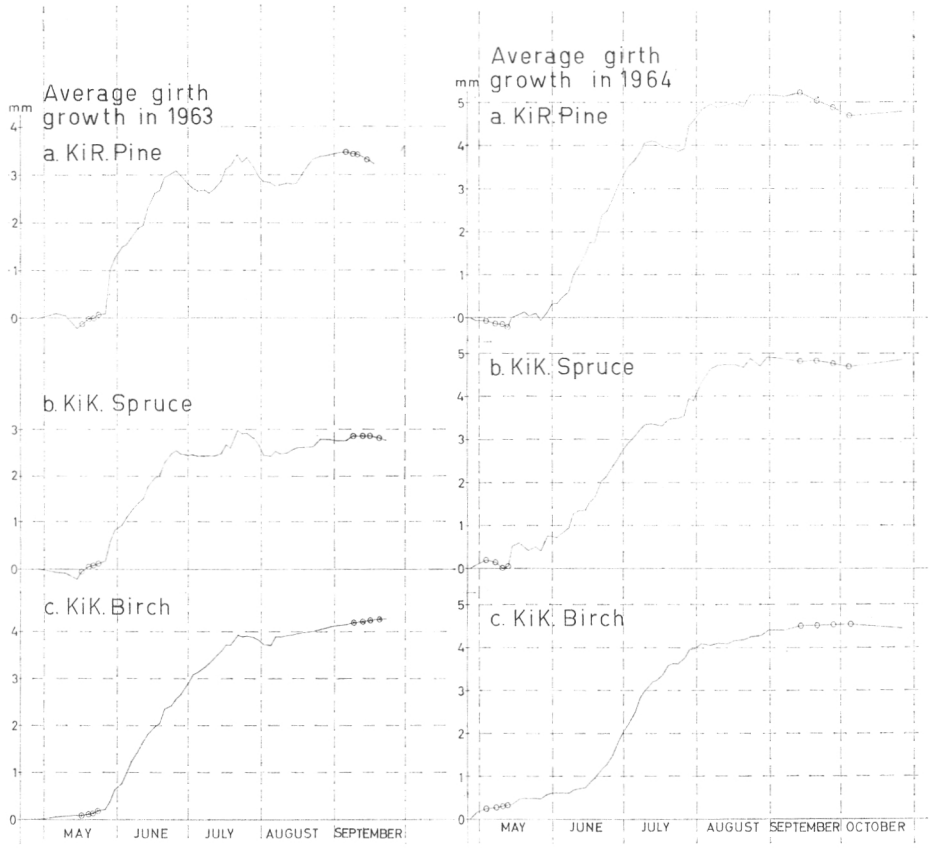

Figure 57. Cumulative circumference growth in 1963 and 1964. Pine, spruce and birch. Kivalo.
The total increment is calculated by subtracting the average of the four May measurements from the average of the four Sept.-Oct. measurements (eight measurements indicated by circles).

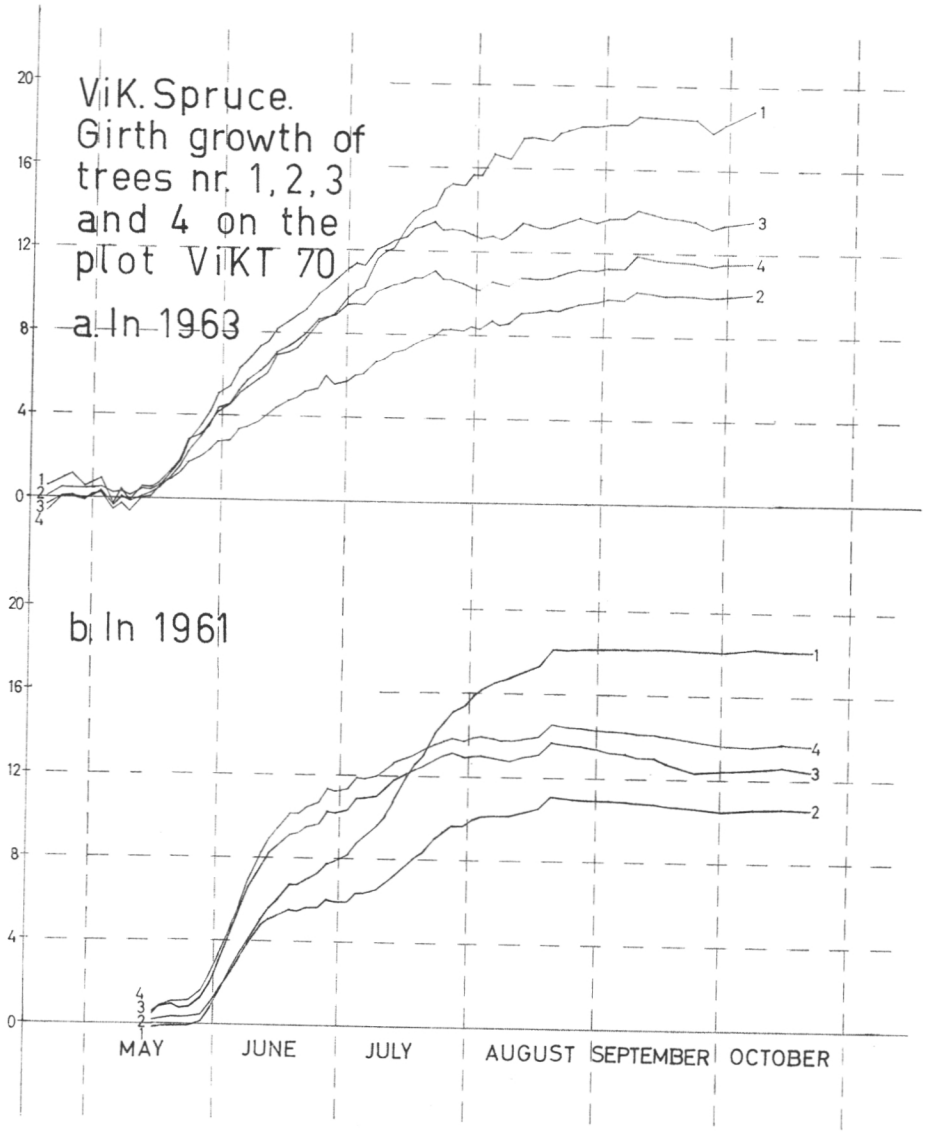

Figure 58. Cumulative circumference growth of spruce (four trees) in 1961 and 1963. ViK.

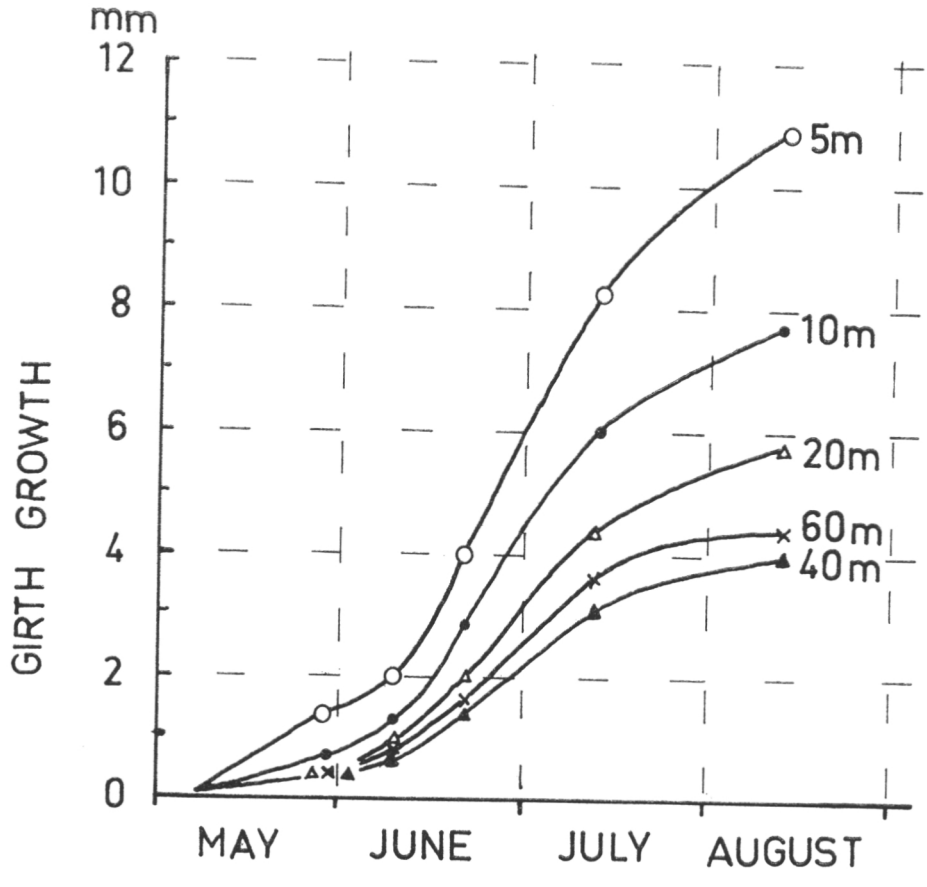

Figure 59. Circumference growth (in mm), at breast height, in tree stands on an open-ditched area with different strip widths (sample plots I-V). Circumference growth from May through August 1962.

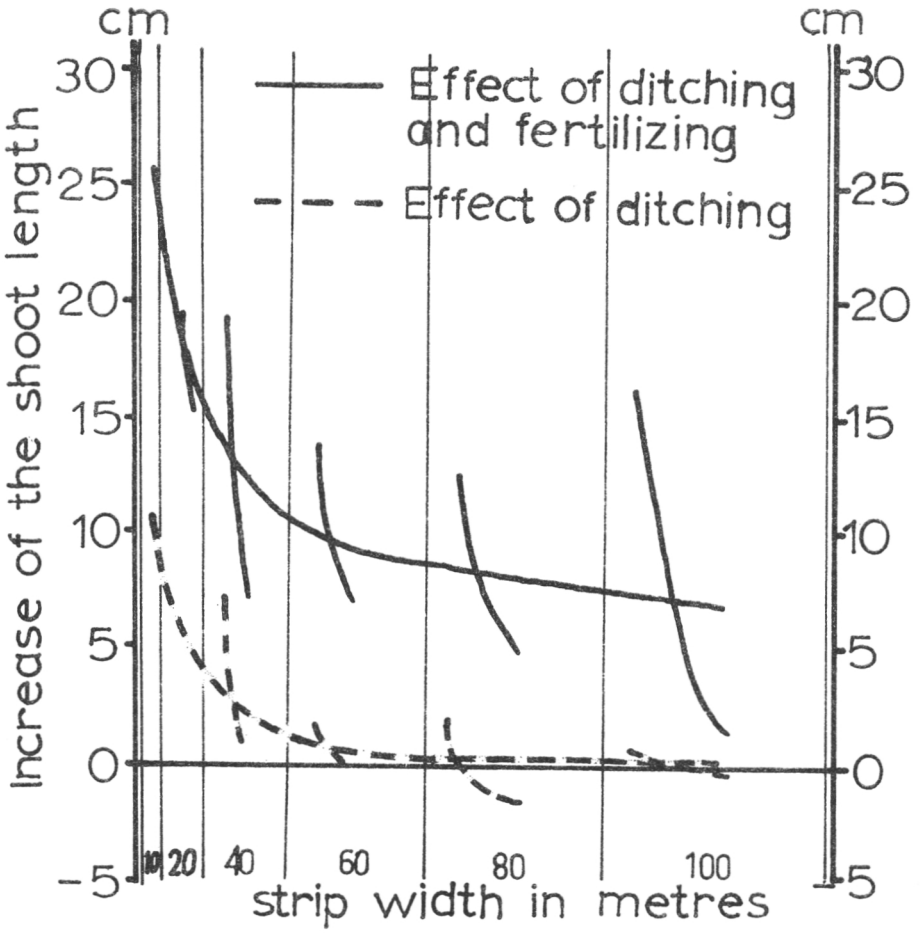

Figure 60. Effect of ditching in 1961 and effect of ditching and fertilizing in 1964 on the height growth of spruce in a Carex globularis spruce-pine swamp with shallow peat. Ditched in 1956, fertilized in 1961. The height growth average for the five years preceding the ditching served as reference. Mortti, rural commune of Rovaniemi.

11. Tables (1 - 38)

T a b l e 1

Data of the general climate in the experiment areas in 1921 - 1950

	Kivalo	Vilppula
Mean annual temperature	1°	3°
Mean annual temperature range	28°	26°
Average dates for freezing point and number of days with $0^{o}C$ - $10^{o}C$ mean temperature in the spring	20.IV 50	10.IV 50
Average dates for freezing point and number of days with $0^{o}C$ - $10^{o}C$ mean temperature in the autumn	15.X 50	5.XI 55
Average duration of the growing season ($\geq 5^{o}C$) and the dates of its beginning	135 10.V	160 30.IV
The yearly precipitation (mm)	550	600
Total radiation ($kcal/cm^2$) on a horizontal surface in the year and in December (1931 - 1955)	65 0.2	70 0.3
Total radiation ($kcal/cm^2$) on a horizontal surface in May - September and in June (1931 - 1955)	52 13.0	56 13.5
The sum of those parts of daily average temperatures which exceed $5^{o}C$	900	1 200
Hight about sea level (m) - spruce swamp - pine swamp	 155 166	 119 120

T a b l e 2

Depth of peat layer and time of drainage and ground water regulation at the hydrological experiment areas in Vilppula and Kivalo

	Depth of peat layer, m	Years of drainage	Time of ground water regulation
Vilppula			
pine swamp	0.8 - 1.5	1909	1960-61
spruce swamp	0.5 - 0.8	1909	1961
Kivalo			
pine swamp	2.9 - 3.3	1933	1961
spruce swamp	0.5 - 1.0	1933	1961

T a b l e 3

Average acidity and total amounts of nutrients in the peat of swamp types represented by the experiment areas according to VAHTERA [1955]

Experiment-area	Swamp type	pH in water	N % of air dry peat	P_2O_5	K_2O	CaO	MgO
				% of owen dry peat			
KiK	Herb rich spruce swamp	5.1	1.8	0.50	0.048	0.55	0.28
ViK	Myrtillus spruce swamp	4.8	1.8	0.55	0.047	0.60	0.15
KiR	Herb rich pine swamp	4.6	2.0	0.45	0.030	0.46	0.08
ViR	Cottongrass pine swamp	3.7	1.3	0.32	0.032	0.21	0.08

T a b l e 4

ViR. Tree stand on sample plots treated in different ways. Measured in 1961.

Sample plot haracteristic in 1964	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter, inkl. bark, cm	Dominant height, m
iR U 10	19.2	617	99	11.5	8.5
iR U 30	20.2	617	98	11.3	8.3
iR U 50	19.1	683	97	10.5	8.0
iR U 70	29.9	850	99	11.5	8.6
iR F 0	20.0	467	94	9.4	7.6
iR F 10	22.7	867	96	10.4	8.2
iR F 30	17.0	850	94	9.4	7.9
iR F 50	20.7	650	99	11.5	8.5
iR F 70	17.7	767	95	9.8	8.0
iR T 10	16.7	600	96	10.2	7.8
iR T 30	22.4	1 200	92	8.9	8.0
iR T 50	20.2	1 300	92	8.8	7.8
iR T 70	19.2	1 000	95	9.9	8.2
iR TCS 10	13.0	800	92	8.7	7.5
iR TCS 30	16.8	867	93	9.0	7.5
iR TCS 50	18.2	1 267	89	7.9	7.0
iR TCS 70	17.8	1 067	92	8.8	7.7

Table 5

ViK. Tree stand on sample plots treated in different ways. Measured in 1961.

Sample plot characteristic in 1964	Pine					Spruce					Birch				
	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m
ViK T 10						71.1	567	86	17.1	18.9	57.1	400	67	16.4	18.2
ViK T 30	5.3	33	84	16.0	16.5	91.8	633	85	17.0	19.0	41.8	267	68	17.4	18.3
ViK T 50						71.5	433	88	18.6	19.7	73.7	533	67	16.9	18.4
ViK T 70						134.6	733	91	20.3	20.6	45.6	233	73	20.0	18.3
ViK TCS 10						48.4	367	84	16.3	18.2	80.4	467	68	17.0	18.4
ViK TCS 30	15.0	33	99	24.0	20.5	38.1	300	82	15.4	16.8	80.3	633	64	14.9	18.0
ViK TCS 50						56.2	300	87	17.8	18.4	98.5	600	67	16.7	18.3
ViK TCS 70						115.6	433	92	20.2	19.7	42.9	267	67	16.7	18.3

KiR. Tree stand on sample plots treated in different ways. Measured in 1961.

Sample plot characteristic in 1964	Pine					Spruce					Birch				
	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height m	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height m
KiR T 10	37.8	1 320	89	13.0	9.2	0.4	80	89	4.6	3.8	1.1	40	89	10.0	7.0
KiR T 30	27.7	1 240		9.7	8.0						1.1	80		7.6	5.8
KiR T 50	29.2	1 240		11.2	8.5	0.1	40		4.0	3.5	1.4	80		9.1	6.0
KiR T 70	46.2	1 640		13.2	9.3	0.5	80		5.0	4.0	1.1	40		10.0	7.0
KiR TCS 10	40.0	1 480		11.6	8.8	0.1	40		4.0	3.5	2.7	120		10.4	6.2
KiR TCS 30	42.7	1 640		12.0	8.8	0.2	80		3.7	3.0					
KiR TCS 50	36.6	1 920		10.3	8.5	0.1	80		3.0	2.5					
KiR TCS 70	27.7	1 600		10.3	8.5						0.7	40		8.0	6.0
KiR U 10	27.6	1 240		11.0	8.5	0.8	180		4.8	3.7	1.7	40		12.0	7.5
KiR U 30	30.2	1 280		11.2	8.7	1.2	280		4.7	4.0	3.8	100		11.9	7.1
KiR U 50	25.6	1 280		11.6	8.8	0.8	180		4.6	3.8	4.2	120		11.6	7.5
KiR U 70	25.0	1 220		11.3	8.6	0.2	20		6.0	4.0	1.3	60		9.7	6.5
KiR F 10	25.7	1 260		10.7	8.5	0.3	80		4.3	3.4	0.7	20		11.0	7.5
KiR F 30	26.8	1 280		11.9	9.0	0.4	120		4.6	3.4	2.8	120		9.6	6.8
KiR F 50	30.5	1 360		12.9	9.2	0.1	40		3.7	3.0	3.2	80		11.7	7.5
KiR F 70	38.3	1 300		13.9	9.5	0.7	180		4.6	3.8	1.1	60		8.8	6.2

T a b l e 7

KiK. Tree stand on sample plots treated in different ways. Measured in 1961.

Sample plot characteristic in 1964	Spruce					Birch				
	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m	Cubic volume incl. bark, cu.m/ha	Stem number per hectare	Age, years	Mean diameter incl. bark, cm	Dominant height, m
KiK U 10	36.8	683	175	15.2	13.9	48.4	433	107	17.7	14.6
KiK U 30	36.3	1 100	151	12.8	13.3	63.6	633	108	18.2	14.8
KiK U 50	54.3	1 350	167	14.4	14.6	40.1	283	115	20.5	14.8
KiK U 70	59.1	1 383	174	15.1	15.6	31.0	267	108	18.0	14.4
KiK F 10	30.5	700	155	13.1	12.7	47.9	633	101	15.8	14.3
KiK F 30	41.6	1 250	156	13.4	13.7	54.2	383	116	21.3	15.1
KiK F 50	67.6	567	231	23.5	18.2	56.1	350	118	21.5	15.0
KiK F 70	35.0	933	163	14.0	13.4	52.8	600	105	17.3	14.6

Table 8

Tree stand on hydrological experiment areas in Vilppula and Kivalo in 1961

	Vilppula								Kivalo							
	Pine swamp				Spruce swamp				Pine swamp				Spruce swamp			
	Pine	Spruce	Birch	Total	Pine	Spruce	Birch	Total	Pine	Spruce	Birch	Total	Pine	Spruce	Birch	Total
Cubic volume incl. bark, cu.m/ha	19.0			19.0	5.3	78.4	65.0	148.7	33.6	0.4	1.8	35.8		45.2	49.3	94.5
Stem number per hectare	903			903	33	471	425	929	1433	94	70	1597		996	448	1444
Mean diameter incl. bark, cm	9.6				16.0	17.8	17.0		11.5	4.3	8.9			15.2	18.8	
Dominant height, m	7.9				16.5	18.9	18.3		8.8	3.5	6.6			14.4	14.7	
Age, years	94				84	87	68		89	89	89			172	110	

T a b l e 9

Time of soil frost melting on the cooled and control plots in Vilppula and Kivalo

Year	V i l p p u l a				K i v a l o	
	Pine swamp		Spruce swamp		Pine swamp	
	Cooled	Control	Cooled	Control	Cooled	Control
1962	13.6.	16.5.	13.6.	30.5.	8.8.	20.6.
1963	19.6.	8.5.	19.6.	15.5.	30.8.	14.6.
1964	7.8.	18.5.	24.7.	24.4.	24.8.	8.6.

T a b l e 1 0

Relative water permeability of peat according to the "Augerhole"-method in different experiment areas and depth layers

Depth layer cm	K i v a l o		V i l p p u l a	
	Pine swamp	Spruce swamp	Pine swamp	Spruce swamp
0 - 10	24.5	20.1	42.9	100.0
10 - 20	9.4	10.0	7.1	42.5
20 - 30	5.0	3.7	1.6	74.9
30 - 40	2.9	2.5	1.0	3.7
40 - 50	1.6	1.9	0.9	2.9
50 - 60	1.3	1.8	0.8	1.4
60 - 70	-	1.8	-	1.4

T a b l e 1 1

ViR. Number of pines in which height growth has started on different days of observation in 1961 - 1964

Year	April											May												Trees in total
	20/4	21	22	23	24	25	26	27	28	29	30	1/5	2	3	4	5	6	7	8	9	10	11	12	13	
1961									0						112				32						144
1962							0				1				96			48				11			156
1963							0			10				62				32			41			10	155
1964	0				56			45			46				9										156

T a b l e 1 2

KiR. Number of pines in which height growth has started on different days of observation in 1962 - 1964

Year	May																								Trees in total
	4/5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
1962															0			57				86			1	144
1963											0				139			5								144
1964	0				59				61				24													144

T a b l e 1 3

ViR. Daily min. and max. temperatures (^{o}C) three days before and after growth has started and on the day growth has started

Year	Days before						Height growth starts		Days after					
	3.		2.		1.				1.		2.		3.	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
1962	1.5	4.7	-3.2	7.4	-8.1	9.7	1.8	4.3	-1.6	9.9	2.1	15.2	0.0	16.3
1963	-2.4	7.5	-4.3	15.7	4.3	18.3	8.3	21.3	-2.1	14.9	-4.3	17.1	-3.3	19.6
1964	-6.5	4.4	-5.6	4.1	-4.7	8.7	-7.5	10.9	1.6	13.9	5.4	18.9	5.3	11.8

T a b l e 1 4

KiR. Daily min. and max. temperatures (^{o}C) three days before and after growth has started and on the day growth has started

Year	Days before						Height growth starts		Days after					
	3.		2.		1.				1.		2.		3.	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
1962	1.1	17.4	8.9	11.6	5.4	17.4	0.9	11.1	6.4	11.8	3.4	8.1	-1.1	10.0
1963	3.2	16.8	-0.9	20.3	2.1	23.6	3.4	20.7	0.8	15.0	1.1	20.1	0.4	21.5
1964	1.1	8.9	-0.6	8.3	-2.1	10.5	-0.8	12.8	2.1	5.8	-2.1	11.7	4.3	7.5

T a b l e 15

VIR. Soil temperature (°C) at depths of 5, 15 and 40 cm and the beginning of height growth (underlined)

Depth	Year	April							May																
		24/4	25	26	27	28	29	30	1/5	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
5	1961			0.4		-0.1			-0.1		1.2		4.5			5.2		5.4		6.5			8.1		6.3	
	1962							0.1		0.2			0.2				0.8		1.2			2.2		3.8		5.6
	1963			0.1			0.2		0.9		0.6			1.2		0.2		0.5			6.2		3.6		4.1	
	1964	-0.8			-0.3			-0.2				0.3		0.4		1.0			2.0		1.2		1.2			0.9
15	1961			0.7		0.2			0.2		0.6		1.7			3.0		3.9		4.3			5.1		5.1	
	1962							0.3		0.4		0.5			0.8		1.4		1.9			2.7		3.5		4.8
	1963			0.0			0.0		0.1		0.0			0.1		0.2		0.4			3.0		2.5		3.5	
	1964				-0.5			-0.5				-0.5		-0.5		-0.5			-0.5		-0.5		-0.4			-0.5
40	1961			1.0		0.9			0.9		1.0		1.1			1.8		2.2		2.6			3.2		3.6	
	1962							0.9		0.9		1.1			1.2		1.7		2.0			2.6		3.0		3.7
	1963			0.0			0.0		0.1		0.3			0.3		0.4		0.5			0.8		1.3		1.6	
	1964	0.0			0.0			0.0				0.0		0.0		0.0			0.1		0.1		0.1			0.0

Table 16

KiR. Soil temperature (°C) at depths of 5, 15 and 40 cm and the beginning of height growth (underlined)

Depth	Year	May																				June			
		11/5	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1/6	2	3	4
5	1962								0.0			1.3		1.2		2.0			2.9		4.3		3.2			1.8
	1963	0.7				2.4	___	3.2			2.2		2.7		3.4			6.0		8.4		7.9			7.4	
	1964	-0.2		0.4		1.5			0.7		1.5		2.5			4.1		7.0		6.0			3.6		3.0	
	Plastic house -64	-0.3		0.3		0.5			1.4		3.0		3.6			6.2		7.8		5.5			4.8		4.8	
15	1962								-0.2			-0.1		0.0		1.1			2.3		3.4		3.2			2.4
	1963					0.2		0.6			0.8		1.0		1.5			3.3		5.4		5.4			3.8	
	1964	-0.1		0.0		0.0			-0.1		0.0		0.3			1.5		3.0		4.1			3.0		2.4	
	Plastic house -64	-0.1		-0.1		0.0			0.0		0.0		0.4			2.7		4.9		5.1			4.1		3.9	
40	1962								-0.2			-0.1		0.0		0.1			0.4		0.9		1.1			1.0
	1963					-0.3		-0.2			-0.2		0.0		0.1			0.7		1.3		2.0			2.1	
	1964	0.0		0.1		0.1			0.1		0.1		0.2			0.4		1.2		1.6		1.9			2.1	
	Plastic house -64	0.0		0.0		0.0			0.0		0.0		0.2			1.2		2.0		2.4		2.6			2.4	

T a b l e 1 7

ViR. Soil temperature (^{o}C) at 40 cm depth on the cooled plots

Year	April							May																
	24/4	25	26	27	28	29	30	1/5	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1962							0.4		0.4		0.4			0.3		0.3		0.3			0.3		0.3		0.5
1963			-0.1			0.0		0.0		0.1			0.0		0.0		0.0			0.1		0.1		0.0	
1964				-0.8			-0.9				-0.7		-0.8		-0.7			-0.8		-0.7		-0.9			-0.9

Table 18

KiR. Soil temperature (°C) at 40 cm depth on the cooled plots

Year	May																				June			
	11/5	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1/6	2	3	4
1962								-0.5			-0.3		-0.3		-0.3			-0.3		-0.2		-0.3			-0.3
1963					-0.2		-0.2			-0.2		-0.1		-0.2			-0.1		-0.1		-0.1			-0.1	
1964	-0.2		-0.1		-0.1			-0.1		-0.1		-0.1			-0.1		-0.1		-0.1			-0.1		-0.1	

T a b l e 1 9

ViR and KiR. Thickness of snow, melted layer and soil frost at the beginning of the height growth

Year	Characteristic of temperature	ViRTC	ViRT	KiRTC	KiRT
1962	Snow, cm	-	-	-	-
	Melted layer, cm	5 - 10	-	10 - 15	10 - 15
	Soil frost, cm	10 - 20	-	25 - 30	0 - 10
1963	Snow, cm	-	-	-	-
	Melted layer, cm	9 - 12	9 - 12	9 - 12	9 - 12
	Soil frost, cm	26 - 30	0 - 3	over 40	18 - 20
1964	Snow, cm	22 - 32	-	25 - 55	0 - 25
	Melted layer, cm	-	-	-	-
	Soil frost, cm	28 - 35	0 - 10	over 40	24 - 25

T a b l e 2 0

Terminal bud length (mm) in pines on the first day of growth measurements in different experiment members

Year	Day	ViRTC	ViRT	ViRF	ViRU
1961	28.4.	14.5	14.3	9.8	11.9
1962	26.4.	12.8	12.5	11.8	12.5
1963	26.4.	13.0	13.5	14.3	13.2
1964	20.4.	12.7	12.8	19.6	10.8
		KiRTC	KiRT	KiRF	KiRU
1962	18.5.	9.0	8.7	12.0	10.7
1963	14.5.	8.5	8.2	10.6	11.0
1964	29.4.	7.3	6.5	8.1	7.2

T a b l e 2 1

Initial and finishing times of the diameter growth in pine, spruce and birch and its duration when 20 % from the amount of growth has been deducted

	Year	Vilppula		Kivalo	
		Growing time	Days	Growing time	Days
Pine	1961	4.6. - 26.7.	52	10.6. - 29.6.	19
	1962	28.5. - 11.7.	44	12.6. - 22.7.	39
	1963	23.5. - 11.8.	80	28.5. - 26.6.	29
	1964	27.5. - 6.8.	71	6.6. - 31.7.	55
Spruce	1961	1.6. - 22.7.	51	-	-
	1962	27.5. - 25.7.	59	31.5. - 24.7.	54
	1963	22.5. - 11.8.	81	27.5. - 7.7.	41
	1964	20.4. - 28.7.	99	15.5. - 4.8.	81
Birch	1961	5.6. - 23.7.	48	-	-
	1962	9.6. - 24.7.	45	19.6. - 22.7.	33
	1963	30.5. - 21.7.	52	29.5. - 20.7.	52
	1964	5.6. - 17.7.	42	18.5. - 2.8.	76

T a b l e 2 2 a, b

Soil temperature at depths of 5, 15 and 40 cm at the beginning of the diameter growth on the cooled plots in Vilppula and Kivalo

a. Vilppula

Year	ViRT			ViRTC			ViKT			ViKTC		
	5	15	40	5	15	40	5	15	40	5	15	40
1962	6.3	5.3	3.8	3.6	0.7	0.5	4.7	3.3	2.5	1.5	-0.1	0.7
1963	3.8	4.2	3.9	1.4	0.4	0.1	2.7	1.1	1.0	1.8	0.5	0.0
1964	2.7	0.7	0.5	0.0	-0.6	-0.8	2.7	0.2	0.0	0.8	-0.1	-0.2

b. Kivalo

Year	KiRT			KiRTC		
	5	15	40	5	15	40
1962	6.1	5.5	3.6	3.5	1.4	-0.3
1963	6.4	7.6	4.3	4.0	4.1	0.0
1964	3.7	4.1	2.8	-0.1	-0.1	-0.1

T a b l e 2 3

Vilppula. Temperature sums between beginning of growth and flowering of trees

Year	Flowering time	Time from the beginning of growth	Sum of mean temperatures	Temperature sum	
				$\sum(\bar{C}^{o} - 5^{o})$	Grade hours
1961	7.6	32	358	199	-
1962	21.6	47	467	230	5 986
1963	4.6	29	359	214	5 598
1964	16.6	51	500	248	6 358

T a b l e 2 4

ViR. Soil temperature (^{o}C) at depths of 5, 15 and 40 cm at the beginning of flowering

Year	Untreated			Fertilized 1962			Cooled 1962 - 1964 Covered 1964			Covered 1964		
	5	15	40	5	15	40	5	15	40	5	15	40
1961	15.1	12.0	8.0	15.1	12.0	8.0	15.1	12.0	8.0	15.1	12.0	8.0
1962	9.6	9.1	8.0	9.6	9.1	8.0	8.9	8.0	6.3	9.2	9.0	7.5
1963	10.7	9.3	7.1	10.3	8.8	6.3	7.7	2.7	0.2	10.8	9.0	6.8
1964	11.3	8.3	6.7	9.5	5.2	3.9	1.9	-0.3	-0.8	6.8	4.8	3.1

T a b l e 2 5

ViR. Growing time, sums of mean temperatures and temperature sums during the growing time

Year	Growing time, days	$\sum \bar{C}^{o}$	Temperature sum	
			$\sum (\bar{C}^{o} - 5^{o})$	Grade hours
1961	45	599	374	*
1962	61	665	362	9 322
1963	47	575	340	8 832
1964	66	706	379	9 960
Plastic house -64	50	639	390	10 090
Comparison	66	672	359	9 435

T a b l e 2 6

Kivalo. Growing time, sums of mean temperatures during the growing time and temperature sums

Year	Growing time, days	$\bar{C}^{o}$	Temperature sum	
			$(\bar{C}^{o} - 5^{o})$	Grade hours
1961	over 35	over 504	over 329	over 7 913
1962	50	601	354	8 748
1963	38	405	216	5 528
1964	57	518	252	6 590
Plastic house -64	48	584	346	9 196
Comparison	70	684	353	9 072

T a b l e 2 7

Radiation sums of the growing time in the experimental areas in Vilppula and Kivalo

Year	V i l p p u l a *		K i v a l o *	
	Growing time	Radiation sum	Growing time	Radiation sum
1961	45	18 357	over 35	over 16 400
1962	61	27 815	50	23 200
1963	47	23 400	38	17 400
1964	66	27 511	57	24 300

* The radiation sums have been calculated for Vilppula at the weather observation station in Luonetjärvi and for Kivalo in Sodankylä

T a b l e 2 8

Data of termination of height growth in sample plots treated in different ways. Pine swamps in Vilppula and Kivalo, 1961 - 1964.

Vilppula	ViRU	ViRF 1962	ViRTCS 1962-1964	ViRT 1964
1961		18.6.	21.6.	20.6.
1962	5.7.	5.7.	5.7.	5.7.
1963	21.6.	24.6.	20.6.	20.6.
1964	1.7.	8.7.	2.7.	2.7.
Kivalo	KiRU	KiRF	KiRTCS	KiRT
1961	10.7.	10.7.	4.7.	3.7.
1962	13.7.	14.7.	13.7.	11.7.
1963	22.6.	26.6.	21.6.	20.6.
1964	8.7.	11.7.	2.7.	4.7.

T a b l e 2 9

Plot totals for girth growth (0.01 mm) in Vilppula, Jaakkoinsuo in 1961 and 1962. The lower numbers are used for the year 1961. Numbers in the plot corners are tree numbers.

	10 cm	30 cm	50 cm	70 cm	A
TC 1962	2 969 [6]	2 578 [6]	1 457 [6]	2 657 [6]	9 661 [24]
T 1961	3 204	2 513	1 285	2 222	9 224
T	2 627 [6]	1 900 [6]	2 561 [6]	2 774 [6]	9 862 [24]
T	2 454	1 679	2 008	2 451	8 592
F	5 271 [12]	5 258 [12]	6 056 [12]	5 365 [12]	21 950 [48]
U	4 423	4 281	3 868	3 739	16 311
B	10 867 [24]	9 736 [24]	10 074 [24]	10 796 [24]	41 473 [96]
	10 081	8 473	7 161	8 412	34 127

T a b l e 3 0

Adjusted plot means for radial growth in Vilppula, Jaakkoinsuo, i 1962. Basic year for covarience adjustment is the year 1961 (b.y.cov. = 1961).

	10 cm	30 cm	50 cm	70 cm	A
TC 1962	0.57	0.60	0.56	0.69	0.60
T	0.63	0.60	0.70	0.67	0.65
F 1962	0.68	0.70	0.84	0.77	0.75
B	0.64	0.65	0.74	0.72	0.69

T a b l e 3 1 a, b

ViR. Average height growth of pine (mm) on cooled (TC), strawcovered (TS), fertilized (F) and untreated (U) plots with different water depths

a. In 1963 (b.y.cov. = 1962)

ViR	10	30	50	70	A
TC 1962-63	89	139	99	96	106
T	98	98	109	98	101
F 1962	167	215	236	219	209
U	86	95	107	121	102
B	117	144	150	146	139

b. In 1964 (b.y.cov. = 1962)

ViR	10	30	50	70	A
TCS 1964	49	92	105	123	92
TS 1964	79	135	125	127	116
F 1962	294	388	400	427	377
U	33	87	103	141	91
B	133	199	209	234	194

T a b l e 3 2 a, b

ViR. Average radial growth of pine (mm) on cooled (TC), strawcoverad (TS), fertilized (F) and untreated (U) plots with different water depths

a. In 1963 (b.y.cov. = 1961)

ViR	0 *	10	30	50	70	A
TC 1962-63	-	0.21	0.47	0.65	0.62	0.58
T	-	0.44	0.64	0.68	0.58	0.63
F 1962	0.43	1.28	1.85	1.92	1.68	1.82
U	-	-	0.55	0.51	0.56	0.54
B			1.03	1.03	0.95	0.99

b. In 1964 (b.y.cov. = 1961)

ViR	0 *	10	30	50	70	A
TCS 1964	-	0.26	1.01	1.01	1.54	1.09
TS 1964	-	0.79	0.91	1.21	1.22	1.12
F 1962	0.54	1.92	2.84	2.95	2.30	2.70
U	-	-	0.50	0.55	0.61	0.55
B			1.43	1.54	1.39	1.45

* No covariance adjusment

T a b l e 3 3 a, b, c

ViK. Average radial growth of birch (mm) on cooled (TC) and untreated (T) plots with different water depths

a. In 1962 (b.y.cov. = 1961)

ViK	10	30	50	70	A
TC 1962	0.92	0.94	0.99	1.19	1.02
T	0.64	0.91	1.10	1.17	0.96
B	0.78	0.92	1.04	1.18	0.99

b. In 1963 (b.y.cov. = 1961)

ViK	10	30	50	70	A
TC 1962-63	1.16	1.25	1.49	1.51	1.36
T	1.11	1.08	1.37	1.45	1.26
B	1.13	1.16	1.43	1.48	1.31

c. In 1964 (b.y.cov. = 1963)

ViK	10	30	50	70	A
TCS 1964	1.18	0.96	1.62	1.66	1.38
T	0.97	1.19	1.09	1.12	1.09
B	1.08	1.08	1.36	1.39	1.24

T a b l e 3 4 a, b, c

ViK. Average radial growth of spruce (mm) on cooled (TC) and untreated (T) plots with different water depths

a. In 1962 (b.y.cov. = 1961)

ViK	10	30	50	70	A
TC 1962	1.50	1.91	1.94	1.70	1.76
T	1.22	1.42	1.80	1.77	1.55
B	1.36	1.66	1.87	1.73	1.66

b. In 1963 (b.y.cov. = 1961)

ViK	10	30	50	70	A
TC 1962-63	1.34	1.55	1.50	1.54	1.48
T	1.34	1.08	1.70	1.44	1.39
B	1.34	1.31	1.60	1.49	1.43

c. In 1964 (b.y.cov. = 1963)

ViK	10	30	50	70	A
TCS 1964	1.81	1.65	1.96	2.03	1.86
T	1.27	1.43	1.33	1.30	1.33
B	1.54	1.54	1.65	1.66	1.60

Table 35 a, b, c, d, e

KiR. Average height growth of pine (mm) on cooled (TC), strawcovered (TS), fertilized (F) and untreated (U) plots with different water depths

a. In 1962 (b.y.cov. = 1961)

KiR	10	30	50	70	A
TC 1962	88	89	112	83	93
T	84	77	93	104	89
B	86	84	103	92	91

b. In 1963 (b.y.cov. = 1962)

KiR	10	30	50	70	A
TC 1962-63	84	97	72	76	82
T	90	88	70	89	84
B	87	92	71	83	83

c. In 1964 (b.y.cov. = 1963)

KiR	10	30	50	70	A
TCS 1964	64	58	74	57	63
T	74	100	88	92	88
B	69	79	81	74	76

d. In 1963 (b.y.cov. = 1962)

KiR	10	30	50	70	A
F 1962	94	126	120	160	126
U	101	120	90	103	103
B	97	123	105	132	114

e. In 1964 (b.y.cov. = 1962)

KiR	10	30	50	70	A
F 1962	186	141	197	223	187
U	135	141	141	149	143
B	160	141	169	186	165

Table 36 a, b, c, d, e

KiR. Average radial growth of pine (mm) on cooled (TC), strawcovered (TS), fertilized (F) and untreated (U) plots with different water depths

a. In 1962 (b.y.cov. = 1961)

KiR	10	30	50	70	A
TC 1962	0.22	0.25	0.21	0.29	0.24
T	0.28	0.24	0.32	0.33	0.29
B	0.25	0.24	0.26	0.31	0.27

b. In 1963 (b.y.cov. 1961)

KiR	10	30	50	70	A
TC 1962-63	0.27	0.32	0.33	0.30	0.31
T	0.42	0.36	0.41	0.44	0.41
B	0.34	0.34	0.37	0.37	0.36

c. In 1964 (b.y.cov. = 1963)

KiR	10	30	50	70	A
TCS 1962-64	0.43	0.39	0.44	0.45	0.43
T	0.35	0.43	0.43	0.43	0.41
B	0.39	0.41	0.43	0.45	0.42

d. In 1963 (b.y.cov. = 1962)

KiR	10	30	50	70	A
TC 1962-63	0.40	0.44	0.44	0.39	0.42
T	0.50	0.47	0.48	0.50	0.49
F 1962	0.50	0.77	0.57	0.89	0.68
U	0.50	0.50	0.55	0.44	0.50
B	0.48	0.58	0.53	0.59	0.54

e. In 1964 (b.y.cov. = 1962)

KiR	10	30	50	70	A
TCS 1964	0.44	0.46	0.50	0.47	0.47
T	0.49	0.54	0.56	0.58	0.54
F 1962	0.56	1.47	1.20	1.55	1.20
U	0.57	0.77	0.85	0.68	0.72
B	0.53	0.91	0.86	0.92	0.81

Table 37 a, b

KiK. Average radial growth of birch (mm) on fertilized (F) and untreated (U) plots with different water depths

a. In 1963 (b.y.cov. = 1962)

KiK	10	30	50	70	A
F 1962	0.56	0.78	0.84	0.68	0.72
U	0.41	0.69	0.64	0.78	0.63
B	0.49	0.73	0.74	0.73	0.67

b. In 1964 (b.y.cov. = 1962)

KiK	10	30	50	70	A
F 1962	0.50	0.69	0.88	0.72	0.70
U	0.56	0.63	0.66	0.77	0.65
B	0.53	0.66	0.77	0.75	0.68

T a b l e 3 8 a, b

KiK. Average radial growth of spruce (mm) on fertilized (F) and untreated (U) plots with different water depths

a. In 1963 (b.y.cov. = 1962)

KiK	10	30	50	70	A
F 1962	0.41	0.51	0.55	0.48	0.49
U	0.43	0.43	0.46	0.39	0.43
B	0.42	0.47	0.50	0.43	0.46

b. In 1964 (b.y.cov. = 1962)

KiK	10	30	50	70	A
F 1962	0.75	1.12	0.92	0.90	0.92
U	0.58	0.66	0.78	0.59	0.65
B	0.66	0.89	0.85	0.75	0.79

Appendix 1

Root systems in Scots pine stands in swamp-hydrology experimental areas in North and South Finland.

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Helsinki 1965

1. Introduction

Earlier investigators (Melin 1917, Kokkonen 1923, Multamäki 1923, Laitakari 1927, Malmström 1935, Björkman 1941, Heikurainen 1955 b) have demonstrated that the root systems of trees growing on swamps penetrate the soil deeper after drainage, and that both the total quantity of all roots and the ratio of true mycorrhizae to the total number of short roots increase.

None of the above studies, however, have thrown any light on the effect of strip width and ditch spacing upon the development of tree root systems in swampy soils after drainage. Nor has there been any enquiry into whether the structure and development of tree root systems on Finnish swamps vary regionally according to macroclimate. These are essential questions to answer if it is to be decided which methods of ditching will lead to the best results in different parts of Finland. Research is of immediate interest at the present stage of progress in forest drainage, in which the cutting of costs due to mechanization allows greater attention to be paid to biological factors in ditching.

The principal object of the present study is to clarify the effect of different strip widths between ditches on the development of root systems in swamp pine stands. From an immediately practical point of view, we wished to determine whether the effect of ditch spacing is always the same, despite variations of climate. The test were made on strip-width experimental areas at Liesneva and Jaakkoinsuo in South Finland, and Mortti near Rovaniemi in North

Finland. At the time the study was made, six or more growing seasons had elapsed since drainage.

For additional data on the way in which root systems in swamp pine stands react to hydrological changes in the site in different climates, tests were also made in ditch depth experimental areas at Sattasuo (Kivalo) and Jaakkoinsuo. Here we compared root systems on sample plots of the same size, surrounded by ditches in which the water table had been kept constant at fixed levels for 2-3 years. To achieve this effect, we dammed the main ditches and allowed water to run in to make up deficiencies caused by evaporation. Thus the distance between the ditches was the same on all the sample plots and differences in their water economy were caused by the levels to which the water in the ditches was regulated. The difference in depth between the ground level and the water level in the ditches around the sample plots is here termed ditch depth.

In the ditch depth experimental areas, different growth factors were measured and their peat microbiology and nutrient balance were studied. Our results have enabled us to demonstrate the correlation between the post-drainage development of root systems in swamp pine stands and changes in site factors - in particular the correlation between the depths of the root systems and that of the ground water.

The study provided data on the total length, distribution into thickness classes and vertical distribution of long roots between the trees, and also on the number and vertical distribution on short roots. These data were obtained using quantitative methods developed by Kalela (1949, 1954, 1955) and Heikurainen (1955 a, 1955 b). The proportion of mycorrhizae in short roots was also investigated. In addition we

looked for regression ratios between the structure of the root system and stand increment, in both the strip-width and ditch-depth experimental areas.

2. Methods of Research

21. Root systems

It is virtually impossible to study the thinnest roots by methods used earlier, such as digging them up and making drawings of them. This is specially so when the root systems of entire tree stands are being investigated. (cf. Kalela 1949). Kalela (ibid.) has therefore developed a method by which roots are studied after being separated from soil samples of a given size. This method has been further developed by Heikurainen (1955 a, 1955 b) for the study of roots in swamp stands. We ourselves used the method as adapted by Heikurainen (1955 b).

Most of our samples measured 10x10 cm in cross section. Since 1963, however, we have been taking samples of 5x4 cm. After removal of litter and living mosses, the samples were divided into subsamples 5 cm long. In the laboratory, they were rinsed in water and the living pine roots were separated from the subsamples and examined in detail under a stereomicroscope. The roots were divided into three thickness categories: under 1 mm, 1-2 mm, and over 2 mm. Then they were measured for length. This enabled us to determine the length of pine long roots at depths of 0-5 cm, 5-10 cm, 10-15 cm, etc., in each root sample.

In the samples referred to below in Sections 3 and 4, the short roots were separated from the long roots and counted. Each tip was counted separately, in the same way as Heikurai-

nen (1955 b) did. The density per length unit of long roots was calculated on the basis of the actual number of short roots counted. But we only took into account long roots of a thickness less than 1 mm, because, with a few exceptions, short roots were found only on long roots in this thickness class.

The proportion of mycorrhizae was studied stereo-microscopically, mainly from the external appearance of the short roots. Since the distinction between the different types of mycorrhizae presented in the literature (Melin 1917, 1923, 1927, Björkman 1941, 1942, etc.) is somewhat uncertain when based solely on the external appearance of the short roots (cf. Mikola & Laiho 1962) we confined ourselves to counting the number of "good" mycorrhizae, which differ quite distinctly from other short roots. In this study, "good" mycorrhizae are taken to be ramified or unramified, light-coloured, fairly thick short roots which can be seen even with the naked eye to be mycorrhizae. Thus they correspond to the short roots referred to as "good-A-mycorrhizae" by Mikola & Laiho (1962).

The number of good mycorrhizae in the samples taken in 1964 was counted by means of paraffine sections. Slides were prepared according to Mikola & Persidky's (1951) method. In the microscopical examination, a short root was counted as a good mycorrhiza when both the mantle formed around the root by mycorrhizal fungi and the Hartig net in the intercellular spaces of the cortex were well developed, and when the mantle formation was strong. Short roots lacking a mantle or a Hartig net were not considered to be true mycorrhizae.

The research method used probably gives reliable data on

the depth of root systems when the number of samples is small. In poorly drained swamps, for example, most of the roots are located rigth near the surface of the swamp and are prevented from penetrating deeper into the peat by purely incidental factors. The method does not make it absolute clear how deep the root system reaches, because the roots were separated from subsamples 5 cm long. In this study, the lower limit of the deepest soil layer in which living pine roots were encountered in at least one sample per plot was regarded as the lower limit of the root system.

In examining vertical root distribution by the method under scrutiny here, the root system depth has generally been indicated by the mean depth weighed by the number of roots (Kalela 1949, Heikurainen 1955 b). The mean depth thus calculated, however, does not always give a correct picture of the effect of strip width and ditch depth on the root system depth. For this reason the mean root depth is used here to describe the root system depths. By this is meant the quotient:

$$D = \frac{\sum d}{n}$$

in which D = mean root depth per sample plot

d = root depth of individual sample

n = number of samples per sample plot.

The lower limit of lowest depth layer at which roots were found in amounts not less than 1 per cent of the total number of roots in the sample was regarded as the root depth of each individual sample. This modification was necessary in order to avoid making the mean root depths dependent on roots that,

owing to their small quantity, probably have no importance for the growth of the stand.

Further reliability tests of our method of study showed that the various laboratory procedures and the quality of the sample stands had practically no effect on the comparability of the results of the study.

Where comparability between samples was required, these were taken as nearly simultaneously as possible to avoid discrepancies due to structural changes occuring in the root systems during the growing season. With a few exceptions, the samples were taken in August and September - a period when the root systems of trees growing on swamps are in a fairly constant state (cf. Heikurainen 1955 a).

22. Other investigations

In this study, ground-water level refers to the distance between the ground surface and the water table formed in ground water holes. Our measurements were taken in open ground water holes with a cross sectional area of 100 sq.cm. bored in the peat. This method has been used by Huikari (1959 b), among others. The ground-water observations for each growing season were made three days in June-August in order to even out variations caused by weather conditions.

In additions we determined the swamp types of our sample plots using the terminology of Heikurainen (1960). Peat structure, stand quality, and stand increment were also examined.

The depth of the peat layer on the sample plots was measured. To determine the peat type and degree of humification, we used von Post's (1922) scale. The peat types were also determined by a microscopical method presented by Heiku-

rainen & Huikari (1952). In the Liesneva area, the degree of humification was further ascertained by measuring the volume weight of the peat, which is distinctly correlated to the degree of humification (cf. Kivinen 1948, Kaila 1956 and Sarasto 1960).

The age, cubic volume, number of stems (and in the ditch-depth experimental areas their me diameter) and their height and diameter growth were all noted. The growth of the trees was further studied by Huikari's (1962) banding method. By this method the circumference growth at breast height of the sample trees was measured.

3. Strip Width Experimental Areas

31. Material

The strip-width experimental areas studied were situated at Liesneva, and Jaakkoinsuo in South Finland, and at Mortti near Rovaniemi in North Finland.

At Liesneva, three strip width sample plot series were established in 1954-1955. Each series included strips 5, 10, 20, 40, 60, 80 and 100 metres wide (cf. Huikari 1959 b). The three series were divided into three sections as follows:

1. Sample plots I-VII, established on strips of varying widths on an open-ditch sample plot series.
2. Lines A-C transversing the covered-ditch series.
3. Plots 1-10 located in the middle of strips of varying width in the covered-ditch sample plot series.

The original swamp type of plots I-VII was cotton-grass pine swamp. Their ground vegetation and stand quality are shown in Table 1. Root samples were taken from plots I-VII at distances as uniform as possible from each other, but not

closer than 1.5 metres to the ditches. The only exceptions to the latter were the sample series taken from plots I and II on which sampling was performed on the 7th of September 1962. These samples were used to study root distribution near ditches. For the study of the growth of trees, trees as equal in size as possible were selected at regular intervals along diagonals running N.E.-S.W. on sample plots I-V. Their circumference growth was measured in 1962 and 1963 by the banding method. Diameter growth was determined from increment cores and height growth of the same trees was also measured for seven years before and after drainage.

The original swamp type of the Liesneva covered-ditch sample plot area was cotton-grass pine swamp with some features denoting ordinary sedge pine swamp.

The root samples from lines A-C were taken along the ground-water hole lines, one sample at each ground-water hole. In the 5 and 10 m strips, additional samples were taken near the ground water hole in a longitudinal direction in order to obtain the eight samples required from these strips. Along lines A and B, the growth of trees was examined by measuring the height growth, for eight years before and after ditching, of the tree stems closest to each sampling point that had a breast-height diameter of at least 6 cm. Diameter growth was also measured by means of increment core in the same trees.

Ten root samples between the swamp surface and a depth of 30 cm were taken from plots 1-10 at equal distances along their centre lines. Further samples were taken from plots 5 and 6 for the purpose of studying vertical distribution and growth of roots. The growth of trees on plots 1-10 was

measured in the same way as on lines A and B, from the 10 stems nearest to the centre lines.

At Jaakkoinsuo, too, the distances between ditches varied. Here, we studied the effect of these differences on root systems more than ten growing seasons after ditching. The original swamp type in the Jaakkoinsuo area was cotton-grass pine swamp with undershrubs. Root samples were taken at regular distances from each other, 12 from each plot, on the 30th of August 1963. The growth of trees was examined by measuring 6-7 trees on each sample plot by the banding method. The same trees were used to study diameter growth. Stand volume was also measured. Ground water measurements were carried out in June-August 1956-63.

In the experimental area at Mortti there were four sample plots 5x40 metres. The original swamp type was herb-rich sedge pine swamp. Ten samples were taken at regular intervals along the centre-line of each sample plot on the 15th of August 1962. The samples measured 30x10x10 cm. Height and diameter growth in the stand were determined from the ten sample trees nearest to the centre-line of the sample plot in each plot.

32. Long roots

As can be seen from Table 2, the length of long roots increased after ditching at Liesneva. On the plots on which the space between the ditches varied between 20-80 metres, the total length of the roots was the greater the narrower the strip was. On the contrary, the 5 and 10 metre strips, generally contained roots of a smaller total length than the 20m strips. This phenomenon may be partly due to a tendency of the roots to reach out towards the ditch banks or,

in covered-ditch swamps, the peat covering ditches. It is also possible that drainage has so far improved conditions for tree growth on the 5 and 10 m strips that the stands are able to thrive on a smaller root system.

The correlation between strip width and the total length of roots was similar both in the older drainage area at Jaakkoinsuo and at Liesneva. More than 25 years after ditching, the total length of roots at Jaakkoinsuo varied inversely with the distance between ditches. Jaakkoinsuo has no 5 or 10 metre strips, so no comparison could be made in this respect. The total length of the roots increases most during the 10-15 years immediately after ditching.

Data from the Mortti experimental area indicate that in N. Finland, too, the total length of roots in swamp pine stands increases after drainage. It seems that the effect of strip width on total root length at Mortti was similar to that in the South-Finnish experimental areas.

The total length of the roots on all the sample plots at Mortti was quite small - a mere 51-117 m/sq.m. The total length of roots in swamp pine stands of a similar cubic volume in South Finland was 616 m/sq.m. in Heikurainen's (1955 b) study. Our results, too, make it clear that the total length of the roots in swamp pine stands of equal volume is noticeably smaller in North Finland than in the South.

The distribution of roots into thickness classes was studied at Liesneva, Jaakkoinsuo and Mortti. We found that the root systems of swamp pine stands are very largely formed of thin roots (Table 3). Our results also seem to indicate that ditch spacing has no clear effect on the distribution

of roots into thickness classes.

From tables 4-6 it can be seen that drainage has deepened the root systems at Liesneva in less than 10 years. After this initial period, the increase in the root system depth is rather slow, according to the data obtained at Jaakkoinsuo (Table 7). The narrower the width between the ditches in 5-80 metre wide strips, the greater has been the increase in depth of the root systems. But even in very effectively drained swamps, the bulk of the roots was encountered at depths of a mere 0-10 cm. Only on very narrow (5 and 10 metre) strips the roots have penetrated noticeably deeper than this. Similar results came to light at Mortti in N. Finland. (Table 8).

A comparison between North and South Finland shows that roots in swamp pine stands have not penetrated the peat layers so deep in the Mortti area as they have at Liesneva. For example, the mean root depth on the Liesneva sample plots varied between 10.7-23.6 cm, while that in the Mortti area only exceeded 10 cm on the 10 metre strip. The lower limit of the root systems, too, was deeper at Liesneva than at Mortti. In the light of the results, it is obvious that root systems in swamp pine stands are nearer the surface in N. Finland than in the South.

A study of the correlation between the depth of the root systems and ground-water level showed that solitary roots sometimes follow the ground-water level quite deep into the peat close to ditches (Fig. 1). But the mean depth of root systems is much smaller than the distance between the swamp surface and the ground-water table. This is because the deeper a peat layer becomes, the less the root system deepens

in relation to the drop in the ground-water level (Fig. 2). Even after they have been drained for a long time, swamp pine roots only penetrate part of the increased depth between the ground surface and the ground-water table brought about by ditching.

33. Short roots.

The total number of short roots has increased after drainage at Liesneva, and in strips 20-80 metres wide, the increase is the greater the narrower the strips. But in this case, too, the number of short roots was smaller in the 5 and 10 metre wide strips than in the 20 metre strips. Moreover, we found that in densely ditched swamps there were not so many short roots per length unit of long roots as there were in swamps with wider ditch spacing. At Jaakkoinsuo, the total number of short roots was roughly the same on plots 12, 14 and 15. Plot 13 had more short roots owing to its greater quantity of long roots.

Examination of the vertical distribution of short roots at Liesneva revealed that these roots lie nearer the surface even than the long roots. Drainage increased the depth at which short roots were found, but it is only on the 5 and 10 metre strips that the number of short roots has grown in depth layers others than just below the surface. Elsewhere, it has only affected their density in the superficial layers. At Jaakkoinsuo, the depth of occurence of short roots has grown to some extent with the passing of time since drainage.

Ditch spacing was found to have a decisive effect on the proportion, total number and vertical distribution of such mycorrhizae which are characteristic of good forest soils (Table 10). At Liesneva "good" mycorrhizae were found in

greater numbers and at greater depths in the 5 and 20 m strips than in the 40-60 m strips or on the undrained cotton grass pine swamps. At Jaakkoinsuo it has been found out that, just like other short roots, mycorrhizae tend to go deeper as time passes after drainage.

34. Structure of root systems, and stand increment.

The narrower the strips, the greater the increment, such has been the finding at Liesneva, since the drainage of the sample plots there (Fig. 14). On comparing stand increment with our data on roots, we found no clear correlation between the increase in total root quantities and the revival of growth. But the greater the depths at which both long and short roots have been encountered, the greater has been the stand increment since drainage. There is quite a clear correlation between stand increment and the number of "good" mycorrhizae found. On the narrowest (5-20 m) strips, where the increment has been greatest, there were more "good" mycorrhizae and they were encountered at greater depths than on strips over 20 metres wide. The correlation between stand increment and the number of "good" mycorrhizae is born out by earlier studies (Melin 1927, Björkman 1942, Bergemann 1955, Mikola & Laiho 1962 etc.).

At Jaakkoinsuo, too, the stand increment on the narrow strips has been quite remarkable. Diameter growth accelerated rapidly, quite soon after ditching, at the same time as the root system deepened and the number of roots increased.

At Mortti, our material consisted mainly of young stands with a good growth potential. The height and diameter growth have increased on all sample plots, thanks to drainage. The height growth has been roughly similar on strips of different

widths. Diameter growth accelerated a little more on the 10-20 m strips than it did on the wider ones. The increase in both the total quantity of roots and the root system depths was found to correlate with the revival of stand increment.

4. Ditch-depth experimental areas

41. Material

As stated in the Introduction, the reaction of swamp pine root systems to hydrological changes in the site was studied in ditch-depth experimental areas at Jaakkoinsuo in S. Finland and Sattasuo in North Finland. As far climate is concerned, the Jaakkoinsuo area resembles the Liesneva strip-width area, while Sattasuo is similar to Mortti, which is also in Finnish Lapland.

Water conditions on different sample plots were varied for comparion's sake by regulating the water level in the ditches surrounding them. In both experimental areas the regulated levels, here termed "ditch depths" are 10, 30, 50 and 70 cm below the ground surface. Where the ditches were 10 cm deep, the distance between the ground water talbe and the soil surface was roughly the same after regulation as it had been during rainy weather before regulation. At the other ditch depths, the ground water level was lower than it had been previously.

The swamp type of the ditch-depth experimental areas at Jaakkoinsuo was cotton grass pine swamp with undershrubs. Sample plot series A was established in autumn 1960, series B in 1961. In series A, examination of roots began before water conditions were regulated. Five samples 10x10 cm were

taken from each parcel on the 6th and 7th of October 1960. Sampling was repeated between the 27th and the 29th of August 1963. The 1963 samples measured 5x4 cm. Further samples were taken on the 29th of June 1964 from the 10 and 70 cm ditch-depth plots in series B. The sampling points and the number and size of the samples were the same as in 1963. The circumference and height growth of all trees on the sample plots were measured in 1962 and 1963. The level of the ground-water table was noted at the water holes.

The Sattasuo ditch-depth experimental area was established in early summer, 1961. The swamp type was herb-rich sedge pine swamp. Root samples, 5x4 cm, were taken between the 1st and the 3rd of August 1963. On the 7th and 8th of July 1964, further samples were taken from sample plots with ditch depths of 10 and 70 cm. The number and size of the samples and the sampling points were the same as in 1963. The height and diameter growth of all the pines on the sample plots were measured in 1962 and 1963.

Since the structure of root systems at Sattasuo was almost similar in series A and B, the root system data from these series have been combined.

42. Long roots

Variations in ditch depth had little effect on the total length of long roots at Jaakkoinsuo. On sample plot series A, there was in fact a significant difference in root averages on the 10 and the 50 cm ditch depth plots, but no comparable results were obtained on series B. At Sattasuo the total length of long roots was smaller on plots with a ditch depth of 70 cm.

The difference between Jaakkoinsuo and Sattasuo was remarkable. At Jaakkoinsuo the amount of long roots varied between 363 and 752 m/sq.m. Nowhere at Sattasuo did they exceed 300 m/sq.m. On the basis of our results, therefore, it seems that the total length of roots in swamp pine stands with equal volumes is smaller in N. Finland than in S. Finland. This agrees with the results obtained in our strip-width areas.

There is no correlation between ditch depth and the distribution of roots into thickness classes at either Jaakkoinsuo or Sattasuo (Table 11). It seems from our findings that the ratio of thin roots (under 1 mm) to the total length of roots is greater in S. Finland than in the North.

The vertical distribution of roots varied hardly at all on the sample plots at Jaakkoinsuo (Table 12). Sattasuo was similar in this respect. Not even the biggest differences in ditch depths seem to have any effect on the vertical distribution of long roots in either area.

At both Jaakkoinsuo and Sattasuo, we looked for a correlation between the root system depths and the ground-water level (Tables 13-14). We found no clear correlation between the ground-water level and either the lower limits or the mean depths of the root systems. Obviously, therefore, a drop in the ground-water level does not increase the root system depth within a period of three years.

The root systems were found to be nearer the surface at Sattasuo than at Jaakkoinsuo. The mean depth of the root systems at Jaakkoinsuo varied between 9.6 and 13.4 cm, but on none of the sample plots at Sattasuo did it exceed 8 cm. These results, which accord with the data from the strip-

width areas, show that the root systems of swamp pine stands penetrate a thinner layer of peat in the north of Finland than in the South.

43. Short roots

Variations in ditch depth at Jaakkoinsuo had no clear effect on the total number of short roots (Table 15). At Sattasuo there were fewer short roots on plots with ditches 70 cm deep. This was largely because the total length of the long roots was less at this ditch depth. Probably, too, the density of short roots on 70 cm ditch depth plots was lower in both experimental areas. Our data makes it clear that in both climatic regions roughly equal quantities of short roots are formed per length unit of long roots.

At neither place was there any clear correlation between ditch depth and the vertical distribution of short roots (Tables 16-17). In both areas, a decrease in the total density of short roots was observed only at depths of 0-5 cm.

The ratio of mycorrhizae to total short roots was studied in 1963 by counting the number of "good" mycorrhizae based on the appearance of the short roots under a stereo-microscope (Table 18). We found that a ditch depth of 70 cm reduced the depth at which "good" mycorrhizae were found at Jaakkoinsuo, but not at Sattasuo. In the latter area there were less "good" mycorrhizae than at Jaakkoinsuo - counted both per area unit and as percentage of all short roots. Microscopic examination the following year did not bear out the above results in every respect (Table 19). In 1964 we used permanent slides, 3-10 for each subsample. Our results then indicated that 70 cm ditch-depth had a favourable effect on the formation on mycorrhizae at both Jaakkoinsuo and Sattasuo,

though only near the surface of the swamps. The formation of mycorrhizae became clearly poorer as we penetrated deeper into the peat layer.

44. Structure of root systems and stand increment

From Table 20 it can be seen that differences in ditch depth had little effect upon swamp pine increment in the Jaakkoinsuo and Sattasuo ditch-depth areas during the three years immediately following water regulation. Neither were there any great changes in the root systems during that time. None of the differences observed in respect of the density of short roots, the proportion of mycorrhizae and, at Sattasuo, the total quantities of long and short roots seemed to have effected increment.

5. Conclusions and Summary

51. Effect of strip width on the development of root systems in swamp pine stands after drainage.

In the strip-width experimental areas at Liesneva and Mortti the correlation between strip width and the structure of root systems in swamp pine stands was studied 6-9 growing seasons after these stands had been drained. At Liesneva in S. Finland, it was found that ditch spacing effected the quantity of long and short roots, the depth of the root systems and the proportion of mycorrhizae in short roots. Similar results were obtained at Mortti in N. Finland as regards long roots, but short roots were not studied there. At neither place was any correlation found between strip width and the distribution of roots into thickness classes.

When the correlation between the strip widths and the quantity of roots was examined, it was found on strip widths

varying between 20-80 metres that, the narrower the strips were, the more both long and short roots increased in quantity after drainage. On the narrowest strips, 5 and 10 metres wide, the quantity of roots was generally smaller than it was in the 20 metre strips.

Even though drainage did not greatly increase the total quantity of roots on the 5 and 10 metre strips, stand increment after ditching on these strips was noticeably greater than it was on the wider strips in the Liesneva experimental area. This seems to indicate that a rapid increase in root quantity is not absolutely necessary for the revival of the increment under conditions such as those prevailing in S. Finland. In N. Finland, where the quantity of roots is very small to start with, an increase in the total quantity of roots up to a certain limit may well be unreservedly advantageous for stand increment. This is borne out by our data from Mortti, which revealed a correlation between the increase in the total quantity of roots after drainage and the revival of stand increment.

A clear correlation was found between strip width and the depth of root systems at both Liesneva and Mortti: the narrower the strips used, the greater was the depth of root systems. The proportion of mycorrhizae typical of good forest soils also correlated with the strip width. Mycorrhizae were encountered in narrow strips more frequently and at greater depths than in wide strips.

According to our results, narrow ditch spacing improves the ability of swamp pine stands to take in nutrients. It increases the quantity of mycorrhizae, both absolutely and proportionally, and enables the roots to obtain nutrients

lying beneath the superficial peat. It is very probable that this improved nutrition accelerates stand increment, for a clear correlation could be observed between root system depth and the proportion of "good" mycorrhizae.

Investigations in an old drainage area at Jaakkoinsuo in S. Finland bore out the results obtained in other areas concerning the effect of strip width on root systems in swamp pine stands. They also demonstrated that the structure of root systems does not change very much as time goes by after drainage. Only the depth of occurence of short roots and the proportion of "good" mycorrhizae seem to have increased with the passage of time in the older drainage areas.

Data from the Liesneva, Mortti and Jaakkoinsuo strip-width experimental areas indicate that strip width plays a decisive role in the structural changes in the root systems in swamp pine stands and in the acceleration of increment after ditching: the narrower the strips used, the better is the effect of drainage on both the root systems and their aerial parts.

52. Ground water level and depth of root system.

Earlier investigators (Kokkonen 1927, Metsävainio 1931, Linkola & Tiirikka 1936, etc.) considered that the superficial structure of the roots of coniferous trees and swamp plants in general is largely the result of the nearness of the ground water to the soil surface. They felt that ditching to deepen the ground water table would also deepen the root systems.

A study of the ditch-depth experimental areas at Jaakkoinsuo (S. Finland) and Sattasuo (N. Finland) revealed that the root system depth of these swamp pine stands had not

changed to any noteworthy degree in three years, even though the ground water table during this period was as much as 0.5 metres lower than it had been before water regulation. In the old drainage areas at Liesneva and Jaakkoinsuo, root systems were indeed found to have become deeper as a result of lowering the ground water-table, but the new root system depths were nowhere nearly as great as the distance between the ground surface and the lowered ground water table. This latter point has been confirmed by Multamäki (1923) and Heikurainen (1955 b), among others.

In the light of our results it seems that the principal effect of deepening the ground water table on the growth and efficiency of swamp pine root systems is to be seen in the parts of the swamp soil nearest to the surface; the water content decreases and airspaces increase correspondingly as the distance between the soil surface and the ground water table grows (cf. Eggelsmann 1957, Paavilainen 1963, Heikurainen 1964, etc.).

At depths below this superficial layer, the efficiency of the root systems does not improve so quickly as to augment the depth of the root systems in the years immediately following water regulation. It takes rather a long time for the roots to penetrate the deeper layers. Probably, they can only do so after other site factors, besides the ground water level, have produced a beneficial effect on the roots.

53. Macroclimate and root systems in swamp pine stands.

Our results in both the strip-width and the ditch-depth experimental areas agree in indicating that the quantities of long and short roots in swamp pine stands of similar

volume are smaller in N. Finland than in S. Finland, and that the root systems in such stands are closer to the surface in the north of the country. In N. Finland these systems have a much smaller root mass with which to take up the water and nutrients essential for tree growth than they have in S. Finland, and the water and nutrients are contained in a considerably thinner layer of peat. The data show clearly that the disparity between North and South Finland as regards increment in swamp pine stand are partly due to differences in the structure on the root systems of the stands caused by the dissimilarity of climate.

The soil temperature at Sattasuo in N. Finland is noticeably lower than at Jaakkoinsuo in S. Finland. This unfavourable soil temperature probably accounts for the poorer growth of the root systems in the North-Finnish swamp pine stands. It may be well that one reason for the differences in the vertical distribution of roots is that in the North roots get their nutrition only from a very thin layer - i.e. the warmest surface layer of the peat, whereas the South Finnish temperatures are more favourable for the vertical growth of the roots.

The data from the ditch-depth experimental areas indicate that the effect of hydrological changes in the root systems of swamp pine stands was much the same in South and North Finland. The most remarkable climatic difference was that a decrease in the quantities of long and short roots following effective drainage was only encountered in N. Finland. On the other hand, in the strip-width wxperimental areas the development of root systems after drainage was very similar in

both parts of the country. From the results of our study, it is evident that the macroclimate has no decisive effect on the reaction of swamp pine root systems to water regulation caused by ditching.

6. Literature

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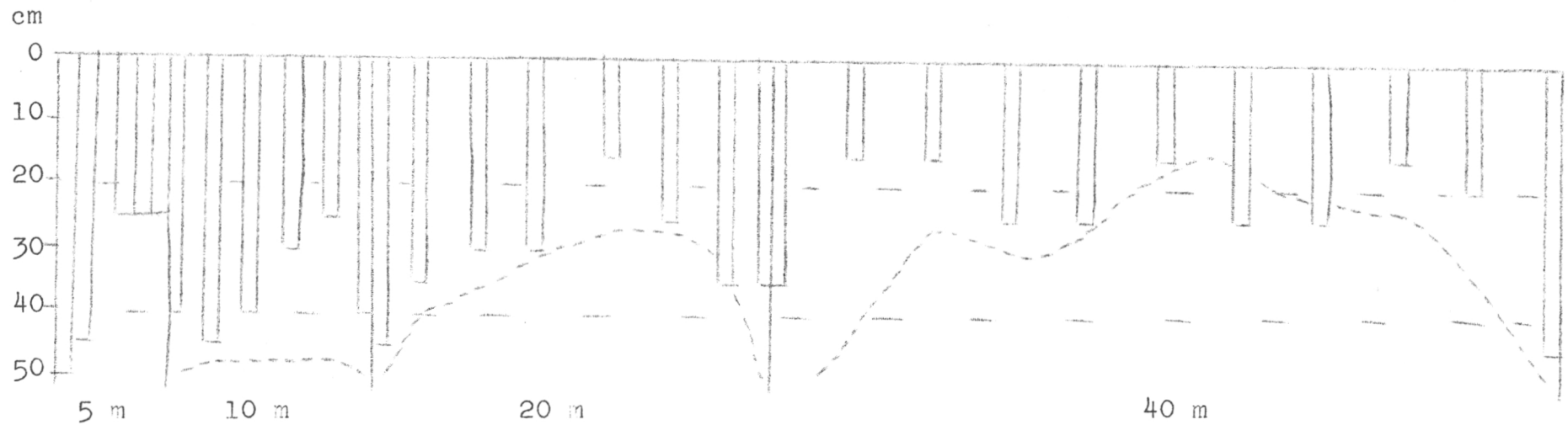

Figure 1. Root depth on strips 5 to 40 metres wide at various distances from the ditches on the covered ditch experimental plot at Liesneva. The ground water level (the mean of measurements made from June through August in 1962) is indicated in the figure by a dashed line.

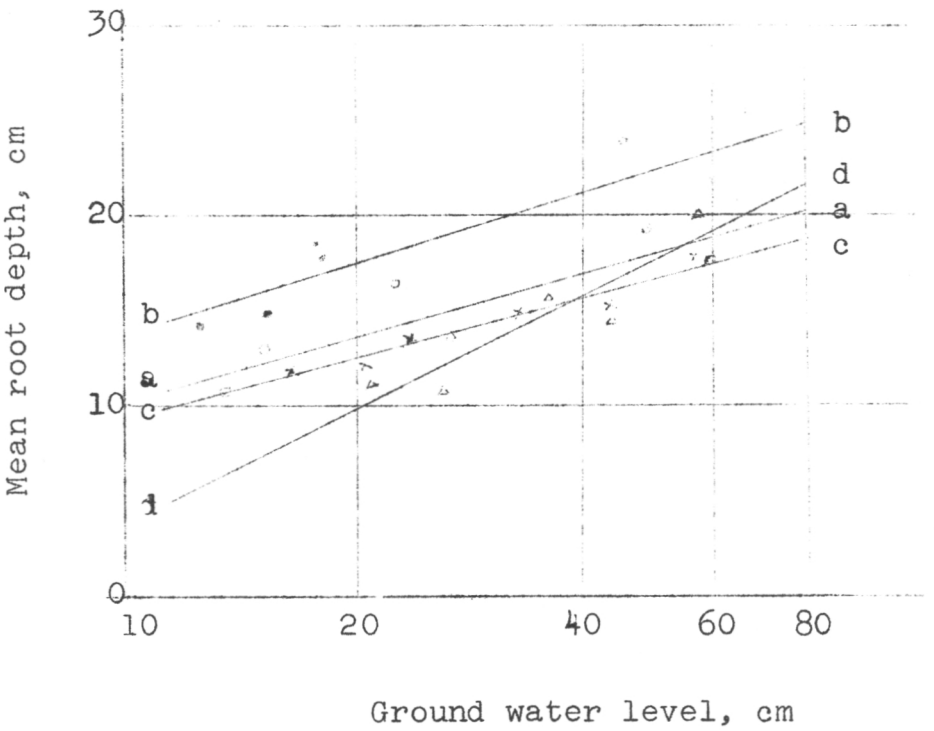

Figure 2. The regression of the mean root depth on the ground water level in the sample plots at Liesneva.

a) $y = 10.97 \log x - 0.67$ ($r = 0.89$)

b) $y = 13.57 \log x - 1.12$ ($r = 0.96$)

c) $y = 10.45 \log x - 1.17$ ($r = 0.98$)

d) $y = 19.96 \log x - 16.28$ ($r = 0.93$)

T a b l e 1

The ground vegetation of sample plots I - VII on the openditch experimental field at Liesneva in 1963

Plant species	Sample plot						
	I	II	III	IV	V	VI	VII
	Per cent of coverage[1)]						
Cladonia spp.	0.3	+	-	+	+	+	+
Sphagnum fuscum	-	-	-	0.4	2.5	6.5	6.2
Sphagnum magellanicum	+	0.3	0.1	0.5	0.2	2.2	6.8
Sphagnum parvifolium	0.6	25.2	60.0	72.0	62.0	74.0	75.5
Sphagnum rubellum	-	-	-	-	+	-	-
Pleurozium Schreberi	7.6	0.1	+	+	+	+	-
Polytrichum strictum	1.4	0.7	0.4	0.2	3.0	0.5	+
Aulacomnium palustre	3.7	3.4	0.6	0.4	+	+	+
Eriophorum vaginatum	0.1	0.2	1.7	4.7	4.9	6.0	3.8
Rubus chamaemorus	-	0.1	0.2	0.7	0.5	1.5	2.1
Andromeda polifolia	+	+	+	+	+	+	0.2
Calluna vulgaris	+	7.5	6.4	6.9	3.3	3.4	0.8
Empetrum nigrum	1.8	1.3	1.7	2.2	2.5	2.0	2.3
Betula nana	0.6	0.6	0.1	0.1	+	+	+
Ledum palustre	0.1	-	-	-	-	-	-
Vaccinium myrtillus	+	+	+	-	-	-	-
Vaccinium uliginosum	22.3	10.5	7.5	8.7	6.1	5.5	2.4
Vaccinium vitis-idaea	0.6	-	-	-	-	-	-
Vaccinium oxycoccos	+	+	+	+	+	+	0.1
Vaccinium microcarpum	-	+	+	+	+	+	+
Pinus silvestris	+	-	-	+	+	-	-
Betula pubescens	0.1	-	-	-	-	-	-

1) Mean of 10 subplots (size 0.25 sq.m) situated at regular intervals and distances in each sample plot

T a b l e 2

Total length of roots in sample plots at Liesneva

Sample series[1]	Strip width, m													
	LT[2]	80	60	40	20	10	5	LT	80	60	40	20	10	5
	Roots, m/sq.m							Roots, km per cu.m of growing stock						
a	-	324	362	525	502	848	312	-	98	82	74	76	81	44
b	-	484	486	651	686	513	382	-	87	95	136	123	107	73
c	-	304	304	405	512	354	669	-	298	163	162	161	109	204
d	419	-	368	601	1 026	816	680	220	-	197	241	323	251	207
e	-	324	718	669	658	-	-	-	71	162	136	145	-	-

1) a = Lines A - B, b = Sample plots 5 - 10, c = Sample plots I - VI in 1962, d = Sample plots I - V and VII in 1963, e = Sample plots 1 - 4

2) LT = Undrained cottongrass pine swamp

T a b l e 3

Distribution of roots into thickness classes in sample plots at Liesneva

Thickness class, mm	Strip width, m						
	LT[1)]	80	60	40	20	10	5
	Per cent of total length of roots						
	Sample plots I - VI in 1962						
1	-	87.9	95.6	88.9	90.7	91.6	88.6
1 - 2	-	9.8	3.0	7.7	6.7	5.4	8.8
2	-	2.3	1.4	3.4	2.7	3.0	2.7
Total	-	100.0	100.0	100.0	100	100.0	100
	Sample plots I - V and VII in 1963						
1	84.9	-	83.9	83.8	90.9	85.0	87.5
1 - 2	11.5	-	12.2	12.3	7.3	11.5	11.1
2	3.6	-	3.9	3.9	1.8	3.5	1.3
Total	100.0	-	100.0	100.0	100.0	100.0	100
	Sample plots 5 - 10						
1	-	83.0	88.0	93.5	84.7	90.2	82.0
1 - 2	-	14.2	8.4	4.8	11.0	6.7	15.3
2	-	2.8	3.6	1.6	4.2	3.1	2.8
Total	-	100.0	100.0	100	100	100.0	100
	Lines A - B						
1	-	87.9	88.0	89.4	86.2	86.4	79.3
1 - 2	-	9.9	8.9	8.9	9.5	9.8	16.4
2	-	2.3	3.1	1.7	4.3	3.7	4.4
Total	-	100	100.0	100.0	100.0	100	100

1) LT = Undrained cottongrass pine swamp

Table 4

Vertical distribution of roots on the open-ditch experimental plot at Liesneva

Depth layer, cm	Strip width, m													
	LT[1]	80	60	40	20	10	5	LT	80	60	40	20	10	5
	Roots, m/sq.m							Per cent of total legth of roots						
	Sample plots I - VI in 1962 (sample depth 50 cm)													
0 - 5	-	171	212	271	311	224	258	-	56.3	69.7	66.9	60.7	63.3	38.6
5 - 10	-	116	87	107	166	103	202	-	38.2	28.6	26.4	32.4	29.1	30.2
10 - 15	-	17	4	22	30	18	83	-	5.6	1.3	5.4	5.9	5.1	12.4
15 - 20	-	-	1	5	3	6	47	-	-	0.3	1.2	0.6	1.7	7.0
20 - 25	-	-	-	-	2	3	46	-	-	-	-	0.4	0.8	6.9
25 - 30	-	-	-	-	-	-	24	-	-	-	-	-	-	3.6
30 - 35	-	-	-	-	-	-	7	-	-	-	-	-	-	1.0
35 - 40	-	-	-	-	-	-	2	-	-	-	-	-	-	0.3
Total	-	304	304	405	512	354	669	-	100	100	100	100.0	100.0	100.0
	Sample plots I - V and VII in 1963 (sample depth 50 cm)													
0 - 5	249	-	254	465	702	610	460	59.4	-	69.0	77.4	68.4	74.8	67.6
5 - 10	162	-	101	127	251	150	136	38.7	-	27.4	21.1	24.5	18.4	20.0
10 - 15	6	-	11	9	64	39	54	1.4	-	3.0	1.5	6.2	4.8	7.9
15 - 20	2	-	2	-	6	16	22	0.5	-	0.5	-	0.6	2.0	3.2
20 - 25	-	-	-	-	3	1	4	-	-	-	-	0.3	0.1	0.6
25 - 30	-	-	-	-	-	-	2	-	-	-	-	-	-	0.3
30 - 35	-	-	-	-	-	-	1	-	-	-	-	-	-	0.1
35 - 40	-	-	-	-	-	-	1	-	-	-	-	-	-	0.1
Total	419	-	368	601	1026	816	680	100.0	-	100	100.0	100.0	100	100

1) LT = Undrained cottongrass pine swamp

T a b l e 5

Vertical distribution of roots on the covered-ditch experimental plot at Liesneva

Depth layer, cm	Strip width, m											
	80	60	40	20	10	5	80	60	40	20	10	5
	Roots, m/sq.m						Per cent of total length of roots					
	Sample plots 5 - 10 (sample depth 30 cm)											
0 - 5	274	275	409	333	311	170	56.6	56.6	62.8	48.5	60.6	44.5
5 - 10	162	160	166	264	107	84	33.5	32.9	25.5	38.5	20.9	22.0
10 - 15	48	50	59	81	40	37	9.9	10.3	9.1	11.8	7.8	9.7
15 - 20	△	1	15	8	14	20	0.1	0.2	2.3	1.2	2.7	5.2
20 - 25	-	-	2	-	22	41	-	-	0.3	-	4.3	10.7
25 - 30	-	-	-	-	19	30	-	-	-	-	3.7	7.9
Total	484	486	651	686	513	382	100	100.0	100.0	100.0	100.0	100.0
	Lines A - B (sample depth 20 cm)											
0 - 5	219	212	304	338	436	144	67.6	58.6	57.9	67.3	51.4	46.2
5 - 10	71	130	155	133	181	98	21.9	35.9	19.5	26.5	21.3	31.4
10 - 15	28	17	46	27	121	38	8.6	4.7	8.8	5.4	14.3	12.2
15 - 20	6	3	20	4	110	32	1.9	0.8	3.8	0.8	13.0	10.3
Total	324	362	525	502	848	312	100.0	100.0	100.0	100.0	100.0	100

T a b l e 6

Mean root depth in sample plots at Liesneva

Sample series[1)]	Strip width, m					
	80	60	40	20	10	5
	Mean root depth, cm					
a	11.0	13.0	16.0	13.8	19.4	17.6
b	14.6	15.0	17.6	18.0	23.6	21.6
c	12.0	12.6	13.6	14.9	15.4	17.8
d	-	11.2	10.7	15.6	14.8	20.0

1) Symbols for sample series a - d are the same as those used in Table 2

T a b l e 7

Vertical distribution of roots in sample plots 11 - 15 at Jaakkoinsuo (sample depth 50 cm)

Depth layer, cm	Strip width, m									
	40 (11)	30 (15)	25 (14)	22 (12)	15 (13)	40 (11)	30 (15)	25 (14)	22 (12)	15 (13)
	Roots, m/sq.m					Per cent of total length of roots				
0 - 5	550	685	630	636	1 097	77.6	72.9	78.4	78.3	72.0
5 - 10	143	183	134	101	283	20.2	19.5	16.7	12.4	18.6
10 - 15	14	56	35	60	112	2.0	6.0	4.4	7.4	7.3
15 - 20	1	14	5	15	24	0.1	1.5	0.6	1.8	1.6
20 - 25	1	2	-	-	8	0.1	0.2	-	-	0.5
Total	709	940	804	812	1 524	100.0	100	100	100	100.0

T a b l e 8

Vertical distribution of roots in sample plots at Mortti (sample depth 30 cm)

Depth layer, cm	Strip width, m							
	80	50	20	10	80	50	20	10
	Roots, m/sq.m				Per cent of total length of roots			
0 - 5	38	34	90	85	76.0	65.4	78.3	72.6
5 - 10	12	18	25	29	24.0	34.6	21.7	24.8
10 - 15	-	-	-	2	-	-	-	1.7
15 - 20	-	-	-	1	-	-	-	0.9
Total	50	52	115	117	100.0	100.0	100.0	100.0

T a b l e 9

Depth of root system and ground-water level (mean of measurements taken from June through August) in sample plots 11 - 15 at Jaakkoinsuo

Sample plot	Lower limit of root system, cm	Mean root depth, cm	Year		
			1938-1941[1)]	1956-1963	1963
			Ground-water level, cm		
11	25	13.0	-	29	40
15	25	15.0	-	30	46
14	20	13.8	-	29	40
12	20	13.4	82	32	52
13	25	17.6	102	44	50

1) According to the investigations by L u k k a l a (1951, p. 21)

T a b l e 1 0

Vertical distribution of "good" mycorrhizae in sample plots I - V and VII at Liesneva

Depth layer, cm	Strip width, m											
	LT[1)]	60	40	20	10	5	LT	60	40	20	10	5
	Thousande of "good" mycorrhizae per sq.m						"Good" mycorrhizae, per cent of total amount of short roots					
0 - 5	1.3	4.4	4.7	12.9	12.6	5.8	3.2	10.0	6.9	11.0	12.1	10.9
5 - 10	0.3	0.2	0.1	0.5	0.2	0.5	2.2	1.8	1.8	3.6	2.7	8.1
10 - 15	-	-	-	0.3	0.2	0.3	-	-	-	(5.2)	(7.1)	(5.0)
15 - 20	-	-	-	-	0.2	0.2	-	-	-	-	(18.2)	(9.5)
20 - 25	-	-	-	-	-	0.1	-	-	-	-	-	(20.0)
25 - 30	-	-	-	-	-	△	-	-	-	-	-	-
0 - 30	1.6	4.6	4.8	13.7	13.2	6.9	3.0	8.2	6.5	10.0	11.5	10.1

1) LT = Undrained cottongrass pine swamp

T a b l e 1 1

Distribution of roots into thickness classes on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Thickness class, mm	Ditch depth, cm				
	10	30	50	70	N[1)]
	Per cent of total length of roots				
	Experimental plot A at Jaakkoinsuo				
1	92.1	85.0	82.7	86.8	87.7
1 - 2	7.5	9.3	14.2	9.8	10.4
2	0.5	5.8	3.1	3.4	1.9
Total	100	100	100.0	100.0	100.0
	Experimental plot B at Jaakkoinsuo				
1	88.0	87.6	85.9	85.8	-
1 - 2	9.0	8.9	9.8	10.5	-
2	3.1	3.5	4.3	3.8	-
Total	100	100.0	100.0	100	-
	Experimental plot at Sattasuo				
1	72.4	80.2	80.2	71.4	-
1 - 2	17.6	14.5	15.8	20.1	-
2	10.0	5.3	4.0	8.6	-
Total	100.0	100.0	100.0	100	-

1) N = Distribution of root according to thickness, prior to drainage

T a b l e 1 2

Vertical distribution of roots on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Depth layer, cm	Ditch depth, cm								
	10	30	50	70	10	30	50	70	N[1)]
	Roots, m/sq.m				Per cent of total length of roots				
	Experimental plot A at Jaakkoinsuo								
0 - 5	320	458	529	437	87.9	90.3	82.9	75.9	66.8
5 - 10	38	44	77	99	10.4	8.7	12.1	17.2	25.1
10 - 15	6	5	24	28	1.6	1.0	3.8	4.9	6.3
15 - 20	-	-	8	12	-	-	1.3	2.1	1.8
Total	364	507	638	576	100	100.0	100	100	100.0
	Experimental plot B at Jaakkoinsuo								
0 - 5	341	418	425	629	64.3	79.6	80.2	83.6	-
5 - 10	148	89	80	112	27.9	17.0	15.1	14.9	-
10 - 15	30	16	23	11	5.7	3.0	4.3	1.5	-
15 - 20	10	2	2	-	1.9	0.4	0.4	-	-
20 - 25	1	-	-	-	0.2	-	-	-	-
Total	530	525	530	752	100.0	100.0	100.0	100.0	100.0
	Experimental plot at Sattasuo								
0 - 5	178	264	228	120	84.0	89.8	93.1	90.2	-
5 - 10	34	25	16	11	16.0	8.5	6.5	8.3	-
10 - 15	-	4	1	2	-	1.4	0.4	1.5	-
15 - 20	-	1	-	-	-	0.3	-	-	-
Total	212	294	245	133	100.0	100.0	100.0	100.0	-

1) N = Vertical distribution of roots, prior to drainage

T a b l e 1 3

Depth of root system and ground-water level (mean of measurements taken from June through August) on ditch-depth experimental plots at Jaakkoinsuo

Experimental	Ditch depth, cm	Lower limit of root system, cm		Mean root depth, cm		Ground-water level, cm
		1963	1964	1963	1964	1963
B	10	25	20	12.8	13.4	12.3
A	10	15	-	9.6	-	12.5
A	30	15	-	9.6	-	37.7
B	30	20	-	11.5	-	45.7
A	50	20	-	13.3	-	45.8
B	50	20	-	11.0	-	57.8
A	70	20	-	12.9	-	57.9
B	70	15	20	11.3	10.8	64.1

T a b l e 1 4

Depth of root system and ground-water level (mean of measurements taken from June through August) on ditch-depth experimental plot at Sattasuo

Ditch depth, cm	Lower limit of root system, cm		Mean root depth, cm		Ground-water level, cm
	1963	1964	1963	1964	1963
10	10	15	7.0	7.9	12.2
30	20	-	7.7	-	30.1
50	15	-	7.2	-	40.7
70	15	15	6.4	7.1	54.3

T a b l e 1 5

Total amount and density of short roots on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Experimental field	Ditch depth, cm								
	10	30	50	70	GD[1)]	10	30	50	70
	Thousands of short roots per sq.m					Number of short roots per dm of root			
Experimental plot A at Jaakkoinsuo	54.3	67.6	55.0	67.1	42.4	16.2	15.7	10.4	13.4
Experimental plot B at Jaakkoinsuo	100.6	85.2	66.8	98.6	54.0	21.6	18.6	14.7	15.3
Experimental plot at Sattasuo	28.9	28.6	28.4	10.5	5.2	18.8	12.1	14.6	11.1

1) GD = Statistically significant difference between the means at the 95 % confidence level

T a b l e 1 6

Vertical distribution of short roots on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Depth layer, cm	Ditch depth, cm							
	10	30	50	70	10	30	50	70
	Thousands of short roots per sq.m				Per cent of total number of short roots			
	Experimental plot A at Jaakkoinsuo							
0 - 5	51.6	65.4	47.5	56.0	95.0	96.7	86.4	83.5
5 - 10	2.0	1.9	4.5	7.7	3.7	2.8	8.2	11.5
10 - 15	0.7	0.3	2.3	3.0	1.3	0.4	4.2	4.5
15 - 20	-	-	0.7	0.4	-	-	1.3	0.6
Total	54.3	67.6	55.0	67.1	100.0	100	100	100
	Experimental plot B at Jaakkoinsuo							
0 - 5	83.5	73.1	57.7	91.3	83.0	85.8	86.4	92.6
5 - 10	14.6	11.3	7.0	6.3	14.5	13.3	10.5	6.4
10 - 15	1.4	0.8	2.1	1.0	1.4	0.9	3.1	1.0
15 - 20	1.1	-	-	-	1.1	-	-	-
Total	100.6	85.2	66.8	98.6	100.0	100.0	100	100.0
	Experimental plot at Sattasuo							
0 - 5	26.3	27.1	27.3	10.0	91.0	94.8	96.1	95.2
5 - 10	2.6	1.1	1.1	0.5	9.0	3.8	3.9	4.8
10 - 15	-	0.3	-	-	-	1.0	-	-
15 - 20	-	0.1	-	-	-	0.3	-	-
Total	28.9	28.6	28.4	10.5	100.0	100	100.0	100.0

Table 17

Density of short roots in different depth layers on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Depth layer, cm	Ditch depth, cm			
	10	30	50	70
	Number of short roots per dm of root			
	Experimental plot A at Jaakkoinsuo			
0 - 5	16.9	15.9	10.7	14.9
5 - 10	8.3	10.7	8.1	8.6
10 - 20	11.4	10.0	11.1	9.9
	Experimental plot B at Jaakkoinsuo			
0 - 5	25.9	19.1	15.2	15.9
5 - 10	12.6	17.4	11.8	9.7
10 - 20	9.3	6.7	12.3	14.1
	Experimental plot at Sattasuo			
0 - 5	20.0	12.4	14.7	11.5
5 - 10	11.9	8.4	12.2	6.4

T a b l e 18

Vertical distribution of "good" mycorrhizae on Jaakkoinsuo and Sattasuo ditch-depth experimental plots

Depth layer, cm	Ditch depth, cm							
	10	30	50	70	10	30	50	70
	Thousands of "good" mycorrhizae per sq.m				"Good" mycorrhizae, per cent of total number of short roots			
	Experimental plot A at Jaakkoinsuo							
0 - 5	8.0	5.0	6.5	10.8	15.5	7.6	13.7	19.3
5 - 10	-	-	0.3	0.1	-	-	6.7	1.3
0 - 10	8.0	5.0	6.8	10.9	14.7	7.4	12.4	16.2
	Experimental plot B at Jaakkoinsuo							
0 - 5	9.5	4.0	2.6	11.8	11.4	5.5	4.5	12.9
5 - 10	1.1	0.4	0.1	1.2	7.5	3.5	1.4	19.0
10 - 15	-	-	-	0.1	-	-	-	(10.0)
0 - 15	10.6	4.4	2.7	13.1	10.5	5.2	4.0	13.3
	Experimental plot at Sattasuo							
0 - 5	1.5	0.6	0.7	0.1	5.7	2.2	2.6	1.0
5 - 10	0.1	-	-	-	3.8	-	-	-
0 - 10	1.6	0.6	0.7	0.1	5.5	2.1	2.5	1.0

Table 19

Vertical distribution of mycorrhizae on Jaakkoinsuo and Sattasuo ditch-depth experimental plots in 1964

Depth layer, cm	Ditch depth, cm									
	10					70				
	Number of short roots examined	True mycorrhizae				Number of short roots examined	True mycorrhizae			
		"Good"	Others	Total			"Good"	Others	Total	
				Number	Per cent of short roots examined				Number	Per cent of short roots examined
	Experimental plot B at Jaakkoinsuo									
0 - 5	58	4	25	29	50	89	5	45	50	56
5 - 10	20	-	7	7	35	17	-	7	7	41
	Experimental plot at Sattasuo									
0 - 5	150	4	65	69	46	105	15	46	61	58
5 - 10	36	2	11	13	36	34	-	12	12	35

T a b l e 2 0

Mean circumference growth and height growth of trees on Jaakkoinsuo and Sattasuo ditch-depth experimental plots in 1963

Experimental plot	Ditch depth, cm							
	10	30	50	70	10	30	50	70
	Circumference growth, mm in 1963				Height growth, mm in 1963			
Experimental plot A at Jaakkoinsuo	4.7	3.7	5.5	4.7	78	85	93	79
Experimental plot B at Jaakkoinsuo	4.5	4.4	3.5	3.9	82	89	90	132
Series A at Sattasuo	2.4	2.5	2.4	2.2	75	70	70	83
Series B at Sattasuo	2.2	4.0	4.7	4.1	63	117	88	88

Appendix 2

Observations on the Effect of the Ground Water Level on the Decomposition of Cellulose in Peat of Pine and Spruce Swamps.

Kimmo Paarlahti

Helsinki 1964

Introduction.

In normal raw humus, there is a dynamic equilibrium prevailing between the amount of litter yearly added to the soil and the amount decaying there; thus the amount of humus remains almost constant. The quantity of nutrients remobilized through mouldering into a form useful for plants thus corresponds to the amount added yearly to the soil by litter. If conditions in the soil change in such a way that decomposition - in our forest soils mainly produced by aerobic organisms - becomes slower, the equilibrium is disturbed and the result is increasing amounts of organic matter in the soil. This happens, e.g., in connection with swamp formation, when excessive soil humidity and its consequences - the most important of which is the slowing up of oxygen penetration into the soil - make effective decomposition more difficult, or even prevent it altogether, except in some cases, for the soil layer closest to the surface. Since in this case fewer plant remains decompose than are added to the soil, the consequence is an accumulation of organic matter and the formation of peat. At the same time the quantity of nutrients in circulation continually decreases and accumulates in the soil in a form unusable for plants.

The purpose of drainage is to improve the conditions for tree growth through changes in the hydrological conditions of the soil which will enable the micro-orgamisms to work more

effectively. From this follows increased decomposition and hence better mobilization of the nutrients necessary for higher plant life.

Changes in the soil resulting from both swamp formation and forest ditching are apparently, to a great degree, microbiological phenomena regulated by changes in the oxygen economy of the soil. Thus investigation and knowledge of swamp microbiology give, to a certain degree, basic insights into the factors which determine how the water economy in swamps should be regulated by ditching.

The versatile and important investigational work on swamps which has been done in Finland includes only a few studies on swamp microbiology. The results of foreign investigations - and there are not many of them, either - cannot be adapted to our conditions without adjustments. Isotalo (1951) has studied the physiology and ecology of cellulose decomposing bacteria in raised bogs, and Huikari (1953) the effect of drainage and ash fertilization on the micro-organisms in peat soils. Further, Gyllenberg, Hanioja, and Vartiovaara (1954) have confirmed the occurrence of some groups of microbes in alluvial meadows and in drained pine swamps, and Paarlahti and Vartiovaara (1958) have carried out a investigation of the micro-organisms in some natural and some drained swamps.

One of the central questions in connection with the study of swamp biology is the vertical distribution of different factors and phenomena. Particularly when the question

is about the effect of drainage, it is important to clarify how deep in the peat layer it reaches or can be made to reach.

Several investigations regarding biological phenomena in swamps have yielded the conclusion that by ditching it is possible to produce an effect only on a rather thin surface layer of the peat. Multamäki (1923) and Heikurainen (1955) have found out that the root systems of pine stands in swamps are concentrated, even in effectively drained swamps, mainly in the 0-10 cm layer, and that roots only rarely penetrate deeper than 20 cm from the surface. Since, for example, the author´s analyses of the vertical distribution of exchangeable nutrients in peat have revealed that in such cases the exchangeable nutrients are mainly concentrated in a rather thin surface layer of the peat, it seems probable that the superficiality of the roots depends, to a significant degree, upon this. As Huikari (1953), Paarlahti and Vartiovaara (1958), among others, have proved that the changes caused by drainage, even as regards the micro-organisms of the peat, are limited to a thin surface layer, it is obvious that the consequent decomposition and nutrient mobilization are limited to the surface layer mentioned.

In order to ascertain whether it is possible to deepen effective drainage by means of increased efficiency in ditching, strip-width experiment areas have been established on behalf of the Department of Swamp Forestry, at the Forest Research Institute in Finland. In addition, hydrological

experiment areas have been set up, where the ground water level, or the drainage depth, has been variously adjusted. In 1962-63 the author carried out soil microbiological investigations in experiment areas of this kind at Jaakkoinsuo in Vilppula , both on cottongrass pine swamp and on Myrtillus spruce swamp.

Method.

Using ordinary soil microbiological methods of investigation - primarily cultivation - it is possible to account for, among other things, the quantities of soil fungi and aerobic bacteria, at least as proportional values. These methods offer possibilities of clarifying the changes in the vertical distribution of the abovementioned groups, caused by drainage. However, it is uncertain whether the results obtained by this method are able to account for the distribution of the most important groups with respect to decomposition and the activating of the very decomposition process which, for reasons mentioned before, must be considered extremely important. During the summer of 1963 the author tried out a method for the study of the vertical distribution of the decomposing activity. The results obtained look promising. Five pieces of cellulose, 3 cm wide and 10 cm long, were sewn, one after

another, into doubled nylon crepe pockets. The pieces were weighed after drying for 24 hours at 105° C. The bleached sulphite cellulose used was manufactured by Kaukas Ltd. and it consisted of 94,5 % α -cellulose, the rest being mainly β- and γ-cellulose and about 0,1 % decomposition products of resin. The pockets were placed vertically into the ground so that the upper end of the topmost one was at surface level. The test pieces were put into the ground on the 13 - 15th of June 1963. Tree sample plots, 15 x 40 m in area, were chosen in a pine swamp and as many again in a spruce swamp. Since 1961 the water in the ditches surrounding the sample plots had been kept constantly 10, 30, and 50 cm below the ground surface. Forty pockets in groups of ten were placed in each sample plot, each group within a square of the size 2 x 2 m, with ground water holes for measuring the ground water level at each corner. On the 28th of October 1963, 16 pockets were taken from each square for examination in the laboratory. Peat particles which had got stuck to the nylon cloth and the cellulose were carefully rinsed out with water, after which the cellulose pieces were dried for 24 hours at 105° C and weighed.

To measure the activity of decompositon "in situ" Nömmik (1938), among others, used a method according to which the litter to be decomposed was inserted into the ground in metal wire bags. Mikola (1954) placed the litter in the humus between two layers of glass wool. Richard (1945) used viscose silk threads a material to be decomposed. The threads were put

horizontally in the ground at different depths. As an indicator for the activity of decomposition, he used the decreased tensile strength of the threads.

None of the abovementioned methods were really suitable for the present work, since the test pieces for the clarification of the vertical distribution of the decomposition activity had to be put in unbroken series down to a depth of 50 cm, disturbing the soil structure as little as possible, even in sample plots where the ground water almost reached the ground surface.

Results.

Table 1 (p.7) reveals the decrease in weight of cellulose pieces from different depth-layers of the soil, where they were kept from 15th of June to the 28th of October, 1963. In addition, the median of the ground water level is shown, as well as the range of its changes. The weight of the test pieces was 1700-1900 mg before they were put into the ground.

Examination of the figures concering the sample plots in pine swamp reveals that ground water regulation has had an apparent effect upon the vertical distribution of cellulose decomposition. The deeper the ground water table was placed, the more cellulose decomposed, in the lower layers as well. Decomposition, however, seems to be concentrated principally at 0-10 cm depth; for deeper layers, the figures are noticeably smaller.

Table 1. Avarage decrease in weight of cellulose in different depth layers and sample plots; medians ( ) and ranges of fluctuation (( )) of the ground water level in cm from the ground surface.

Sampling depth, cm from the ground surface	Adjusted ground water level, cm from the groundesurface		
	10	30	50
	Decrease in weight of cellulose, mg		
Pine swamp (ViR)			
0-10	159	119	317
10-20	(10)	37	67
20-30	((8-14)) 9	20	38
30-40	8	(35) 10	13
40-50	5	((9-51)) 4	(47) 7
			((14-62))
Spruce swamp (ViK)			
0-10	423	363	584
10-20	(16)	216	327
20-30	((8-20)) 52	(36) 94	312
30-40	32	((25-41)) 46	219
40-50	30	41	(51) 48
			((33-65))

Cellulose decomposition was clearly more pronounced in the spruce swamp sample plots than in those on pine swamp. It was also observed that the decomposition activity is more inclined to follow the lowering of the ground water level in spruce swamps than in pine swamps, and that it is not, to the same degree, limited to the very topmost layer of the peat.

In the pine swamps, the range of variation in the ground water level was considerably greater in the sample plots where the water level was adjusted to 30 and 50 cm than in corresponding sample plots in spruce swamps. The results reveal that, in the pine swamp, it has not been possible to affect the values for the ground water level at its highest level, to any significant extent, in spite of the fact that the average level of the ground water was considerably lowered, by bringing down the water level in the ditches surrounding the sample plots. In this respect, the sample plots in spruce swamps differ essentially from those mentioned above. A comparision between the figures indicating the decreace in weight of the cellulose and corresponding ground water levels reveals that vertical distribution of the decomposition of cellulose is more clearly regulated by the upper limit in the range of variation in the ground water than by its average level. In all sample plots, cellulose decomposition seems to be decisively reduced precisely at the level where the upper limit of the range of variation in the ground water level is located.

Examination of the results.

Since the oxygen economy in peat is principally dependent on the oxygen which penetrates into the ground in rain water, the amount of oxygen which reaches the deeper strata of the earth is noticeably less in soils in which the ground water easily rises close to the surface than in soils where the ground water level remains constantly lower. The so called ground water table in open ground water holes can be interpreted, in the first place, to mean the level at which the soil moisture content reaches the limit value at which water tension is 0 (cf., e.g. Heinonen 1954), but it does not mean any sharp rise in the moisture content (e.g.Paarlahti 1961). If the escaping of the water from the ground proceeds slowly, because of the poor water permeability of the soil, the layer with a moisture content close to the limit value mentioned can almost reach the ground surface even during rainless periods. Under such conditions, even small amounts of precipitation are enough to raise the moisture content to the limit value in a comparatively thick ground layer, which hinders the rain water and its oxygen from penetrating this layer. This, obviously, is the most essential reason for the differences in the vertical distribution of decomposition between the sample plots in pine and spruce swamps. In pine swamps, the peat is homogeneous and of poorer water permeability compared to the peat in spruce swamps, which

lets the water through easily. The comparative immobility of water in peat with poor water permeability also means that the transport of nutrients is slow. Thus they concentrate in places where mobilization takes place.

The presented above, made, in fact, to test the method, do not entitle us to draw far-reaching conclusions. It seems, however, that the above method, either in its present form or with further improvements, can be very useful for investigations of the variation in the process of decomposition in soil. One of the best features of this method is its simplicity and suitability for experiments involving large numbers of materials. Further, it enables us to observe colonies of microbes grown on the cellulose pieces, or to isolate them for closer examination.

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Appendix 3.

Ground vegetation and homogeneity of the experiment areas.

Vegetation analyses were carried out during the months of June and July in 1962 at Jaakkoinsuo (Vilppula), and the Sattasuo and Alajärvi swamps (Kivalo). On each ground water sample plot in the experiment areas, eight subsquares of 1 sq.m. each were designated and the coverage percentages of each plant species occurring was measured. On the basis of the results of these vegetation analyses, mean values were calculated for each species in the ground water sample plots. In addition, their frequency was established, i.e., on which of the eight possible squares the species in question occurred. Average coverages and frequencies obtained for the different experiment areas are shown in tables 1 - 4: Vilppula, cotton grass pine swamp (ViR); Vilppula, Myrtillus spruce swamp (ViK); Kivalo, herb-rich pine swamp (KiR); and Kivalo, herb-rich spruce swamp (KiK).

In the sample plots, attempts were made to clarify the effect of different ecological factors on tree growth. Thus, the experiment areas were set up to be quite homogeneous. As homogeneity of the milieu, and specially the site, is reflected first of all by the ground vegetation, the material of vegetation analyses was checked for its homogeneity in the following way: in each experiment area, equality coefficients were calculated for the mean coverage in certain sample plots, that is the equality in percentages between the consistency of species in two sample plots (cf. Braun- Blauquet, 1951). The formula used is:

$$Gm = \frac{Mc : 2}{Ma + Mb + Mc : 2} \cdot 100\ (\%),$$

in which Ma and Mb refer to the sums of coverage of species occurring only in the first and the second sample plots respectively, and Mc the sum of coverage of species common to

both sample plots.

In the pine swamp at Vilppula, the equality coefficients of the coverage were obtained by comparing each sample plot and RF 50. In the spruce swamp at Vilppula the plots were compared with KT 50, in the pine swamp at Kivalo with RF 50, and in the spruce swamp at Kivalo with KF 30. Fig. 1 reveals the equality coefficients obtained in each experiment area. The percentages indicating the equality all exceed 60, and as the equality is considered positive when Gm is greater than 50 %, the experiment areas can be considered homogeneous enough for the ecological experiments to be carried out.

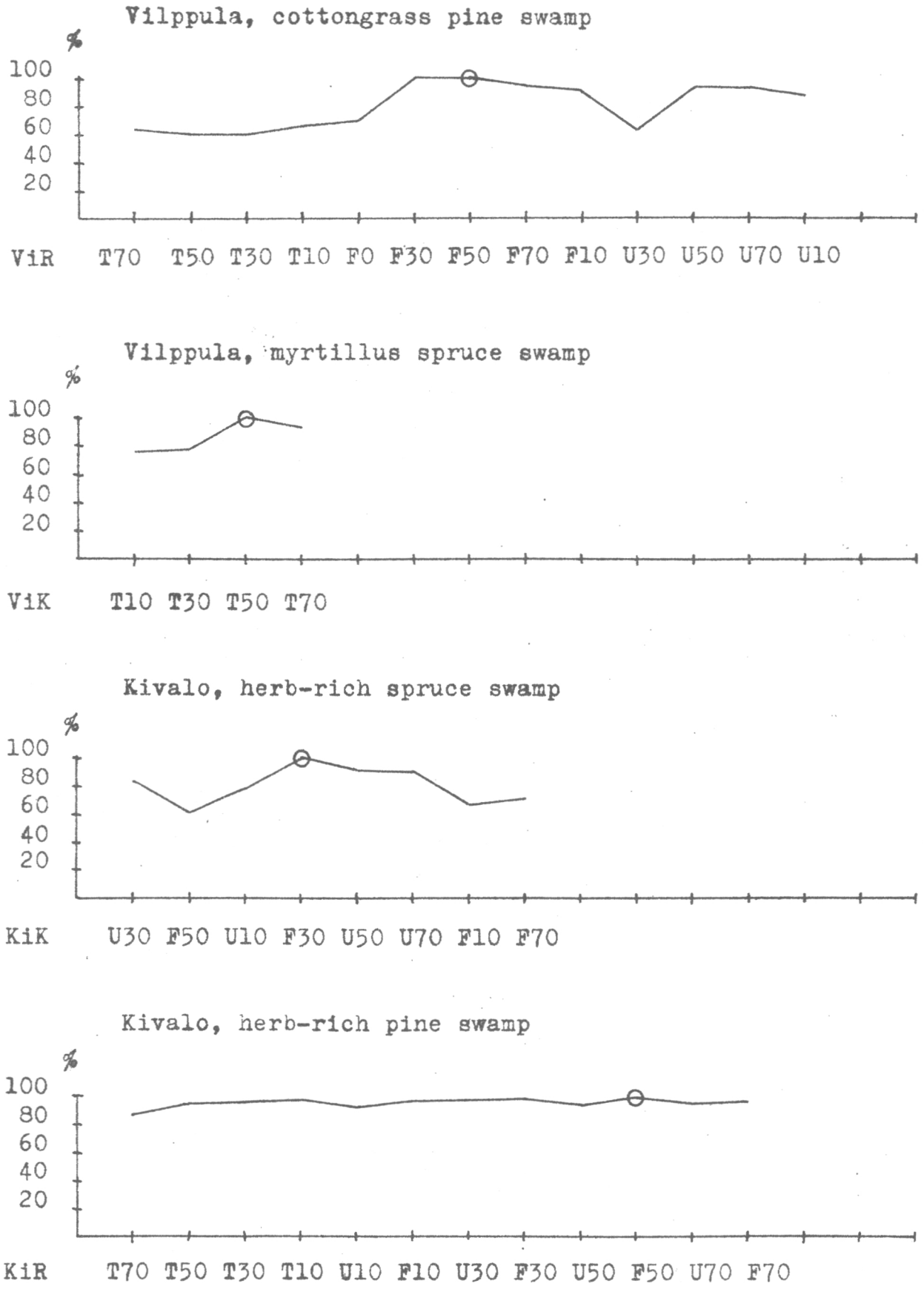

Figure 1. Homogeneity curves.

	RT 70		RT 50		RT 30		RT 10		RF 0		RF 30		RF 50		RF 70		RF 10		RU 30		RU 50		RU 70		RU 10	
	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Betula pubescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--	-	0.6	2
Pinus silvestris	+	2	0.6	5	0.9	6	+	4	0.5	5	+	4	+	4	+	3	0.4	2	0.4	4	+	3	0.7	4	0.4	4
Picea abies	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Betula nana	1.6	2	0.5	3	0.6	3	0.4	1	-	-	0.5	2	+	1	+	1	+	4	-	-	-	-	-	-	+	1
Ledum palustre	18.5	8	21.9	8	12.9	8	7.4	8	13.3	8	17.4	8	21.9	8	17.3	8	17.8	8	17.5	8	16.9	8	20.6	8	16.9	8
Vaccinium uliginosum	0.9	3	+	1	1.8	3	6.5	6	0.9	8	3.9	7	1.9	4	1.8	6	-	-	-	-	0.6	1	+	1	-	-
V. vitis-idaea	3.8	7	6.8	7	6.8	8	2.9	7	+	1	-	-	-	-	-	-	-	-	-	-	+	1	0.4	1	2.1	3
V. myrtillus	1.3	6	1.4	5	0.9	6	-	-	-	-	-	-	-	-	-	-	0.5	3	+	1	+	1	0.4	3	0.7	2
Oxycoccus quadripetalus	0.5	8	0.8	8	0.6	8	0.7	8	1.8	8	1.3	8	0.8	8	1.3	8	0.7	8	0.9	8	0.8	8	1.2	8	0.9	8
Andromeda polifolia	1.5	7	1.6	7	1.5	8	1.6	8	1.4	8	2.0	8	1.3	8	3.0	8	1.8	8	2.4	8	2.4	8	2.3	8	2.1	8
Empetrum nigrum	7.3	8	20.9	8	14.4	8	17.9	8	3.4	8	15.0	8	8.1	8	10.1	5	4.8	6	14.5	8	11.1	8	9.4	8	3.8	5
Rubus chamaemorus	1.1	8	+	2	+	3	1.1	8	2.0	7	3.3	8	1.1	8	2.0	8	0.9	6	1.1	8	0.9	5	1.4	8	0.7	6
Eriophorum vaginatum	6.5	8	4.6	7	11.6	8	18.9	8	28.8	8	9.0	8	17.8	8	15.6	8	14.1	8	8.9	8	8.3	8	7.4	8	12.8	8
Carex pauciflora	-	-	-	-	-	-	+	1	-	-	+	1	-	-	+	2	+	2	-	-	+	1	-	-	-	-
C. globularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1
Pleurozium Scheberi	31.3	8	24.9	8	24.5	8	7.1	6	-	-	3.5	3	+	1	0.6	2	11.4	5	+	1	4.4	4	2.9	5	0.6	1
Hylocomium splendens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	1
Dicranum undulatum	0.9	6	+	4	1.1	3	+	2	+	1	1.4	3	+	1	+	1	+	2	+	1	-	-	0.4	3	+	1
D. scoparium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polytrichum strictum	0.4	3	0.5	5	4.4	2	1.0	3	3.1	3	-	-	+	1	-	-	+	2	-	-	-	-	-	-	0.4	3
Aulacomnium palustre	3.9	3	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1
Pohlia nutans	-	-	-	-	-	-	0.5	3	-	-	-	-	-	-	-	-	+	3	+	2	-	-	+	3	+	3
Sphagnum magellanicum	1.3	7	0.6	5	2.4	4	3.3	7	17.1	8	4.3	7	2.8	7	9.4	8	1.7	7	3.3	8	7.0	8	7.4	8	5.9	8
S. parvifolium	14.3	8	12.5	7	13.5	7	25.0	8	25.9	8	+	1	0.9	5	1.4	2	1.4	2	51.3	8	46.3	8	44.4	8	-	-
S. recurvum coll.	-	-	-	-	-	-	-	-	-	-	15.1	8	34.1	8	35.6	8	43.1	8	-	-	3.0	2	0.6	1	50.0	8
S. fuscum	+	1	-	-	-	-	0.4	1	0.6	1	18.1	4	5.9	3	-	-	-	-	-	-	-	-	-	-	-	-
Cladonia rangiferina	3.1	8	3.8	7	2.4	8	+	2	+	1	0.6	1	0.4	3	+	3	1.3	4	-	-	+	1	0.7	3	0.7	2
C. silvatica	0.5	4	0.8	6	0.4	4	+	4	+	1	+	1	0.4	2	+	2	0.8	5	-	-	-	-	+	1	+	1
C. spp.	+	1	-	-	+	1	+	4	+	1	+	2	0.4	2	+	2	0.8	4	+	1	+	2	0.8	3	+	1
Peltigera aphthosa	-	-	-	-	-	-	+	1	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	99.0	116	102.5	103	101.0	107	95.5	109	99.3	85	96.0	93	98.3	90	98.8	85	102.0	97	100.8	74	102.3	77	101.3	92	99.7	86

Table 2 - VILPPULA, KORPI (ViK), MYRTILLUS SPRUCE SWAMP

	KT 10		KT 30		KT 50		KT 70	
	%	F	%	F	%	F	%	F
Betula pubescens	0.6	1	-	-	-	-	+	1
Picea abies	0.6	4	0.8	3	+	2	-	-
Vaccinium myrtillus	24.1	8	25.0	7	17.8	8	19.5	8
V. vitis-idaea	7.4	8	6.3	8	5.4	8	9.4	8
Rubus chamaemorus	+	1	0.4	2	-	-	+	1
R. idaeus	-	-	-	-	-	-	4.3	5
Lycopodium annotinum	-	-	-	-	15.6	3	5.0	1
Dryopteris spinulosa	0.6	1	0.4	1	+	1	+	2
Pirola secunda	-	-	-	-	+	1	+	3
Dryopteris linnaeana	-	-	-	-	0.5	1	3.1	2
Equisetum silvaticum	-	-	-	-	0.5	2	4.3	4
Athyrium filix-femina	-	-	-	-	-	-	0.4	1
Trientalis europaea	-	-	-	-	+	1	+	1
Chamaenerium angustifolium	-	-	-	-	-	-	+	1
Eriophorum vaginatum	-	-	+	1	-	-	-	-
Carex canescens	-	-	-	-	-	-	+	3
C. Goodenowii	+	1	+	1	-	-	-	-
Polytrichum commune	+	1	-	-	-	-	+	1
Dicranum undulatum	5.5	7	2.9	5	1.9	4	4.4	5
D. majus	4.3	8	1.5	6	+	1	1.3	6
D. fuscescens	1.3	1	0.8	4	1.1	4	2.0	3
Pleurozium Schreberi	15.0	8	12.3	8	3.8	7	9.0	8
Hylocomium splendens	14.8	8	24.5	8	30.0	7	22.5	8
Aulacomnium palustre	+	3	0.4	1	-	-	-	-
Pohlia nutans	5.6	7	1.4	6	1.7	7	4.0	8
Sphagnum riparium	4.4	2	1.9	2	-	-	0.6	1
Cladonia spp.	+	1	-	-	-	-	-	-
	84.7	70	78.8	63	78.8	57	90.6	81

	RT 70		RT 50		RT 30		RT 10		RU 10		RF 10		RU 30		RF 30		RU 50		RF 50		RU 70		RF 70	
	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Betula pubescens	+	1	-	-	-	-	+	1	+	1	-	-	+	5	0.5	3	0.7	6	+	3	1.1	4	+	2
Picea abies	-	-	-	-	+	1	-	-	-	-	+	1	+	1	-	-	-	-	-	-	+	1	-	-
Pinus silvestris	+	5	+	1	+	3	+	4	1.3	6	2.2	8	1.0	6	2.6	6	+	3	1.2	6	1.0	6	0.9	4
Betula nana	7.0	8	7.6	8	4.9	8	8.6	7	7.3	8	12.5	8	4.9	8	8.1	7	5.9	8	5.7	8	5.4	7	4.9	8
Ledum palustre	1.6	6	+	3	0.5	3	2.2	6	1.0	5	3.4	7	0.5	5	1.3	4	1.9	5	2.8	5	2.6	5	3.2	5
Salix repens	-	-	-	-	-	-	-	-	-	-	1.0	4	-	-	1.2	5	+	1	+	1	0.8	2	+	2
Vaccinium myrtillus	-	-	1.1	3	2.0	3	+	2	+	2	0.6	1	+	3	-	-	-	-	-	-	0.6	1	+	3
V. vitis-idaea	2.5	7	8.2	7	5.6	5	1.8	7	0.6	3	10.4	6	3.5	7	1.8	4	4.8	5	1.8	4	6.8	8	8.0	7
V. uliginosum	2.9	5	4.5	8	2.3	7	1.0	8	2.4	6	1.0	5	1.7	7	2.8	5	5.1	5	4.3	5	1.5	5	4.7	5
Oxycoccus quadripetalus	1.5	8	0.7	8	0.9	8	0.6	8	1.0	8	1.1	8	1.4	8	2.1	8	2.0	8	0.7	8	1.4	8	1.1	8
Andromeda polifolia	3.5	8	1.2	7	1.8	8	1.0	8	1.1	8	0.9	8	1.1	8	1.3	8	1.6	8	1.8	8	1.9	8	1.4	8
Empetrum nigrum	2.5	8	1.7	7	7.5	8	3.3	6	1.0	3	3.1	2	3.6	4	6.4	4	2.9	3	1.3	3	6.8	5	2.0	5
Rubus chamaemorus	2.1	8	2.2	8	3.6	8	3.5	8	3.6	8	1.5	6	1.1	4	2.8	4	+	1	0.8	3	+	2	1.1	2
Salix lapponum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9	1	-	-	-	-
Menyanthes trifoliata	-	-	-	-	-	-	-	-	+	1	+	5	+	4	1.0	7	+	1	0.7	6	+	5	1.0	8
Listera cordata	-	-	-	-	-	-	-	-	-	-	-	-	-	5	+	1	+	3	+	1	+	1	+	2
Pirola secunda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1	+	1	-	-	-	-
Melampyrum pratense	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	3	-	-	+	2	+	1
Potentilla palustris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1	+	1	-	-	+	1	+	1
Drosera rotundifolia	-	-	-	-	-	-	-	-	-	-	-	-	+	1	-	-	+	1	-	-	-	-	-	-
Eriophorum vaginatum	0.8	8	1.0	8	3.5	8	1.0	8	1.1	7	5.9	7	0.9	6	0.8	6	0.5	5	1.3	3	-	-	0.6	4
Carex pauciflora	+	4	+	3	+	2	+	3	+	4	+	1	+	4	+	6	0.8	7	0.7	8	+	5	+	5
C. chordorrhiza	-	-	-	-	-	-	-	-	+	3	+	2	+	3	+	1	0.6	6	0.5	4	0.7	5	+	3
C. lasiocarpa	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1	-	-	-	-	+	2
C. globularis	4.8	4	0.6	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C. livida	+	2	+	4	+	1	+	3	+	3	-	-	+	3	+	2	+	3	+	5	-	-	+	2
C. rostrata	-	-	-	-	-	-	-	-	-	-	+	1	-	-	+	2	-	-	-	-	-	-	-	-
C. limosa	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-	+	2	+	1	+	1	+	3
Equisetum palustre	+	2	0.8	5	+	3	0.8	4	2.9	7	1.6	7	2.9	7	3.9	8	3.9	8	-	-	6.8	8	7.4	8
Polytrichum strictum	0.5	4	+	2	0.9	4	+	4	+	1	+	2	0.7	3	0.6	3	3.0	5	4.5	3	1.2	4	0.5	3
P. commune	+	1	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	1
Pleurozium Schreberi	17.6	8	19.2	8	14.1	8	24.4	6	10.3	7	15.9	7	11.5	6	10.4	7	10.6	5	7.0	6	8.2	7	7.9	8
Aulacomnium palustre	1.1	8	0.8	8	1.3	8	1.2	8	1.6	8	0.8	8	0.8	8	1.0	8	0.8	8	1.9	8	1.1	8	1.1	8
Hylocomium splendens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.1	1	2.5	2
Dicranum scoparium	2.8	3	1.0	2	-	-	-	-	-	-	0.5	3	1.5	2	+	2	-	-	+	2	+	1	+	2
Pohlia nutans	+	3	+	2	0.5	2	+	5	+	5	+	1	0.8	5	+	4	+	3	+	1	1.2	4	+	1
Mnium spp.	-	-	-	-	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-
Ptilium crista-castrensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	1
Sphagnum rubellum	35.0	8	43.8	8	33.1	8	41.9	8	53.1	8	34.4	8	53.1	8	50.0	8	39.4	8	52.5	8	34.4	8	35.8	8
S. magellanicum	5.6	8	3.2	5	5.0	7	4.7	7	5.0	8	2.8	8	6.5	8	2.3	6	14.5	8	6.3	8	12.1	8	12.8	8
S. fuscum	2.9	2	-	-	-	-	1.0	1	6.3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. nemoreum	1.0	3	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladonia rangiferina	-	-	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-	-	-
C. silvatica	+	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C. spp.	+	2	+	2	-	-	-	-	-	-	+	3	+	1	-	-	-	-	-	-	-	-	-	-
Peltigera aphthosa	-	-	-	-	-	-	-	-	-	-	+	1	+	1	+	1	+	1	-	-	-	-	-	-
	96.7	136	98.3	119	88.1	114	97.8	123	100.5	123	100.6	129	98.7	142	101.8	131	100.4	133	97.5	120	99.6	131	98.9	140

Table 4 - KIVALO, KORPI (KIK), HERB-RICH SPRUCE SWAMP

	KU 30		KF 50		KU 10		KF 30		KU 50		KU 70		KF 10		KF 70	
	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Juniperus communis	-	-	-	-	+	1	-	-	-	-	-	-	-	-	-	-
Alnus incana	-	-	0.7	4	0.5	2	-	-	-	-	-	-	0.5	4	+	1
Salix phylicifolia	+	2	+	1	-	-	0.5	2	0.4	3	1.4	2	-	-	0.6	1
Betula pubescens	-	-	-	-	+	1	+	1	-	-	0.4	3	-	-	-	-
Picea excelsa	-	-	-	-	-	-	-	-	-	-	-	-	+	1	-	-
Vaccinium myrtillus	+	1	-	-	1.5	2	3.5	3	1.8	3	1.0	4	-	-	2.0	5
V. vitis-idaea	5.0	7	2.5	8	3.1	6	7.3	8	13.6	8	13.3	8	9.7	8	14.3	8
V. uliginosum	-	-	-	-	+	1	+	1	-	-	0.4	2	-	-	-	-
Oxycoccus quadripetalus	-	-	-	-	-	-	+	1	-	-	+	2	-	-	-	-
Ledum palustre	-	-	-	-	-	-	-	-	-	-	0.6	1	-	-	-	-
Potentilla palustris	0.9	4	3.2	6	2.8	8	-	-	-	-	-	-	1.5	7	2.6	8
Rubus arcticus	0.4	3	2.6	5	1.3	5	+	1	-	-	-	-	0.8	4	0.8	5
R. chamaemorus	1.8	8	2.0	6	1.6	5	4.8	7	5.0	8	3.5	8	1.8	7	2.4	7
Linnaea borealis	0.9	5	0.4	3	+	3	+	1	1.1	7	0.8	5	+	2	0.6	6
Empetrum nigrum	-	-	-	-	-	-	-	-	-	-	0.9	3	-	-	-	-
Geranium silvaticum	-	-	0.5	2	+	2	+	2	-	-	-	-	+	4	+	3
Chamaenerium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	+	1	0.6	1
Pyrola secunda	+	1	-	-	-	-	+	2	+	2	1.9	8	+	1	0.5	3
P. minor	-	-	-	-	-	-	-	-	-	-	-	-	0.9	4	-	-
P. rotundifolia	+	1	-	-	0.7	3	0.8	5	-	-	+	1	-	-	+	1
Solidago virgaurea	-	-	-	-	0.6	3	-	-	-	-	-	-	+	2	0.4	3
Majanthemum bifolium	-	-	1.3	1	-	-	-	-	-	-	-	-	2.5	5	1.9	6
Trientalis europaea	0.4	2	2.8	8	2.9	7	1.0	3	2.4	5	0.4	1	2.8	8	0.5	4
Cornus suecica	-	-	1.6	6	0.9	5	-	-	-	-	-	-	+	2	-	-
Viola epipsila	+	1	1.9	6	1.3	7	-	-	-	-	-	-	+	1	-	-
Listera cordata	-	-	-	-	-	-	+	2	+	3	+	4	-	-	-	-
Melampyrum pratense	-	-	-	-	-	-	-	-	-	-	0.5	3	-	-	-	-
Luzula pilosa	-	-	-	-	-	-	+	1	-	-	+	1	-	-	-	-
Caltha palustris	+	2	-	-	-	-	-	-	+	1	+	1	-	-	+	1
Equisetum arvense	0.6	3	1.6	7	0.6	5	+	2	7.1	6	2.5	4	0.8	6	-	-
E. silvaticum	2.1	7	2.1	5	0.9	4	2.8	8	3.4	8	3.0	8	1.6	7	1.8	7
E. pratense	4.5	7	-	-	-	-	4.2	8	1.8	8	2.0	5	2.0	7	1.5	6
E. palustre	-	-	-	-	2.6	7	2.8	5	0.8	2	-	-	-	-	-	-
Dryopteris linnaeana	-	-	7.1	5	2.4	4	-	-	-	-	-	-	4.1	4	1.3	3
Lycopodium annotinum	-	-	0.9	1	+	1	-	-	-	-	-	-	0.6	2	3.3	5
Calamagrostis arundinacea	+	2	3.8	7	6.3	8	3.9	7	0.5	5	1.6	6	2.4	7	1.4	7
Agrostis tenuis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Deschampsia flexuosa	-	-	-	-	-	-	+	1	+	4	0.6	1	-	-	-	-
Poa palustris	-	-	-	-	-	-	+	1	-	-	-	-	-	-	-	-
Calamagrostis purpurea	0.8	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex canescens	1.7	5	4.1	4	1.2	5	0.8	3	0.5	2	0.9	3	1.4	2	+	3
C. globularis	-	-	0.9	3	-	-	-	-	-	-	-	-	+	1	-	-
C. caespitosa	4.0	2	5.0	1	0.6	2	-	-	3.8	1	-	-	1.3	2	1.3	2
C. tenella	5.9	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C. panicea	1.2	5	1.5	6	0.4	3	2.8	2	0.6	2	-	-	1.6	4	0.8	6
Pleurozium Schreberi	1.3	5	1.8	6	1.7	5	4.8	7	7.4	8	6.8	8	2.9	7	10.9	8
Hylocomium splendens	22.5	6	4.4	2	10.3	6	20.0	8	27.5	8	32.0	8	3.9	3	17.4	6
Aulacomnium palustre	5.3	7	-	-	0.9	5	1.6	8	1.8	6	1.5	8	0.4	5	+	4
Dicranum scoparium	-	-	0.6	1	-	-	1.2	1	0.4	2	6.3	2	-	-	-	-
D. fuscescens	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-
D. majus	+	1	-	-	-	-	1.2	2	0.9	3	2.4	4	-	-	-	-
D. undulatum	-	-	-	-	+	3	+	1	-	-	-	-	-	-	+	1
Polytrichum strictum	-	-	-	-	-	-	-	-	-	-	+	1	-	-	-	-
P. commune	-	-	+	1	-	-	-	-	-	-	-	-	+	1	-	-
Mnium spp.	12.3	7	11.4	6	10.9	7	3.3	6	1.5	7	1.2	5	3.1	6	0.5	4
Climacium dendroides	-	-	0.6	1	-	-	-	-	-	-	-	-	-	-	-	-
Rhodobryum roseum	-	-	-	-	-	-	-	-	-	-	-	-	+	1	+	1
Lophozia lycopodioides	-	-	-	-	-	-	-	-	-	-	-	-	+	2	+	3
Ptilidium ciliare	-	-	-	-	+	1	-	-	-	-	-	-	0.5	6	+	2
Musci imperfecti	3.8	2	4.6	8	3.2	5	1.6	5	1.9	5	-	-	0.5	4	0.6	1
Sphagnum squarrosum	+	2	0.8	3	6.3	4	-	-	-	-	-	-	2.2	6	2.9	5
S. warnstorfianum	17.8	7	7.6	5	18.5	7	25.6	8	16.3	7	16.9	7	19.0	7	8.9	5
S. centrale	-	-	-	-	-	-	-	-	-	-	-	-	0.5	4	3.1	4
S. girgensohnii	-	-	2.5	-	-	-	-	-	-	-	-	-	6.4	5	5.3	3
S. recurvum coll.	-	-	-	-	-	-	+	1	-	-	0.5	3	-	-	-	-
S. fuscum	-	-	-	-	-	-	-	-	+	1	-	-	-	-	-	-
Peltigera aphthosa	1.3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladonia spp.	-	-	-	-	+	1	-	-	-	-	-	-	0.4	1	+	1
	95.4	112	81.0	129	84.9	144	95.5	124	101.1	126	107.9	130	77.3	161	89.2	150

Appendix 4

Preliminary data on height and diameter growth, with reference to sample plots and tree species (1961-1964).

Table 39

ViR. Average height growth (mm) of pine on different plots in 1961 - 1964

Treatment	Ground water level	70 cm	50 cm	30 cm	10 cm	0 cm	Average 10 - 70 cm
1961	T	105	100	123	87	-	104
1962	TC	142	144	135	126	-	137
1963	TC	94	98	135	70	-	99
1964	TCS	121	104	88	28	-	85
1961	T	80	113	86	86	-	91
1962	T	139	142	144	139	-	141
1963	T	92	107	98	92	-	97
1964	TS	125	123	135	73	-	114
1961	U	85	85	77	130	61	94
1962	F	141	146	128	146	52	140
1963	F	215	257	198	174	26	211
1964	F	424	428	370	311	9	383
1961	U	126	111	116	*	-	118
1962	U	169	145	153	151	-	154
1963	U	145	104	103	95	-	112
1964	U	165	103	99	40	-	102

* No plot in 1961

Table 40

KiR. Average height growth (mm) of pine on different plots in 1961 - 1964

Treatment	Ground water level	70 cm	50 cm	30 cm	10 cm	Average 10 - 70 cm
1961	T	126	123	112	165	132
1962	TC	82	111	83	96	93
1963	TC	66	89	93	89	84
1964	TCS	46	83	59	70	64
1961	T	116	138	110	126	122
1962	T	86	102	67	81	84
1963	T	89	80	78	84	83
1964	T	91	96	81	60	82
1961	U	*	*	225	177	201
1962	F	158	173	196	77	151
1963	F	180	128	130	72	128
1964	F	238	200	149	97	171
1961	U	*	*	210	155	182
1962	U	140	156	156	72	131
1963	U	100	98	130	72	100
1964	U	138	138	146	58	120

* No plot in 1961

Table 41

ViR. Average radial growth (mm) of pine on different plots in 1961 - 1964

Treatment \ Ground water level		70 cm	50 cm	30 cm	10 cm	0 cm	Average 10 - 70 cm
1961	T	0.59	0.34	0.66	0.85	-	0.61
1962	TC	0.70	0.39	0.68	0.79	-	0.64
1963	TC	0.64	0.38	0.58	0.60	-	0.55
1964	TCS	1.29	0.71	1.12	0.71	-	0.96
1961	T	0.65	0.53	0.45	0.65	-	0.57
1962	T	0.74	0.68	0.50	0.70	-	0.66
1963	T	0.67	0.63	0.49	0.56	-	0.59
1964	TS	1.32	1.16	0.75	0.92	-	1.04
1961	U	0.50	0.51	0.57	0.59	0.63	0.54
1962	F	0.71	0.80	0.70	0.70	0.43	0.73
1963	F	1.59	1.85	1.84	1.33	0.43	1.65
1964	F	2.20	2.88	2.84	2.12	0.54	2.51
1961	U	0.68	0.57	0.74	*	-	0.66
1962	U	0.74	0.58	0.84	0.85	-	0.75
1963	U	0.68	0.50	0.73	0.58	-	0.62
1964	U	0.74	0.54	0.70	0.65	-	0.66

* No plot in 1961

T a b l e 4 2

ViK. Average radial growth (mm) of spruce and birch on different plots in 1961 - 1964

	Treatment / Ground water level		70 cm	50 cm	30 cm	10 cm	Average 10 - 70 cm
Birch	1961	T	1.22	1.18	1.29	1.63	1.33
	1962	TC	1.10	0.88	0.93	1.04	0.99
	1963	TC	1.33	1.27	1.04	1.38	1.26
	1964	TCS	1.68	1.60	0.91	1.23	1.36
	1961	T	1.39	1.39	1.70	1.39	1.47
	1962	T	1.16	1.09	1.06	1.63	0.98
	1963	T	1.44	1.36	1.22	1.09	1.28
	1964	T	1.21	1.13	1.08	0.81	1.06
Spruce	1961	T	1.24	1.30	1.08	1.09	1.18
	1962	TC	1.57	1.87	1.64	1.25	1.58
	1963	TC	1.40	1.42	1.27	1.07	1.29
	1964	TCS	1.99	1.94	1.47	1.40	1.70
	1961	T	1.86	1.45	1.54	1.55	1.60
	1962	T	2.17	1.85	1.55	1.36	1.73
	1963	T	1.85	1.75	1.22	1.49	1.58
	1964	T	1.78	1.69	1.18	1.33	1.50

Table 43

KiR. Avarage radial growth (mm) of pine on different plots in 1961 - 1964

Treatment	Ground water level	70 cm	50 cm	30 cm	10 cm	Average 10 - 70 cm
1961	T	0.40	0.25	0.37	0.32	0.34
1962	TC	0.32	0.16	0.26	0.21	0.24
1963	TC	0.33	0.27	0.34	0.26	0.30
1964	TCS	0.42	0.35	0.38	0.32	0.37
1961	T	0.36	0.37	0.32	0.32	0.34
1962	T	0.34	0.34	0.23	0.27	0.30
1963	T	0.45	0.43	0.35	0.40	0.41
1964	T	0.54	0.51	0.42	0.40	0.47
1961	U	*	*	0.53	0.51	0.52
1962	F	0.59	0.61	0.66	0.22	0.52
1963	F	1.02	0.71	0.95	0.37	0.76
1964	F	1.67	1.34	1.63	0.42	1.26
1961	U	*	*	0.43	0.37	0.40
1962	U	0.48	0.51	0.43	0.26	0.42
1963	U	0.49	0.62	0.52	0.41	0.51
1964	U	0.73	0.92	0.80	0.48	0.73

* No plot in 1961

Table 44

KiK. Average radial growth (mm) of spruce and birch on different plots in 1962 - 1964

	Treatment / Ground water level		70 cm	50 cm	30 cm	10 cm	Average 10 - 70 cm
Birch	1962	F	0.39	0.42	0.39	0.52	0.43
	1963	F	0.61	0.79	0.70	0.61	0.68
	1964	F	0.66	0.84	0.62	0.54	0.66
	1962	U	0.69	0.40	0.41	0.57	0.52
	1963	U	0.98	0.57	0.63	0.50	0.67
	1964	U	0.93	0.60	0.56	0.66	0.69
Spruce	1962	F	0.30	0.39	0.44	0.26	0.35
	1963	F	0.48	0.64	0.66	0.37	0.54
	1964	F	0.91	1.08	1.37	0.68	1.01
	1962	U	0.26	0.26	0.23	0.26	0.25
	1963	U	0.34	0.42	0.35	0.38	0.37
	1964	U	0.52	0.71	0.52	0.50	0.56